Chapter 2: Atoms

2021 for IMAT 2022

- organisms r made up of matter = anything that takes up space & has mass

matter exists in many forms: rocks, metals, oils, gases + organisms r arrangement of matter

- matter is made up of elements

element is a substance that can't be broken down to other substances by chemical reactions

there r 92 elements in nature

ie. gold, copper, oxygen

element has a symbol the first letter / 2 of its name

symbol for sodium is Na comes from latin word natrium

a compound is a substance made of 2/more different elements combined in a fixed ratio

table salt is sodium chloride (NaCl) compound made of elements sodium (Na) & chlorine (Cl) in a 1:1 ratio!

pure sodium is a metal & pure chlorine is poisonous gas when combined sodium + chlorine make edible compound

→ so it has emergent properties: compound has characteristics different from those of its elements! → PIC

of the 92 elements 25% r essential elements that organism needs to live healthy life & reproduce

→ PIC tabelle

humans need 25 elements + plants 17

oxygen (O), carbon (C), hydrogen (H) & nitrogen (N) make up 96% of living matter

calcium (Ca), phosphorus (P), potassium (K), sulfur (S) + other elements make up the rest of organism's mass

- trace elements r needed by organism in minute quantities

trace elements like iron (Fe) is needed by all forms of life ~~others r needed by certain species~~

ie in vertebrates element iodine (I) is essential ingredient of a hormone made by thyroid gland

daily intake of 0,15 mg is enough for normal activity of thyroid gland

iodine deficiency in diet causes growth of thyroid gland (to abnormal size) = goiter prevent by eating seafood / iodized salt

element arsenic is ~~extre~~ toxic to organisms → causes diseases & is deadly
its in ~~water~~ groundwater

- Species have become adapted to environments with toxic elements i.e serpentine plant communities

serpentine is jade like mineral that contains high concentrations of nickel, cobalt & chromium
↳ elements usually toxic to plants!

most plants can't survive in soil that forms from serpentine rocks but some plant species have adaptations that allow them to

different versions of ancestral nonserpentine species

developed that could survive in serpentine soils & natural

selection led to the variety of species there today
→ PIC

concept
• 1.2 each element is made of a ~~certain~~ type of atom that's different from the atoms of another element

atom = smallest unit of matter that keeps properties of an element

atoms r small

* the symbol C stands for the element carbon and 1 carbon atom
~~(element carbon is made up of C atoms)~~
* atoms r symbolized with the symbol of the element that's made up of those atoms

atoms r made of smaller parts "subatomic particles"

3 kinds of particles r important:
neutrons, protons & electrons

protons & electrons r electrically charged
proton has 1 unit of ⊕ charge & each electron 1 unit of ⊖ charge

neutron is ~~neutrally charged~~ electrically neutral

- protons & neutrons r packed together in an atomic nucleus at the center of atom
- protons give the nucleus a ⊕ charge

moving electrons form a cloud of ⊖ charge around the nucleus & its ~~this~~ the attraction between opposite charges that keeps the electrons near the nucleus
→ PIC 2 models of helium atom

- the neutron & proton r identical in mass
- for atoms & subatomic particles we use a unit of measurement called the dalton

the dalton is the same as atomic mass unit / amu

- neutrons & protons have masses ~~of~~ close to 1 dalton
- coz mass of an electron is $\frac{1}{2000}$ that of a neutron or proton
  → we ignore electrons when measuring mass of an atom

atoms of different elements differ in their nr of subatomic particles

all atoms of certain element have the same nr of protons in their nuclei

this number of protons that's unique to that element is the atomic number & is written as a subscript to left of the symbol for the element

$_2He$ ~~[illegible]~~ ~~[illegible]~~ atom of the element helium has 2 protons in its nucleus!

an atom is ~~[illegible]~~ neutral in electrical charge = its protons r balanced by an equal nr of electrons

so atomic number = number of protons = number of electrons ~~[illegible]~~ in a neutral atom

we can work out the nr of neutrons from the mass number = total nr of protons & neutrons in nucleus of atom

