Gr. 12 Structure and Properties of Matter Cheat Sheet

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The History of the Atom

Democritus (300 B.C.)

First person to conceive the idea of **tiny, indivisible particles** called **atoms**

John Dalton (1805) - The billiard ball model

Pure substances are made up of atoms

Atoms of the **same element** are **exactly alike**

Atoms **cannot** be **created**, **destroyed**, or **divided** into smaller particles

Compounds are formed by **joining 2 or more elements**

William Crookes (1875) - Discovery of the electron

Created an **electric discharge tube** (a **cathode ray tube**) with a screen and magnet

Discovered the bar magnet could deflect/move the cathode rays (they have a **charge**)

If he added a paddle wheel inside the tube, it moved (the rays had **mass**)

J.J. Thomson (1897) - The raisin bun model

Using Crooke's cathode ray tube, determined rays were **made up of negatively charged particles** called **electrons**

Electrons were **2000x lighter** than hydrogen, the lightest known element

Ernest Rutherford (1903) - The beehive model

Conducted the **gold foil experiment**; if the atom was like Thomson proposed, any alpha particles sent through it would **pass straight through**

Most of the particles went through, but **some were scattered**

Determined that atoms were **mostly empty space**, with a **small, dense, positively charged nucleus** in the centre with e^- scattered around it

The History of the Atom (cont)

1932 - determined with James Chadwick that the mass of the nucleus **did not equal the mass of the protons only**, i.e. electrically neutral **neutrons**

Niels Bohr (1913) - The planetary model

Proposed that electrons are **not allowed to orbit anywhere**, but rather they occupy certain **defined (fixed) orbits**

Based off experiments with hydrogen atoms and spectroscopes

Electrons can **jump to higher orbits** when they are given energy in **quantized** amounts (**no partial amounts**), usually in the form of **photons** (light particles)

Quantum Mechanical Model of the Atom

Louis de Broglie (1924) proposed that if light waves properties of particles, then **particles can have properties of waves**

Erwin Schrodinger (1933) realized that a **wave theory** and mathematical equations were needed to **explain atoms with more than 2 e^-**

Schrodinger's Wave Function

Contains 3 variables called **quantum numbers** (n, l_n, m_l) to help determine a **region in space** where the electron spends **90%** of its time (the **atomic orbital**)

A fourth number (**m_s**) was added so that all characteristics of atoms could be explained

Heisenberg's Uncertainty Principle: it is **impossible** to know both the **exact location and speed** of an e^- at a given time

Quantum Theory and Chemical Bonding

Valence Bond Theory: atomic orbitals of one atom can overlap with atomic orbitals of another atom to **share a common region of space**

Molecular Orbital Theory: when orbitals overlap, they **combine to form new orbitals** called **molecular orbitals** (**hybridization**); the **greater** the overlap, the **more stable** the bond

Double/Triple Bonds: Sigma (σ) bonds (**end-to-end** overlap of orbitals) and **pi (π)** bonds ("**sideways**" orbitals—usually *p* orbitals—overlap **above and below** the plane of the bond)

Single bond = 1 σ bond; **Double bond** = 1 σ bond + 1 π bond; **Triple bond** = 1 σ bond + 2 π bonds

Quantum Numbers

Quantum number	Symbol	Meaning	Possibilities
Principal quantum number	n	Energy level	$n \in \mathbb{N}$ (any whole number > 0)
Secondary quantum number	l	Shape of orbital	$0 \leq l \leq n - 1$
Magnetic quantum number	m_l	Direction/orientation	$-l \leq m_l \leq l$
Spin quantum number	m_s	Spin	$\pm 1/2$

Shape of Electron Orbitals (l and ml)

Value of l	Symbol	Shape	# of suborbitals (m_l)
0	*s* (sharp)	Sphere	1 (m_l = 0)

Shape of Electron Orbitals (l and ml) (cont)

1	*p* (principal)	Dumbbell	3 (m_l = -1, 0, 1)
2	*d* (diffuse)	Flower/petal	5 (m_l = -2, -1, 0, 1, 2)
3	*f* (fundamental)	Double flower	7 (m_l = -3, -2, -1, 0, 1, 2, 3)

VSEPR Theory

VSEPR: **V**alence **S**hell **E**lectron **P**air **R**epulsion

Helps determine the structure around an atom by **minimizing the repulsive force** between e^- pairs

