



Ionic & Metallic Bonding & Structure

Contents

- * Evidence of Ions
- * Ionic Bonding & Structures
- * Ionic Bond Strength
- * Polarisation
- * Metallic Bonding & Lattices

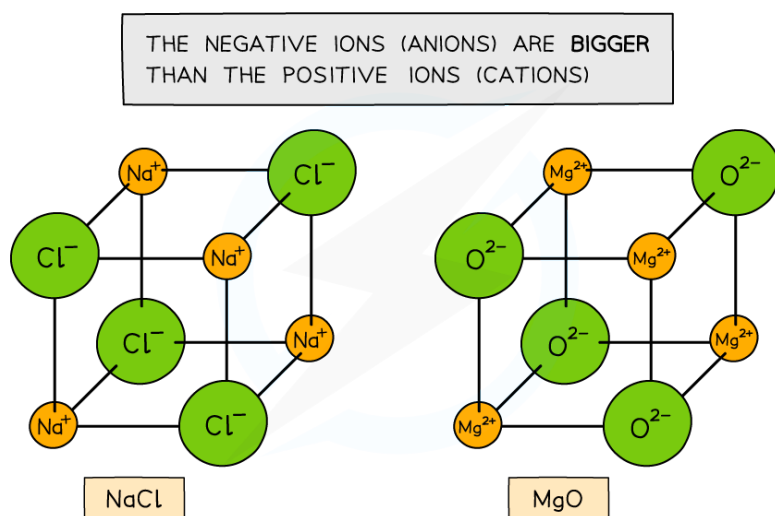


Evidence of Ions

- Most ionic, metallic and covalent solids are **crystalline lattices**
- The ions, atoms or molecules are arranged in a **regular and repeating arrangement**

Giant ionic lattices

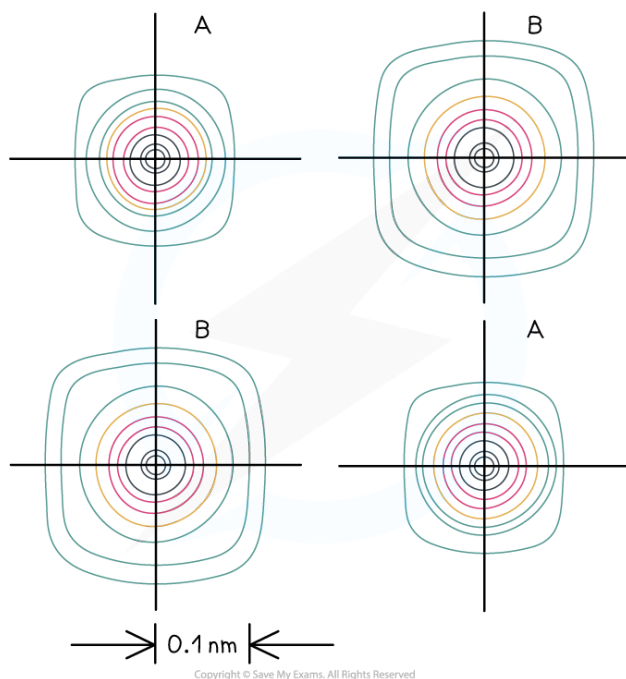
- An **ionic bond** is an electrostatic force of attraction between a positively charged metal (**cation**) ion and a negatively charged non-metal (**anion**) ion
 - The metal becomes positively charged as it transfers electrons to the non-metal which then becomes negatively charged
 - When an ionic compound is formed, the attraction between the ions happens in all directions
- Ionic compounds are arranged in giant **ionic lattices** (also called **giant ionic structures**)
- The type of lattice formed depends on the sizes of the **positive** and **negative** ions which are arranged in an **alternating** fashion
 - The ionic lattice of MgO and NaCl are **cubic**



Ionic lattices of the ionic compounds NaCl and MgO

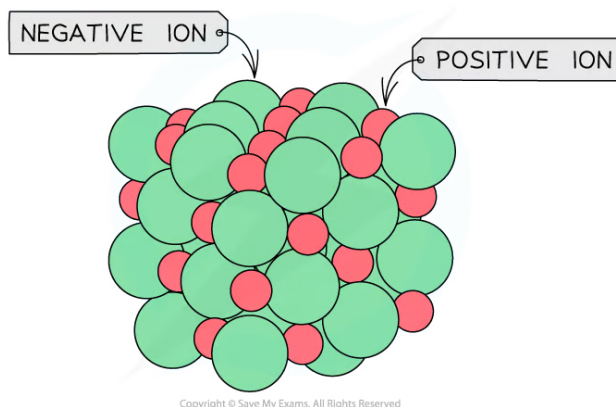


Your notes



Electron density maps shown above show the likelihood of finding electrons in a region.

This shows the electron density map for NaCl. The contours are lines of equal electron density. A = Na^+ ions (smaller), B = Cl^- ions (larger). Between the ions the electron density falls to zero.



General ionic lattice which shows the actual packing of the ions

Melting and boiling point

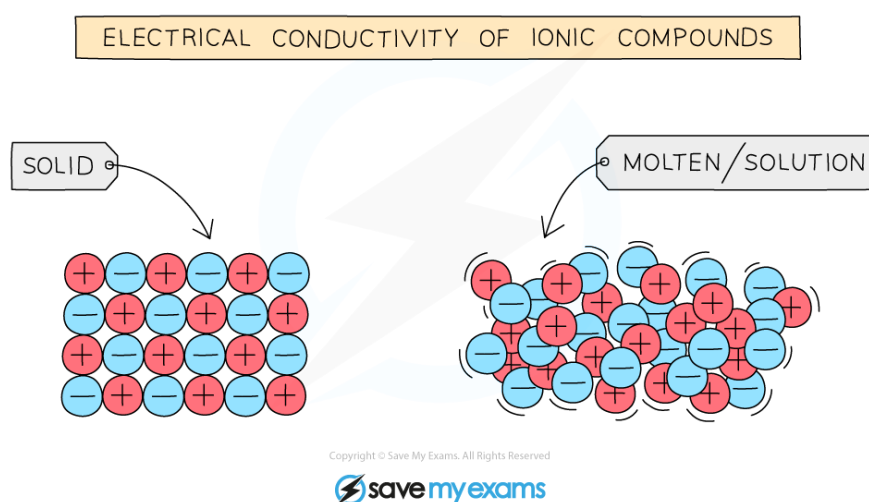
- Most ionic compounds are solids at room temperature
- This is because there isn't enough energy to overcome the strong electrostatic forces of attraction between the oppositely charged ions that make up the lattice
- Therefore, high temperatures are required to make an ionic compound melt or boil



- Melting (and boiling) points are also higher for lattices that contain ions with a greater ionic charge
 - For example, the melting point of sodium oxide, Na_2O , is 1405 K while the melting point of calcium oxide, CaO , is 2845 K
 - This is due to a stronger attraction between the ions - the size of the ions is not a factor here as the Na^+ and Ca^{2+} ions are a similar size

Electrical Conductivity

- For electrical current to flow there must be present freely moving charged particles such as electrons or ions
- Ionic compounds can conduct electricity in the **molten** state or in **solution** as they have ions that can move and carry charge
- They cannot conduct electricity in the solid state as the ions are in fixed positions within the lattice and are unable to move