→ so mass nr = nr of protons + nr of neutrons

mass nr is written as superscript to left of element's symbol → ^4_2He

coz atomic nr = nr of protons we determine the nr of neutrons by doing

nr of neutrons = mass nr − atomic nr

helium has 2 neutrons → p.c with Na

simplest atom is hydrogen ^1_1H → has no neutrons
it is made up of 1 proton with 1 electron

coz ~~[illegible]~~ electrons contribute little to mass ~~of~~ → all an atom's mass is concentrated in its nucleus

neutrons & protons each have a mass close to 1 dalton so the mass nr is close to but different from the total mass of an atom = its atomic mass

i.e mass nr of sodium $^{23}_{11}Na$ is 23 but its atomic mass is 22,9898 daltons

- all atoms of an element have same nr of protons but some atoms have more neutrons than other atoms of the same element & ~~[illegible]~~ have bigger mass
- these different atomic forms of the same element r isotopes of the element

in nature an element occurs as a mix of its isotopes
i.e. element carbon has atomic nr 6
has 3 naturally occuring isotopes
~~%~~ ~~of carbon~~ in nature is
~~most common~~ isotope is carbon 12 $^{12}_{6}C$
isotope $^{12}_{6}C$ has 6 neutrons
(~1%)
the rest of carbon is made up of atoms of the isotope
$^{13}_{6}C$ with 7 neutrons

an even rarer isotope $^{14}_{6}C$ has 8 neutrons
all 3 isotopes ~~have~~ of carbon have 6 protons coz they r carbon!

^{12}C & ^{13}C r stable isotopes = their nuclei don't ~~have~~ ~~tendency to~~ lose subatomic particles = decay =
isotope ^{14}C is unstable / radioactive

radioactive isotope is 1 in which the nucleus decays giving off particles & energy

- when the radioactive decay leads to change in the nr of protons it transforms the atoms to an atom of a different element

- i.e when a ~~14~~ ^{14}C atom decays a neutron decays into a proton
  -> transforms the atom into a nitrogen ^{14}N atom

radio active tracers text
- radioactive isotopes r used as diagnostic tools in medicine

the radioactive isotopes r ~~added~~ introduced into biologically active molecules -> r then used as tracers to track atoms during metabolism = chemical processes of organism

- i.e kidney diseases r diagnosed by injecting ~~small~~ doses of radioactively labeled substances into blood + analyzing tracer molecules excreted in the urine

- radioactive tracers r ~~also~~ used with imaging instruments like PET scanners that ~~monitor~~ check growth & metabolism of cancers in body

- radiation from decaying isotopes is dangerous ~~to life~~ coz it damages cellular molecules
  -> amount of damage depends on the type + amount of radiation organism absorbs

- doses of isotopes in medical diagnosis r safe

dating text
- researchers measure radio active decay in fossils to date these relics of past life
- fossils give evidence for evolution, document differences between organisms from past + those living now &
in ~~fixed~~

give us info into species that have disappeared over time

layering of fossil beds ~~...~~ ~~determines~~ reveals that deeper fossils r older than more shallow ones → age of the fossils in each layer can't be determined by position
↳ we use radioactive isotopes!

parent isotope decays into its daughter isotope at a fixed rate ⇒ half life = time it takes for 50% of the parent ~~isot~~ isotope to decay
~~isotope~~

each radioactive isotope has a certain half-life that's not affected by temp, pressure / other environmental factor

with radiometric dating scientists measure the ratio of different isotopes & calculate how many half lives ~~...~~ ~~...~~ have passed since an organism was fossilized / a rock was formed

half life values r ~~measured in~~ short seconds / days for some isotopes or ~~in years~~ long (i.e. uranium 238 has half life of 4,5 billion years)

energy levels text

the ~~x~~ nucleus is a lot smaller than in PIC on p. 78 of atom
↳ atoms r mostly empty space!

only electrons r ~~directly~~ involved in chemical reactions!

an atom's electrons vary in amount of energy they have

energy = capacity to cause change by doing work

potential energy = energy that matter has coz of its location / structure

~~matter ~~has~~ tends to move toward the lowest state of potential energy i.e. water moves downhill~~

