

Chapter 2: Atoms

2021 for IMAT
2022

organisms are made ^{UP} OF matter = any ~~thing~~ that takes UP space & has mass
matter exists in many forms: rocks, metals, ~~orgs~~, gases & organisms 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 are 92 elements in nature
i.e. 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 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% are essential elements that

organism needs to live healthy life & reproduce
→ PIC Febelle

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 are needed by organism in minute quantities

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

i.e. 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 ~~the~~ growth of thyroid gland (to abnormal size) = goiter
prevent by eating iodized salt
→ ~~consume~~ seafood

element arsenic is ~~extremely toxic~~ ^{toxic to organisms} → causes disease & is deadly
↳ in ~~water~~ groundwater

Species have become adapted to environments with ~~toxic~~ ^{arsenic} elements i.e. serpentine plant communities

Serpentine is jade like mineral that contains high concentrations of ~~nickel, cobalt & chromium~~ ^{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} ~~survived~~ in serpentine soils & natural

selection led to the variety of species there today
→ PIC

concept → PIC

→ 1.2 each element is made of a ~~single~~ ^{specific} type of atom that's different from the atoms of ~~any~~ ^{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 \oplus charge & each electron 1 unit of \ominus charge

neutron is ~~neutral~~ ^{electrically} neutral

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

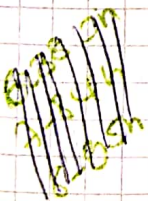
- protons give the nucleus a \oplus charge

moving electrons form a cloud of \ominus charge around the nucleus & ~~its~~ ^{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

1 the dalton is the same as atomic mass unit (amu)



- neutrons & protons have masses ^{close to} 1 dalton

- coz mass of an electron is $\frac{1}{2000}$ that of a neutron & proton
→ we ignore electrons when measuring mass of an atom

atoms of different elements differ in their nr of sub-atomic particles

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

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

${}^2\text{He}$ ~~is~~ ~~the~~ atom of the element helium has 2 protons in its nucleus

an atom's ~~net~~ electrical charge = its protons r balanced by an equal nr of electrons

so atomic number = number of protons = number of electrons 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 → ${}^4\text{He}$

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 → PIC with Na

simplest atom is hydrogen ${}^1\text{H}$ → has no neutrons
it is made up of 1 proton with 1 electron

coz electrons contribute little to mass of 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

ie mass nr of sodium ${}^{23}_{11}\text{Na}$ is 23 but its atomic mass is 22.9898 dalton

- all atoms of an element have same nr of protons but some atoms have more neutrons than other atoms of the same element & 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 occurring isotopes
most common isotope is carbon $^{12}_6\text{C}$
isotope $^{12}_6\text{C}$ has 6 neutrons

the rest of carbon is made up of atoms of the isotope
 $^{13}_6\text{C}$ with 7 neutrons

an even rarer isotope $^{14}_6\text{C}$ has 8 neutrons
all 3 isotopes have 6 protons coz they
r carbon!

$^{12}_6\text{C}$ & $^{13}_6\text{C}$ r stable isotopes = their nuclei don't lose
subatomic particles = decay =

isotope $^{14}_6\text{C}$ 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 $^{14}_6\text{C}$ atom decays a neutron decays into a proton
→ transforms the atom into a nitrogen $^{14}_7\text{N}$ atom

Radio
active

- radioactive isotopes r used as diagnostic tools in
medicine

traces
text

the radioactive isotopes r introduced into biologically
active molecules → r used as tracers to track
atoms during metabolism = chemical processes of organism

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

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

- radiation from decaying isotopes is dangerous
by coz it damages cellular molecules
→ depends on the type & amount of radiation organism
absorbs

- doses of isotopes in medical diagnosis r safe

dating
text

researchers measure radioactive decay in fossils
to date their relics of past life

- fossils give evidence for evolution, document differences
between organisms from past & those living now &

give us info into species that have disappeared over time

layering of fossil beds ~~can be determined~~ ^{you can see} their deeper families wider than more shallow ones → age of the fossils in each layer can it 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 isotope to decay**

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 ~~it's~~ ~~it's~~ have passed since an organism was fossilized / a rock was formed

half life values ^{short} measured in seconds / days for some isotopes or ~~in years~~ long (i.e. uranium 238 has half life of 4.5 billion years)

every levels text

the 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 ~~tends~~ 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 \ominus charged electrons r attracted to the \oplus 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 a staircase \rightarrow 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 shells!

