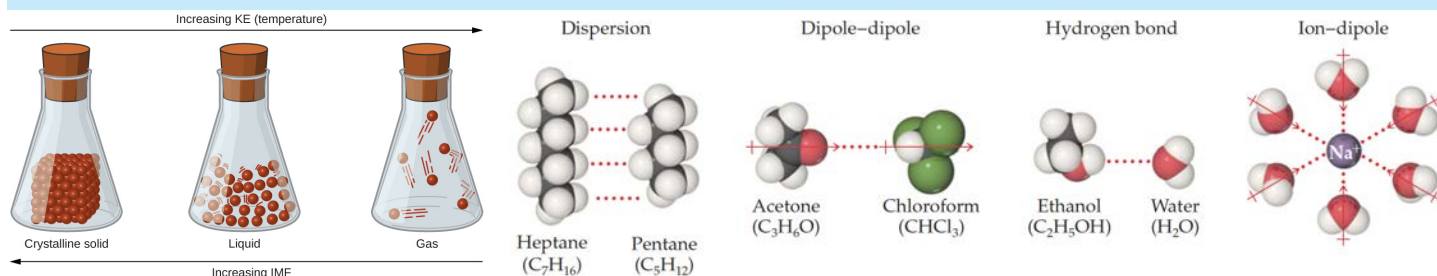


Unit 3 - Intermolecular Forces & Properties



3.1 Intermolecular Forces

3.2 Properties of Solids

3.3 Solids, Liquids & Gases

3.4 Ideal Gas Law

3.5 Kinetic Molecular Theory

3.6 Deviation from Ideal Gas Law

3.7 Solutions & Mixtures

3.8 Representations of Solutions

3.9 Separation of Solutions & Mixtures Chromatography

3.10 Solubility

3.11 Spectroscopy & Electromagnetic Spectrum

3.12 Photoelectric Effect

3.13 Beer-Lambert Law

UNIT 3

Intermolecular Forces and Properties



This logo shows it is a *Topic Question* - it should only require knowledge included in this Topic *and* it should be giving practice in the *Science Practice* associated with this Topic.

Science Practices

18–22% AP Exam Weighting

2.C 2.D 2.E 3.C 4.C 4.D 5.C 5.F

| Enduring Understanding | Topic | Suggested Skill |
|------------------------|---|--|
| SAP-5 | 3.1 Intermolecular Forces | 4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties. |
| | 3.2 Properties of Solids | 4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations. |
| SAP-6 | 3.3 Solids, Liquids, and Gases | 3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic). |
| SAP-7 | 3.4 Ideal Gas Law | 5.C Explain the relationship between variables within an equation when one variable changes. |
| | 3.5 Kinetic Molecular Theory | 4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations. |
| | 3.6 Deviation from Ideal Gas Law | 6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels. |
| | 3.7 Solutions and Mixtures | 5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures). |

| Enduring Understanding | Topic | Suggested Skill |
|------------------------|--|--|
| SPQ-3 | 3.8 Representations of Solutions | 3.C Represent visually the relationship between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic). |
| | 3.9 Separation of Solutions and Mixtures Chromatography | 2.C Identify experimental procedures that are aligned to the question (which may include a sketch of a lab setup). |
| | 3.10 Solubility | 4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties. |
| SAP-8 | 3.11 Spectroscopy and the Electromagnetic Spectrum | 4.A Explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations. |
| | 3.12 Photoelectric Effect | 5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures). |
| | 3.13 Beer-Lambert Law | 2.E Identify or describe potential sources of experimental error. |

LEARNING OBJECTIVE

SAP-5.B

Explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.

ESSENTIAL KNOWLEDGE

SAP-5.B.4

In covalent network solids, the atoms are covalently bonded together into a three-dimensional network (e.g., diamond) or layers of two-dimensional networks (e.g., graphite). These are only formed from nonmetals: elemental (e.g., diamond, graphite) or binary compounds of two nonmetals (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points. Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However, graphite is soft because adjacent layers can slide past each other relatively easily.

SAP-5.B.5

Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers.

SAP-5.B.6

Metallic solids are good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting.

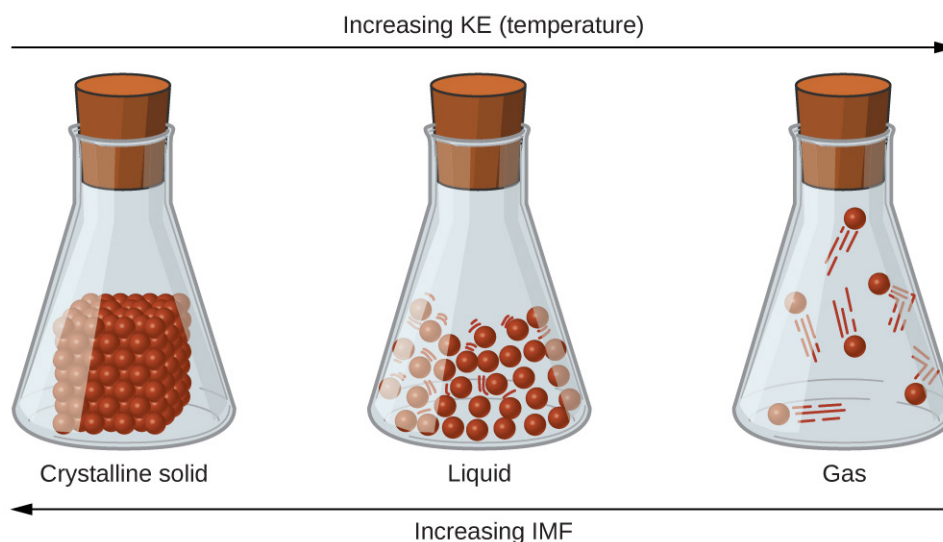
LEARNING OBJECTIVE

ESSENTIAL KNOWLEDGE

SAP-5.B.7

In large biomolecules or polymers, noncovalent interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions.

3.2 Properties of Solids

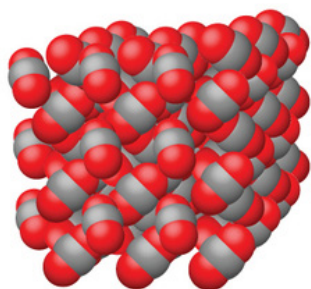


Just about all substances can be found in the solid, liquid or gas phase, depending on temperature and pressure. Those with the strongest *Intermolecular Forces* are most likely to be found in the solid phase at s.t.p. (*standard temperature & pressure* - 25° C and 1 atm pressure)

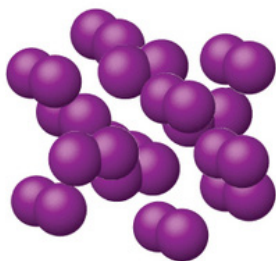
Typically,

Ionic bonding -
Metallic bonding -
Covalent bonding -

all ionic compounds are solids at s.t.p.
all metals except *Mercury* are solids at s.t.p.
all covalent networks are solids at s.t.p.
covalent molecules depend on strength of *van der waals forces*.



carbon dioxide

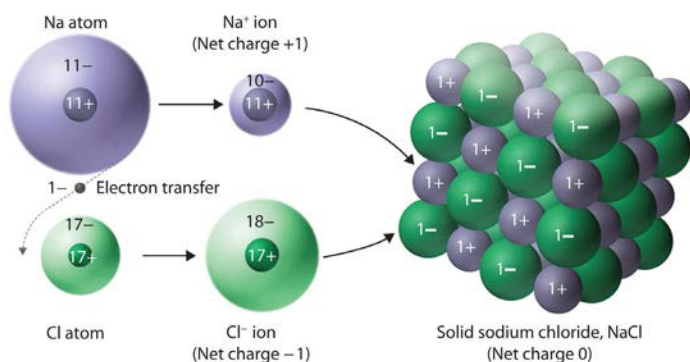


iodine

CO₂ and I₂ are both non-polar molecules and rely on *London Dispersion Forces*.

CO₂ is a gas at s.t.p. so LDF's are relatively weak. LDF's in I₂ are stronger and iodine is a solid at s.t.p.

Ionic Lattices

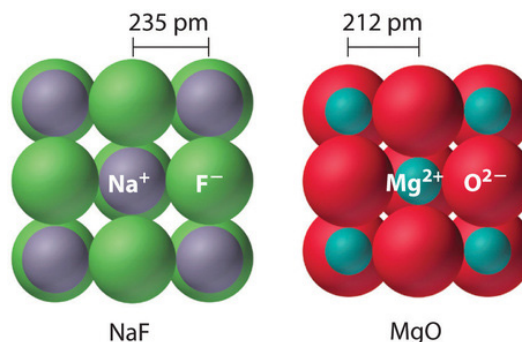


Ionic compounds benefit from *many strong interactions at short distances*.

$$F = q_1 q_2 / r^2$$

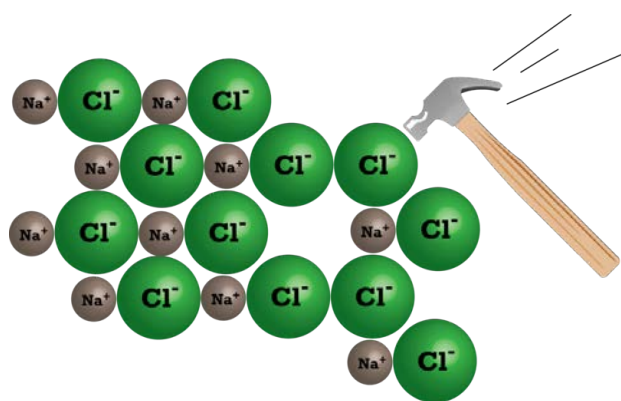
Melting points and lattice enthalpies can be used to compare the strengths of ionic bonds.

| COMPOUND | FORMULA | MELTING POINT (°C) | SUM OF IONIC RADII (PM) |
|-----------------|---------|--------------------|-------------------------|
| Sodium Chloride | NaCl | 801 | 283 |
| Sodium Fluoride | NaF | 996 | 235 |
| Calcium Oxide | CaO | 2898 | 240 |
| Strontium Oxide | SrO | 2531 | 258 |
| Barium Oxide | BaO | 1972 | 275 |



From the table, it can be deduced that the *charge on the ions* ($q_1 q_2$) has the biggest influence on the force of attraction but, when comparing compounds with same charges, the *distance* (r^2) will explain differences. Distance can be considered to be the sum of the two ionic radii.

