CHEM1901 Notes

NUCLEAR CHEMISTRY

Significant figures -

- Rules:
    1. All non-zero digits - significant
    2. Zeros between 2 non-zero digits - significant
    3. Trailing zeros in number containing decimal point - significant
    4. Leading zeros - NOT significant
    5. When multiplying or dividing - answer should contain SAME number of s.f. as the measurement with the FEWEST s.f. in data provided
    6. When adding or subtracting - answer should contain SAME number of DECIMAL PLACES as the measurement with the FEWEST d.p. in data provided
    7. When rounding off, if the digit removed is:
        (1) >5 - increase preceding number by 1
        (2) <5 - don't change preceding number
        (3) =5
            (a) Increase preceding number by 1 if it's odd
            (b) Do not change preceding number if it's even
- NOTE: only round at end of calculations; carry full numbers through

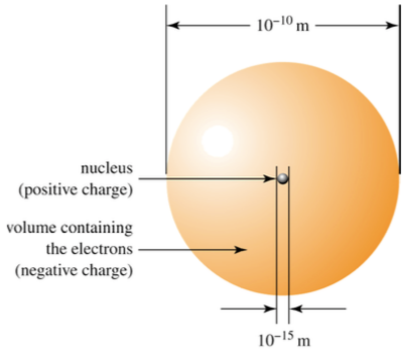
Number	# sig. figs.
0.024	2
42400	3
4.0024	5
4240.0	5

Units -

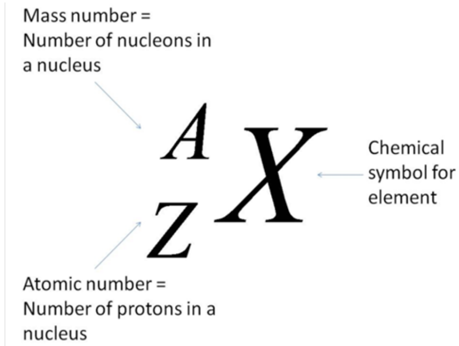
- ***Fundamental units*** - units for physical quantities from which all other units can be generated
- 7 SI fundamental units:
    1. Ampere (A)
    2. Candela (cd)
    3. Kelvin (K)
    4. Kilogram (kg)
    5. Metre (m)
    6. Mole (mol)
    7. Second (s)
- Units composed of combination of fundamental units
- *E.g. Newton (N): force (N) = mass (kg) x acceleration (ms^{-2}) = $kgms^{-2}$*
- *E.g. Joule (J): energy (J) = force ($kgms^{-2}$) x distance (m) = kgm^2s^{-2}*

Sub-atomic particles -

- ***Atom*** - electrically neutral particle formed by:
    - Positively charged nucleus, composed of ***nucleons***:
        - Positively charged protons (p^+)
        - Neutrons (n^0)
    - Surrounded by a cloud of negatively charged electrons
- 1 ***atomic mass unit*** (a.m.u.) ~1.66×10^{-27} kg (defined by setting mass of 1 atom of carbon-12 to exactly 12 a.m.u.)



Notation -



E.g. carbon has 6 protons and 6 neutrons, ${}^{12}_{6}C$:
Atomic Symbol = X = C (identifies the element)
Atomic Number = Z = protons = 6 (= number of electrons in a NEUTRAL atom)
Mass number = A = protons + neutrons = 6 + 6 = 12
Number of neutrons = N = A - Z = 12 - 6 = 6

- ***Nuclide*** - atom with a particular mass number + atomic number
- ***Isotope*** - nuclides with same atomic number (Z) but different mass numbers (A)
  E.g. carbon exists in nature in 3 different isotopes: ${}^{12}_{6}C$ ${}^{13}_{6}C$ ${}^{14}_{6}C$
- NOTE: isotopes of hydrogen = protium, deuterium, tritium

- ***Atomic mass of an element*** - average of the atomic masses/abundances of each of the <u>naturally-occurring</u> isotopes

Isotope	^{28}Si	^{29}Si	^{30}Si
Natural abundance	92.21%	4.70%	3.09%
Mass (a.m.u.)	27.97693	28.97649	29.97376

  E.g. 1) atomic mass of silicon:
  = (0.9221 x 27.97693) + (0.0470 x 28.97649) + (0.0309 x 29.97376)
  = 25.80 + 1.36 + 0.926
  = 28.086 a.m.u. (aka g/mol)
  E.g. 2) Naturally occurring chlorine consists of 2 main isotopes, ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ with masses 34.969 and 36.966 a.m.u. respectively. Use the atomic mass of chlorine of 35.453 g/mol to calculate the relative abundance of these 2 isotopes.
  Let the relative abundances of ${}^{35}_{17}Cl$ and ${}^{37}_{17}Cl$ be a% and b% respectively.

$$\left(34.969 \times \frac{a}{100}\right) + \left(36.966 \times \frac{b}{100}\right) = 35.453\,\mathrm{g\,mol^{-1}}$$

  Since these are the only 2 isotopes, then a + b = 100 —> b = 100 - a

$$\left(34.969 \times \frac{a}{100}\right) + \left(36.966 \times \frac{100-a}{100}\right) = 35.453\,\mathrm{g\,mol^{-1}}$$

