TOPIC 3 BONDING AND STRUCTURE.

Competency; The learners analyse the types of chemical bonds and molecular structures and relates them to properties and uses of substance in real-life contexts

SUB TOPIC 3.1

FORMATION OF IONIC AND METALLIC BONDS

LEARNIG OUT COMES.

1. **The learners should be able to justify the formation of ionic and metallic bonds based on electron transfer and electrostatic forces.**
2. **The learners should be able to evaluate the properties of ionic and metallic compounds in relation to bond strength and structural composition.**

Ionic Bond Formation

Definition: An ionic bond (also called an electrovalent bond) is formed by the complete transfer of one or more electrons from one atom to another, creating oppositely charged ions.

Electron Transfer:

The metallic element loses electrons and becomes an electropositive ion (cation).

The nonmetallic element gains electrons and becomes an electronegative ion (anion).

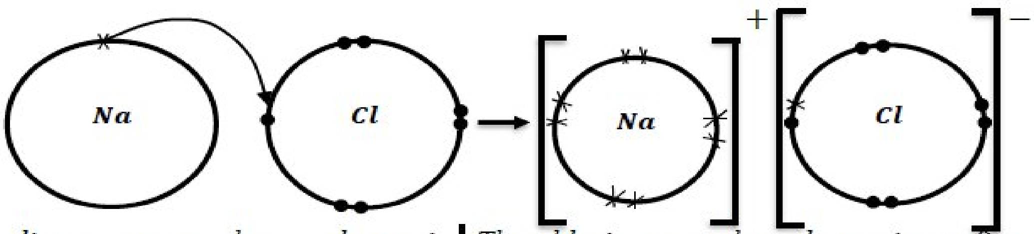
Electrostatic Attraction: The cation and anion are held together by strong electrostatic forces of attraction.

An ionic bond is also called an electrovalent bond. It is formed by **complete transfer of one or more electrons** from one atom to another to form **oppositely charged ions**.

The electron or electrons are transferred from **a metallic element** to a **nonmetallic element**. The element that **loses electrons is electropositive** since it forms **a positive ion**. The element **gaining electrons is electronegative** since it forms a **negative ion**. The cation and anion formed are held together by **strong electrostatic forces of attraction.**

Examples;

(i) Formation of sodium chloride



The sodium atom has electronic configuration, $1s^2 2s^2 2p^6 3s^1$. The 3s subenergy level has one electron and is unstable. This electron is transferred to the chlorine atom by sodium to form noble gas configuration, $1s^2 2s^2 2p^6$. A Sodium ion is formed.

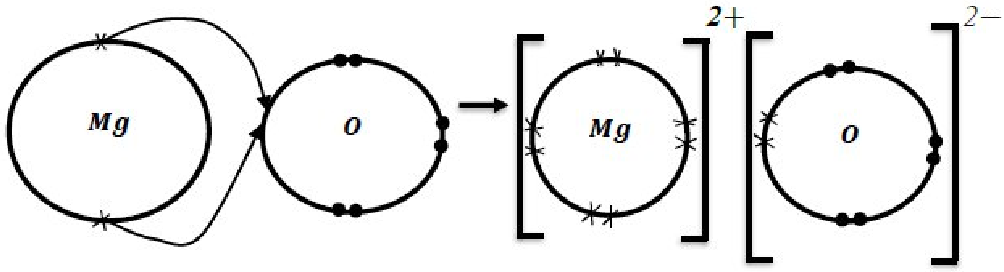
$$Na \longrightarrow Na^+ + e$$

The chlorine atom has electronic configuration, $1s^2 2s^2 2p^6 3s^2 3p^5$. The 3p subenergy level has five electrons and is unstable. The electron transferred from sodium occupies this sub energy level to form noble gas configuration, $1s^2 2s^2 2p^6 3s^2 3p^6$. A chloride ion is formed.

$$Cl + e \longrightarrow Cl^-$$

The sodium ion and chloride ion get hold together by strong electrostatic forces of attraction.

(ii) Formation of magnesium oxide



The magnesium atom has electronic configuration, $1s^2 2s^2 2p^6 3s^2$. The two 3s electrons are transferred to the oxygen atom by magnesium to form noble gas configuration, $1s^2 2s^2 2p^6$. A magnesium ion is formed.

$$Mg \longrightarrow Mg^{2+} + 2e$$

The oxygen atom has electronic configuration, $1s^2 2s^2 2p^4$. The 2p sub energy level has four electrons and is unstable. The two electrons transferred from magnesium occupy this sub energy level form noble gas configuration, $1s^2 2s^2 2p^6$. An oxide ion is formed.

$$O + 2e \longrightarrow O^{2-}$$

The magnesium ion and oxide ion get hold together by strong electrostatic forces of attraction.

Giant ionic structures

In giant ionic structures, metallic elements combine with non-metallic elements. The ionic bonds formed in these compounds are strong electrostatic attractions between the ions of opposite charges (cations and anions). Each ion is surrounded by the greatest number of oppositely charged ions called the coordination number.