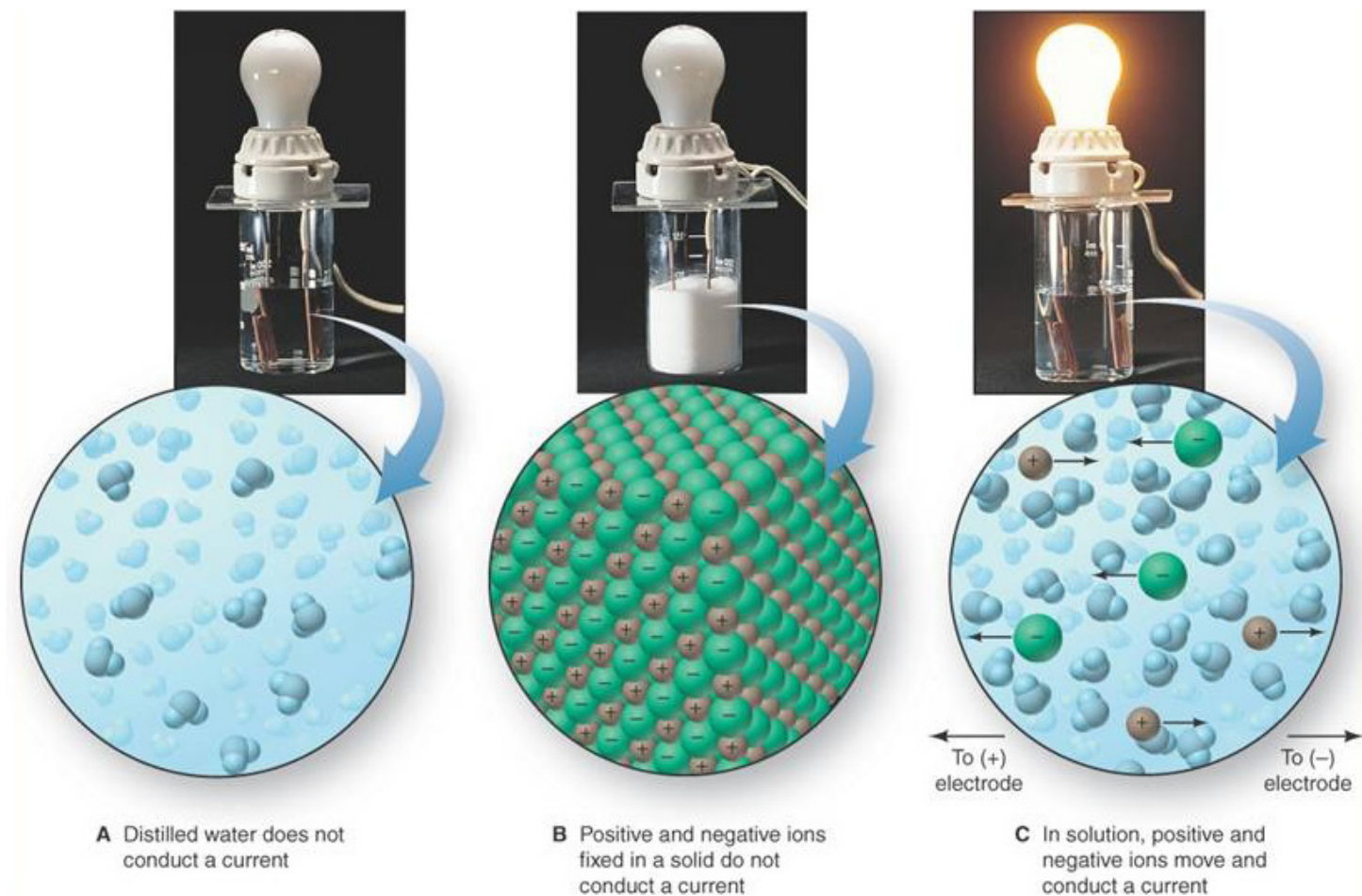
| TABLE 6.3 Lattice Energies of Some Ionic Solids (kJ/mol) | | | | | |
|--|----------------|-----------------|-----------------|----------------|-----------------|
| Cation | Anion | | | | |
| | F ⁻ | Cl ⁻ | Br ⁻ | I ⁻ | O ²⁻ |
| Li ⁺ | 1036 | 853 | 807 | 757 | 2925 |
| Na ⁺ | 923 | 787 | 747 | 704 | 2695 |
| K ⁺ | 821 | 715 | 682 | 649 | 2360 |
| Be ²⁺ | 3505 | 3020 | 2914 | 2800 | 4443 |
| Mg ²⁺ | 2957 | 2524 | 2440 | 2327 | 3791 |
| Ca ²⁺ | 2630 | 2258 | 2176 | 2074 | 3401 |
| Al ³⁺ | 5215 | 5492 | 5361 | 5218 | 15,916 |



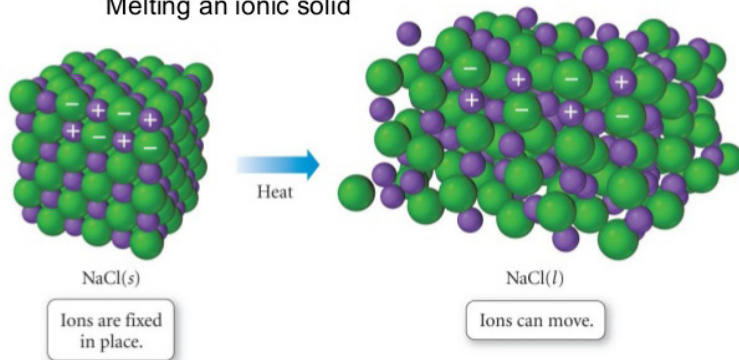
The same pattern is seen when considering lattice enthalpies. In general, ionic compounds will have *high melting and boiling points*. There will be very little tendency to produce gas so *vapour pressures will be extremely low*.

Though they can be considered *hard solids*, ionic compounds are *very brittle* as any distortion in the ionic lattice can produce strong repulsion forces that will break the crystal apart.

The best definitions of an *electric current* describe it in terms of the *movement of charge*. Charge carriers can include *electrons, protons, ions* and even 'positive holes'.



Melting an ionic solid



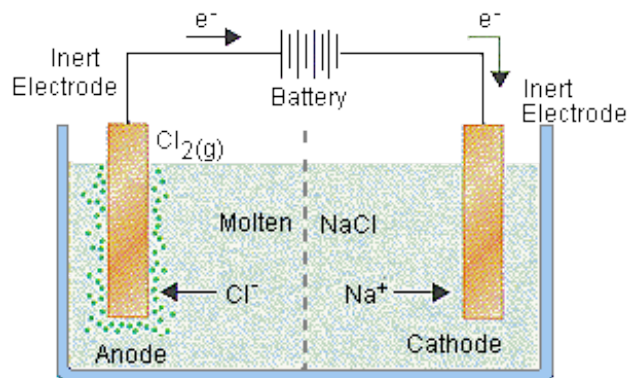
Ionic compounds can be considered as *conductors* - more often referred to as *electrolytes* - but only when *their ions are free to move*.

This can be achieved by *melting* the ionic compound or (usually easier) by *dissolving it in water* or some other suitable solvent.

It must be stressed that *electrons do not flow through ionic compounds*. They do not conduct like metals.

Instead, *reactions at the electrodes* will produce a *flow of electrons in the external circuit* - allowing bulbs to light, buzzers to ring etc.

The ionic compound is broken down as a result - *Electrolysis*.



Intermolecular Forces

3.2 Practice Problems - Part 1

1.

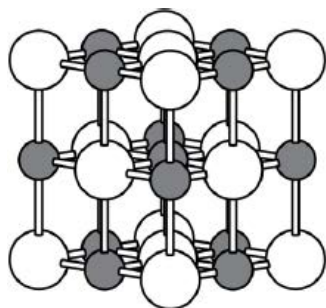


Diagram 1

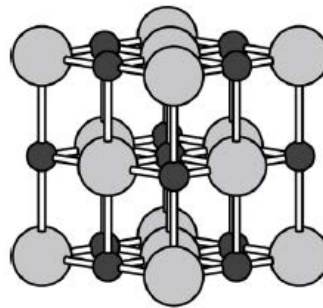


Diagram 2

The ionic compounds NaCl and MgS are represented by the diagrams above. Which statement correctly identifies diagram 1 and identifies the compound with the lower melting point, explaining why?

- A** Diagram 1 represents NaCl ; it has a lower melting point than MgS has because the coulombic attractions between the singly charged Na^+ ions and the Cl^- ions in NaCl are stronger than those between the ions in MgS.
- B** Diagram 1 represents NaCl ; it has a lower melting point than MgS because the coulombic attractions between its singly charged Na^+ ions and the Cl^- ions are weaker than those between the ions in MgS.
- C** Diagram 1 represents MgS ; it has a lower melting point than NaCl because the coulombic attractions between its doubly charged Mg^{2+} ions and the S^{2-} ions are stronger than those between the ions in NaCl.
- D** Diagram 1 represents MgS ; it has a lower melting point than NaCl because the coulombic attractions between the doubly charged Mg^{2+} ions and the S^{2-} ions are weaker than those between the ions in NaCl.
2. A sample of a hard, solid binary compound at room temperature did not conduct electricity as a pure solid but became highly conductive when dissolved in water.

Which of the following types of interactions is most likely found between the particles in the substance?

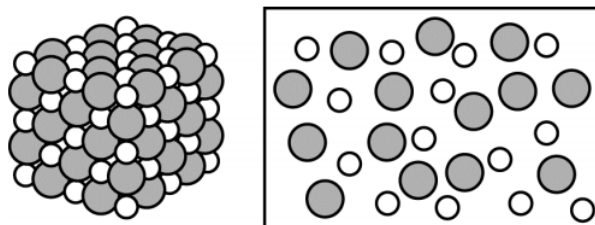
- | | |
|-------------------------|-------------------------|
| A ionic bonds | B metallic bonds |
| C covalent bonds | D hydrogen bonds |

3. A student is given a sample of a pure, white crystalline substance.

Which of the following would be most useful in providing data to determine if the substance is an ionic compound?

- A Examining the crystals of the substance under a microscope
- B Determining the density of the substance
- C Testing the electrical conductivity of the crystals
- D Testing the electrical conductivity of an aqueous solution of the substance

4.



Solid MgO

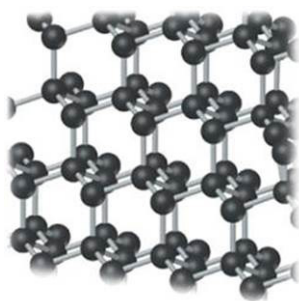
Liquid MgO

Based on the diagram above, which of the following best helps to explain why $\text{MgO}_{(s)}$ is not able to conduct electricity, but $\text{MgO}_{(l)}$ is a good conductor of electricity?

