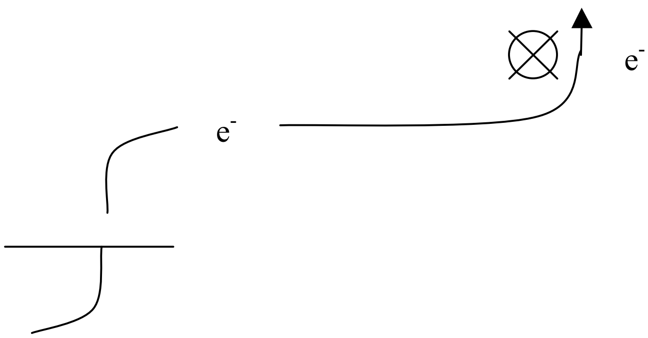
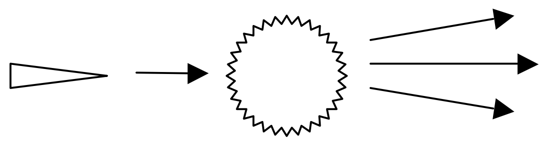
Atomic Structure   L12,p2

- Cathode rays



  - Measure properties of electron (charge/mass)
    - Assume atom is blob of positive "pudding" with electrons embedded
    - Or fragments of onion in a meatball!
      - Onion weighs almost nothing, meatball has no heavy components (uniform mass distribution in meatball).
      - So when shoot bullet at a meatball, it largely passes thru without altering it's motion (momentum)

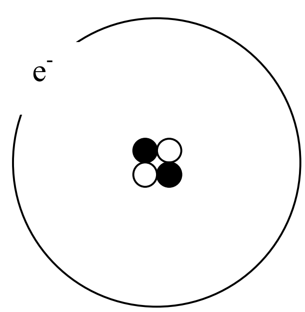


Expected result

  - Scattering experiment (Rutherford)

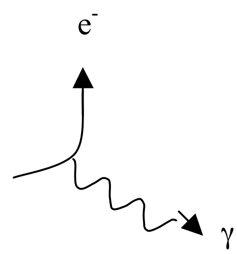
    α particles directed at a thin gold foil

    Gold has a large mass per atom: (ie, the non onion part of meatball is massive)
    - Expect same behavior
    - Except sometimes, α comes back at you! (bullet reflected back by meatball)
    - So positive charged mass of atom must be concentrated at center of an atom
      - This gives us a "Planetary model of atom"



Bohr Model   L12,p3

- Problem
  - When electrons in orbit around positive nucleus, they are accelerated to bend around the nucleus. Accelerated charges emit energy in the form of photons:
    - Accelerate means change velocity



    - So e^-'s loose energy and spiral into atomic nucleus
      - atomic structure not stable
      - but we see stable atoms
- Ideas
  - Circumference of electron orbit = n λ_e.
    - In these cases, no emitted radiation
    - Only certain λ's permitted to create an integer multiple
      - Each wavelength is associated with a particular energy
      - This, in turn, means that electrons can only have discrete energy levels
  - Radiation mitted when e^- makes transition from one level to another ($\Delta\lambda$)

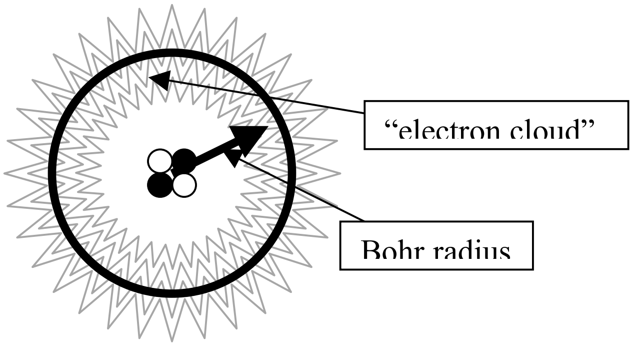
"transition"