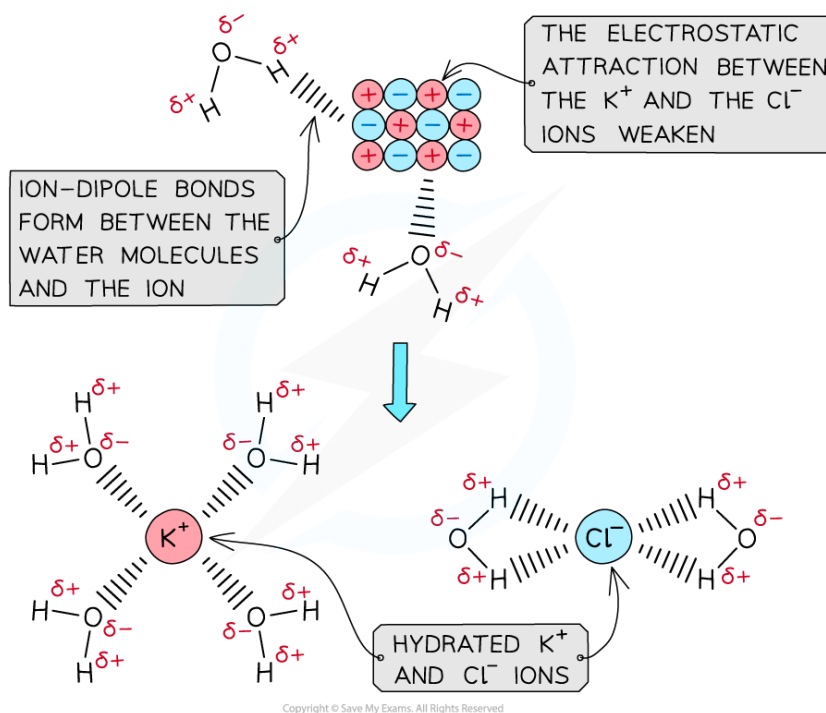
Molten or aqueous particles move and conduct electricity but cannot in the solid state

Solubility

- Many ionic compounds will dissolve in **polar** solvents, e.g. water
- Solubility is dependent on two main factors:
 1. Breaking down the ionic lattice
 2. The polar molecules attracting and surrounding the ions
- Polar molecules, such as water, can break down or disrupt the ionic lattice and surround each ion in solution
- The $\delta+$ end of the polar molecule can surround the negative anion
- The $\delta-$ end of the polar molecule can surround the positive cation



- The solubility of an ionic compound depends on the relative strength of the electrostatic forces of attraction within the ionic lattice and the attractions between the ions and the polar molecule
- In general, the greater the ionic charge the less soluble an ionic compound is
 - For example, 356.9 g of sodium chloride, NaCl, will dissolve in one dm^3 of water while only 74.4 g of calcium chloride will dissolve in one dm^3 of water
 - This is a general rule though and there are many exceptions



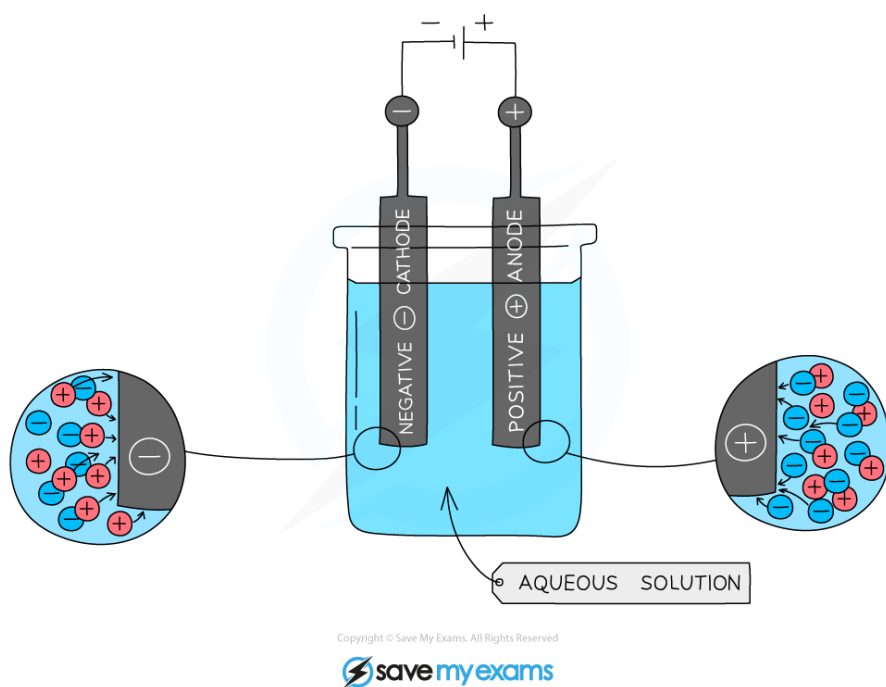
The polar water molecules will form ion-dipole bonds with the ions in solution causing the ions to become hydrated

Evidence

- The behaviour of ionic substances during electrolysis is a clear piece of evidence for the existence of ions
 - Positive ions in solution are attracted to the negative electrode
 - Negative ions in solution are attracted to the positive electrode



Your notes



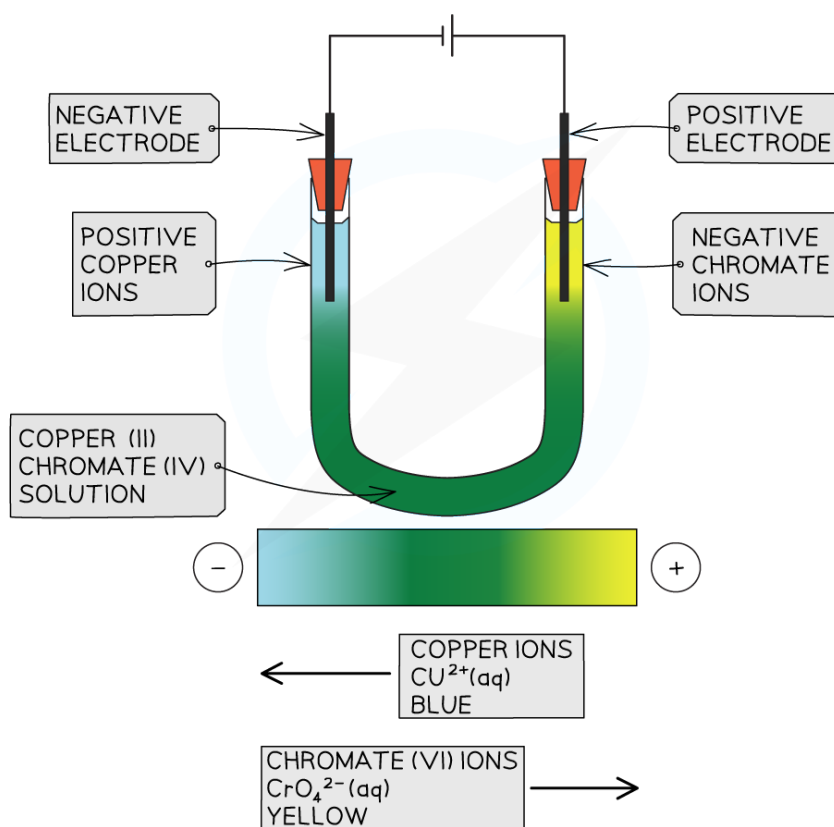
Set up of electrolysis

- An example which is simple to see the separation is using copper(II) chromate(VI), CuCrO_4
- The solution contains
 - Cu^{2+} ions (blue)
 - CrO_4^{2-} ions (yellow)

ELECTROLYSIS OF COPPER (II) CHROMATE (IV)
SHOWING THE MIGRATIONS OF IONS.