~~to restore the pot. energy of a reservoir work is done to elevate the water against gravity~~

electrons of atom have pot. energy coz of their distance from nucleus

the ⊖ charged electrons r attracted to the ⊕ charged nucleus

it takes work to move an electron further away from nucleus

so the more distant electron is from nucleus → the bigger its potential energy

changes in the potential energy of electrons occur in steps in fixed amounts an electron having a ~~certain~~ amount of energy is like a ball on stair case → PIC

the ball ~~can~~ have different amounts of pot. energy depending on which step it's on but it can't spend much time between the steps

= an electron's potential energy is determined by its energy level

an electron exists at a certain energy level or between shell!

electron's energy level is connected with its distance from the nucleus

electrons r in different electron shells each with a certain distance & energy level

shells r concentric circles in PIC p.81

the 1st shell is closest to nucleus & electrons in this shell have lowest pot. energy

electrons in 2nd shell have more energy & electrons in 3rd shell even more energy

- an electron moves from 1 shell to another by

absorbing / losing amount of energy equal to the difference in pot. energy between its position in old shell & that in new shell

when electron absorbs energy it moves to shell further out from nucleus

i.e. light energy excites an electron to a higher energy level

when electron loses energy it falls back to shell closer to the nucleus & the lost energy is released to environment as visible light or uv radiation!

periodic table text

- the chemical behavior of atom is determined by the distribution of electron in atom's electron shells

- starting with Hydrogen we build the atoms of the other elements by adding 1 proton & 1 electron from left to right to each element in rows

- periodic table of elements shows the distribution of electrons from H to $_{18}Ar$

- the elements r arranged in 3 rows (periods) = nr of electron shells in their atoms

- ~~left to~~ right sequence of elements in each row is the atoms when u add 1 proton & 1 electron to each left to right

H's 1 electron & He's 2 electrons r in 1st shell

electrons exist in the lowest state of potential energy = 1st shell in atom

BUT 1st shell holds 2 electrons max so H & He r the only elements in 1st row!

- in atom with > 2 electrons the other electrons occupy higher shells coz the 1st shell is full

the 2nd shell holds max 8 electrons

* (Neon has 8 electrons in 2nd shell (& 2 electrons in 1st shell)
→ has 10 electrons in total!)

the chemical behavior of atom depends on the nr of electrons in its outermost shell
= "valence electrons" & ~~the outerm~~
the outermost electron shell = valence shell

- atoms with the same nr of electrons in their valence shells show similar chemical behavior
i.e. F & Cl have 7 valence electrons & form compounds when combined with sodium (Na)
NaCl (table salt) & NaF (sodium fluoride)

atom with completed valence shell is unreactive
→ it doesn't affect other atoms (have an effect on them)

affect each other

- helium, neon & argon have full valence shells
→ it's r inert elements = chemically unreactive
- all other atoms r chemically reactive coz they have incomplete valence shells!

orbitals

text

- electron shells of atom r concentric paths of electrons orbiting the nucleus → diagram p. 82

~~(we use 2D concentric circle diagrams to symbolize 3D electron shells)~~

each concentric circle is the average distance between an electron in that shell & the nucleus

concentric circle diagrams don't give a real picture of an atom

we don't know the exact location of an electron
BUT we describe the space in which an electron spends most of its time = orbital

each electron shell contains electrons at a certain energy level distributed among orbitals of different shapes & orientations

an orbital is a part of electron shell

- for atoms with valence electrons in s & p orbitals the

1st electron shell has 1 spherical s orbital (1s)

the 2nd shell has 4 orbitals: 1 large spherical orbital (2s) & 3 dumbbell shaped p orbitals (2p orbitals)

there r max 2 electrons in 1 orbital

1st electron shell holds up to 2 electrons in its s orbital

the 4 orbitals of 2nd electron shell hold up to 8 electrons → 2 in each orbital

electrons in the 4 orbitals in 2nd shell have ~~mostly~~ the same energy but they move in different volumes of space! → PICS a, b & c)

Concept 2.3 — how do atoms combine to form molecules & ionic compounds?

afternoon or evening 8

- atoms with incomplete valence shells have effect on other atoms so each partner atom completes its valence shell: the atoms share or transfer valence electrons!