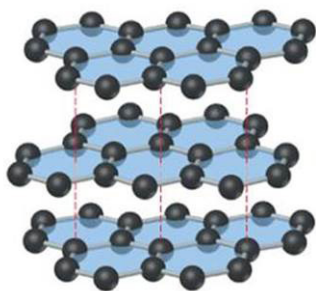
- A $\text{MgO}_{(s)}$ does not contain free electrons, but $\text{MgO}_{(l)}$ contains free electrons that can flow.
 - B $\text{MgO}_{(s)}$ contains no water, but $\text{MgO}_{(l)}$ contains water that can conduct electricity.
 - C $\text{MgO}_{(s)}$ consists of separate Mg^{2+} ions and O^{2-} ions, but $\text{MgO}_{(l)}$ contains MgO molecules that can conduct electricity.
 - D $\text{MgO}_{(s)}$ consists of separate Mg^{2+} ions and O^{2-} ions held in a fixed lattice, but in $\text{MgO}_{(l)}$ the ions are free to move and conduct electricity.
5. Which of the following could be the identity of a white crystalline solid that exhibits the following properties?
- It melts at 320°C .
 - It does not conduct electricity as a solid.
 - It conducts electricity in an aqueous solution.

- A $\text{C}_6\text{H}_{12}\text{O}_{6(s)}$
- B $\text{NaOH}_{(s)}$
- C $\text{SiO}_{2(s)}$
- D $\text{Cu}_{(s)}$

Covalent Networks



(a) Diamond



(b) Graphite

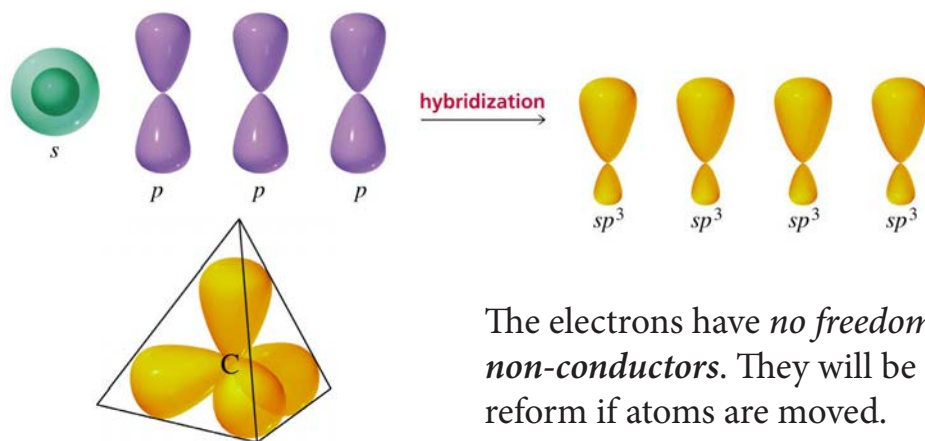
Covalent networks also benefit from *many strong interactions at short distances*.

$$F = q_1 q_2 / r^2$$

Melting points can be used to compare the strengths of covalent networks.

| Basic Unit | | | | |
|---------------------------------------|---------|-----------------|-----------------|-----------------------------|
| Structure | | | | |
| Name | diamond | silicon dioxide | silicon carbide | graphite |
| Bond length (pm) | 154 | 165 | 186 | 142 (335 between layers) |
| Bond Strength (kJ mol ⁻¹) | 607 | 408 | 451 | 825 (~13 between layers) |
| Melting Point (°C) | 3500* | 1700 | 2730 | 3500* |

* Under normal atmospheric pressures, diamonds would convert to graphite at about 1000 °C and then sublime to vapour at about 3500 °C.



Most covalent networks have a *tetrahedral* structure based on *sp³ hybrid orbitals*.

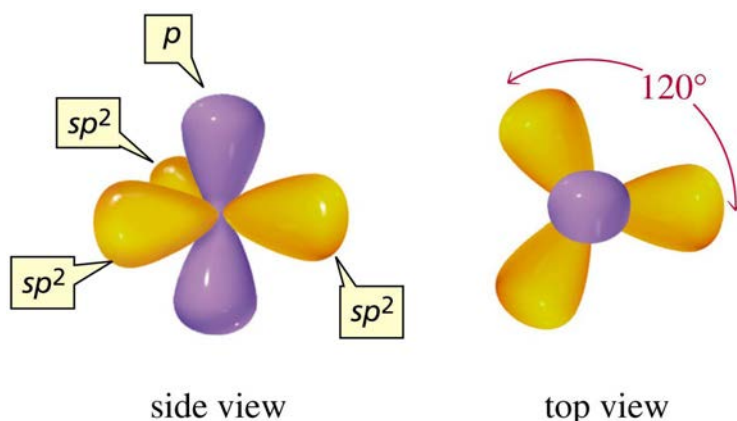
All electrons will be held in *strong covalent bonds* which result in *high melting points*.

The electrons have *no freedom to move* so *covalent networks* are *non-conductors*. They will be *hard* but *brittle*:- bonds cannot reform if atoms are moved.

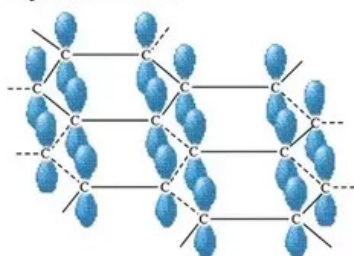
The *exception* amongst covalent networks is **graphite**.

Each carbon is only bonded to 3 other carbon atoms so only does sp^2 hybridisation.

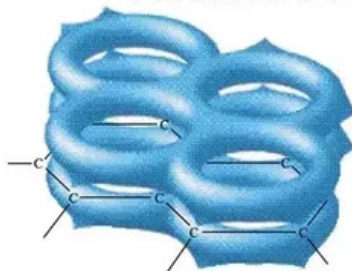
The remaining p-orbitals overlap to form π **bonding molecular orbitals** that extend over all the carbon atoms within a layer - this results in **delocalised electrons**.



sp^2 hybridization



Delocalized π orbitals



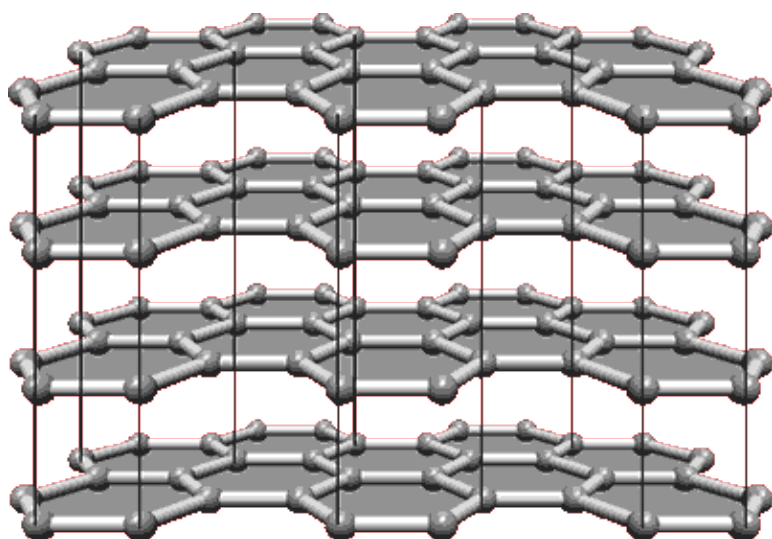
The *delocalised electrons* can be made to flow in any direction so graphite is a **good conductor** of electricity.

The extra bonding (bond order = 1.5) ensures a strong C—C bond, which contributes to the **high melting point**.

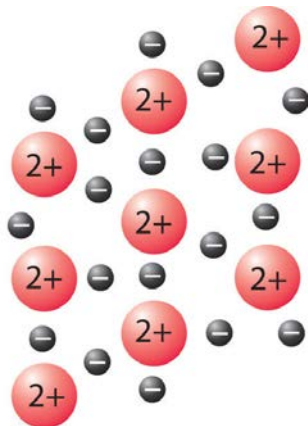
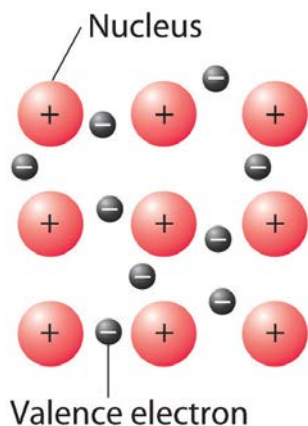
The *delocalised electrons* can also 'wobble' creating **temporary dipoles** within a layer.

This can then **induce dipoles** in nearby layers and will lead to **weak London Dispersion Forces between the layers**.

As a result **graphite** is **relatively soft** (*pencils*) while the ease with which layers can slide over each other makes graphite a **good lubricant**.



Metallic Lattices

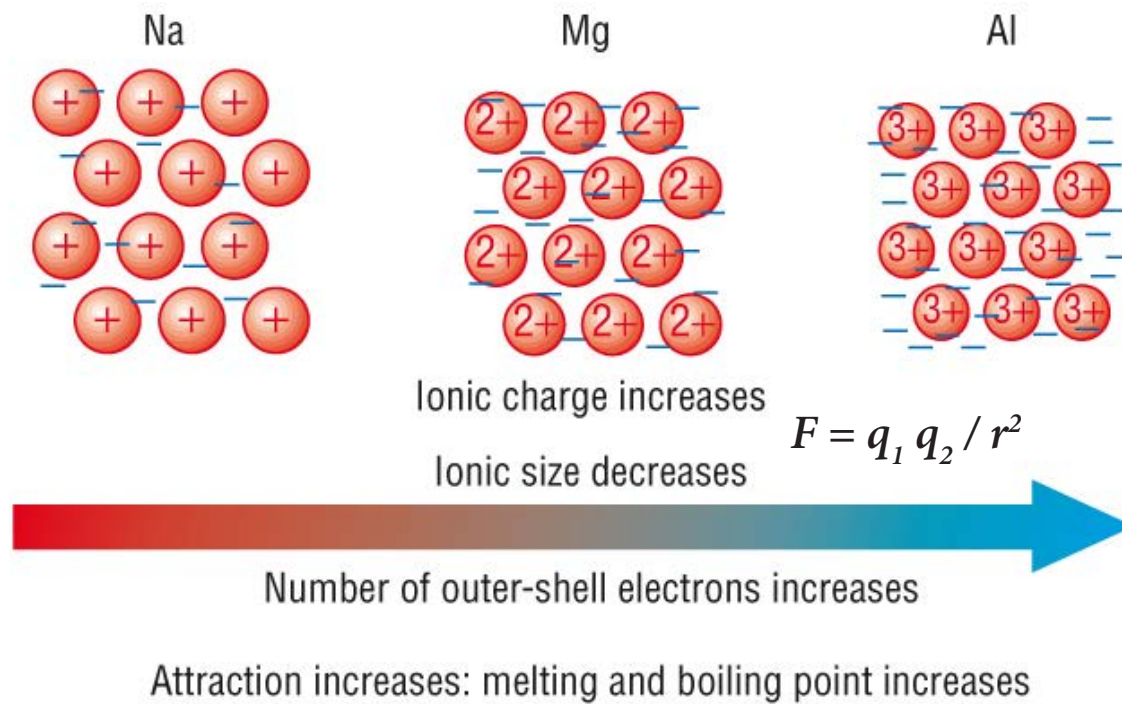


Metallic lattices (elements and alloys) benefit from **many strong interactions at short distances**.

$$F = q_1 q_2 / r^2$$

Melting points can be used to **compare the strengths of metallic bonds**.