Examples of giant ionic solids include ***sodium chloride***, ***caesium chloride*** and ***zinc sulphide***

Structures of some ionic compounds

Compound	*Structure*
Sodium oxide	$(Na^+)_2O^{2-}$
Magnesium oxide	$Mg^{2+}O^{2-}$
Calcium chloride	$Ca^{2+}(Cl^-)_2$
Sodium hydride	Na^+H^-
Magnesium sulphate	$Mg^{2+}SO_4^{2-}$

Properties of Ionic Compounds

1. **High Melting and Boiling Points**: Due to strong electrostatic forces that require a large amount of energy to break.
2. **Good Electrical Conductivity in Molten and Aqueous States**: Ions are free to move and conduct electricity.
3. **Solubility in Polar Solvents (e.g., Water)**: The ion-solvent interactions are stronger than the ion-ion interactions in the solid lattice.
4. **Exist as Crystalline Solids**: Strong electrostatic forces keep ions closely packed in a regular arrangement.

The properties of ionic compounds

Property	Explanation
1. **High melting and boiling points.**	*There are strong electrostatic forces of attraction between the oppositely charged ions that require a high amount of energy to break.*
2. **They are strong electrolytes in molten state or aqueous state**	*In the ionizing solvent, the forces of attraction between the ions are greatly reduced and the oppositely charged ions become free to move in molten or aqueous state under the influence of an electric field.*
3. **They readily dissolve polar solvents like water but insoluble in non-polar solvents like methylbenzene**	*The ion-solvent interactions are stronger than ion-ion interactions of the compound for polar solvents. Ion-ion interaction is stronger than ion-solvent interaction and solvent-solvent interaction for non-polar solvents.*
4. **Exist as crystalline solids at room temperature**	*There are strong electrostatic forces of attraction between the oppositely charged ions that require a high amount of energy to break at room temperature, keeping the molecules so closely packed together.*

NB.

- **Electron Transfer**: Ionic bonds form when a **metal loses electrons** to a **nonmetal**, resulting in the formation of positively charged **cations** and negatively charged **anions**.
- **Electrostatic Forces**: The cations and anions are held together by **strong electrostatic attractions**, forming a **giant ionic lattice**

- **Properties of Ionic Compounds**
- Ionic compounds have **strong electrostatic forces** due to their giant ionic lattice, leading to the following properties:

Property	Explanation
High Melting and Boiling Points	Strong electrostatic attractions require **high energy** to break.
Electrical Conductivity	Conducts electricity **only in molten or aqueous state**, as ions are **free to move**.
Solubility in Polar Solvents	Ionic compounds dissolve in polar solvents (e.g., water) because water molecules **stabilize separated ions**.
Brittleness	When stress is applied, **like charges repel**, causing the lattice to break.
Giant Ionic Structure	Each ion is surrounded by oppositely charged ions in a **rigid, well-organized lattice**.

Questions.

Sarah is conducting an experiment in the chemistry lab and observes that when sodium metal reacts with fluorine gas, a white crystalline solid, sodium fluoride (NaF), is formed.

(a) Using electron configuration, explain how an ionic bond is formed between sodium and fluorine.
(b) Justify the role of electrostatic forces in holding the NaF compound together.
(c) Predict what will happen if sodium fluoride is dissolved in water and explain why.

EXPECTED ANSWERS

(a) **Formation of Ionic Bond between Sodium and Fluorine**:

Sodium (Na) has an atomic number of 11, meaning its electron configuration is $\mathbf{1s^2\ 2s^2\ 2p^6\ 3s^1}$. This means sodium has one electron in its outermost shell. Fluorine (F), with an atomic number of 9, has the electron configuration $\mathbf{1s^2\ 2s^2\ 2p^5}$, and needs one more electron to complete its outer shell, achieving a stable octet.

When sodium reacts with fluorine, sodium loses its single valence electron from the 3s orbital. This results in the formation of a sodium ion (Na^+) with a positive charge. On the other hand, fluorine gains the electron that sodium loses, forming a fluoride ion (F^-) with a negative charge. The electron transfer from sodium to fluorine creates oppositely charged ions, Na^+ and F^-.

These ions are held together by the electrostatic force of attraction between the positively charged sodium ion and the negatively charged fluoride ion, forming an ionic bond. This results in the formation of sodium fluoride (NaF).

(b) **Role of Electrostatic Forces in Holding NaF Together**:

In sodium fluoride, the Na^+ and F^- ions are held together by **strong electrostatic forces** of attraction, also known as ionic bonds. These forces occur because opposite charges attract each other. The Na^+ ion has a positive charge due to the loss of an electron, and the F^- ion has a negative charge due to the gain of an electron. The electrostatic attraction between these oppositely charged ions creates a stable ionic compound. The stronger the charge on the ions and the smaller their radii, the stronger the electrostatic force, making the ionic bond in NaF particularly strong.

(c) **What Happens When Sodium Fluoride Dissolves in Water**:

When sodium fluoride (NaF) is dissolved in water, it dissociates into its constituent ions: Na^+ and F^-. This happens because water molecules surround the Na^+ and F^- ions, effectively breaking the ionic bond between them.

The process can be explained by the polarity of water molecules. Water is a polar solvent, meaning it has a partial positive charge on the hydrogen atoms and a partial negative charge on the oxygen atom. The positive sodium ions (Na^+) are attracted to the negative side (oxygen) of the water molecules, while the negative fluoride ions (F^-) are attracted to the positive side (hydrogen) of the water molecules. This interaction between water molecules and ions helps to separate and disperse the Na^+ and F^- ions throughout the solution, dissolving NaF in water.