Your notes

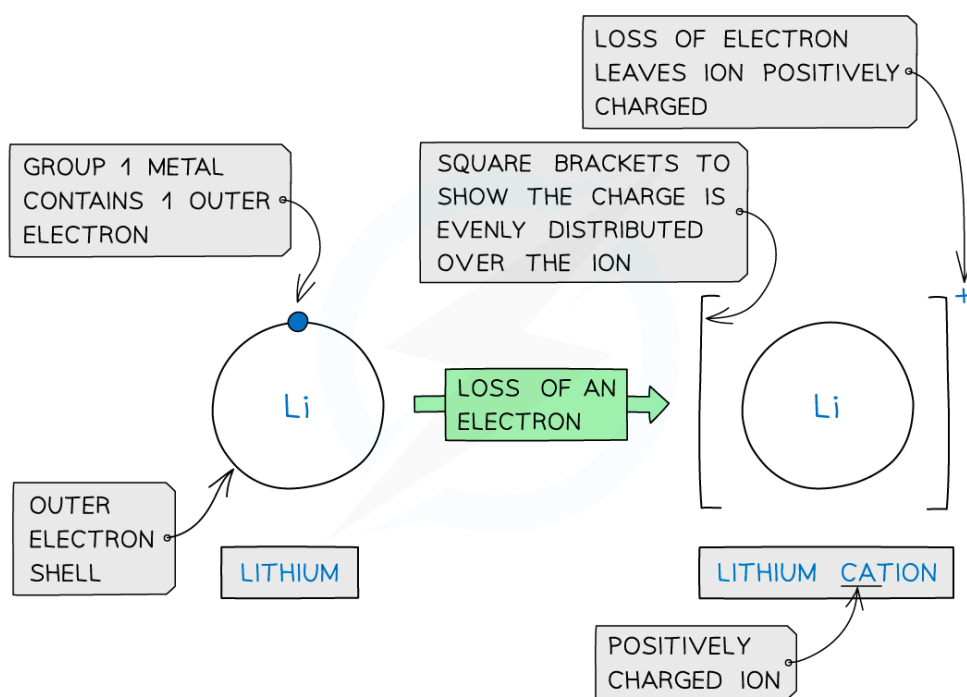


- Overall the solution is an olive green colour, but when the solution undergoes electrolysis a blue colour appears around the negative electrode, and a yellow colour appears around the positive electrode
- This is because the Cu^{2+} ions are attracted to the negative electrode and their blue colour is observed and the CrO_4^{2-} ions are attracted to the positive electrode and their yellow colour is observed



Ionic Dot-and-Cross Diagrams

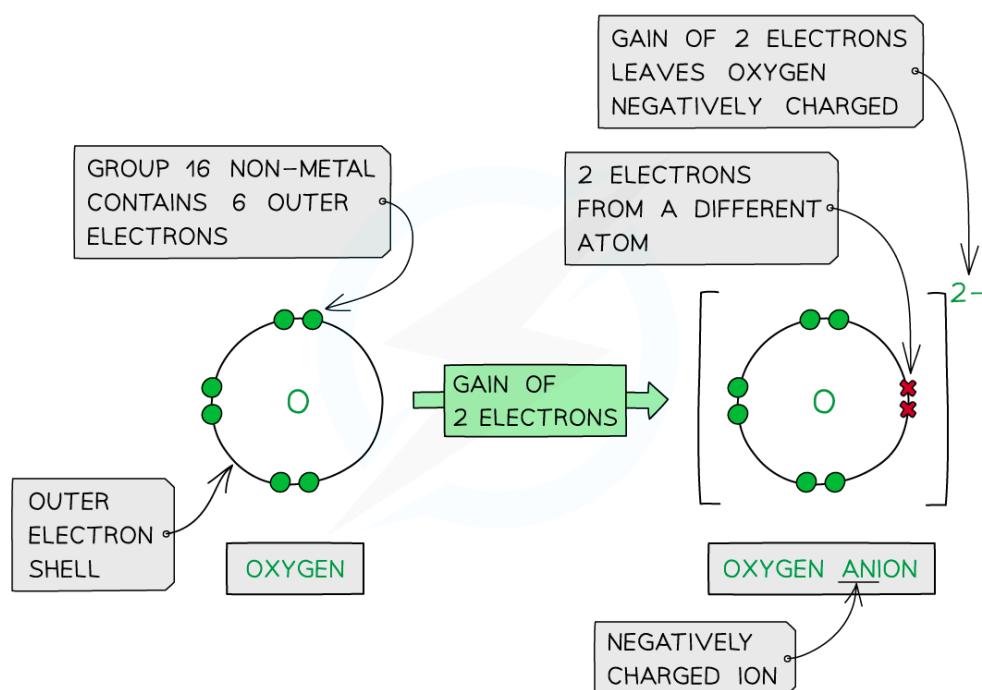
- As a general rule, **metals** are on the **left** of the periodic table and **nonmetals** are on the **right-hand** side
- Ionic bonding** involves the **transfer** of electrons from a **metallic** element to a **non-metallic** element
- Transferring electrons usually leaves the metal and the non-metal with a **full outer shell**
- Metals **lose** electrons from their valence shell forming **positively charged cations**
- Non-metal atoms **gain** electrons forming **negatively charged anions**
- Once the atoms become ions, their electronic configurations are the same as a noble gas
 - A potassium ion (K^+) has the same electronic configuration as argon: $[2,8,8]^+$
 - A chloride ion (Cl^-) also has the same electronic configuration as argon: $[2,8,8]^-$



