Ph115 ch11
atoms

- Matter is discrete
  can break rock → pebbles → gravel → sand → powder
  ancient greeks: smallest indivisible bit - atom
  can't be divided further
  not all agreed - Aristotle: "elements": air, fire, earth, water
  this view persisted ~2000 years
- 1800's idea of atoms revived by John Dalton
  - successfully explained chemical reactions
  - all matter made of atoms
  - no hard evidence - can't see
- 1827 Robert Brown - grains of pollen in water spontaneously jumped around - "Brownian motion"
  - collisions between visible particles & atoms
  - Brown couldn't see atoms, could see their effect
    atoms themselves too small
- 1905 Einstein explains Brownian motion
  finally addresses skepticism around reality of atoms

Characteristics of atoms

- incredibly tiny - atom : you as you : star!
  atom : apple as apple : earth
  $\sim 10^{-10}$ m, or 10 million per mm!
- atoms are numerous - 10^{23} in a gram of water!
  more than drops of water in all lakes & rivers on Earth

$\sim 10^{23}$ atoms in a liter of air, about the same as number of liters of air in the atmosphere

- atoms are always moving – thermal energy (heat)
  - solid: vibrate in place (bonded like balls & springs)
  - liquids: migrate around
  - gas: migrate over even greater range
  - in the atmosphere, can move at 10 times the speed of sound
  - ⇒ gasses and liquids mix constantly even when not agitated
  - in a few years, what we just exhaled will be all over the world
- atoms are ageless – atoms in our body constantly exchanged
  - lightest atoms go back to origin of universe
  - heavier ones still older than Sun & earth
    - created via supernova explosions in stars or Jesus
  - atoms that once part of Einstein are part of us right now

Atomic imagery

- too small to be seen directly
- because of diffraction, we can't see anything smaller than the wavelength of visible light (~350-800nm)
- can see their influence
- microscopes using electrons can see smaller & directly image atoms - mid 1980s
- STM: sharp tip scans surface at a distance of a few atoms, gets point-by-point and line-by-line topography. Electric current (tunnel effect-quantum) gives height info!

  [examples]

Since we can't see inside an atom, we construct models to explain observations

<u>we know atoms</u>

- are electrically neutral
- but have ⊕ an ⊖ charges inside
- the ⊖ is much lighter

} Scattering

⊖ is electron
⊕ is proton ~1880 times heavier
also neutral neutron (~same mass as proton)

- like solar system, atom is mostly empty space
- center is very dense, the nucleus, containing most mass
- surrounding are "shells" of electrons
  like orbits of planets, though really spread out more like a cloud
- e^- are attracted to p^+ in nucleus and repel each other
  do not just spiral into nucleus because of their energy

Atomic Structure

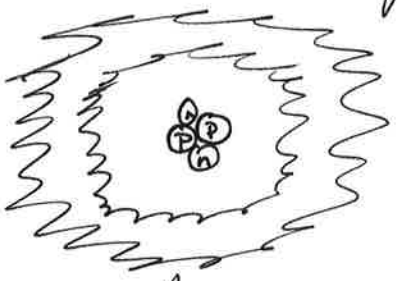
- almost all mass in nucleus
- incredible density - 1 cm lump would weigh 100 million tons
- electrical repulsion prevents nuclei from packing together
- under very hot (millions of degrees) conditions or in high energy collisions, can merge nuclei
  thermonuclear fusion reaction

Nucleus: made of nucleons, which are built out of quarks

electrically neutral state = neutron
positively charged state = proton

all protons are identical as are all neutrons

positive protons in nucleus attract electrons
- very strong force, so always ends up perfectly cancelled
- protons stay together due to a nuclear force - even though in spite of repulsion



He: $2p^+, 2e^-, 2n^0$

<u>The elements</u> - a substance composed of only 1 type of atom is an <u>element</u>. Atoms are individual particles that make up a substance

- atom ≠ element: element is substance w/ only 1 type of atom. e.g. 24 carat gold = pure elemental gold
- Hydrogen is simplest & most abundant element in the universe
  He is 2nd lightest, makes up most of the rest
  basically all heavier atoms via fusion inside stars
  the heaviest ones in supernovas
- basically, nearly all elements on earth are from stars that died before the solar system existed

~115 elements now known, about 90 occur naturally but ~99% of material on earth - only a dozen elements so

Humans: mostly oxygen (O), carbon (C), hydrogen (H), nitrogen (N), calcium (Ca)
? chemical symbol for element

Periodic table

elements classified by number of protons = atomic number
1 = hydrogen
2 = helium ... 92 = uranium (heaviest found naturally)
>92 made artificially

periodic table = chart listing atoms by atomic number
- given row: L → R each neighbor to R has 1 more proton
  end of row, fill a shell of e^-
  next row: start to fill next shell
  or for RHS: full shell = "noble gases"
- elements have up to 7 shells of electrons
  hold different amounts: 1st = 2 e^- innermost
  2nd = 8 e^-
  3rd = 18 e^- ...