Thus, when NaF dissolves in water, it forms a solution of Na^+ and F^- ions in water.

2.Alex is preparing a solution by dissolving table salt (NaCl) and sugar ($C_{12}H_{22}O_{11}$) in water. He notices that NaCl **conducts electricity**, but sugar does not.

(a) Explain why NaCl is able to conduct electricity in solution, but sugar is not.
(b) Compare the structural composition of NaCl and sugar.
(c) Based on bond strength, explain why NaCl has a higher melting point than sugar.

EXPECTED ANSWERS.

(a) **Why NaCl Conducts Electricity in Solution, but Sugar Does Not:**

NaCl (sodium chloride) is an ionic compound, and when it dissolves in water, it dissociates into its constituent ions: Na^+ (sodium ion) and Cl^- (chloride ion). These free-moving ions are capable of carrying electrical charge through the solution, allowing it to conduct electricity. The water molecules, being polar, surround and separate the Na^+ and Cl^- ions, facilitating their movement and conductivity.

On the other hand, sugar ($C_{12}H_{22}O_{11}$) is a covalent compound, and when it dissolves in water, it does not dissociate into ions. Instead, it dissolves as whole molecules. Since there are no free ions to move and carry electrical charge, sugar solution does not conduct electricity.

(b) **Comparison of the Structural Composition of NaCl and Sugar:**

- **NaCl (Sodium Chloride):** NaCl has an **ionic** structure. It is composed of Na^+ (sodium ions) and Cl^- (chloride ions) arranged in a **regular, repeating 3D lattice**. The ions are held together by **strong electrostatic forces of attraction** between oppositely charged ions. This ionic bonding is what gives NaCl its high melting and boiling points.
- **Sugar ($C_{12}H_{22}O_{11}$):** Sugar, specifically sucrose, is a **covalent** compound composed of carbon, hydrogen, and oxygen atoms. The atoms are connected by **covalent bonds**, where electrons are shared between atoms. Sugar molecules are neutral and do not form ions in solution, which is why it does not conduct electricity. The structure of sugar consists of long carbon chains with hydroxyl (OH) groups attached, forming a molecular compound.

(c) **Why NaCl Has a Higher Melting Point than Sugar:**

NaCl has a **higher melting point** than sugar due to the **strong ionic bonds** that hold the sodium and chloride ions together in the crystal lattice. These electrostatic forces of attraction are very strong, requiring a large amount of energy to break the bonds and separate the ions, leading to a high melting point for NaCl.

In contrast, sugar is held together by **covalent bonds** between the atoms within its molecules. While covalent bonds are strong within the molecules themselves, the forces between individual sugar molecules (called intermolecular forces) are much weaker than the ionic bonds in NaCl. Therefore, it takes less energy to separate the sugar molecules and melt the substance, resulting in a lower melting point for sugar.

Question:3
In cold regions, **calcium chloride ($CaCl_2$) is used to melt ice** on roads faster than sodium chloride (NaCl).

(a) Explain the formation of $CaCl_2$ in terms of electron transfer.
(b) How does the ionic structure of $CaCl_2$ contribute to its effectiveness in melting ice faster than NaCl?
(c) Predict what happens to the **conductivity** of an aqueous $CaCl_2$ solution when more water is added.

EXPECTED ANSWERS

(a) **Formation of $CaCl_2$ in Terms of Electron Transfer:**

Calcium chloride ($CaCl_2$) is an ionic compound formed when calcium (Ca) reacts with chlorine (Cl). Calcium has an atomic number of 20, with an electron configuration of **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$**. Calcium has two valence electrons in its outermost shell (the $4s^2$ electrons). To achieve a stable electron configuration, calcium loses these two electrons, forming a **Ca^{2+} ion** with a 2+ charge.

Chlorine, on the other hand, has an atomic number of 17 with an electron configuration of **$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$**. Chlorine needs one more electron to complete its outer shell and achieve a stable octet. Each chlorine atom gains one electron to form a **Cl^- ion** with a negative charge. Since two chloride ions are needed to balance the charge of one calcium ion, the formula for calcium chloride is **$CaCl_2$**.

In summary, calcium loses two electrons to form **Ca^{2+}**, and each chlorine atom gains one electron to form **Cl^-**, resulting in the formation of an ionic compound, $CaCl_2$.

(b) **How the Ionic Structure of $CaCl_2$ Contributes to Its Effectiveness in Melting Ice Faster Than NaCl:**

The ionic structure of $CaCl_2$ plays a significant role in its ability to melt ice faster than NaCl. The key differences include:

- **Ionic Dissociation:** When $CaCl_2$ dissolves in water, it dissociates into **Ca^{2+}** and **Cl^-** ions. Since $CaCl_2$ dissociates into **three ions** (one Ca^{2+} and two Cl^- ions), it increases the number of ions in solution compared to NaCl, which dissociates into only two ions (one Na^+ and one Cl^-). More ions in solution means more **collisions** with the ice, leading to a faster melting rate because the presence of more ions helps to lower the freezing point of water more effectively.
- **Charge and Ionic Size:** The **Ca^{2+} ion** has a **higher charge** and is **smaller** than the Na^+ ion, making it more effective at disrupting the hydrogen bonding in ice. The higher charge density of the Ca^{2+} ion leads to a stronger attraction to water molecules, further lowering the freezing point and causing the ice to melt faster.