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

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

shells are 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 \rightarrow to reach element in rows

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

- the elements 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 you add 1 proton & 1 electron to each (left to right)

one electron shell ... holds the

H is 1 electron & He is 2 electrons 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 are 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 outermost shell = valence shell

- atoms with the same nr of electrons in their valence shells show similar chemical behavior
ie. 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 (never an effect on them)

effect - helium, neon & argon have full valence shells
each other → inert elements = chemically unreactive
- all other atoms are chemically reactive coz they have incomplete valence shells!

orbitals - electron shells of atom are 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
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 can 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 ~~exactly~~ the same energy but they move in different volumes of space! → PICS a, b & c)

Concept 1.3 - how do atoms combine to form molecules & ionic compounds?

afternoon

of sharing

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

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

nor x bold

the stronger type of chemical bonds = covalent bonds in molecules & ionic bonds in 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 orbitals to overlap they share their electrons

each H atom has 2 electrons & has completed valence shell

2 or more atoms held together by covalent bonds make a molecule → ~~the hydrogen~~

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 are shared in covalent bond → forming a H₂ molecule

its molecular formula H₂ 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 surrounded

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

We also use structural formula $H-H \rightarrow$ 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

\rightarrow 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~~ bonding capacity is atom's "valence" & ~~is~~ = 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 or more different elements)
2 atoms of H r needed to satisfy the valence of 1 O atom $\rightarrow (2)$

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.
 \rightarrow PICS learn text

Wed \rightarrow 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 \rightarrow coz the atoms have the same electronegativity

\rightarrow 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 2 atoms compared to each other
ie. the bonds between oxygen & hydrogen atoms of water molecule r polar \rightarrow PICS learn text

on 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

co electrons have \ominus charge & pulled toward oxygen in water molecule \rightarrow oxygen atom has \ominus charges and H atoms have \oplus charges

ionic bonds:

- 2 atoms ~~have~~ ^{have} unequal ~~their~~ their attraction for valence electrons that the more electronegative atom strips 1 electron away from its partner

- \rightarrow the 2 oppositely charged atoms "ions"

- a \oplus charged ion is a cation

- a \ominus 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 \rightarrow 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

\rightarrow ~~with~~ 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 \rightarrow is now 2nd shell)

- the electron transfer between the 2 atoms moves 1 unit of \ominus 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's ~~an~~ an anion - a chloride ion \Rightarrow ^{learn} \oplus & \ominus

- compounds formed by ionic bonds ionic compounds / salts

\Rightarrow ionic compound sodium chloride (NaCl) is (table salt)

what
cher
inter
x

salt in nature as crystals

each salt crystal is ^{made (body of parts)} ~~group~~ 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 ~~to~~ 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 are 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

~~note~~ the ammonium 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 \rightarrow the bonds are so strong that u need a hammer to break enough of them to crack crystal

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

Weak
Chemical
interactions
text

- in organisms the strongest chemical bonds are covalent bonds \rightarrow link atoms to form a cell's molecules
- weaker interactions within & between molecules are important \rightarrow contribute to emergent properties of life
- ~~large~~ biological molecules are held in their functional form by weak interactions
- when 2 molecules in cell make contact they stick temporarily to each other by weak interactions
^{reversibility}
 \rightarrow this is an advantage: 2 molecules can come together affect 1 another & separate
- ^{weak} ~~important~~ 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 \oplus charge that allows it to be attracted to a different electronegative atom with a partial \ominus 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 \rightarrow PIC H bonds

vander waals interactions

- a molecule with nonpolar covalent bonds has \oplus & \ominus charged regions

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

resulting in ^{charge} changing regions of \oplus & \ominus charge that enable all atoms & molecules to stick to another

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

- when many vander waals interactions occur at same time \rightarrow they r strong!

form

\hookrightarrow v.d.w interactions allow gecko lizard to walk up wall!

- the structure of gecko's foot pads with hundreds of hairs each with projections \rightarrow 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!