- these ~~interactions~~ effects lead to atoms staying close together held by attractions "chemical bonds"

not x in bold

- the strongest type of chemical bonds r covalent bonds in molecules & ionic bonds in dry ionic compounds

- covalent bond = sharing of a pair of valence electrons by 2 atoms

(H has 1 valence electron in 1st shell but shell holds up to 2 electrons)

when 2 H atoms come close ~~enough for their 1s orbitals to overlap~~ they share their electrons

each H atom has 2 electrons & has completed valence shell

2/more atoms held together by covalent bonds make a molecule → ~~H2 hydrog~~

PIC

1) in each hydrogen atom 1 electron is held in its orbital by its attraction to the proton in nucleus

2) when 2 H atoms approach each other the electron of each atom is attracted to the proton in the other nucleus

3) the 2 electrons r shared in covalent bond → forming a H_2 molecule

its molecular formula H_2 shows that molecule is made up of 2 atoms of hydrogen

electron sharing is shown by electron distribution diagram or Lewis dot structure → element symbols r surrounded

Par ... with ...

by dots that show the valence electrons (H : H)

we can use structural formula H — H → line is a single bond = pair of shared electrons

- oxygen has 6 electrons in its 2nd electron shell & needs 2 more electrons to complete its valence shell

- 2 oxygen atoms form a molecule by sharing 2 pairs of valence electrons

↳ the atoms r joined by a double bond O=O

- each atom that shares valence electrons has a bonding capacity = nr of covalent bonds it forms

- when the bonds form the atom has 8 electrons in valence shell

- bonding capacity of oxygen is 2
this ~~is the at~~ bonding capacity is atom's "valence" & ~~eo~~ = nr of electrons needed to complete the atom's valence shell

- valence of H is 1; oxygen 2; nitrogen 3 & carbon 4
phosphorus has valence of 3 or 5

water H_2O is a compound (= combination of 2/more different elements)
2 atoms of H r needed to satisfy the valence of 1 O atom is (2)

methane is compound with molecular formula CH_4
it takes 4 H atoms each with valence of 1 to complete the valence of a carbon atom with its valence of 4!
→ pics ~~learn ... ...~~

wed → atoms in molecule attract shared bonding electrons

the attraction of an atom for electrons of a covalent bond is its electronegativity

the more electronegative an atom is the more strongly it pulls shared electrons towards itself

- in a covalent bond between 2 atoms of the same element the electrons r shared equally bc the atoms have the same electronegativity
↳ this bond is a "nonpolar covalent bond"
ie single bond of H_2 is nonpolar & double bond of O_2

when an atom is bonded to a more electronegative atom the electrons of the bond n't shared equally

this bond is "polar covalent bond"

these bonds vary in their polarity depending on the electronegativity of the ~~atoms~~ 2 atoms compared to each other
ie. the bonds between oxygen & hydrogen atoms of water molecule r polar → pic learn text

... atoms with valence electrons ...

Oxygen is more electronegative than H so it attracts electrons more strongly than H does

in covalent bond between O & H electrons spend more time near oxygen nucleus than near hydrogen nucleus

coz electrons have ⊖ charge & r pulled toward oxygen in water molecule → oxygen atom has δ− charges and H atoms have δ+ charges

ionic bonds:

- 2 atoms r so unequal in their attraction for valence electrons that the more electronegative atom strips 1 electron away from its partner
- → the 2 oppositely charged atoms r "ions"
- a ⊕ charged ion is a cation
- a ⊖ charged ion is an "anion"
- coz of their opposite charges cations & anions attract each other, this attraction is "ionic bond"
- the transfer of an electron isn't the formation of a bond → it allows bond to form coz it leads to 2 ions of opposite charge
- any 2 ions of opposite charge can form an ionic bond
  → this happens when sodium atom (Na) meets a chlorine atom (Cl)
- a Na atom has 11 electrons with 1 valence electron in 3rd electron shell
- a Cl atom has 17 electrons with 7 electrons in its valence shell
- when these 2 atoms meet sodium's valence electron is transferred to Cl atom & both atoms have complete valence shells (sodium has 8 electrons in its valence shell → its now 2nd shell)
- the electron transfer between the 2 atoms moves 1 unit of ⊖ charge from Na to Cl
- Na with 11 protons but 10 electrons has electrical charge of 1+ sodium atom is a cation
- Cl atom has gained 1 electron now has 17 protons & 18 electrons it has electrical charge of 1− it is an anion − a chloride ion ⇒ PIC Learn ① & ②
- compounds formed by ionic bonds r ionic compounds / salts
  i.e ionic compound sodium chloride (NaCl) is = (table salt)

weak chem inter

... ... electrons in d & p orbitals the

salts r in nature as crystals

each salt crystal is ~~group~~ mass (body of parts) of cations & anions bonded by their electrical attraction & arranged in 3D lattice

- ionic compound isn't made of molecules
- formula for ionic compound NaCl shows ratio of elements in a crystal of the salt

NaCl isn't a molecule

not all salts have equal numbers of cations & anions i.e. ionic compound magnesium chloride $MgCl_2$ has 2 chloride ions for each magnesium ion

magnesium must lose 2 outer electrons ~~if it~~ to have a complete valence shell so it becomes a cation with charge of 2+ (Mg^{2+})

1 magnesium cation forms ionic bonds with 2 chloride anions (Cl^-)

"ion" = entire → molecules that r electrically charged

in salt ammonium chloride NH_4Cl the anion is 1 chloride ion (Cl^-), the cation is ammonium (NH_4^+) = nitrogen atom covalently bonded to 4 H atoms

the ammonium ~~ion~~ ion has electrical charge of 1+ coz it has given up 1 electron & is 1 electron short

environment affects the strength of ionic bonds
in dry salt crystal → the bonds r so strong that u need ~~to~~ a hammer to break enough of them to crack crystal in 2

if salt crystal is dissolved in water the ionic bonds r weaker coz each ion is protected from its interactions with water molecules

weak chemical interactions text

- in organisms the strongest chemical bonds r covalent bonds → link atoms to form a cell's molecules
- weaker interactions within & between molecules r important → contribute to emergent properties of life
- ~~large~~ large biological molecules r held in their functional form by weak interactions
- when 2 molecules in cell make contact they stick temporarily to each other by weak interactions
  → this is an advantage (reversibility): 2 molecules can come together affect 1 another & separate
- 1 ~~important~~ weak interaction is ionic bond coz it exists between ions dissociated in water, H bonds & van der Waals interactions

r important to life as well.

(H bonds) - when a hydrogen atom is covalently bonded to an electronegative atom the hydrogen atom has partial ⊕ charge that allows it to be attracted to a different electronegative atom with a partial ⊖ charge

- this noncovalent attraction between a Hydrogen & an electronegative atom is a hydrogen bond

- in living cells the electronegative partners r oxygen or nitrogen atoms → PIC ~~H bonds~~

(van der waals interactions) - a molecule with nonpolar covalent bonds has ⊕ & ⊖ charged regions

- electrons r n't always evenly distributed at any moment they accumulate in 1 part of a molecule or another

~~results~~ → (ever) changing regions of ⊕ & ⊖ charge that enable all atoms & molecules to stick to 1 another

- these van der waals interactions r individually weak & occur when atoms & molecules r close together

- when many van der waals interactions occur at same time → they r strong!

(learn →)
↳ V.d.W interactions allow gecko lizard to walk up wall!

- the structure of gecko's foot & toes with hundreds of hairs each with projections → maximises surface contact with wall

- V.d.W interactions between foot molecules & molecules of wall's surface r so numerous that they support gecko's body weight!

- V.d.W interactions, H bonds, ionic bonds in water form also between parts of large molecules like protein / nucleic acid!