For example, *mercury* is a liquid at room temperature, and *caesium* melts at 28.4°C, whereas *tungsten* melts at 3680°C.



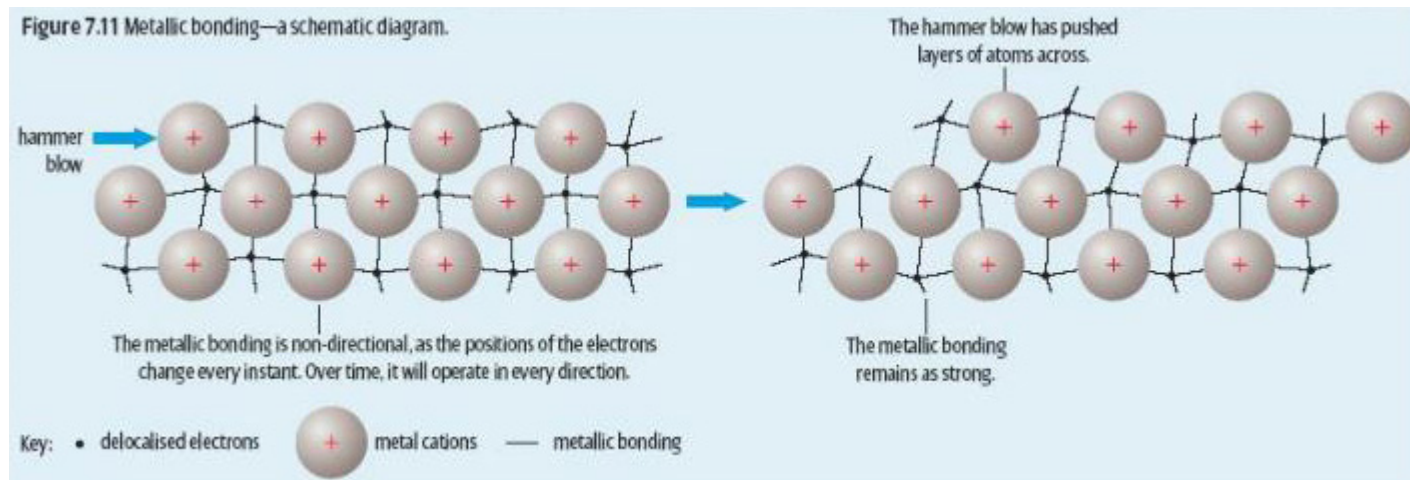
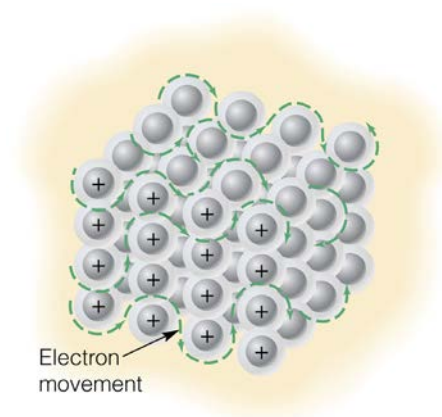
There is a similar range in hardness of metals with *caesium* being a very soft metal and *chromium* being the hardest pure metal, though many *alloys*, such as *chromium steel* are even harder.

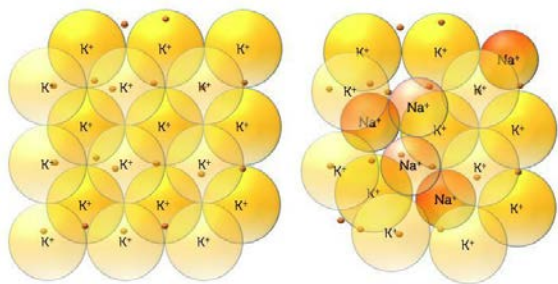
The *delocalised electrons* mean that metals and alloys of metals are all *good conductors*.

Metals are also *malleable* and *ductile*. Both *malleability* and *ductility* refer to the *ability of metals to be deformed (reshaped)* without any loss in structural strength.

Malleable refers to the ability to be beaten or rolled into sheet metal - *gold* is the most malleable metal and can form sheets that are only a few atoms thick.

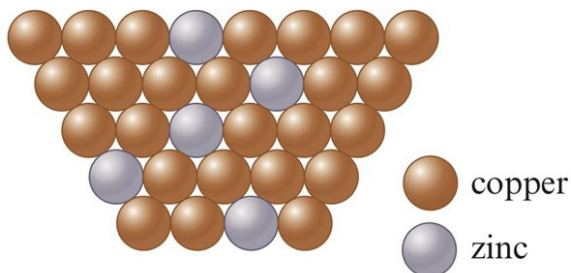
Ductility is the ability of a substance to be pulled or stretched, in this case into a thin wire, without breaking. The most ductile metal is *platinum*. A single gram of *platinum* can be drawn into a wire more than 2.5 km long without breaking.





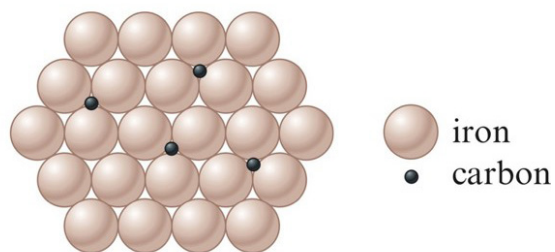
Metals can form **alloys** so easily because replacing one metal atom with another metal atom rarely disrupts the strength of the *metallic bonding* too much.

For example, an alloy of *sodium* and *potassium* can be made, but the alloy formed is a liquid at room temperature so the *metallic bond* is *slightly weaker*.



Brass is an example of a **substitutional alloy**. Zinc and copper atoms are of *very similar size* so the original structure is maintained, though *strengthened*.

This alloy retains properties such as *malleability* and *ductility* as *metallic bonding* is *easily re-established*.



Steel is an **interstitial alloy** with *much smaller carbon* atoms in the spaces between the *iron* atoms.

The presence of the *carbon* atoms enhances the structure so steel is *harder* than the original iron, but it will also be *less malleable* and *less ductile* as a result.

The wide variety of alloys makes it difficult to make accurate predictions about properties, but, *in general*, *alloys will be poorer conductors, less malleable, less ductile but stronger/harder*.

Also, *in general*, **smaller atoms** that are able to form **interstitial alloys** will have a more disruptive effect on metallic bonding, making it harder to displace atoms resulting in **stronger alloys**.

| Alloy of Iron | Components | Uses |
|---------------------|---------------------------------|---|
| (1) Stainless steel | Iron, Carbon Nickel, Chromium | Surgical instruments. |
| (2) Nickel steel | Iron and Nickel | Utensils, drilling instruments. |
| (3) Alnico | Iron, Nickel, Aluminium, Cobalt | Magnets. |
| (4) Invar steel | Iron, Nickel, Carbon | Making pendulum. |
| (5) Nichrome | Iron, Nickel Chromium | Heating coils. |
| (6) Steel | Iron , Carbon | Pipes, nails, sheets and cutting tools. |

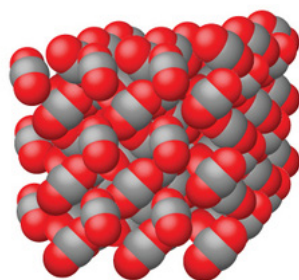
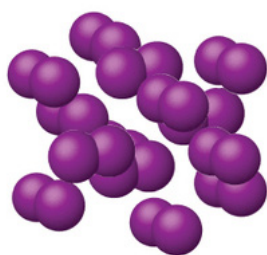
3.2 Practice Problems - Part 2

7.

| Type of Steel | % Carbon | Characteristics | Uses |
|-------------------|-------------|-----------------------|------------------|
| Low-carbon steel | < 0.2 % | Malleable and ductile | Chains and nails |
| High-carbon steel | 0.6 – 1.5 % | Hard and brittle | Cutting tools |


The table above provides some information about two types of steel, both of which are alloys of iron and carbon. Which of the following best helps to explain why high-carbon steel is more rigid than low-carbon steel?

- A Elemental carbon is harder than elemental iron.
- B The additional carbon atoms within the alloy make the high-carbon steel less dense.
- C The additional carbon atoms within the alloy increase the thermal conductivity of the high-carbon steel.
- D The additional carbon atoms within the alloy make it more difficult for the iron atoms to slide past one another.


$$M_{pt} = -78\text{ }^{\circ}\text{C}$$

$$M_{pt} = 113.5\text{ }^{\circ}\text{C}$$

However, some have strong enough intermolecular forces to be solids at s.t.p, though they will usually have low melting points.

Molecular Elements



Hydrogen
(H₂)




Nitrogen
(N₂)



Oxygen
(O₂)




Fluorine
(F₂)



Chlorine
(Cl₂)

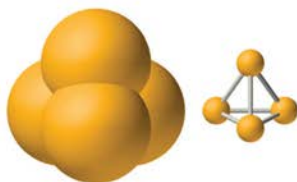
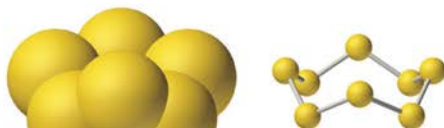


Bromine
(Br₂)



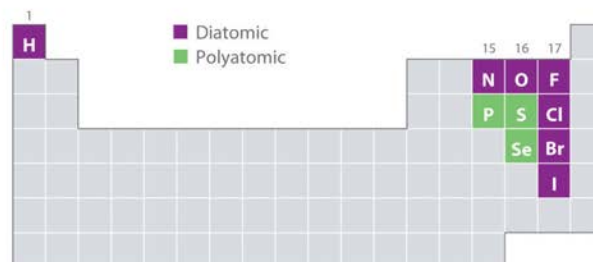
Iodine
(I₂)

(a) Elements that exist as diatomic molecules

Phosphorus
(P₄)

Sulfur
(S₈)

(b) Elements that exist as polyatomic molecules



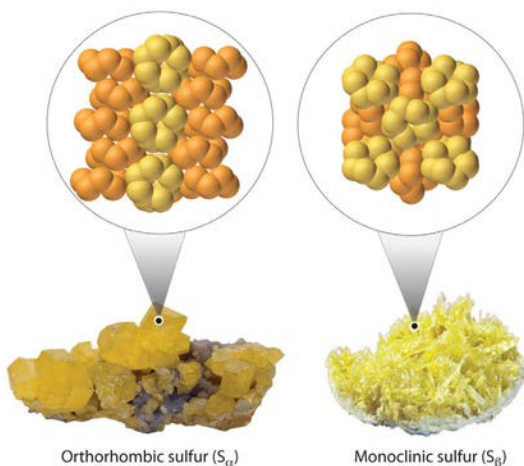
Only *iodine*, with electrons in the 5th shell, wobbles enough to produce large enough partial charges ($\delta+$ and $\delta-$) to be solid at room temperature.

$$F = q_1 q_2 / r^2$$

However, being *polyatomic molecules*, they can set up *multiple LDF's*.