\rightarrow ~~these~~ they reinforce the 3D shape of the molecule molecular shape + function

- a molecule has certain shape & size \rightarrow 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 atoms & orbitals \rightarrow PIC

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

\hookrightarrow PIC p-87

concept 2.4 - the many & charges in composition

of matter r common

- for atoms with valence electrons in s & p orbitals the single s & 3p orbitals form 4 ~~new~~ 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 tetrahedron

- For water molecule (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 pairs

- we get a molecule shaped like V with its 2 covalent bonds at angle of $104,5^\circ$

the hybrid orbitals s orbital from 1 s orbital & 3 p orbitals

- the methane molecule CH_4 has the shape of a cornered tetrahedron 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 r to hydrogen nuclei at corners of the tetrahedron spread

- molecular shape is important \rightarrow determines how biological

molecules recognize & respond to 1 another with specificity

biological molecules bind to each other by forming

weak interactions \rightarrow only if their shapes r complementary (fit together)

ie ~~opiate~~ effects of opiates = drugs like morphine derived from opium

\rightarrow 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 \rightarrow not made by body

endorphins (endogenous morphins) r signaling molecules made by pituitary gland that bind to receptors

\rightarrow relieving pain & producing euphoria during times of stress like intense exercise

Opiates have shapes similar to endorphins & can bind to endorphin receptors in brain

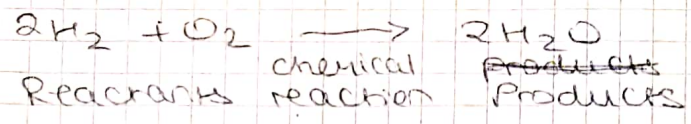
\hookrightarrow that's why opiates & endorphins have similar effects!

PIC p.88

concept 2.4 - the making & breaking of chemical bonds leading to changes in composition of matter r chemical reactions

ie. reaction between H & O molecules that forms water: PIC

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



this reaction ~~breaks~~ breaks the covalent bonds of H_2 & O_2 & forms the ~~new~~ ^{new} bonds of H_2O

when we write the equation for a chemical reaction ^{we} use arrow to show the starting materials (~~reactants~~ ^{reactants}) to ~~convert~~ ^{conversion of} materials (~~products~~ ^{products})

coefficients showing of molecules involved
ie coefficient 2 before H_2 → reacts with 2 molecules of hydrogen

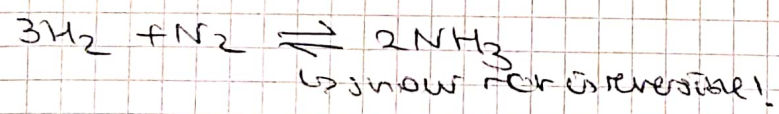
all atoms of reactants included in the products

matter is conserved in chemical reaction: *
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~~ ^{important} example of how chem. reactions rearrange matter → pic

- the raw materials of photosynthesis are 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 n & types of atoms that we had when we started in photosynthesis
→ matter has been rearranged with ^{input of energy from sunlight} ~~putting in~~

- all chemical reactions are reversible with products of forward reaction becoming reactants for the reverse reaction
ie H & N molecules combine to form ammonia BUT ammonia decomposes to regenerate H & N :



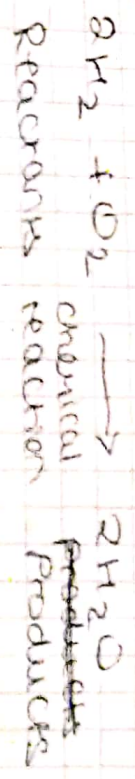
the greater the conc of reactants molecules the more ~~fre~~ often they collide with 1 another & more likely they react & form products

as products accumulate collisions leading to reverse rxn more frequent
the forward + reverse rxns 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 = rxns going on in both directions with no effect on concentrations of reactants & products

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



then reaction requires the cleavage bonds of H_2 & O_2 & forms the ~~equilibrium~~ bonds of H_2O

when we write the equation for a chemical ^{use} reverse arrow to show the ~~reverse~~ ^{reverse} reaction. (for ~~reactants~~ ^{reactants} to ~~reverse~~ ^{reverse} materials) ~~(products)~~

coefficients in front of molecules involved. ~~the~~ ^{the} coefficients \neq before $H_2 \rightarrow$ ~~reactants~~ ^{reactants} with 2 molecules of hydrogen

all atoms of reactants included in the products

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

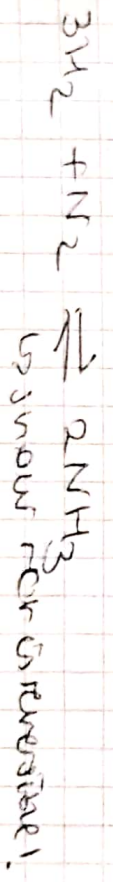
Photosynthesis that takes place in cells of green plants involves its ~~important~~ ^{important} example of how chem. reactions rearrange matter \rightarrow ATP

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 i.e. H & N molecules combine to form ammonia BUT ammonia decomposes to regenerate H & N:



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