Semester 1

Discovering Atomic Structure

Dalton

- Claims
  - Different elements vary in size and mass
    - Measuring mass
  - Law of Multiple Proportions (1804)
    - When two elements combine with each other to form more than one compound, the weights of one element that combine with a fixed weight of the othere are in a ratio of small whole numbers.
      - Nitrogen + Oxygen → NO, NO_2, NO_3, NO_4, NO_5. Oxygen weight in increasing order = 8, 16, 24, 32, 40. Ratios of 1:2:3:4:5
- Experiments
  - Pressure and other properties of gasses
    - Tiny, individual particles in constant, random motion
  - Properties of compounds
    - Elements are made of separate, discrete particles that cannot be subdivided.

JJ Thomson

- Cathode ray tubes (sealed glass tubes where most air is evacuated)
  - High voltage applied across two electrodes → beam of particles flow from cathode (negatively charged electrode) → anode (positive).
    - Beam of particles can be called cathode ray
      - Can be detected with phosphors
  - Thomson placed 2 opposite charged electric plates around cathode ray
    - Cathode ray deflected from pos charge ⇒ electrons

- Also put 2 magnets at end of tube
↳ Mass to charge ratio
  - Mass of particles was much smaller than atoms
  - He repeated experiment with different metals as electrode materials
    - Constant result
- Conclusions
  - Cathode ray = negative particles
  - Only exist as part of atoms since mass is ~$\frac{1}{2000}$ the mass of hydrogen.
  - Found in atoms of all elements
- Plum pudding model
  - Atoms have overall neutral charge
  - Negative electrons floating in positive soup.

Rutherford
- Gold foil experiment
  - Fire thin beam of alpha particles at very thin sheet of gold.
    - Alpha particles are helium nuclei ($^{4}_{2}He^{2+}$). Radioactive decay processes.
    - Put radium in lead box with small pinhole
    - Gold foil surrounded by detector screen which flashed of there were alpha particles
  - He predicted most rays would go through based on plum pudding (nothing dense enough to reflect)
    - + particles assumed to be spread out
  - Most rays past through but some were deflected 90+°
- Conclusion
  - Positive charge localised in small area of atom (nucleus)
  - Atom made of mostly empty space

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- Nuclear model

Bohr

- Quantizing structure of atom
  - Suggested electrons could orbit as part of shells with a fixed radius.
    - Electrons couldn't exist out of the shells
  - $r(n) = n^2 \times r(1)$ where n = positive integer and r(1) = Bohr radius (smallest allowed radius for hydrogen)
  - $r(1) = 0.529 \times 10^{-10}$ m
  - Energy level of hydrogen : $E(n) = \frac{-1}{n^2} \times 13.6eV$
  - Lowest possible energy of hydrogen electron $-E(1)$ is $-13.6eV$

  Not needed

  ↳ Energy level always going to be a negative number
- Conclusion
  - Just for hydrogen and other single electron systems

Chadwick

- Beryllium bombardment
  - Radiation from it was concluded something of neutral charge as big as a proton.

Quantative Chemistry

Relative atomic mass = average mass of atom compared to 1/12 mass of carbon-12
- takes in account isotopes } not always whole number
- Weighed average }
- Relative atomic mass = A_r
- In data book or periodic table
  - [6 C 12] ← relative atomic mass

Relative formula mass = M_r
- Step 1: write down formula of molecule | H_2O
- Step 2: find A_r of each type of atom in molecule | Hydrogen = 1 Oxygen = 16
- Multiply and add | $(2 \times 1) + (1 \times 16) = 18$

Moles
- 1 mole of a substance = its relative atomic mass OR relative formula mass in grams.
- A_r of carbon = 12 so 1 mole of carbon atoms = 12 g
- 1 mole of any substance contains 6.022×10^{23} particles
  - 1 mole of carbon contain 6.022×10^{23} carbon atoms.
  - Avogadro's number
    - Amedeo Avogadro - Italian + Early 19th century
- number of moles = $\frac{\text{mass of substance}}{\text{molar mass}}$
  - mass of substance = g
  - Elements which exist as molecules (7 + 4) (O_2) need molecular mass rather than atomic mass
  - Compounds molar mass is sum of all relative atomic masses (M_r)
  - $n = \frac{m}{M_r}$
  - 28g of pure iron: number of moles = $\frac{28}{56}$ = 0.5 moles iron
  - 11g of CO_2: Mr = 44 = $\frac{11}{44}$ = 0.25 moles of CO_2

Percentage by mass
- % element = $\frac{A_r \text{ of element} \times \text{number of atoms}}{M_r \text{ of compound}} \times 100$
- % of mass of nitrogen in ammonia
  - M_r of NH_3 = (1×14) + (3×1) = 17
  - % of nitrogen in NH_3 = $\frac{(14 \times 1)}{17} \times 100$
    = 82%