  Solving gives a = 75.764%, b = 24.236%

Nuclear Reactions -

- ***Nucleogenesis*** - formation of new nuclei from existing nucleons
- Primary nucleogenesis reaction = proton-proton chain, i.e. all atoms generated from simplest nuclide (H) by nuclear reactions
- NOTE: H nucleus = proton (${}^{1}_{1}H$ or ${}^{1}_{1}p$)
- Fundamental nuclear reaction: $2\,{}^{1}_{1}H \longrightarrow {}^{2}_{1}H + {}^{0}_{1}e$, which is rapidly followed by

$${}^{2}_{1}H + {}^{1}_{1}H \longrightarrow {}^{3}_{2}He + \gamma$$
$$2\,{}^{3}_{2}He \longrightarrow {}^{4}_{2}He + 2\,{}^{1}_{1}p, \text{ etc.}$$

- Reaction rate controlled by number of nuclei present (temperature, catalysts, etc. DO NOT affect rate of nuclear reactions)
- Overall reaction releases energy into surroundings as heat (EXOTHERMIC) + radiation
- Energy comes from change in mass, according to $E = mc^2$
- To balance nuclear equations:

$${}^{\text{Total A}}_{\text{Total Z}}\text{Reactants} = {}^{\text{Total A}}_{\text{Total Z}}\text{Products}$$

Synthesis of heavier nuclei -

- ***Nuclear fusion*** - joining together of light nuclei to form heavier nuclei
- *E.g. in stars:*
  - *Clouds of atomic H pulled together by gravity + heat —> extreme temp + pressure causes H nuclei fuse to give He nuclei (cloud ignites as star)*
  - *As star exhausts it's H, it begins He burning to fuse heavier nuclei to form increasingly larger atoms*
  - *Stars —> red giants —> supergiants —> supernovae*
- ***Nuclear fission*** - splitting of heavier nuclei into lighter nuclei
- *E.g. production of nuclear power*
- Both processes produce significant amounts of energy

Radioactivity -

- Atomic nuclei can be divided into 2 types:
  A. Stable
    - Most stable nuclides have:
      - Z = even number
      - N = even number
      - NOTE: this is related to spins of nucleons —> when 2 protons or neutrons have opposite spins (paired), their combined energy < when spins are same (unpaired))
      - Isotopes with specific 'magic' numbers (2, 8, 20, 28, 50, 82, 126) of N + Z are more stable than the rest
  B. Radioactive (unstable)
    - ***Radioactive nuclei*** undergo spontaneous decay to achieve a stable nucleus with a more favourable N/Z ratio —> generally decays in mode that shifts N/Z ratio towards ***band of stability***
    - Key factor in nuclear stability = neutron/proton (N/Z) ratio in nucleus:
      - Light nuclei (Z<20) stable when N/Z = 1
      - Heavier nuclei (Z>20) stable when N/Z = 1.15-1.5. EXPLANATION:
        - Strong nuclear force (holding nucleus together) operates at very small distances
        - As Z increases, electrostatic repulsion (between protons) increases + more neutrons required to generate enough nuclear force to stabilise nucleus
    - All nuclides with Z > 83 —> unstable
    - Unstable nuclei present in nature because:
      (1) Some unstable nuclides have long half-lives (haven't decayed yet)
      (2) Continually formed by nuclear reactions

Types of decay -

Decay type	Alpha	Beta	Positron	Gamma
Decay 'particle'	He nucleus	Negatively charged electron	Positively charged electron	High frequency EM radiation (high-energy photons)
Symbol	α	${}_{-1}\beta$ or ${}_{-1}e$	e^+ or ${}_1\beta$ or ${}_1e$	γ
Charge	+2	-1	+1	0
Results from		Conversion of neutron into proton + electron (+ antineutrino) which is ejected from nucleus ${}^1_0n \longrightarrow {}^1_1p + {}_{-1}\beta$	Conversion of proton into neutron + positron (+ neutrino) which is ejected from nucleus ${}^1_1p \longrightarrow {}^1_0n + {}_1\beta$ NOTE: antimatter	Transitions between energy levels in nucleus
Leads to	- Decrease in N - Decrease in Z	- Decrease in N - Increase in Z - Decrease in N/Z ratio	- Increase in N - Decrease in Z - Increase in N/Z ratio	No change in N or Z
Occurs when	Heavier nuclei (Z > 82) to reduce repulsions between large number of protons in nucleus	N/Z ratio > zone of stability (more neutrons than stable nucleus)	N/Z ratio < zone of stability (fewer neutrons than stable nucleus)	Accompanies other forms of decay - emission of gamma-rays allows nucleus to relax to lower energy state
Example	${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^4_2He$	${}^{63}_{28}Ni \longrightarrow {}^{63}_{29}Cu + {}^0_{-1}\beta$	${}^{11}_6C \longrightarrow {}^{11}_5B + {}^0_1\beta$	

NOTE: 2 other decay forms (less important):

- ***Neutron emission***
  - Occurs when N/Z > zone of stability
  - Leads to
    - Decrease in N
    - No change in Z
    - Decrease in N/Z ratio
- ***Electron capture***
  - Involves nucleus capturing electron from surrounding inner shells of electrons
  - Followed by emission of EM rays as electrons fall into lower energy states
  - Net effect - proton turned into neutron
  - Leads to
    - Decrease in Z
    - No change in A