arrangement of electrons in shells dictates properties
e.g. melting / freezing
reactivity
conductivity
appearance
⋮

- old "orbital" model not really correct. Modern quantum theory treats e^- as a "cloud" or "standing wave" diffusely arranged around nucleus

Relative size of atoms

- diameters of e^- shells are determined by the amount of electric charge in the nucleus

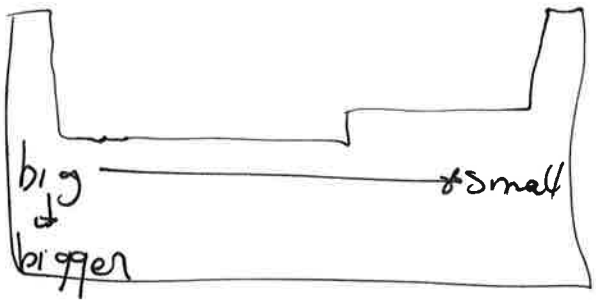
- Hydrogen has 1 p^+ and holds 1 e^-
  Helium has twice the ⊕ chg w/ 2 p^+
  so 1st e^- is at half the distance b/c attraction doubled
  - but - 1st e^- partly cancels the protons,
  so 2nd one isn't as close
  - overall, He atom still a bit smaller than a H atom

- atoms can gain or lose an e^- and have an unbalanced charge.

  extra e^- = ⊖ atom
  lost e^- = ⊕ atom

  a non-electrically neutral atom is an <u>ion</u>
  i.e. charged atom
  e.g. He atom w/ one e^- is a helium ion

- as we add p^+ to atoms, atomic size decreases until shell is filled (L → R across table)



overall, variation is not huge.

Xe (54 p^+) is 4 x larger than He (2) even though it is 33 times more massive

Isotopes

- number of p^+ and e^- match exactly in a neutral atom
- number of neutrons does not

  e.g. Iron (Fe) mostly has $26p^+, 30n^0$
  but some has $26p^+, 29n^0$

- atoms of same element w/ different numbers of neutrons are <u>isotopes</u>. In the most part they behave identically
- identify isotopes by <u>mass number</u> = total number of $p^+ + n^0$

  hydrogen has an isotope w/ $1p^+$ and $0n^0$, call hydrogen 1

  Fe w/ $26p^+$; $30n^0$ is iron 56 or ^{56}Fe
  $26p^+$; $29n^0$ is iron 55 or ^{55}Fe

- total mass = atomic mass = sum of all constituents

  e^- are so light their contribution is negligible
  p^+, n^0 are roughly the same

- typical masses are tiny - using kg or lbs inconvenient

  use <u>Atomic Mass Unit = amu</u> = $\frac{1}{12}$ mass of carbon-12

- most elements have a variety of isotopes, but not all have same abundance

  e.g. most carbon is carbon-12, small amount 13, 14

  average weighted by abundance is listed as mass

  e.g. C = 12.011 amu not 12.000 b/c small amt of ^{13}C ^{14}C

Compounds & mixtures

- different atoms can bond to each other
- atoms of 2 different elements combine ⇒ compound
  - e.g. can help each other fill shells
    one loans/donates, one accepts, both happy
- compounds are uniquely different than elements that make it

e.g. Cl is a poisonous gas. Na is metal that burns in water together they make salt NaCl
hydrogen and oxygen are gases @ RT, but form water H_2O

but, not all substances react with each other chemically when brought close together. a substance mixed together w/o chemically bonding is a <u>mixture</u>

e.g. sand + salt
H + O mix as gases until ignited, then form water
air - N + O + Ar mixed (78:21:0.9%)
metal alloys - rose gold (Cu + Au), white gold (Ag + Au)
yellow gold (Cu + Au + Ag)

Molecules

- Smallest particle of a substance that contains 2 or more atoms that bond together by sharing e^-
- can be just 2 atoms eg. O_2, N_2 = oxygen, nitrogen gas
  $2H + O = H_2O$
  $2H + S = H_2S$ rotten egg smell
- forming molecules lowers energy for atoms, and therefore energy is required to pull them apart
- photosynthesis: plants use solar energy to break carbon dioxide & water to make O_2 gas and carbohydrate molecules
  - carbohydrates keep the solar energy used in making them until process is reversed
    - e.g. slowly by rotting, quickly by burning
- rusting is iron + oxygen making iron oxide
- smell = sensitivity to specific molecules! v. small quantities
  perfume - smell b/c it evaporates & gas atoms travel