Types of Reaction

Definitions & example
- Neutralisation - when an acid and a base react with each other to form a neutral substance
  - $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
- Combustion - exothermic oxidation of a substance - a type of redox reaction
- Precipitation - formation of a solid from 2 solutions
- Redox - involves transfer of electrons from one species to another
  - Can be both redox and something else
- Decomposition - Breaking down a compound to elements / simpler compounds
- Synthesis - combining 1+ elements to make a larger compound

Redox reactions
- Metal & acid
  - Metal + acid → salt + hydrogen
  - $Mg + 2HCl \rightarrow MgCl_2 + H_2$
- Metal + oxygen
  - Metal + oxygen → metal oxide
  - $4Na + O_2 \rightarrow 2Na_2O$
- Combustion

- Burning elements
  - $S + O_2 \rightarrow SO_2$
  - $4Fe + 3O_2 \rightarrow 2Fe_2O_2$
- Burning compounds
  - $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- Displacement
  - Metal + metal compound
    - $Zn + Pb(NO_3)_2 \rightarrow Zn + (NO_3)_2 + Pb$
  - Halogen + metal halide
    - $Cl_2 + 2KBr \rightarrow 2KCl + Br_2$

Atomic Structure

Changes in the nucleus = very rare.
- Only change with nuclear processes
  - Radioactive decay
  - Nuclear bombs
  - Nuclear reactors

Electron shells can also be called energy levels

Isotopes
- Don't really affect chemical properties
- Affect physical properties
  - Melting point
  - Density
- Natural samples of elements are usually mix of isotopes
- Hydroge
  - Hydrogen (no neutrons)
  - Deuterium (1 neutron)
  - Tritium (2 neutrons)

Chemical Calculations

Balancing ionic equations
- Need same overall charge as well

Unbalanced: $Ca^{2+} + Cl^- \rightarrow CaCl_2$

+1 charge — No charge

Balanced: $Ca^{2+} + 2Cl^- \rightarrow CaCl_2$

No charge — No charge

Balaced equations show ratios of reactants and products
- $Mg : O_2 : MgO$ is 2:1:2
= Used to calculate masses of reactants need
  - These amounts are called relative reacting masses.

If you have 48 grams of magnesium, what mass of oxygen will react with this

$2Mg + O_2 \rightarrow 2MgO$

$Mg : O_2$ is 2:1
- Atomic formular of Mg = 24
- Relative formular mass of O_2 = 32

$Mg : O_2 = (2 \times 24) : (1 \times 32) = 48g : 32g$

Calculating mass of product given mass of a reactant
1. Calculate number of moles of reactant
   No. of moles $= \frac{mass}{M_r}$
2. Determine mole ratio of reactant to product
   Ensure equation is balanced
3. Calc no. moles of product
   Use mole ratio
4. Calc mass of product
   mass = moles × M_r

Types of Reactions

Making observations

- Need to describe chemical change
  - What reactants look like
  - Observations during reaction
  - What products look like
- Unambiguous language
  - Give state of matter
  - Colour (basic colours)
    - No colour = colourless
  - Transparent / opaque
  - Translucent = kinda shimmery
    - Rarely seen

Examples

- Good
  - Grey shiny metal dropped in clear blue solution, brown solid forms at the bottom, solution becomes paler blue
  - White solid dropped into clear colourless liquid, colourless gas evolved, leaving a clear colourless solution
  - Colourless gas bubbled through clear colourless liquid, white precipitate forms, solution becomes opaque
- Bad
  - Few word answers

Gas Calculations

Moles of gas

- 1 mole of gas same volume at a given temperature and pressure
- At standard temperature and pressure (STP) (0°C and 100kPa), 1 mol of gas occupies 22.71L
- Litres to moles = L/22.71
- Moles to Litres = moles x 22.71

Volume and mass

- Mass ⟷ volume = first work out moles
  - Use molecular mass

What is the mass of 100L of Nitrogen, N_2?

- 100 / 22.71 = 4.403
- Molecular mass of O_2 = 28.02
- 4.403 x 28.02 = 123.4g

What mass of H_2O would be produced with 11.2L of hydrogen H_2?