Mpt of S = 112.8 °C

Mpt of P = 44.1 °C



Orthorhombic sulfur (S_8)

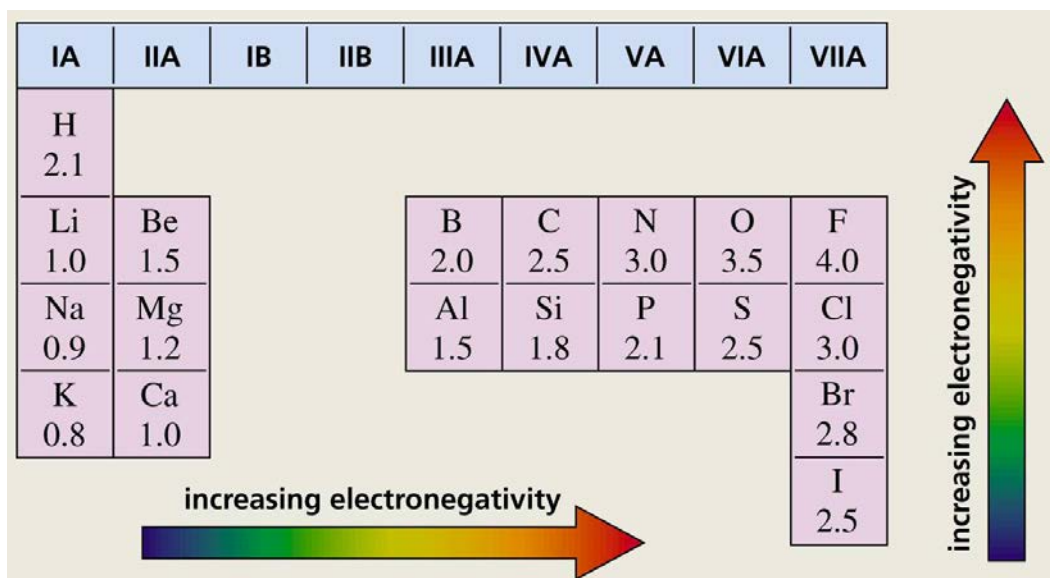
Monoclinic sulfur (S_8)

Molecular Compounds

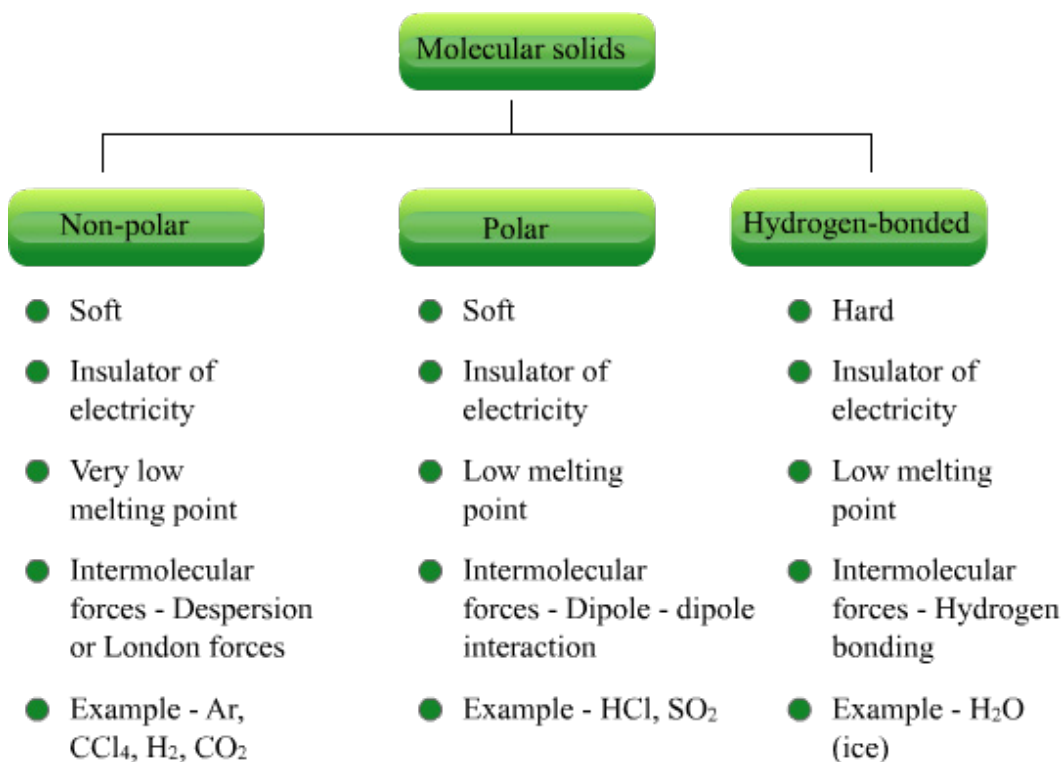
Can either be *non-polar* or *polar*

- *London Dispersion Forces*
- *permanent dipole - dipole*
- *hydrogen bonds*

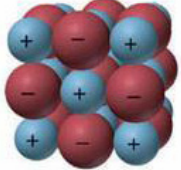
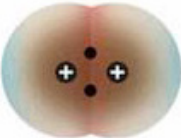
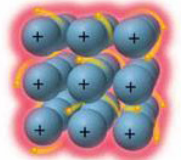
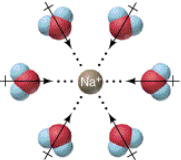
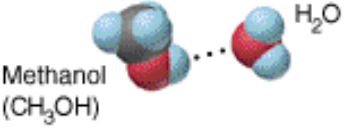
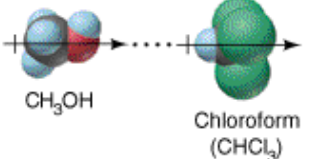
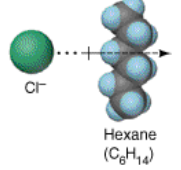
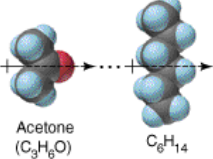
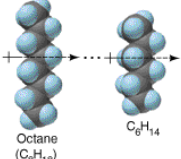
This depends on *electronegativity differences*.

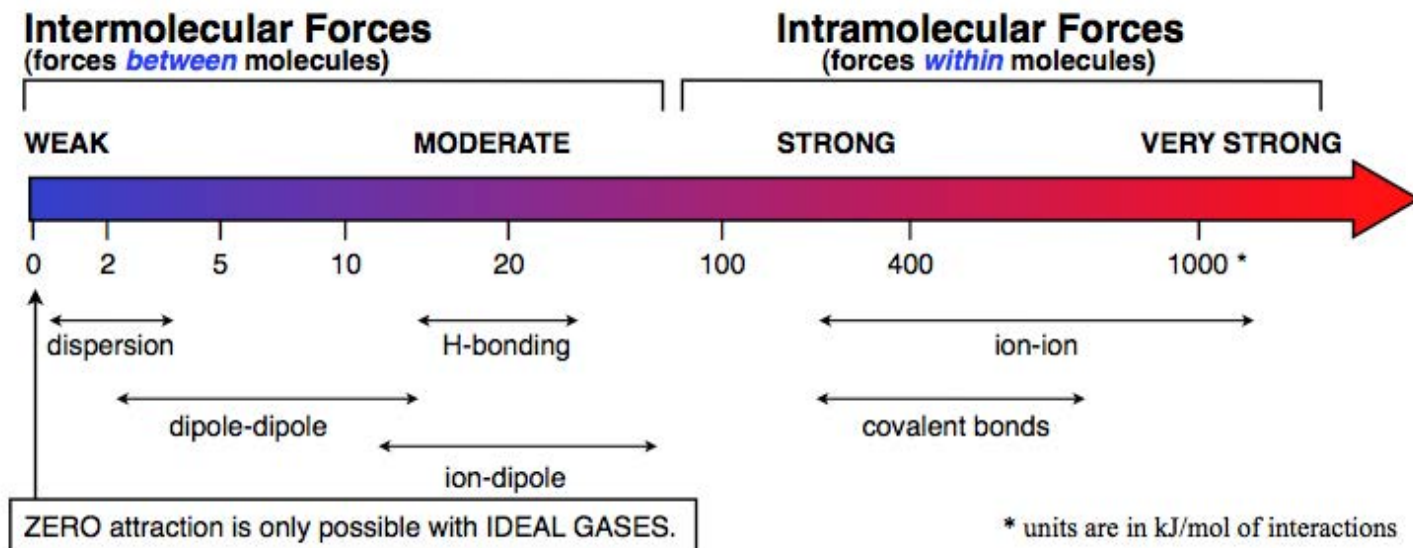


In general, we can assume that *polar molecules* are more likely to form solids at s.t.p, but, in reality many of our covalent molecular solids are *non-polar* due to the presence of *large atoms* (*bigger wobbles, greater partial charges*) or due to the *large number of atoms* per molecule (*more wobbles*).