Forming cations by the removal of electrons from metals



Your notes

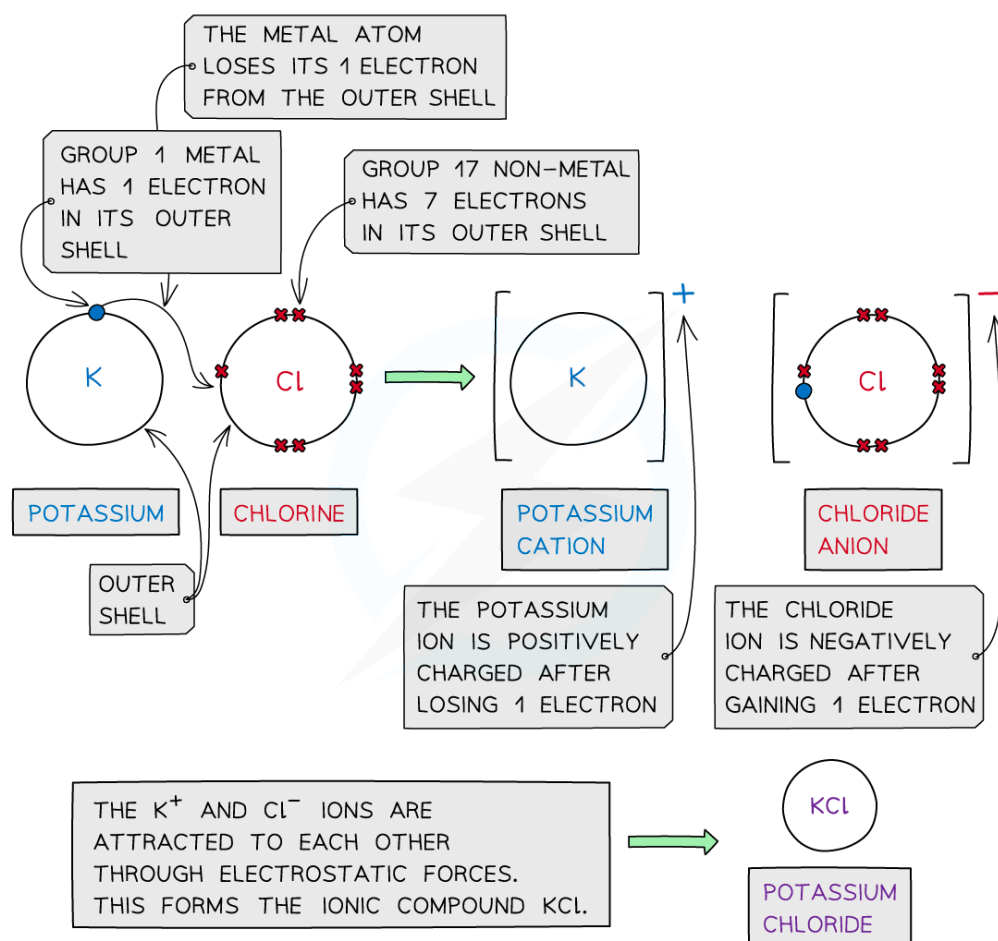


Forming anions by the addition of electrons to nonmetals

- **Cations** and **anions** are oppositely charged and therefore attracted to each other
- **Electrostatic attractions** are formed between the oppositely charged ions to form **ionic compounds**
- The **ionic bond** is the **electrostatic attraction** formed **between the oppositely charged ions**, which occurs in all directions (this called **non-directional bonding**)
- This form of attraction is **very strong** and requires a **lot of energy** to overcome
 - This causes high melting points in ionic compounds



Your notes

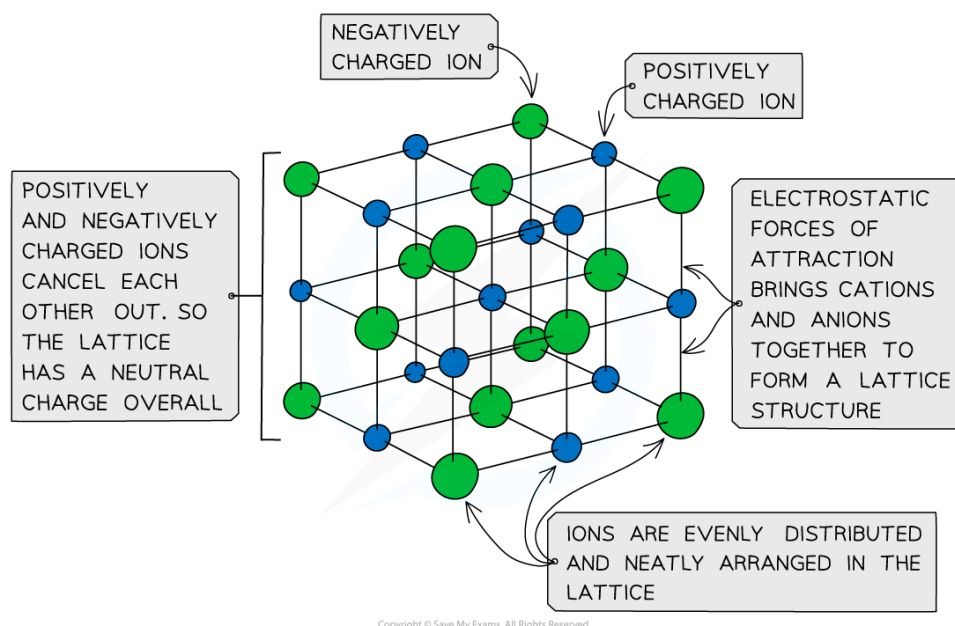


Cations and anions bond together using strong electrostatic forces, which require a lot of energy to overcome

- The ions form a **lattice structure** which is an evenly distributed **crystalline** structure
- Ions in a lattice are arranged in a **regular repeating pattern** so that positive charges cancel out negative charges
- The attraction between the cations and anions is occurring in all directions
 - Each ion is attracted to all of the oppositely charged ions around it
- Therefore the final lattice is overall electrically **neutral**



Your notes



Ionic solids are arranged in lattice structures

Dot and cross diagrams

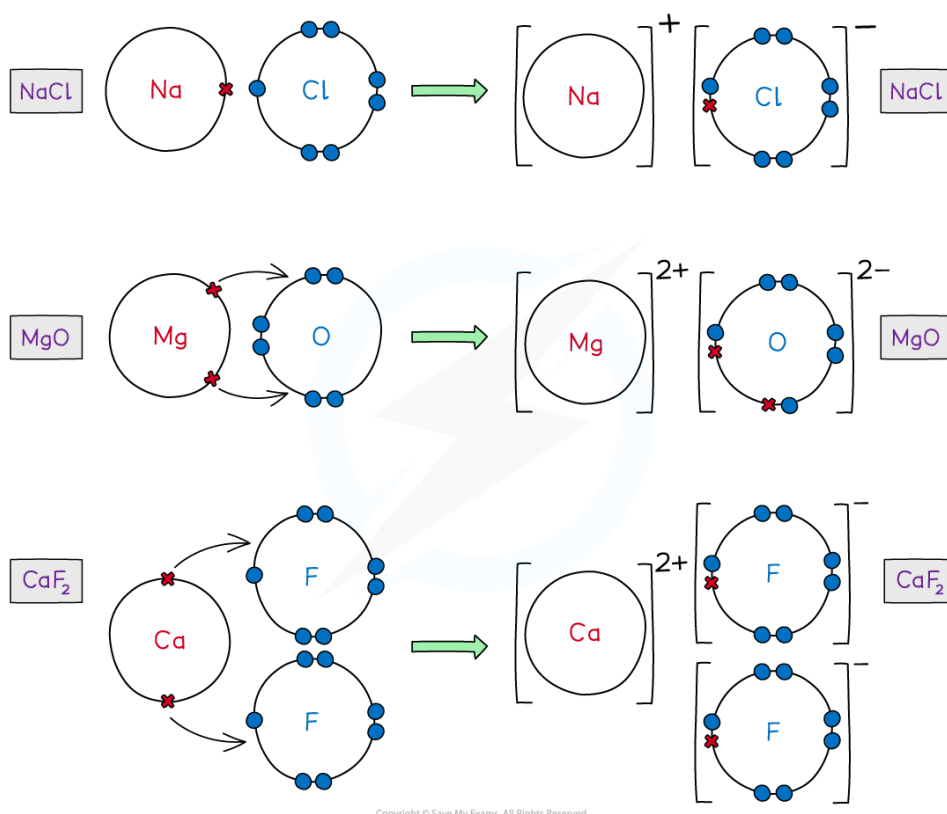
- These are diagrams that show the arrangement of the outer-shell electrons in an **ionic** or **covalent** compound or element
- The electrons are shown as dots and crosses
- In a dot and cross diagram:
 - Only the outer electrons are shown
 - The charge of the ion is spread evenly which is shown by using brackets
 - The charge on each ion is written at the top right-hand corner