Thus, the ionic structure of $CaCl_2$, which produces more ions in solution and features a highly charged Ca^{2+} ion, contributes to its superior ability to melt ice faster than NaCl.

(c) **Effect on the Conductivity of an Aqueous $CaCl_2$ Solution When More Water Is Added:**

When more water is added to an aqueous $CaCl_2$ solution, the **conductivity of the solution will decrease**. This is because conductivity in an ionic solution is dependent on the concentration of ions. When you add more water, the ions are **diluted**, meaning there are fewer ions per unit volume to carry the electric charge. As a result, the solution becomes less conductive.

However, even after dilution, the aqueous $CaCl_2$ solution will remain conductive because it still contains ions (Ca^{2+} and Cl^-), but the conductivity will be **proportional to the concentration of ions** in the solution. Therefore, more water reduces the number of ions per unit of solution, lowering its electrical conductivity.

DISSCUSION QUESTION (LET LEAENERS DISSCUSS IN GROUPS)

The Use of Sodium Chloride in Food Preservation

Imagine you are a food scientist working for a large food processing company. Your team is tasked with improving the shelf life of various food products, especially meats and vegetables, without using harmful preservatives. After conducting research, you find that sodium chloride (NaCl), commonly known as table salt, can be used as an effective preservative due to its ionic nature.

You're now preparing a report for your company's stakeholders on how ionic bonding in sodium chloride helps prevent spoilage in food products. In your report, you must address both the chemistry behind ionic bonding and the real-life application of NaCl in food preservation.

a) Describe the process of ionic bonding between sodium (Na) and chlorine (Cl) atoms in the formation of sodium chloride (NaCl).
b) Explain how the transfer of electrons between sodium and chlorine atoms leads to the formation of ions, and why this process results in the creation of an electrically neutral compound.

C) Explain how sodium chloride, as an ionic compound, contributes to the preservation of food, specifically in meats and vegetables.
d) Discuss the role of ionic bonds in the ability of sodium chloride to draw water out of cells in food, and how this process helps prevent the growth of bacteria and spoilage.
e) What would happen if sodium chloride were replaced by a compound that does not form ionic bonds, such as a molecular compound? How might this impact the preservation process?

f) Sodium chloride is widely used in food preservation, but excessive salt intake can lead to health issues like high blood pressure. Discuss the balance between the effectiveness of NaCl in food preservation and its potential health risks when consumed in large amounts.

e) Suggest alternative ionic compounds or methods that might be used for food preservation to minimize health risks, and explain how these alternatives would function at the molecular level.

Expected response.

a) Process of Ionic Bonding Between Sodium (Na) and Chlorine (Cl) Atoms in NaCl:

- Sodium (Na) is an alkali metal with one electron in its outer shell. Chlorine (Cl) is a halogen with seven electrons in its outer shell. To achieve a stable electron configuration (resembling the nearest noble gas), sodium loses its outer electron, becoming a positively charged ion (Na^+), while chlorine gains the electron, becoming a negatively charged ion (Cl^-).
- The loss of an electron by sodium and the gain of an electron by chlorine results in the formation of Na^+ and Cl^- ions. These oppositely charged ions attract each other due to electrostatic forces, forming an ionic bond and producing the compound sodium chloride (NaCl).

b) Transfer of Electrons and Formation of Electrically Neutral Compound:

- Sodium (Na) has one electron in its outer shell and needs to lose it to achieve a stable electron configuration. When it loses its electron, it becomes a positively charged ion (Na^+). Chlorine (Cl) has seven electrons in its outer shell and needs one more to complete its octet. By gaining the electron from sodium, it becomes a negatively charged ion (Cl^-).

- The Na^+ and Cl^- ions have equal but opposite charges, meaning the total positive charge equals the total negative charge, making the compound electrically neutral. Therefore, sodium chloride (NaCl) is a stable, electrically neutral compound due to the balance between the positive and negative charges.

a) Contribution of Sodium Chloride to Food Preservation:

- Sodium chloride (NaCl) helps preserve food, particularly meats and vegetables, by creating an environment where bacteria and other microorganisms cannot easily grow. It works by drawing water out of the cells of both the food and any microbes present. Without sufficient water, bacteria cannot survive, thus preventing spoilage.
- The high concentration of salt creates a hypertonic environment, where water moves out of the bacterial cells through osmosis, causing the bacteria to dehydrate and die, preventing spoilage in food.

b) Role of Ionic Bonds in Sodium Chloride's Effect on Water in Food:

- Sodium chloride, being an ionic compound, dissociates into Na^+ and Cl^- ions in solution. These ions interact with the water molecules in the food, disrupting the normal balance of water within cells.
- When salt is applied to food, the Na^+ ions surround water molecules and reduce the water's availability to microbes and plant cells. In turn, this leads to the loss of water from food cells and bacteria (osmosis), effectively preserving the food by preventing the growth of microorganisms that require water to thrive.

c) Impact of Replacing Sodium Chloride with a Non-Ionic Compound:

- If sodium chloride were replaced by a compound that does not form ionic bonds (e.g., a molecular compound like sugar), the preservative effect would be significantly reduced. Non-ionic compounds do not dissociate into ions, and therefore would not create the same osmotic pressure needed to draw water out of microbial cells.
- As a result, the ability to prevent bacterial growth and spoilage would be diminished, and the food would spoil more quickly.