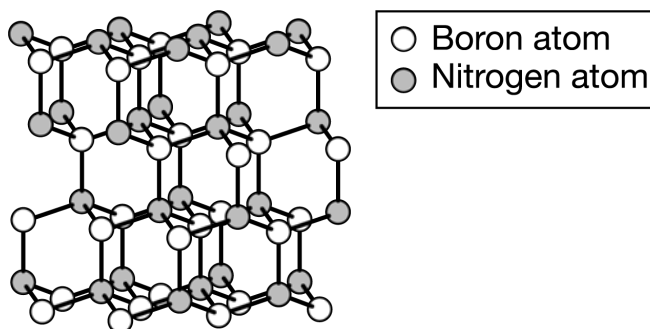
Summary of Main Attractions

| | | |
|--|---|--|
| <i>Ionic</i> |  | <i>Attractions between positive ion (Cation) and Negative ion (Anion)</i> |
| <i>Covalent</i> |  | <i>Attractions between both nuclei (+ve) for same pair of shared electrons (-ve)</i> |
| <i>Metallic</i> |  | <i>Attractions between positive core (temporary cations) and delocalised electrons (-ve)</i> |
| Van Der Waal's Forces | | |
| <i>Ion - Dipole</i> |  | <i>Attractions between an ion and the oppositely charged end of a polar molecule</i> |
| <i>Dipole - Dipole (Hydrogen Bonding)</i> |  | <i>Attractions between the oppositely charged ends of nearby polar molecules with H—O or H—N</i> |
| <i>Dipole - Dipole</i> |  | <i>Attractions between the oppositely charged ends of nearby polar molecules</i> |
| <i>Ion - Non-Polar</i> |  | <i>Attraction between an ion and the induced dipole of a normally non-polar molecule</i> |
| <i>Dipole - Non Polar</i> |  | <i>Attraction between a polar molecule and the induced dipole of a normally non-polar molecule</i> |
| <i>Non Polar - Non Polar (London Dispersion)</i> |  | <i>Attraction between the temporary dipole and induced dipole</i> |



3.2 Practice Problems - Part 3

8. Which statement best helps to explain the observation that $\text{NH}_3(l)$ boils at -28°C , whereas $\text{PH}_3(l)$ boils at -126°C ?
- 
- A The dispersion forces in NH_3 are weaker than the dispersion forces in PH_3 .
- B The dispersion forces in NH_3 are stronger than the dipole-dipole forces in PH_3 .
- C NH_3 has hydrogen bonding that is stronger than the dipole-dipole forces in PH_3 .
- D NH_3 has hydrogen bonding that is weaker than the dipole-dipole forces in PH_3 .
9. A certain crystalline substance that has a low melting point does not conduct electricity in solution or when melted. This substance is likely to be
- A a covalent network solid B a metallic solid
- C a polymer D an ionic solid E a molecular solid
10. At room temperature $\text{I}_{2(s)}$ is a molecular solid. Which of the following provides a characteristic of $\text{I}_{2(s)}$ with a correct explanation?
- A It has a high melting point because it has weak intermolecular forces.
- B It is hard because it forms a three dimensional covalent network.
- C It is not a good conductor of electricity because its valence electrons are localized in bonding and nonbonding pairs.
- D It is very soluble in water because its molecules are polar.



Cubic Form of
Boron Nitride

The structure of one form of boron nitride is represented above.

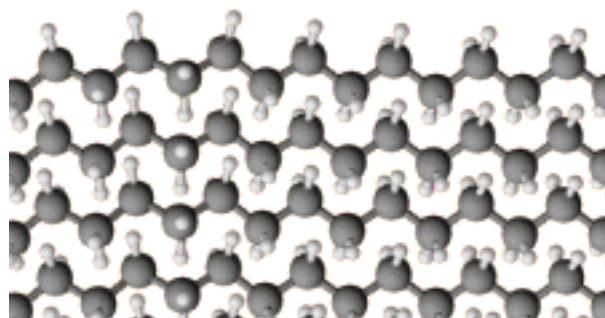
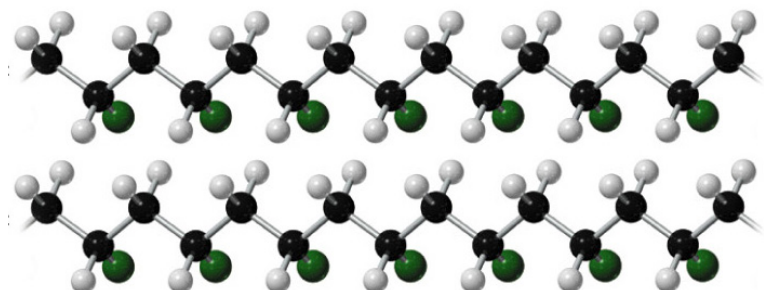
This form of boron nitride is one of the hardest substances known. Which of the following best helps explain why boron nitride is so hard?

- A** Boron ions and nitrogen ions are held together by ionic bonds.
- B** Boron nitride is a network solid of atoms connected by covalent bonds with fixed bond angles.
- C** Boron nitride is an alloy, and alloys are typically harder than the elements used to make them.
- D** Boron nitride is a polymer made of long chains of boron atoms and nitrogen atoms held together by London dispersion forces.
- 12.** In solid methane, the forces between neighboring CH_4 molecules are best characterized as
- A** ionic bonds **B** covalent bonds **C** hydrogen bonds
- D** ion-dipole forces **E** London (dispersion) forces
- 13.** The best explanation for the fact that diamond is extremely hard is that diamond crystals
- A** are made up of atoms that are intrinsically hard because of their electronic structures
- B** consist of positive and negative ions that are strongly attracted to each other
- C** are giant molecules in which each atom forms strong covalent bonds with all of its neighboring atoms
- D** are formed under extreme conditions of temperature and pressure
- E** contain orbitals or bands of delocalized electrons that belong not to single atoms but to each crystal as a whole

Biomolecules & Polymers

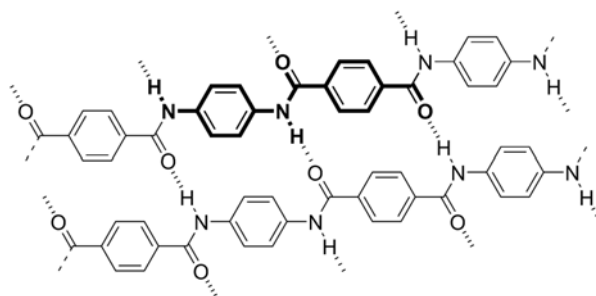
Very large molecules, such as *polymers*, will be solids due to the *large numbers of attractions*, even if only *London Dispersion Forces*, that can be set up.

Polyethene -110 - 130 °C



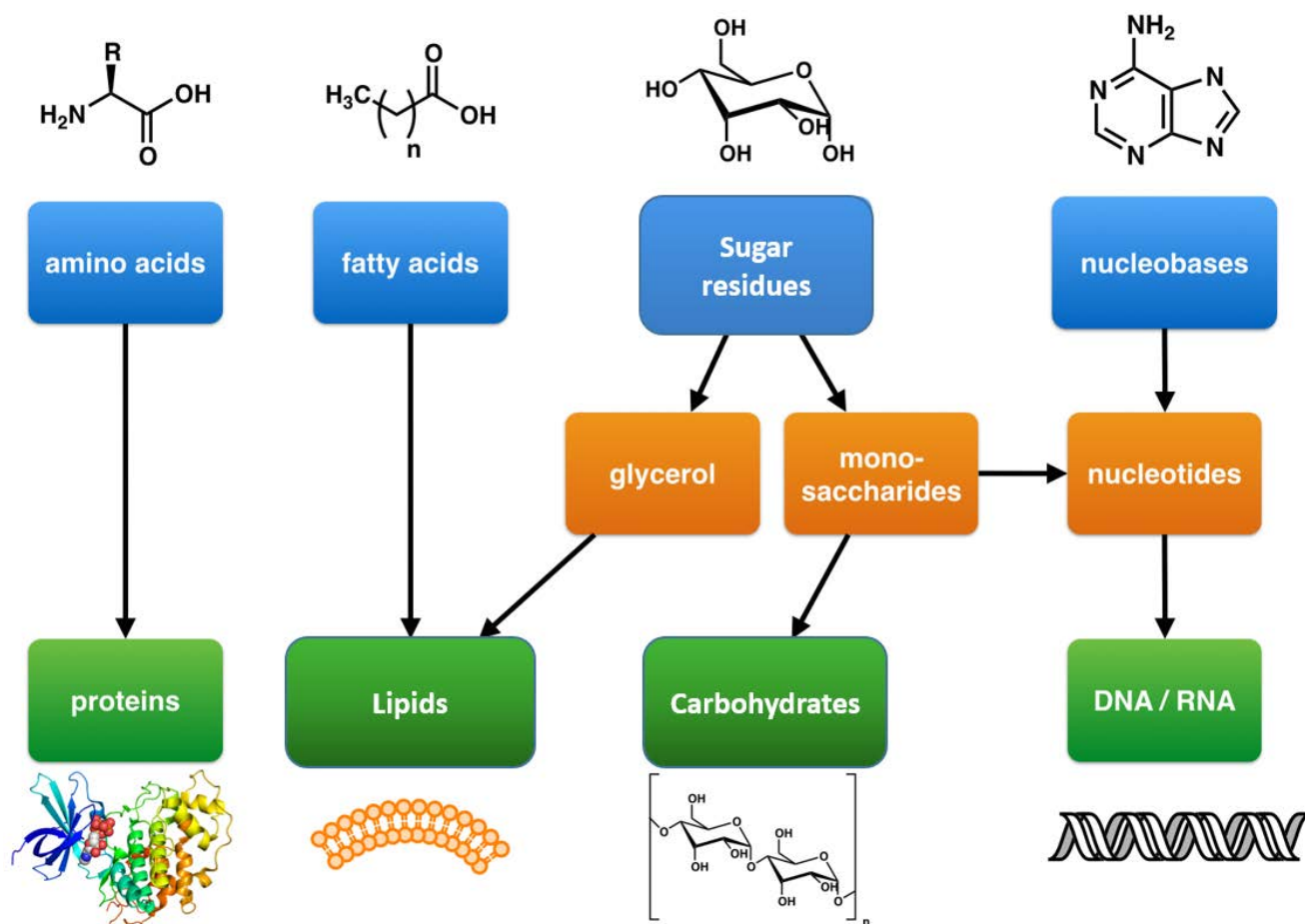
Other polymers can have *permanent dipoles* and will have stronger attractions between the chains.

Polyvinylchloride -180 - 220 °C

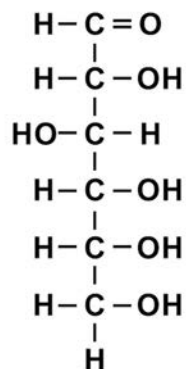


The strongest polymers tend to mimic nature and use the *amide (peptide)* links found in proteins.

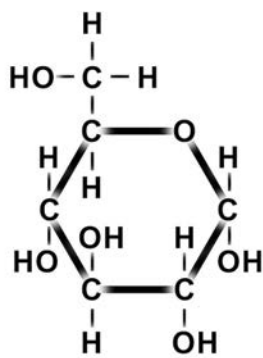
One of the strongest *polyamides* is *Kevlar* and it benefits from *many strong hydrogen bonds* at regular intervals along the chain.