Ionic compounds

- Ionic bonds are formed when **metal atoms** transfer electrons to a **non-metal** to form a positively charged and negatively charged ion
- The atoms achieve a **noble gas** configuration



Your notes



Dot-and-cross diagrams of ionic compounds in which one of the atoms transfers their valence electrons to the other

Calcium fluoride

- Calcium is a Group 2 **metal**
 - It **loses** its 2 outer electrons to form a calcium ion with a +2 charge (Ca²⁺)
- Fluorine is a Group 7 **non-metal**
 - It **gains** 1 electron to form a fluoride ion with a -1 charge (F⁻)
- As before, the positive and negative ions are attracted to each other via an ionic bond
- However, to cancel out the 2+ charge of the calcium ion, 2 fluorine atoms are needed
 - Each fluorine atom can only accept 1 electron from the calcium atom
 - 2 fluoride ions will be formed
- Calcium fluoride is made when 1 calcium ion and 2 fluoride ions form ionic bonds, CaF₂
- The final ionic solid of CaF₂ is **neutral** in charge

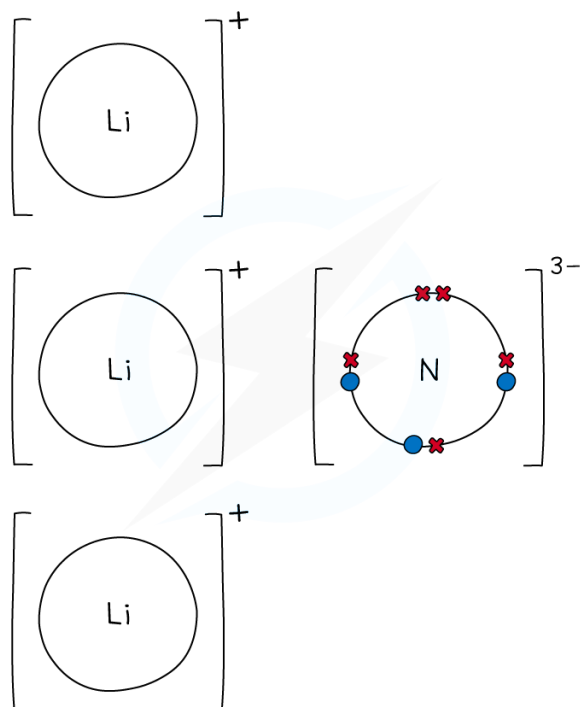


Worked Example

Draw a dot cross diagram for lithium nitride

Answer

- Lithium is a Group 1 **metal**
 - It **loses** its outer electron to form a lithium ion with a +1 charge (Li^+)
 - Nitrogen is a Group 5 **non-metal**
 - It **gains** 3 electrons to form a nitride ion with a -3 charge (N^{3-})
 - To cancel out the -3 charge of the nitride ion, 3 lithium atoms are needed and 3 lithium ions will be formed
 - Lithium nitride is made when 1 nitride ion and 3 lithium ions form ionic bonds
 - The final ionic solid of Li_3N is **neutral** in charge



Copyright © Save My Exams. All Rights Reserved

Dot and cross diagram to show the ionic bonding in lithium nitride



Worked Example

Draw a dot cross diagram for aluminium oxide

Answer

- Aluminium is a Group 3 **metal**
 - It **loses** its outer electrons to form an aluminium ion with a +3 charge (Al^{3+})
 - Oxygen is a Group 6 **non-metal**
 - It **gains** 2 electrons to form an oxide ion with a -2 charge (O^{2-})

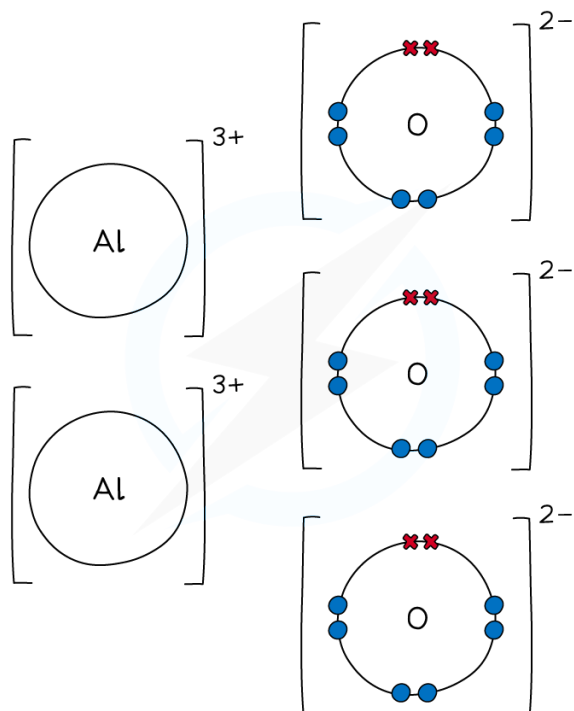


Your notes

- To cancel out the negative and positive charges, 2 aluminium and 3 oxygen atoms are needed
- Aluminium oxide is made when 2 aluminium ions and 3 oxygen ions form ionic bonds
- The final ionic solid of Al_2O_3 is **neutral** in charge



Your notes



Dot and cross diagram to show the ionic bonding in aluminium oxide



Trend: Atomic Radius

- Elements in the periodic table are arranged in order of increasing atomic number and placed in vertical columns (**groups**) and horizontal rows (**periods**)
- The elements across the periods show **repeating patterns** in chemical and physical properties
- This is called **periodicity**