a) Effectiveness of NaCl in Food Preservation vs. Health Risks:

- While sodium chloride is an effective preservative, excessive consumption of salt can lead to health issues such as high blood pressure, cardiovascular disease, and kidney problems. The balance between the effectiveness of NaCl in preserving food and the potential health risks of excessive salt consumption is a major concern in modern diets.
- To mitigate health risks, it is important to limit salt intake while still utilizing its preservative properties in food. This can be achieved through methods like reducing the amount of salt used in food preservation or using salt in combination with other preservation techniques (e.g., refrigeration, drying).

b) Alternative Ionic Compounds or Methods for Food Preservation:

- Alternatives to sodium chloride in food preservation might include other ionic compounds, such as calcium chloride ($CaCl_2$) or potassium chloride (KCl). These compounds also work by drawing water out of microbial cells, but they may be less harmful to health when consumed in larger quantities compared to sodium chloride.
- Calcium chloride is sometimes used in the preservation of fruits and vegetables, especially in pickling, as it maintains the firmness of the produce and inhibits microbial growth.
- Potassium chloride is often used as a salt substitute for people who need to limit sodium intake. It still provides a salty taste but with less sodium, and it can also contribute to food preservation by lowering water activity.

QUESTION.

In Uganda, aluminum oxide (Al_2O_3) is extracted from **bauxite deposits found in Kigezi and other regions**. The extraction of aluminum from **bauxite ore** is an essential process in manufacturing materials such as **roofing sheets, cooking utensils, and electrical cables**.

A group of chemistry students from Makerere University visits **Mpondwe mining site** in Kasese to study the properties of **Al_2O_3**. During their experiments, they make the following observations:

1. **Al_2O_3 has a very high melting point (~2072°C).**
2. **It does not conduct electricity in solid form but does in molten form.**
3. **It is stronger than sodium chloride (NaCl) and is not easily soluble in water.**

a)Using the electron configuration of aluminum and oxygen, explain how Al_2O_3 forms through ionic bonding.

b)Describe the role of electrostatic forces in stabilizing the Al_2O_3 crystal structure

c). Why does Al_2O_3 have a much higher melting point than sodium chloride (NaCl)? Relate your answer to the charge of ions and bond strength.
d) Explain why aluminum oxide does not conduct electricity in solid form but becomes conductive when molten.

e). Compare the ionic bond strength of Al_2O_3 with NaCl and explain why Al_2O_3 is generally stronger and less soluble.

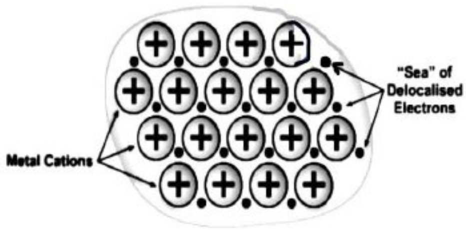
FORMATION OF METALLIC BONDS

- **Definition**: A metallic bond is the electrostatic force of attraction between positively charged metal ions (cationic lattice) and delocalized free electrons.
- **Structure**:

A metallic solid consists of a lattice of metal ions.

The outermost electrons are **delocalized** and move freely throughout the structure,forming a **"sea of electrons."**

Electrostatic Attraction: Exists between delocalized electrons and metal cations.



The metallic bond is the bond that is responsible for the properties of metals.

1.High melting and boiling points.

This is because of a high amount of energy is required to break the strong metallic bonds. Melting point increases as the number of electrons contributed per atom of a metal towards metallic bonding increases. Transition elements have higher melting points than main group elements because their atoms contribute both 4s and 3d electrons towards bonding.

Qn. Explain why group II elements form metals with higher melting and boiling points than group I elements

Both group I and group II elements form **metallic bonds** whose **strength depend on the number of electrons contributed per atom** to the formation of the metallic bonds. Group II elements **contribute two electrons per atom** forming **stronger metallic bonds that require a higher amount of energy to break than Group I elements which only contribute one electron per atom towards forming weaker metallic bonds that require a lower amount of energy to break**.

2.Electrical conductivity Metals are good conductors of electricity and heat due to presence of free mobile electrons throughout the lattice. If a potential difference is applied between the ends of a metal, the delocalized electron cloud will towards the positive potential.

However, electrical conductivity of a metal decreases with increase in temperature because resistance increases. This is because increase in temperature increases thermal vibration within the metal. The regularity within the metallic lattice is upset and therefore the electrons cannot easily move in the lattice.

3.Thermal conductivity They conduct heat due to exchange of kinetic energy between free mobile electrons in the lattice. When heat is supplied to one end of a piece of a metal, the kinetic energy of the electrons is increased. This increase in kinetic energy is transmitted through the system of delocalized electrons to other parts of the metal.

4.Malleability and ductility Metals are malleable (can be hammered-beaten into sheets) and ductile (can be drawn out under tension-pulled out into wires). This is due to the ability of layers of atoms to roll over each other into new positions without breaking the metallic bond.

5.Insoluble in polar and non-polar solvents. The metal-metal attractions are much stronger than the solvent-solvent attractions or the metal-solvent attractions. The solvent molecules cannot penetrate the metal lattice.

Strength of a metallic bond

The strength of a metallic bond is determined by three factors;

1.Charge of the cation

The higher the cationic charge, the stronger the metallic bond because there will be a stronger attraction of the delocalized electrons.