= $2H_2 + O_2 \rightarrow 2H_2O$

= 11.2 / 22.71 = 0.4932

- 2:2 = H_2 : H_2O
- (2.016 x 2) : (18.016 x 2)
- 8.885g of H_2O

What volume of oxygen would completely react with 11.2L of hydrogen

- n (moles) = $\frac{}{22.71}$
- $n(H_2) = \frac{11.2}{22.71}$ = 0.493 mol (3 SF)
- $2H_2 + O_2 \rightarrow 2H_2O$
- 1:2 ratio
- $n(O_2) = \frac{1}{2} \times n(H_2)$ = 0.247 mol
- $V = 22.71n$ ∴ $V(O_2)$ = 22.71 x 0.247 = 5.6L

What mass of H_2O_2 is needed to produce 2 litres of O_2

- $2H_2O_2 \rightarrow 2H_2O + O_2$
- $2 / 22.71 = 0.088$
- $1:2 = O_2 : H_2O_2$
- $(1 \times 16) : (2 \times 34.016)$
- $68.032 \times 0.088 = 5.991$

Limiting reagent

- If you want to make sandwiches and have 16 slices of bread and have 10 slices of ham, the limiting reagent is bread, as it defines how many sandwiches yo can make
- When figuring out which is the limiting reagent
  - pretend volume is moles
  - Guess which is the limiting reagent.
  - Pretend volume is moles (no mass)
  - Find ratio between the 2 molecules
  - Find other amount based on the assumed LR

Valency

Valence electron

- The electrons in the OUTER shell
- Electrons in inner shells can be called core electrons

Valency

- the charge of an atom of it were to become an ion
- No +/- signs
- Al has a valency of 3
- F has a valency of 1
- Typically in roman numerals (transition metals
  - Fe(II) vs Fe(III)

Electronegativity

- The ability for atoms to attract electrons
  - More electromagnetic = attracts electrons easier
- Electronegativity increases when you go to the right of periodic table or up
  - Boron is both metallic and electronegative
    - Boron - Chlorine bonds called covalent
- Most electronegative one NOF

Electron structure and reactivity

- Having more electron shells = further away from nucleus = weaker force of attraction
- Further → less energy to remove → more reactive

Noble gases

- Most unreactive
- Exist as singular atoms
  - Monatomic
- Don't usually bond with other atoms

Redox

- Oxidation - addition of oxygen to a substance
- Reduction - removal of oxygen

Reduction
Oxygen removed

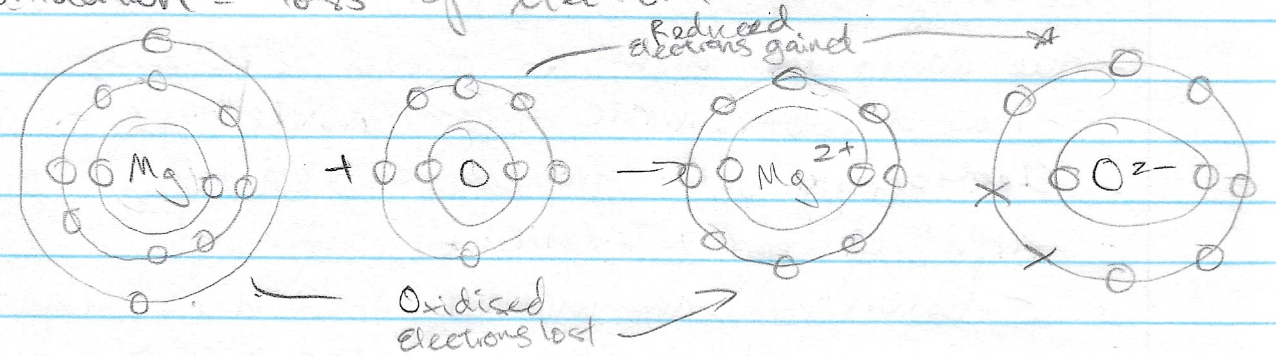
Lead oxide + carbon → lead + carbon monoxide

Oxidation
Oxygen added

→ Oxidation and reduction always take place in same reaction
  - Called red ox

↳ When writing which is oxidised, write molecule in its form without oxygen
  - Lead is reduced and carbon is oxidised

Oxidation = loss of electrons



Reduction = gain electrons

Half - equations
- Equations which show what happens to electrons during oxidation and reduction

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
- Oxidation = $Mg \rightarrow Mg^{2+} + 2e^-$
- Reduction: $O_2 + 4e^- \rightarrow 2O^{2-}$

Oxidation = e^- on products side
Reduction = e^- on reactants side
e^- = electron

$Mg + 2HCl \rightarrow MgCl_2 + H_2$
- Mg = oxidised to Mg^{2+}
- H^+ ions = reduced to H_2

Metal displacement
- Kind of redox reaction
- More reactive metal will displace less reactive one
- More reactive = oxidised, less reactive = reduced

Halogen displacement
- redox
- More reactive displaces less reactive
- More reactive = reduced
- Less reactive = oxidised
↳ Opposite to metals

Ionic bonds

Stability
- Full shells = stable
- Noble gases = unreactive
- Other elements bond to become stable

Ions
- When unstable elements become stable, they gain an overall charge and become ions
- Negative ions equals atom base name + ide
  - Fluoride, Chloride, Oxide
- When different elements complete outer shell, they create ions with same electron configuration
  - O^{2-} and F^-
- Ion made up of a group of atoms = polyatomic ion / compound ion