PERIODIC TABLE OF THE ELEMENTS

																		NOBLE GASES 0/VIII		
1/I		2/II												13/XIII		14/XIV	15/XV	16/XVI	17/XVII	4
3/III		4/IV												5	6	7	8	9	10	20
5/V		6/VI												11	12	13	14	15	16	21
7/VII														17	18	19	20	21	22	32
														23	24	25	26	27	28	38
														29	30	31	32	33	34	40
														35	36	37	38	39	40	48
														41	42	43	44	45	46	54
														47	48	49	50	51	52	60
														53	54	55	56	57	58	66
														59	60	61	62	63	64	72
														65	66	67	68	69	70	78
														71	72	73	74	75	76	84
														77	78	79	80	81	82	90
														83	84	85	86	87	88	96
														89	90	91	92	93	94	102
														95	96	97	98	99	100	108
														101	102	103	104	105	106	114
														107	108	109	110	111	112	120
														113	114	115	116	117	118	126
														119	120	121	122	123	124	132
														125	126	127	128	129	130	138
														131	132	133	134	135	136	144
														137	138	139	140	141	142	150
														143	144	145	146	147	148	156
														149	150	151	152	153	154	162
														155	156	157	158	159	160	168
														161	162	163	164	165	166	174
														167	168	169	170	171	172	180
														173	174	175	176	177	178	186
														179	180	181	182	183	184	192
														185	186	187	188	189	190	198
														191	192	193	194	195	196	204
														197	198	199	200	201	202	210
														203	204	205	206	207	208	216
														209	210	211	212	213	214	222
														215	216	217	218	219	220	228
														221	222	223	224	225	226	234
														227	228	229	230	231	232	240
														233	234	235	236	237	238	246
														239	240	241	242	243	244	252
														245	246	247	248	249	250	258
														251	252	253	254	255	256	264
														257	258	259	260	261	262	270
														263	264	265	266	267	268	276
														269	270	271	272	273	274	282
														275	276	277	278	279	280	288
														281	282	283	284	285	286	294
														287	288	289	290	291	292	300
														293	294	295	296	297	298	306
														299	300	301	302	303	304	312
														305	306	307	308	309	310	318
														311	312	313	314	315	316	324
														317	318	319	320	321	322	330
														323	324	325	326	327	328	336
														329	330	331	332	333	334	342
														335	336	337	338	339	340	348
														341	342	343	344	345	346	354
														347	348	349	350	351	352	360
														353	354	355	356	357	358	366
														359	360	361	362	363	364	372
														365	366	367	368	369	370	378
														371	372	373	374	375	376	384
														377	378	379	380	381	382	390
														383	384	385	386	387	388	396
														389	390	391	392	393	394	402
														395	396	397	398	399	400	408
														401	402	403	404	405	406	414
														407	408	409	410	411	412	420
														413	414	415	416	417	418	426
														419	420	421	422	423	424	432
														425	426	427	428	429	430	438
														431	432	433	434	435	436	444
														437	438	439	440	441	442	450
														443	444	445	446	447	448	456
														449	450	451	452	453	454	462
														455	456	457	458	459	460	468
														461	462	463	464	465	466	474
														467	468	469	470	471	472	480
														473	474	475	476	477	478	486
														479	480	481	482	483	484	492
														485	486	487	488	489	490	498
														491	492	493	494	495	496	504
														497	498	499	500	501	502	510
														503	504	505	506	507	508	516
														509	510	511	512	513	514	522
														515	516	517	518	519	520	528
														521	522	523	524	525	526	534
														527	528	529	530	531	532	540
														533	534	535	536	537	538	546
														539	540	541	542	543	544	552
														545	546	547	548	549	550	558
														551	552	553	554	555	556	564
														557	558	559	560	561	562	570
														563	564	565	566	567	568	576
														569	570	571	572	573	574	582
														575	576	577	578	579	580	588
														581	582	583	584	585	586	594
														587	588	589	590	591	592	600
														593	594	595	596	597	598	606
														599	600	601	602	603	604	612
														605	606	607	608	609	610	618
														611	612	613	614	615	616	624
														617	618	619	620	621	622	630
														623	624	625	626	627	628	636
														629	630	631	632	633	634	642
														635	636	637	638	639	640	648
														641	642	643	644	645	646	654
														647	648	649	650	651	652	660
														653	654	655	656	657	658	666
														659	660	661	662	663	664	672
														665	666	667	668	669	670	678
														671	672	673	674	675	676	684
														677	678	679	680	681	682	690
														683	684	685	686	687	688	696
														689	690	691	692	693	694	702
														695	696	697	698	699	700	708
														701	702	703	704	705	706	714
														707	708	709	710	711	712	720
														713	714	715	716	717	718	726
														719	720	721	722	723	724	732
														725	726	727	728	729	730	738
														731	732	733	734	735	736	744
														737	738	739	740	741	742	750
														743	744	745	746	747	748	756
														749	750	751	752	753	754	762
														755	756	757	758	759	760	768
														761	762	763	764	765	766	774
														767	768	769	770	771	772	780
														773	774	775	776	777	778	786
														779	780	781	782	783	784	792
														785	786	787	788	789	790	798
														791	792	793	794	795	796	804
														797	798	799	800	801	802	810
														803	804	805	806	807	808	816
														809	810	811	812	813	814	822
														815	816	817	818	819	820	828
														821	822	823	824	825	826	834
														827	828	829	830	831	832	840
														833	834	835	836	837	838	846
														839	840	841	842	843	844	852
														845	846	847	848	849	850	858
														851	852	853	854	855	856	864
														857	858	859	860	861	862	870
														863	864	865	866	867	868	876
														869	870	871	872	873	874	882
														875	876	877	878	879	880	888
														881	882	883	884	885	886	894
														887	888	889	890	891	892	900
														893	894	895	896	897	898	906
														899	900	901	902	903	904	912
														905	906	907	908	90		

- In **metals** this is also called the **metallic radius** and in **non-metals**, the **covalent radius**



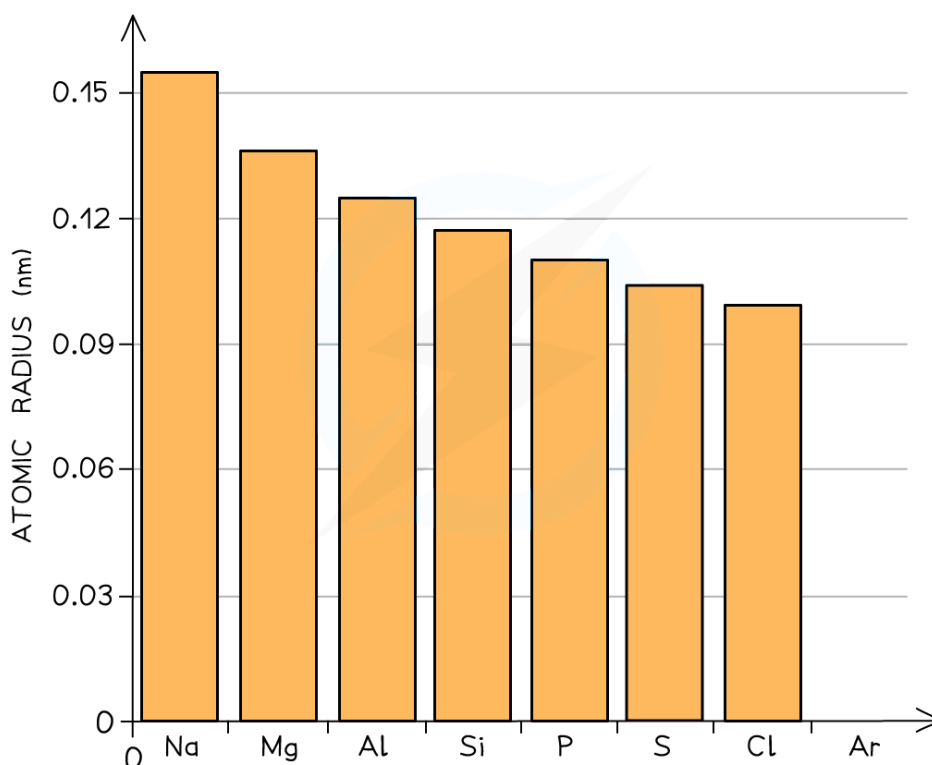
Your notes

Atomic radii of Period 3 elements

- You can see a clear trend across the period:

Period 3 Element	Na	Mg	Al	Si	P	S	Cl	Ar
Atomic Radius (nm)	0.157	0.136	0.125	0.117	0.110	0.104	0.099	No data