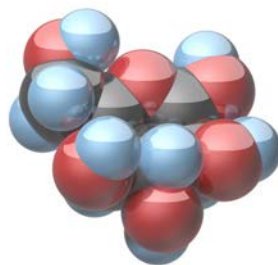
Sugars (Saccharides, Carbohydrates)



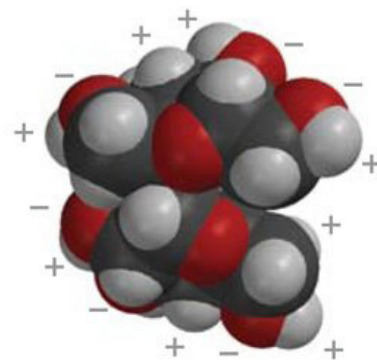
The structural formula of the straight-chain form



Structural formula of the ring form



■ = Carbon
 ■ = Oxygen
 ■ = Hydrogen

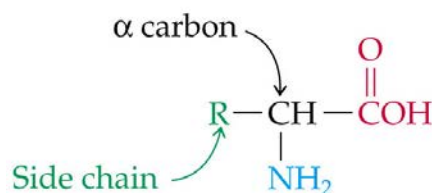
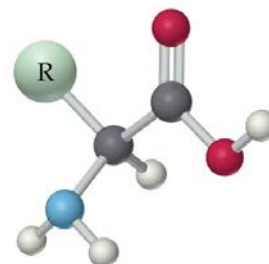


The presence of so many *hydroxyl groups* makes sugar molecules *very polar* and produces *hydrogen bonding* between molecules.

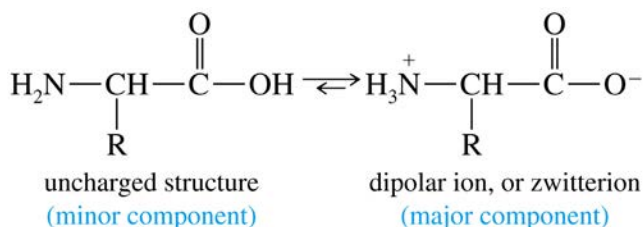
The Structure of Glucose

As a result of this *hydrogen bonding*, all *sugars* are *solids* at s.t.p. and most of them are *soluble in water* - though *polysaccharides* such as *starch* are *sparingly soluble*.

Amino Acids

Generalized structure of an α -amino acid

The presence of the *carboxyl* (COOH) and *amine groups* (NH₂) again leads to *hydrogen bonding*.



However, *hydrogen bonding* alone would not explain why amino acids are crystalline solids at s.t.p.

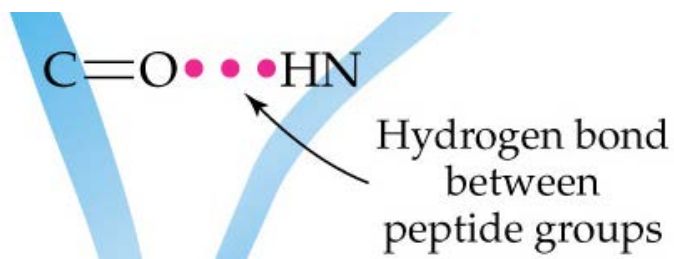
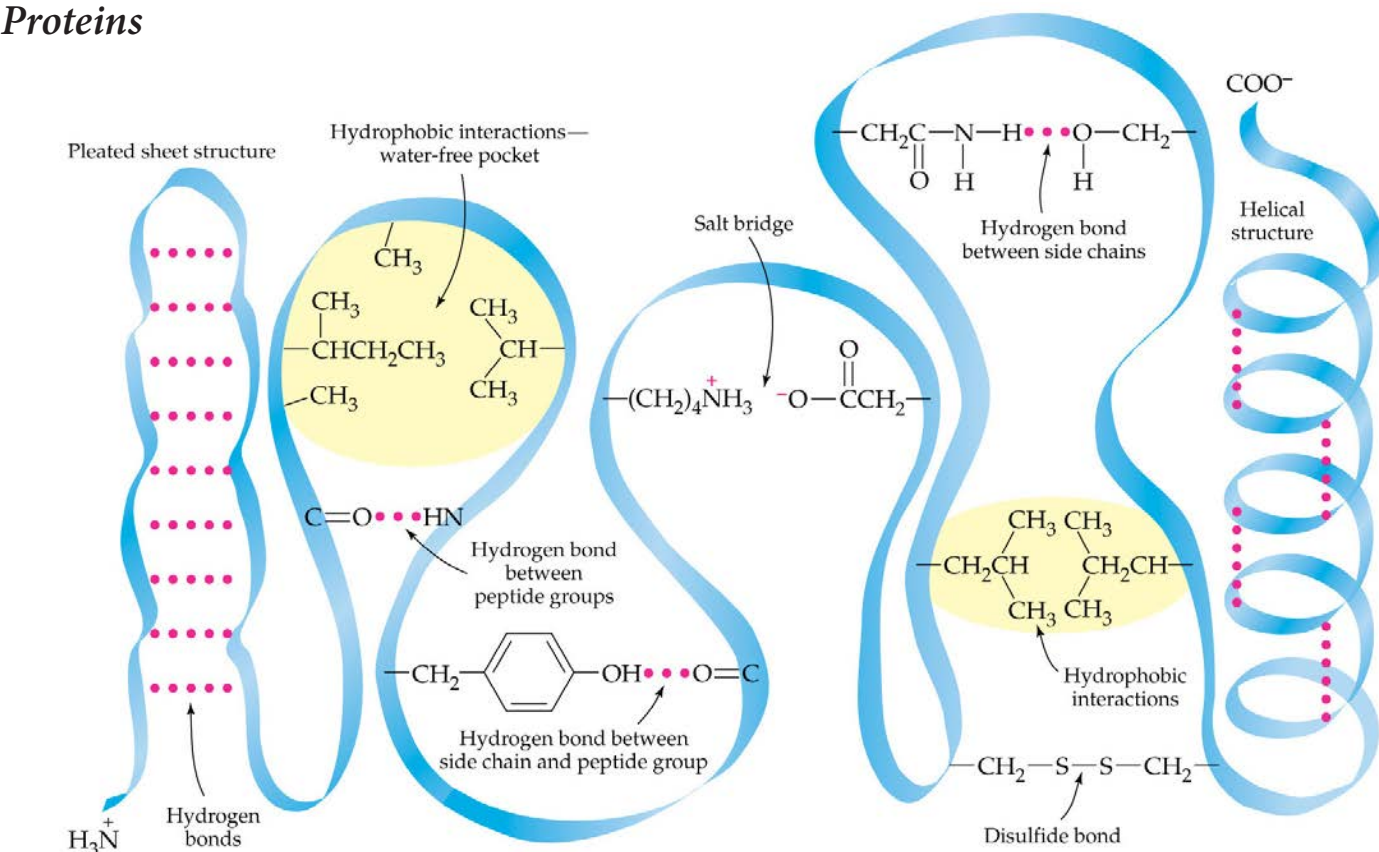
In neutral conditions the hydrogen from the *carboxyl* group migrates to the *amine* group to produce two *ionic* groups.

This produces *attractions between molecules* that are much stronger than expected.

Side chains can also contribute with a *variety of different types of attraction* possible.

| Polarity | | Charge | |
|---|---|--|---|
| Polar | Non-polar | Negative | Positive |
| Cysteine | Leucine | Glutamic acid | Lysine |
| | | | |
| $ \begin{array}{c} \text{SH} \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}(=\text{O})\text{O}^- \\ \\ \text{H} \end{array} $ | $ \begin{array}{c} \text{CH}_3 \quad \text{CH}_3 \\ \quad \\ \text{CH} \\ \\ \text{CH}_2 \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}(=\text{O})\text{O}^- \\ \\ \text{H} \end{array} $ | $ \begin{array}{c} \text{COO}^- \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}(=\text{O})\text{O}^- \\ \\ \text{H} \end{array} $ | $ \begin{array}{c} \text{NH}_3^+ \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{CH}_2 \\ \\ \text{H}_3\text{N}^+-\text{C}-\text{C}(=\text{O})\text{O}^- \\ \\ \text{H} \end{array} $ |

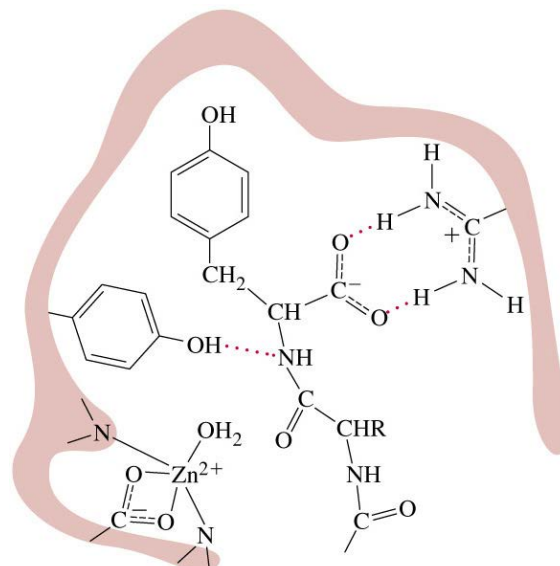
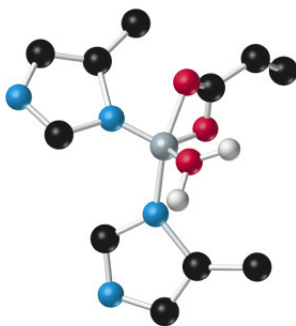
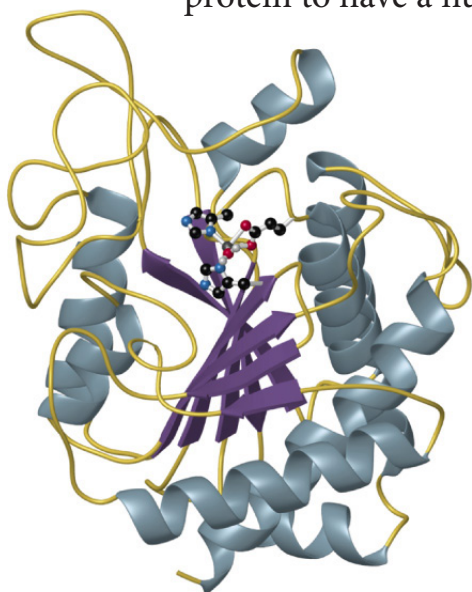
Proteins



The most significant attractions found in protein molecules are the *hydrogen bonds* formed between $\text{C}=\text{O}^{\delta-}$ and $\delta^+\text{H}-\text{N}$ groups.

However, *all forms of attraction* will be present in proteins.

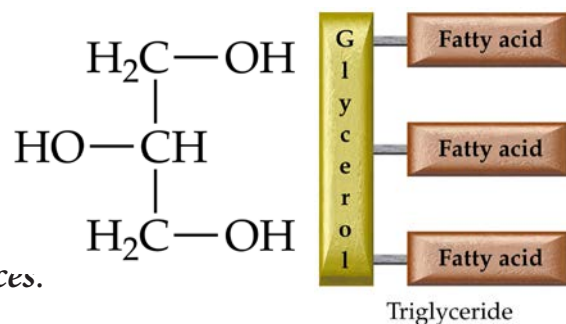
As a result, complex and *unique shaped* sections are formed which can interact with *specific molecules* with complementary groups that can form attractions to the protein. This allows the protein to have a number of useful properties such as enzyme (catalyst) etc.