2. Number of delocalised electrons per atom The higher the number of electrons contributed per atom towards metallic bonding, the stronger the metallic bond. This is because there will be a greater attraction between the nucleus and the delocalised electrons.

3. ***Ionic radius*** The smaller the ionic radius of the cation, the stronger the metallic bond because there will be a stronger attraction of the delocalised electrons

Comparison of Ionic and Metallic Bonds

Aspect	**Ionic Bonds**	**Metallic Bonds**
Electron Behavior	Complete electron transfer from metal to nonmetal	Electrons delocalized in a "sea of electrons"
Bond Strength	Strong electrostatic forces between ions	Strong electrostatic forces between cations and free electrons
Melting/Boiling Points	High	Generally high (varies with metal type)
Electrical Conductivity	Conducts in molten/aqueous state	Conducts in solid and molten states
Malleability & Ductility	Brittle (shatters under stress)	Malleable and ductile (layers slide)
Solubility	Soluble in polar solvents	Insoluble in most solvents
Structural Composition	**Giant ionic lattice** – rigid and strong	**Metallic lattice** – flexible and conductive

Questions.

In Uganda, metals like **copper, aluminum, and steel** are widely used in making **electrical wires, roofing sheets, and coins**. A group of students from Makerere University visits a **metal processing plant in Jinja** to study why these materials are preferred.

During their study, they observe that:

1. **Metals are good conductors of electricity.**
2. **Metals are strong but can be hammered into sheets (malleable) and drawn into wires (ductile).**

3. **Metals have high melting and boiling points.**

Questions

(a) Justification of Metallic Bond Formation Based on Electron Delocalization and Electrostatic Forces.

1. Describe how metallic bonding occurs in copper (Cu) using the electron sea model.
2. Explain the role of electrostatic forces in keeping metallic structures stable.

(b) Evaluation of the Properties of Metals in Relation to Bond Strength and Structural Composition (U)

3. Why is copper (Cu) used in electrical wires instead of sodium (Na)?
4. Explain why metals are malleable and ductile, while ionic compounds like NaCl are brittle.
5. Why do metals have high melting and boiling points? Relate your answer to bond strength.

Expected answers.

(a) Justification of Metallic Bond Formation Based on Electron Delocalization and Electrostatic Forces

1. Metallic Bonding in Copper (Cu) Using the Electron Sea Model:
Copper atoms in a metallic structure release their valence electrons into a shared pool of free-moving electrons, forming a "sea of electrons" that surrounds the positively charged Cu^{2+} ions. These delocalized electrons are not bound to any specific atom but move freely throughout the metal lattice, allowing for electrical and thermal conductivity. The strong attraction between these mobile electrons and the metal cations holds the structure together, creating a metallic bond.

2. Role of Electrostatic Forces in Stabilizing Metallic Structures:
The stability of metallic structures arises from the strong electrostatic forces between the positively charged metal ions and the delocalized electrons. This attraction prevents the metal cations from repelling each other and maintains the solid structure. The flexibility of the electron sea also allows metals to withstand stress without breaking, contributing to their ductility and malleability.

(b) Evaluation of the Properties of Metals in Relation to Bond Strength and Structural Composition

1. Why Copper (Cu) Is Used in Electrical Wires Instead of Sodium (Na):

- Copper has a **higher electrical conductivity** than sodium due to a greater number of delocalized electrons per atom.

- Copper has a **higher melting point (1,085°C) compared to sodium (98°C)**, making it more heat-resistant and durable.
- Copper is **less reactive** than sodium, which readily oxidizes and can react violently with water and air, making it unsuitable for wiring.

2. Why Metals Are Malleable and Ductile, While Ionic Compounds Like NaCl Are Brittle:

- Metals are **malleable and ductile** because their atoms are arranged in layers that can slide over one another without breaking the metallic bonds. The electron sea allows this movement without disrupting the structure.
- Ionic compounds like NaCl are **brittle** because they consist of alternating positive and negative ions in a rigid lattice. When force is applied, like charges align and repel each other, causing the structure to fracture.

3. Why Metals Have High Melting and Boiling Points (Relation to Bond Strength):

- Metallic bonds are **strong due to the powerful attraction between delocalized electrons and positive ions** in the lattice.
- A large amount of energy is required to break these bonds, resulting in **high melting and boiling points**.
- The more delocalized electrons present and the higher the charge of metal cations, the **stronger the metallic bond**, which further increases melting and boiling points. For example, tungsten (W) has a very high melting point due to strong metallic bonding.

Question2.

Aluminum is used to manufacture **boda-boda parts, vehicle bodies, and airplane frames** because it is **lightweight but strong**. A group of students from Kyambogo University investigates why aluminum is preferred in transportation over other metals.

a).How does metallic bonding explain the strength of aluminum?

b) Why does aluminum not break easily when stretched or bent?

c).Why is aluminum used in making boda-boda and car bodies instead of iron?

d).Compare the conductivity of aluminum and iron. Why is aluminum sometimes used instead of copper in electrical transmission lines?

e).Aluminum is used in making airplane frames. How does metallic bonding contribute to its ability to withstand pressure and extreme temperatures?

Expected answers.

(a) How Metallic Bonding Explains the Strength of Aluminum

Aluminum (Al) atoms form a metallic bond through the **electron sea model**, where valence electrons are delocalized and move freely around a lattice of positively charged Al^{3+} ions.