Copyright © Save My Exams. All Rights Reserved



Copyright © Save My Exams. All Rights Reserved

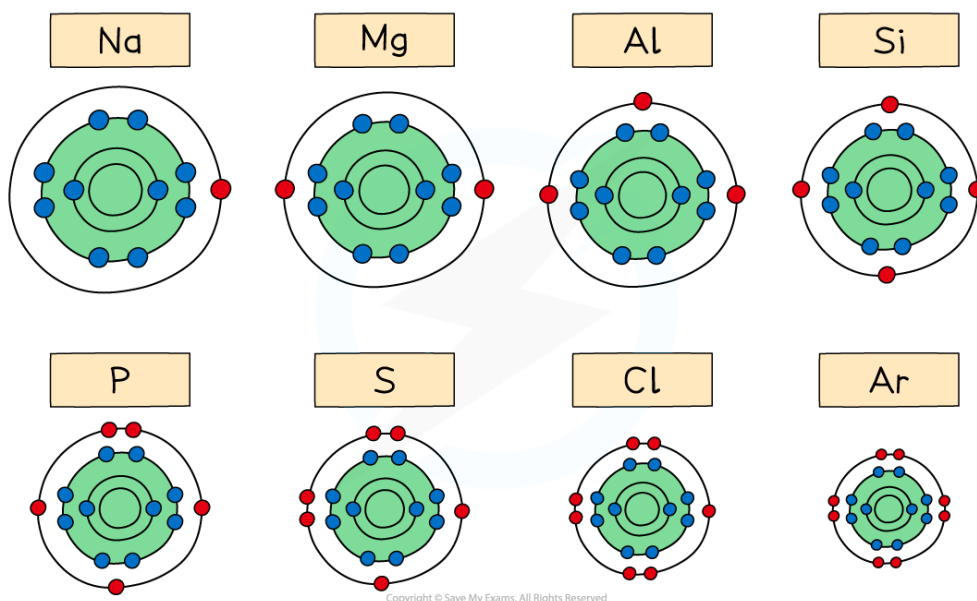
The graph shows a decrease in atomic radii of Period 3 elements across the period

- Across the period, the atomic radii decrease
- This is because the number of protons (**the nuclear charge**) and the number of **electrons** increases by one every time you go an element to the right
- The elements in a period all have the same number of shells (so the **shielding effect** is the same)
- This means that as you go across the period the nucleus attracts the electrons more **strongly pulling them closer** to the nucleus

- Because of this, the atomic radius (and thus the size of the atoms) **decreases** across the period



Your notes



The diagram shows that across Period 3, the elements gain extra electrons in the same principal quantum shell

Ionic Radius & Charge

Ionic radius

- The **ionic radius** of an element is a measure of the size of an ion
- Ionic radii show predictable patterns
 - Ionic radii **increase** with increasing **negative charge**
 - Ionic radii **decrease** with increasing **positive charge**
- For negative ions
 - They are formed by atoms **gaining** electrons
 - The outermost electrons are further away from the positively charged nucleus and are therefore held only weakly to the nucleus which **increases the ionic radius**
 - The greater the negative charge, the larger the ionic radius
- For positive ions
 - Positively charged ions are formed by atoms **losing** electrons
 - The nuclear charge remains the same but there are now fewer electrons that undergo a greater electrostatic force of attraction to the nucleus which **decreases the ionic radius**
 - The greater the positive charge, the smaller the ionic radius

SIZES OF ATOMS AND THEIR IONS IN PM



Your notes

	GROUP 1	GROUP 2	GROUP 13	GROUP 16	GROUP 17
PERIOD 2	Li^+ Li 90 134	Be^{2+} Be 59 90	B^{3+} B 41 82	O^{2-} O 73 126	F^- F 71 119
PERIOD 3	Na^+ Na 116 154	Mg^{2+} Mg 86 130	Al^{3+} Al 68 118	S^{2-} S 102 170	Cl^- Cl 99 167
PERIOD 4	K^+ K 152 196	Ca^{2+} Ca 114 174	Ga^{3+} Ga 76 126	Se^{2-} Se 116 184	Br^- Br 114 182
PERIOD 5	Rb^+ Rb 166 211	Sr^{2+} Sr 132 192	In^{3+} In 94 144	Te^{2-} Te 135 207	I^- I 133 206

Copyright © Save My Exams. All Rights Reserved

Trends in the ionic radii across a period and down a group

- The strength of ionic bonding, therefore, depends on both the charges and the sizes of the two ions
- **Higher charges** and **smaller sizes** produce stronger bonds
- This is because:
 - As the ionic charge increases, or the ionic radius decreases, the charge density increases

Trends in Ionic Radius

Isoelectronic Ions

- These are ions that have the **same electronic configuration**
- For example the following ions all have the electronic configuration of $1s^2 2s^2 2p^6$
- However, they all have different numbers of protons, therefore will have a different ionic radius
 - N^{3-} (7 protons)



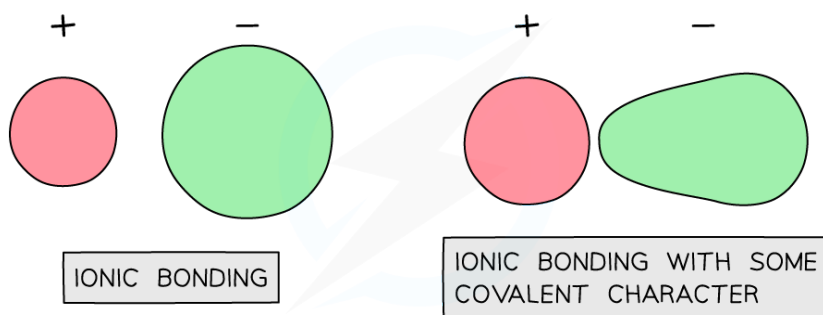
Your notes

- O^{2-} (8 protons)
- F^- (9 protons)
- Na^+ (11 protons)
- Mg^{2+} (12 protons)
- Al^{3+} (13 protons)
- As the number of protons in the nucleus of the ion increases, the electrons get pulled in more closely to the nucleus
- The radii of the isoelectronic ions therefore fall across this series of ions
 - N^{3-} has an ionic radius of 0.171 nm and Al^{3+} has an ionic radius of 0.054 nm



The Polarisation of anions & Cations

- Theoretical lattice energies assume a perfect ionic model where the ions are 100% spherical and the attractions are purely electrostatic
 - So overall, there has been a complete and irreversible exchange of outer shell electrons between the two elements in the compound so that one ion is negatively charged and the other ion positively charged and the charges are whole values
- Theoretical lattice energy can differ from measured lattice energy
- This is because covalent character is introduced when there is **polarisation** of the anions
- When this occurs, the cation attracts electrons from the anion therefore distorting electron density of the anion



Polarisation of anion leading to covalent character

Cations

- A cation with a large charge density will have a larger **polarising power**
- The charge density can be calculated as the charge of the cation divided by the surface area, for example
 - K^+ will have a lower polarising power than Li^+ as the ionic radius is greater
 - Na^+ will have a lower polarising power than Mg^{2+} as the charge is smaller
- So a cation that is small and highly charged will have the greatest polarising power