Lipids (Fats & Oils)

Lipids are long term energy stores and are formed from one *glycerol* molecule and 3 *fatty acids*.

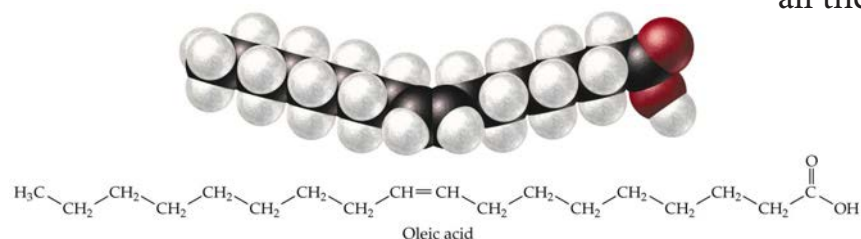
They can also be referred to as *triglycerides*. Though there are *polar groups*, the long *non-polar carbon chains* mean that the main attractions are *London Dispersion Forces*.



The individual fatty acids typically have between 13 and 18 Carbon atoms in the chain.

Most fatty acids are described as *saturated* - all the C to C bonds are single bonds.

Unsaturated fatty acids will have at least one C to C double bond, which will result in a permanent kink in the chain.



Both Fats & Oils have a *mixture of molecules* containing *both* saturated and unsaturated fatty acids.

Saturated fatty acid molecules can rotate around each bond to 'straighten' the chain allowing them to *maximise the London Dispersion forces* between neighbouring molecules.

Unsaturated fatty acid molecules are unable to rotate around the double bond so *London Dispersion forces are reduced*.

Therefore, in general, lipids made by *plants and marine animals*, tend to be *more unsaturated* and are likely to be *liquid oils* at room temperature.

By contrast, most *animals* produce lipids that *more saturated* and tend to *solid fats* at room temperature.

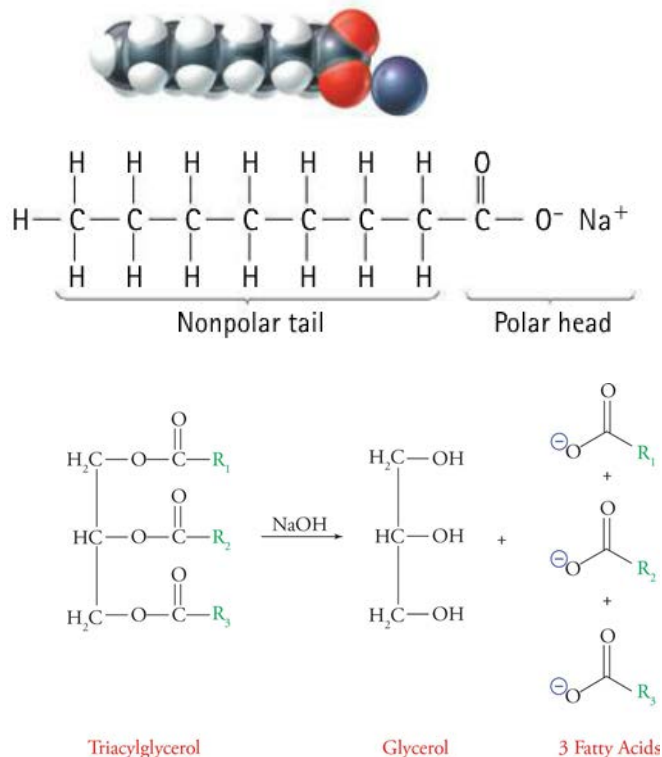
From Fats & Oils, our first *soap molecules* were made which are molecules with *dual properties*.

The polarity of the '*head*' can be greatly enhanced if the acid is fully ionised by reacting with a base, such as NaOH, to form a *soluble salt of the acid*.

Soaps were traditionally made by *hydrolysing* (breaking down) fats or oils using *a base*.

The names of soaps often displayed this link - *Palmolive* soap was made from *palm oil* and *olive oil*.

The *glycerol* formed would find its way into many other cosmetic products such as hand creams and lip balms.



Surfactants, such as soaps, work at the interface of two liquids that would normally not mix - grease and water, for example.

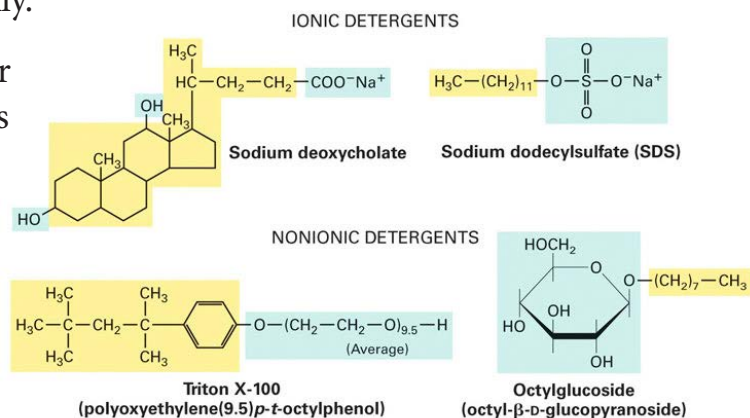
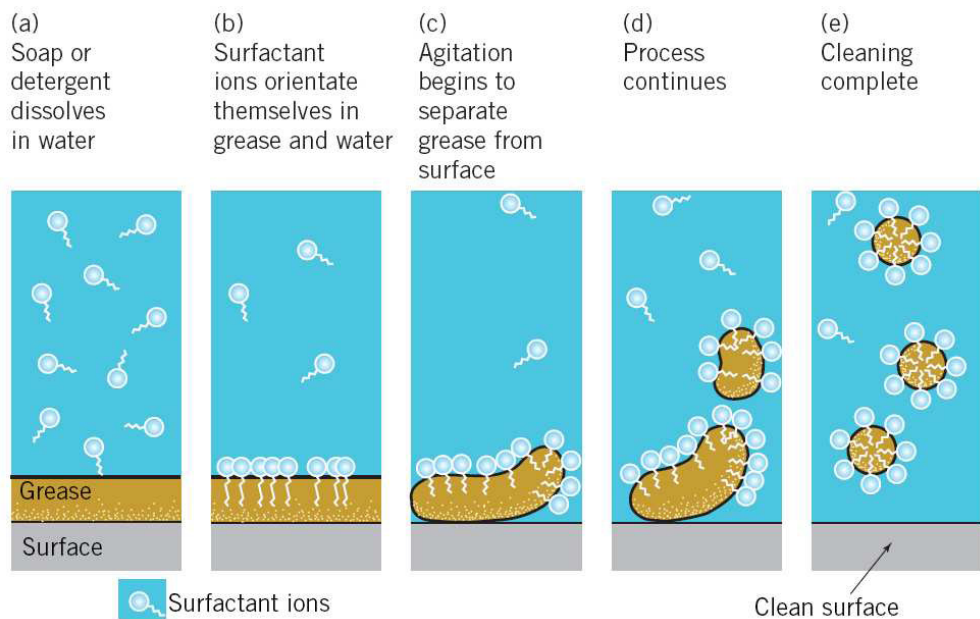
They can help *disperse* the grease into tiny droplets so that the grease appears to dissolve into the water.

In reality, an unstable mixture called an emulsion is formed.

Surfactants help mix oil paint and water to form emulsion paint suitable for covering large surfaces quickly.

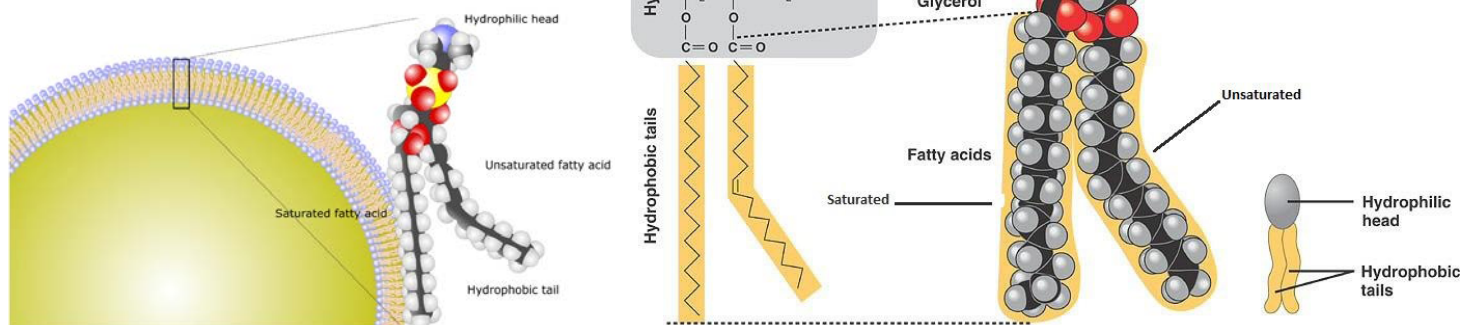
Problems, particularly with 'hard' water - water with Ca^{2+} and Mg^{2+} ions dissolved, led chemists to develop more soluble artificial soaps - called detergents.

Surfactants are widely used in the food industry but are usually labelled as *emulsifying agents*.



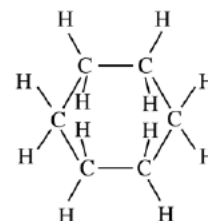
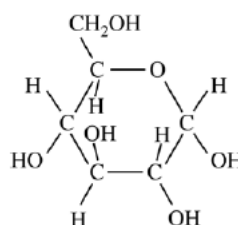
Surfactants - Phospholipids

In nature, a modified lipid is used as the building block for cell membranes.



3.2 Quick Check - AP FRQ Questions

1. The structures for glucose, $C_6H_{12}O_6$, and cyclohexane, C_6H_{12} , are shown opposite.



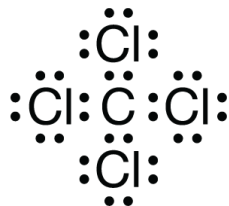
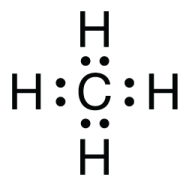
- a) Identify the type(s) of intermolecular attractive forces in

i) pure glucose

ii) pure cyclohexane

- b) Glucose is soluble in water but cyclohexane is not soluble in water. Explain.

2.



The Lewis electron-dot diagrams for molecules of CH_4 and CCl_4 are shown opposite.

Which compound has the higher boiling point? Justify your answer. The type(s) of intermolecular force(s) in both substances should be included in your answer.