This **strong electrostatic attraction** between the mobile electrons and metal cations holds the structure together, giving aluminum its **high strength** while maintaining flexibility.

(b) Why Aluminum Does Not Break Easily When Stretched or Bent

Aluminum is **malleable and ductile**, meaning it can be stretched or bent without breaking. This is because metallic bonds allow layers of aluminum atoms to **slide over each other** without breaking the structure, thanks to the **delocalized electrons** that continue to hold the metal together even when deformed.

(c) Why Aluminum Is Used for Boda-Boda and Car Bodies Instead of Iron

Lightweight: Aluminum is much lighter than iron, reducing the overall weight of vehicles, improving fuel efficiency, and making boda-bodas and cars easier to handle.

Corrosion Resistance: Unlike iron, which rusts when exposed to oxygen and moisture, aluminum forms a **protective oxide layer** that prevents further corrosion.

trength-to-Weight Ratio: Aluminum provides **sufficient strength** while being much lighter than iron, making it ideal for transportation applications.

(d) Comparison of Aluminum and Iron Conductivity & Why Aluminum Is Used Instead of Copper in Electrical Transmission Lines

- **Conductivity**: Aluminum is a **better conductor of electricity** than iron but not as good as copper. However, aluminum's conductivity is still **high enough** for electrical applications.
- **Why Use Aluminum Instead of Copper?**

Lightweight: Aluminum is **much lighter** than copper, making it easier and cheaper to install over long distances.

Cost-Effective: Copper is more expensive than aluminum, making aluminum a **cheaper alternative** for transmission lines.

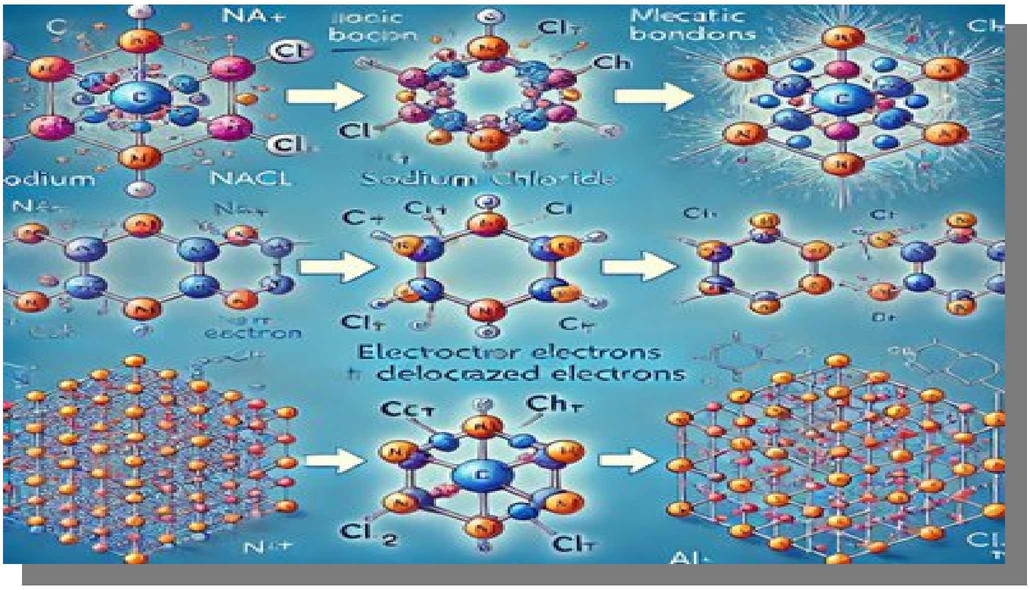
Corrosion Resistance: Aluminum naturally forms an **oxide layer** that protects it from environmental damage, unlike copper, which can corrode over time.

(e) How Metallic Bonding Helps Aluminum Withstand Pressure and Extreme Temperatures in Airplane Frames

- **Metallic bonds are strong**, preventing aluminum from breaking under high pressure or stress.
- **Delocalized electrons help distribute force**, allowing aluminum to bend without snapping.
- **High thermal conductivity** enables aluminum to resist damage from extreme temperature changes at high altitudes.
- **Oxide layer protection** prevents degradation in harsh environmental conditions, such as freezing temperatures or moisture.

END OF TOPIC QUESTION.

Uganda's economy relies heavily on **mining, construction, and manufacturing industries**, which use different types of bonds in materials. Two students, **Aisha and John**, are conducting a research project at **Jinja Steel Rolling Mills and Tororo Cement Factory** to investigate the use of different metallic and ionic compounds in industrial applications.