Bonded and lone pair e^- position themselves **as far away as possible** from each other

Lone pairs of e^- on a central atom **repels a little more** than bonding pairs; they **push the bonding pairs closer together**

VSEPR Molecule Shapes

# of e^- groups	e^- configuration	AXE formula	Molecular shape
2	Linear	AX_2	Linear
3	Trigonal planar	AX_3	Trigonal planar
		AX_2E	Bent
4	Tetrahedral	AX_4	Tetrahedral
		AX_3E	Trigonal pyramidal
		AX_2E_2	Bent
5	Trigonal bipyramidal	AX_5	Trigonal bipyramidal
		AX_4E	See-saw
		AX_3E_2	T-shape
		AX_2E_3	Linear
6	Octahedral	AX_6	Octahedral

VSEPR Molecule Shapes (cont)

AX_5E	Square pyramidal
AX_4E_2	Square planar

See a visual table here.

Bond vs Molecular Polarity

Bond Polarity: the even/uneven distribution of e^- across **one bond** (can be single/double/triple); determined by **ΔEN** (difference in electronegativity)

Molecular Polarity: the even/uneven distribution of e^- across an **entire molecule**; determine many properties of the substance

3 important factors to molecular polarity: **presence/absence of polar bonds**, **shape** of the molecule, and **presence/absence of lone e^- pairs**

It is possible to have a non-polar molecule with polar bonds within, if the shape cancels out any vectors created by the bonds.

Ionic Crystals

Solids in which **positive and negative ions** are arranged in a **crystal lattice**

Boiling/melting point	High
Malleability	Brittle
Conductivity	Poor as solid, high as solution
Solubility in water	Very soluble
Hardness	Very hard (very scratch-resistant)
Types of forces acting on molecule	Ionic bonds

Examples: NaCl (table salt), K_3PO_4 (potassium phosphate), $CuSO_4$ (copper (II) sulfate)

Metallic Crystals

Solids composed of **individual molecules** held together by **intermolecular forces** (**IMFs**); **"neutral"** molecules that form **complex crystal lattice** in solid state

Boiling/melting point	Vary widely
Malleability	Ductile (very flexible)
Conductivity	High as a solid
Solubility in water	Slightly soluble
Hardness	Varied
Types of forces acting on molecule	Metallic bonds

Examples: Au (gold), Ag (silver), Ni (nickel), Fe (iron), Co (cobalt), Cu (copper), Zn (zinc), Cr (chromium)

Ionic vs Metallic Bonds

Ionic Bond: Highly electropositive ion (**cation**) **gives up extra e^-** and gives them to highly electronegative ion (**anion**), then bond through **very strong electrostatic attraction** between the two ions, creating an **ionic crystal** structure

Metallic Bond: Many metal atoms shed a **"-sea" of e^-** that engulf the metal ions (e^- are **delocalized**); pulled from all directions, the metal ions can barely move and **pack tightly together** in crystalline structures

Both ionic and metallic crystals take an immense amount of energy to break the bonds between ions; however, since the metal ions are inside the "sea" of e^-, metallic crystals are **much more malleable** than normal ionic crystals (the e^- mitigate the effect of shifting and sudden repulsion between the ions).

Molecular Crystals

Solids composed of **individual molecules** held together by **intermolecular forces** (**IMFs**); **"neutral"** molecules that form **complex crystal lattice** in solid state

Boiling/melting point	Low
Malleability	N/A
Conductivity	Poor as solids
Solubility in water	Varied
Hardness	Soft (easy to scratch)
Types of forces acting on molecule	IMFs - weaker than ionic/metallic bonds

Examples: $I_2(s)$ (iodine), $At_2(s)$ (astatine)

Covalent Network Crystals

Solids in which the atoms **form covalent bonds** in an **interwoven network**; most contain **C** or **Si atoms**

Boiling/melting point	Very high
Malleability	N/A
Conductivity	Poor as solids
Solubility in water	Varied
Hardness	Extreme hardness or softness
Types of forces acting on molecule	Covalent bonds (strength increases with more bonds); sometimes IMFs (usually LDF)

Examples: Diamond, graphite, silicone (**not** Si (silicon)), semiconductors, buckyballs, nanotubes