Ionic compounds
- Contain ions
  - Na^+ and Cl^-
- Metal ion electrons → non-metals
  - This electrostatic attraction = ionic bonding
- Lattices form as every ion is surrounded by opposite charge
  - Geometry depends on ionic formula unit
    - Size of ions
    - Ratio of ions

Precipitation and Ionic Equations

Spectator ions
- Not involved in reaction
- Use ionic equation to identify
  - $NaI_{(aq)} + AgNO_{3(aq)} \rightarrow AgI_{(s)} + NaNO_{3(aq)}$
  - $Na^+_{(aq)} + I^-_{(aq)} + Ag^+_{(aq)} + NO^-_{3(aq)} \rightarrow AgI + Na^+_{(aq)} + NO^-_{3(aq)}$
    - Na^+ and NO_3^- are spectator ions
  - $I^-_{(aq)} + Ag^+_{(aq)} \rightarrow AgI_{(s)}$
- Solids are bonded in an ionic lattice
  - State symbol (s)
- When ionic compounds are dissolved in water, ions dissociate
  - State symbol (aq)
  - Often only 1 ion reacting
    - Others left out in ionic equations.
  - Solids in reactants or products must have full formula.

How to write ionic equations
1. Write full balanced equation
   - Incl all states of matter
2. Split all ionic substances in solutions which ionise
3. Cancel spectator ions on both sides.
4. Rewrite as net ionic equations

$Zn_{(s)} + CuSO_{4(aq)} \rightarrow Cu_{(s)} + ZnSO_{4(aq)}$

$Zn + Cu^{2+} + \cancel{SO_4} \rightarrow Cu + Zn^{2+} \cancel{+ SO_4}$

$Zn_{(s)} + Cu^{2+}_{(aq)} \rightarrow Cu_{(s)} + Zn^{2+}_{(aq)}$

$Mg_{(s)} + PbNO_{3(aq)} \rightarrow Pb_{(s)} + MgNO_{3(aq)}$

$Mg_{(s)} + Pb^{2+}_{(aq)} + \cancel{NO^{2-}_{3(aq)}} \rightarrow Mg^{2+}_{(aq)} + Pb_{(s)} + \cancel{NO^{2-}_{3}}_{(aq)}$

$Mg_{(s)} + Pb^{2+}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + Pb_{(s)}$

$Br_2 (aq) + 2NaI (aq) \rightarrow I_2 (aq) + 2NaBr (aq)$

$Br_2 (aq) +$ ~~$2Na^+ (aq)$~~ $+ 2I^- (aq) \rightarrow I_2 (aq) +$ ~~$2Na^+ (aq)$~~ $+$
$2Br^- (aq)$

$Br_2 (aq) + 2I^- (aq) \rightarrow I_2 (aq) + 2Br^- (aq)$

↳ BromINE = Br^-, BromIDE = Br_2

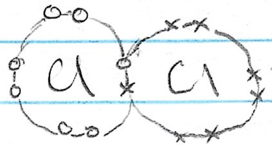
$CuSO_4 (aq) + 2NaOH (aq) \rightarrow Cu(OH)_2 (s) + Na_2SO_4 (aq)$

$Cu^{2+} (aq) +$ ~~$SO_4^{2-} (aq)$~~ $+$ ~~$2Na^+ (aq)$~~ $+ 2OH^- (aq) \rightarrow Cu(OH)_2 (s)$
~~$Na_2^{2+} (aq)$~~ $+$ ~~$SO_4^{2-} (aq)$~~

$Cu^{2+} (aq) + 2OH^- (aq) \rightarrow Cu(OH)_2 (s)$

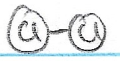
Covalent Bonds

Drawing covalent bonds
- Don't have to draw inner electrons
- Simplified dot and cross diagram:



- Solid line:

Cl – Cl



Diatomic
- Super 7 + hydrogen

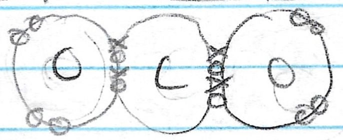
Covalent compounds
- Covalent bonds between two different non-metals
- HCl, H–Cl, 

- Can have more than 1 covalent bond
- H_2O, H–O–H, 

Bonding

- Double bonds

Element	C	O
Electron configuration	(2,4)	(2,6)
Electrons needed	4	2
Ratio of atoms	1	2

-  or O=C=O

Simple covalent structures
- Covalent molecules that only have a few atoms
- Low melting and boiling points
  - Usually liquid or gas
- Intermolecular bonds are strong but intramolecular bonds are weak

Molecular solid
- Iodine
- Low melting and boiling points
- Soft and brittle (shatter when hit)
- Don't conduct electricity