During their study, they observe the following:

1. **Sodium chloride (NaCl) is used in food processing but cannot be used to make electrical cables.**
2. **Aluminum (Al) and Copper (Cu) are widely used in making electrical wires.**
3. **Steel (an alloy of iron and carbon) is used in construction because it is stronger than pure iron.**
4. **Calcium oxide (CaO) is used in making cement and has a high melting point.**

To understand these observations, they investigate the **bonding nature of different materials** and how it influences their propertie

(a) Justification of Ionic Bond Formation Based on Electron Transfer and Electrostatic Forces (10 Marks)

1. **Using electron configurations, explain how sodium chloride (NaCl) is formed through ionic bonding. (3 Marks)**
2. **Draw a diagram showing the electron transfer that occurs in NaCl formation. (3 Marks)**
3. **Why does NaCl dissolve in water but not conduct electricity in solid form? (2 Marks)**
4. **Calcium oxide (CaO) has a very high melting point. Explain how its bonding contributes to this property. (2 Marks)**

(b) Justification of Metallic Bond Formation Based on Electron Delocalization and Electrostatic Forces (U, S) (10 Marks)

5. **Describe how metallic bonding occurs in copper (Cu), including the concept of the "sea of electrons." (3 Marks)**
6. **Draw a labeled diagram illustrating the metallic bonding in aluminum. (3 Marks)**
7. **Why is copper a better conductor of electricity than iron? (2 Marks)**
8. **Explain why metals like aluminum and copper are ductile and malleable, while ionic compounds like NaCl are brittle. (2 Marks)**

Evaluation of Properties of Ionic and Metallic Compounds in Relation to Bond Strength and Structural Composition (U) (10 Marks)

9. **Compare the melting points of NaCl and Cu. Why does copper have a lower melting point than calcium oxide (CaO) but a higher melting point than sodium chloride? (4 Marks)**
10. **Steel (an alloy of iron) is used in construction because it is stronger than pure iron. Explain how metallic bonding contributes to its strength. (3 Marks)**
11. **Aluminum is used in airplane bodies, while steel is used in bridges. How does the nature of metallic bonds help these metals withstand heavy loads and extreme temperatures? (3 Marks)**.

ADDITIONAL READING.

Covalent character in ionic compounds

The partial covalent character of an ionic bond is explained in terms of **polarising power** and **polarisability**.

1. Polarising power ***Polarising power is the power of a cation to distort the electron cloud of an anion.*** The greater the polarising power of the cation, the greater the tendency of the cation to form a covalent bond. Polarising power of a cation depends on;

(i) Charge of the cation Cations with high charges have high polarising power. The larger the positive charge on the ion, the greater the attraction of the valence electrons. The ion therefore has a higher polarising power than the due to its higher charge.

(ii) Cationic radius The smaller the ionic radius, the higher the polarising power of the cation. The ion therefore has a higher polarising power than the due to its smaller ionic radius.

(iii) Charge density or charge-radius ratio. Charge density is the ratio of ionic charge to ionic radius.

Ion	Na^+	Mg^{2+}	Al^{3+}
Ionic radius(nm)	0.095	0.065	0.050
Charge density	$\frac{1}{0.095} = 10.53\ (nm)^{-1}$	$\frac{2}{0.065} = 30.77\ (nm)^{-1}$	$\frac{3}{0.050} = 60\ (nm)^{-1}$

The higher the charge density, the higher the polarising power of the cation. From the table above, charge density and hence polarising power increases in the order .The covalent character of the chlorides formed by the elements increases from sodium chloride to magnesium chloride to aluminium chloride due to the increase in polarising power.

In general, compounds in which a cation has a **high charge** and **small ionic radius** tend to have a **high charge density** and **high polarising power**. This makes such compounds tend to a covalent character and exhibit properties contrary to ionic compounds Aluminium chloride, beryllium chloride, aluminium hydride, beryllium hydride, beryllium oxide and beryllium hydroxide are partly covalent for reasons explained above.

Polarisability ***Polarisability is the ease by which the electron cloud of the anion can be distorted***. The greater the polarisability of the anion, the greater the tendency of the anion to form a covalent bond. Polarisability of an anion depends on the **size of the anion** The smaller the anion, the lower it is polarizable and the larger the anion, the easier it is polarize.

QUESTION.

Imagine you are a Ugandan chemist working at a local factory that manufactures salts used in agricultural fertilizers. The factory produces two types of salts: one is sodium chloride (NaCl) used for general purposes, and the other is magnesium chloride ($MgCl_2$) used to enhance soil nutrients for specific crops.

You are tasked with advising the factory on which salt would be more effective in improving the efficiency of fertilizers, taking into account the covalent character of the salts.

In Uganda, farmers often face challenges with soil that has high levels of clay, which has negatively charged particles that can easily attract cations. You know that the higher the covalent character in an ionic compound, the more likely it is to interact with soil particles and nutrients in a beneficial way.

Question:

Given that the magnesium ion (Mg^{2+}) is smaller and has a higher charge compared to the sodium ion (Na^{+}), and both salts contain chloride ions (Cl^{-}),

which salt—NaCl or $MgCl_2$—would you expect to have more covalent character and why? Consider the effect of polarization and how this might impact its effectiveness in Ugandan soils, particularly in areas with high clay content**.**

QUESTION2.

Scenario: In Uganda, you are conducting an experiment in a local laboratory where you compare two ionic compounds, sodium chloride (NaCl) and aluminum chloride ($AlCl_3$), to determine their melting points.

You observe that sodium chloride has a high melting point of 801°C, while aluminum chloride has a significantly lower melting point of 192°C in its anhydrous form. As you continue your research, you realize that both compounds are commonly used in industrial processes, such as salt production and aluminum refining.

Question: In the context of Ugandan industries, explain the difference in the melting points of sodium chloride and aluminum chloride. How do the covalent character of their ionic bonds and the polarization of the anions by the cations influence their melting points? Consider the size and charge of the cations in relation to their effects on the ionic bonds, and how this might impact their practical applications in Ugandan industries.