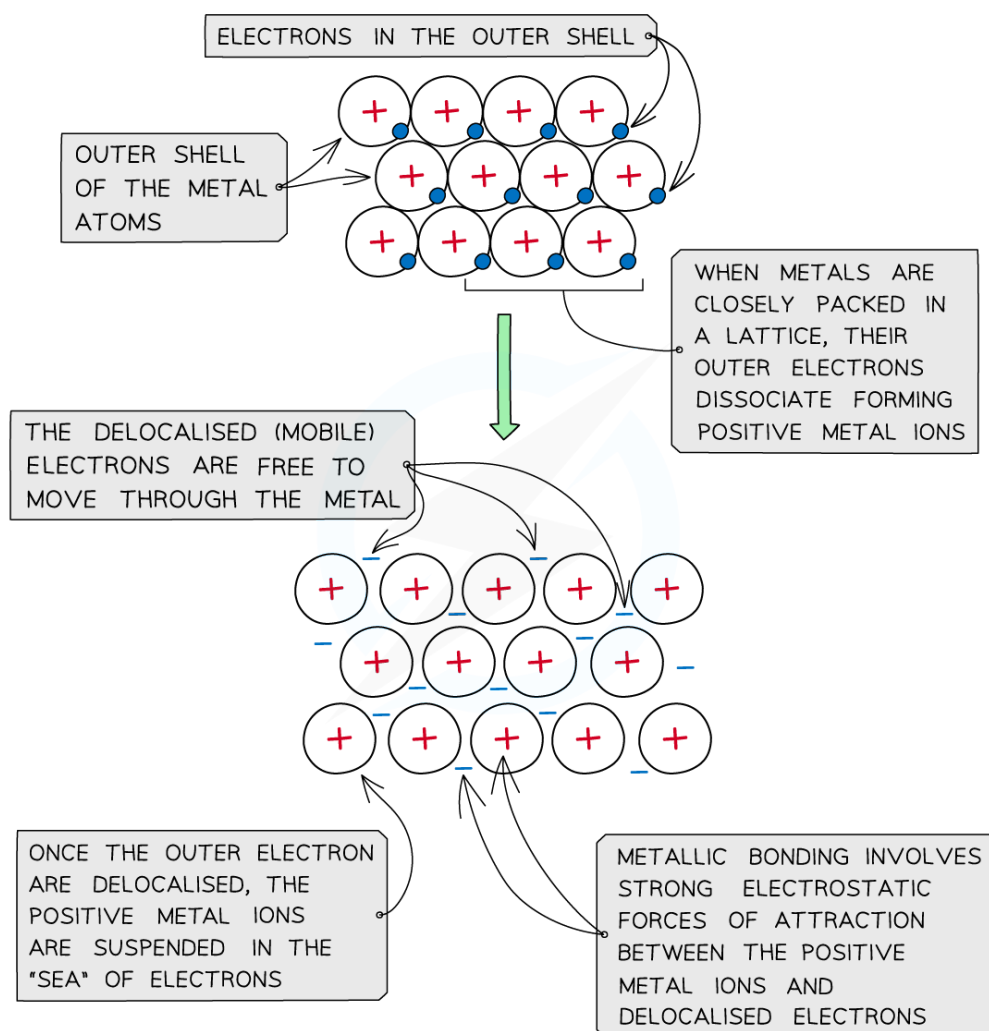
Anions

- Anions are polarised
- The polarisability of the anion depends of its ionic radius
- The larger the ionic radius the more easily it will be distorted, for example
 - Br^- will be more polarisable than Cl^- as the ionic radius is larger



Metallic Bonding & Lattices

- **Metal** atoms are tightly packed together in **lattice** structures
- When the metal atoms are in lattice structures, the electrons in their outer shells are free to move throughout the structure
- The free-moving **electrons** are called '**delocalised electrons**' and they are not bound to their atom
- When the electrons are delocalised, the metal atoms become **positively** charged ions
- The positive ions **repel** each other
- The strong **forces** between the positive metal centres and the 'sea' of delocalised electrons holds the lattice together and keeps it stable



Copyright © Save My Exams. All Rights Reserved

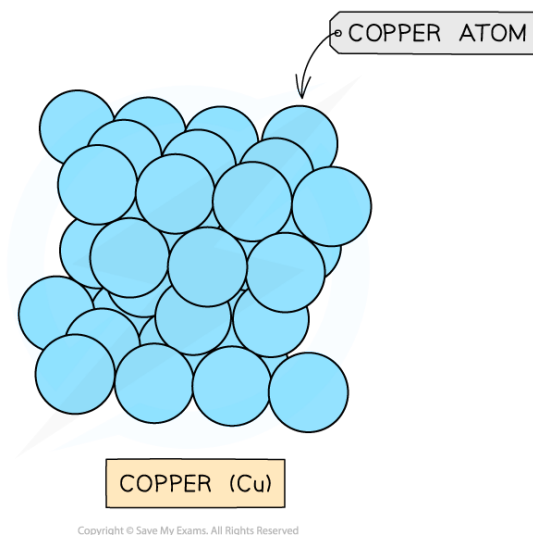
The positive metal ions are suspended in a 'sea' of delocalised electrons



Your notes

Simple Properties of Metals

- Metals form **giant metallic lattices** in which the metal ions are surrounded by a 'sea' of **delocalised** electrons
- The metal ions are often packed in **hexagonal layers** or in a **cubic arrangement**
- This layered structure with the delocalised electrons gives a metal its key properties



Layers of copper ions (the delocalised electrons are not shown in the diagram)

- If other atoms are added to the metal structure, such as carbon atoms, this creates an **alloy**
- Alloys are much stronger than pure metals, because the other atoms stop the layers of metal ions sliding over each other easily
- The **strength** of the metallic attraction can be increased by:
 - Increasing** the number of **delocalised electrons** per metal atom
 - Increasing** the **positive charges** on the metal centres in the lattice
 - Decreasing** the **size** of the metal ions
- Due to the delocalised 'sea' of electrons, metallic structures have some **characteristic properties** shown below:

Metallic Bonding Properties Table

Property	Reason
----------	--------



Your notes

High melting and boiling point	There are strong electrostatic forces of attraction between the delocalised electrons and positive metal ions which results in strong metallic bonds within giant metallic structures. These require large amounts of energy to overcome the forces and break the bonds
Good conductors of electricity	The delocalised electrons are able to move and carry charge. For example, in a circuit, electrons entering one end of the metal cause a delocalised electron to be displaced from the other end. Hence, electrons can flow and conduct electricity
Good conductors of heat	The delocalised electrons are free to move within the metal structure. The conversion of the kinetic energy of the electron to heat energy when it collides with the metal atoms/nuclei results in the transfer of energy. This is alongside the increased vibrations and movement of the particles (positive ions and delocalised electrons)
Malleable and ductile	Layers of positive ions can easily slide over one another to take up different positions. This does not disrupt the metallic bonding as the delocalised electrons do not belong to any particular metal atom and so they can move with the layers of positive ions, maintaining the electrostatic forces. Therefore, the metallic bonds are not broken and, as a result, metallic bonds are strong but flexible/



Examiner Tips and Tricks

You should be able to draw the structure of a metal with positive ions in layers and the delocalised electrons surrounding the ions

If drawing the structure of a metal in the exam, make sure to include labels for metal ions and delocalised electrons