→ ~~these~~ they reinforce the 3D shape of the molecule

molecular shape + function

- a molecule has certain shape & size → important for its function in the cell

a molecule made of 2 atoms like H_2 & O_2 is linear

- molecules with more than 2 atoms have more complicated shapes

- these shapes r determined by the positions of the atom's orbitals → PIC

- when an atom forms covalent bonds the orbitals in its valence shell undergo rearrangement

↳ PIC p-87

concept 2.4 - the making & ... of matter r chemical changes in composition

- for atoms with valence electrons in s & p orbitals the single s & 3 p orbitals form 4 ~~...~~ hybrid orbitals shaped like teardrops reaching from region of the atomic nucleus
- If we connect the larger ends of the teardrops with lines we have a tetrahedon
- For water molecules(H_2O) 2 of the hybrid orbitals in oxygen's valence shell r shared with hydrogens
- the other 2 hybrid orbitals r occupied by unbonded electron pair
- we get a molecule shaped like V with its 2 covalent bonds at angle of 104,5°

- the methane molecule CH_4 has the shape of a completed tetrahedon coz all 4 hybrid orbitals of the C atom r shared with H atoms
- the carbon nucleus is at the center with its 4 covalent bonds ~~radiating~~ spread r to hydrogen nuclei at corners of the tetrahedon
- molecular shape is important → determines how biological molecules recognize & respond to 1 another with specificity
biological molecules bind to each other by forming weak interactions → only if their shapes r complementary (~~fit~~ match)

i.e ~~opiates~~ effects of opiates = drugs like morphine derived from opium
→ relieve pain & change mood by weakly binding to specific receptor molecules on surfaces of brain cells

why do brain cells carry receptors for opiates compounds that r not endogenous → not made by body
endorphins (endogenous morphins) r signaling molecules made by pituitary gland that bind to receptors → relieving pain & producing euphoria during times of stress like intense exercise

opiates have shapes similar to endorphins & can ~~bind~~ bind to endorphin receptors in brain
↳ that's why opiates & endorphins have similar effects!
PIC p.88

Concept 2.4 - the making & breaking of chemical bonds leading to changes in composition of matter r chemical reactions
i.e. reaction between H & O molecules that forms water: PIC

$2H_2 + O_2 \longrightarrow 2H_2O$

Reactants — chemical reaction — ~~products~~ Products

this reaction breaks the covalent bonds of H_2 & O_2 & forms the new bonds of H_2O

when we write the equation for a chemical rct we use arrow to show the starting materials (reactants) to ~~reverse~~ end conversion of materials (products)

coefficients shown nr of molecules involved
i.e coefficient 2 before H_2 → rct starts with 2 molecules of hydrogen

all atoms of reactants r included in the products

matter is conserved in chemical rct. *
reactions can't create / destroy atoms but can only rearrange the electrons among them

Photosynthesis that takes place in cells of green plant tissues is ~~important~~ example of how chem. reactions rearrange matter → PIC

- the raw? materials of photosynthesis r CO_2 & H_2O → land plants absorb from air & soil
- within plant cells sunlight powers conversion of these to sugar "glucose" & O_2 molecules a by product seen when released by water plant → PIC
- we end up with same nr & types of atoms that we had when we started in photosynthesis
  → matter has been rearranged with input? (putting in) of energy from sunlight
- all chemical reactions r reversible with products of forward reaction becoming reactants for the reverse reaction
  i.e H & N molecules combine to form ammonia BUT ammonia decomposes to regenerate H & N:

$3H_2 + N_2 \rightleftharpoons 2NH_3$
↳ show rct is reversible!

the greater the conc of reactant molecules the more ~~freq~~ often they collide with 1 another & more likely they react & form products

as products accumulate collisions leading to reverse rct r more frequent
the forward + reverse rcts eventually occur at same rate & conc. of products & reactants stop changing

point at which the reactions balance one another is "chemical equilibrium"

this is dynamic equilibrium = rcts r going on in both directions with no effect on concentrations of reactants & products

Equilibrium means that concentrations of the reactants & products have stabilized at a certain ratio

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