- $E_i - E_f = h f$ where f is frequency of γ emitted.
- Give roughly correct description of spectral lines for Hydrogen
  - Heavier elements & fine structure not accounted for
  - Electrons in circular, classical orbits not retained

Quantum Model of the Atom, L12p4

- Bohr's theory not fully quantum mechanical
  - So use a probabilistic description (ie Schrödinger's wave equation & wave functions)
    - Electrons can be "spread out" around nucleus
- Description provides
  - n is a "quantum number"
    - What "energy level" are we?
    - n indicates overall energy level
      - related to effective Bohr radius in case of Hydrogen
      - if n is high, then more different angular momentum (i.e. 'spin') possible.

Spin: electron a point particle but behaves as if has "spin" angular momentum
Relativistic description in quantum mechanics.



If in magnetic field, alignment of spin matters: slightly different energy levels if aligned with or against direction of magnetic field

Exclusion Principle L12p5

"No two electrons can ever be in the same quantum state; therefore, no two electrons in the same atom can have the same set of quantum #'s"

- Expression of observation that not all electrons go to lowest energy, or "ground" state

- If have multiple electrons
  - Fill up successively higher energy levels
    - If there is a lower, unfilled level,
      - atom will radiate photons (i.e. energy) until it's filled
    - Fill sub-shells then graduate to next shell
- Chemical Elements
  - Defined by number of electrons
  - Those in periodic table in columns
    - Have the same # of electrons in outermost shell
    - And have similar chemical properties

Nuclear Structure L13p2

- From Rutherford nucleus r ≈ 10^{-14} m
  (for atom ≈ 10^{-9} – 10^{-10} m)

- Composed of protons and neutrons
  - These are generically called 'nucleons'
  - Each element has unique # of protons
    "isotopes" have different #s of neutrons
    $M_p \approx M_n \approx 2000\ M_e$
    Mass is expressed as rest energy equivalent
    For proton: $E_R\ M_pc^2 = 930$ MeV
    $1\text{eV} = 1.6 \times 10^{-19}$ J

- Protons positively charged, so they repel each other
  - Something must hold them together in the nucleus
    "strong nuclear force"
  - Very short range nuclei don't get bigger past $A \approx 10^2$
  - Does not affect electrons

- Measurements Indicate that strength of strong force (i.e. its 'binding energy') increases, per nucleon, until reach 60 nucleons

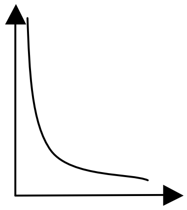
Radioactivity L13,p3

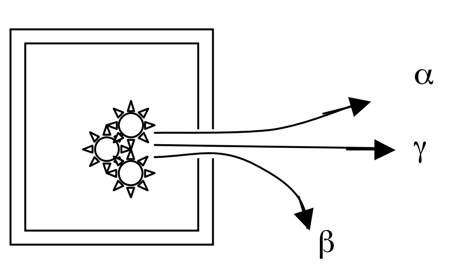
- Observed (Becquerel 1896)
  - Uranyl potassium phosphate crystals (uranium chemical compound)
    - A kind of Invisible emission or radiation
    - Unstimulated
    - Darkens photographic plates, even when covered to block visible light
- Curie's discovery of new elements (Po & Ra)
  - Some substances more so than others
-
- Experiment supports idea of
  - Disintegration or "decay" of unstable nuclei
  - Different penetrating power, mass, and charge of three kinds of radiation:

Penetrate paper	α decay	He nucleus emitted
mm Al	β decay	$e^{\pm}$ emitted.
cm Pb	γ decay	high energy photon emitted

Decay of atomic nuclei is Probabilistic in nature

- Start with sample of N_0 atoms
- # undecayed declines exponentially with time
- Half-life → time interval during which half of a given number of radioactive nuclei decay.





α decay: L13p4

- Nucleus of He emitted in radioactivey from heavy nucleus
    - Potential barrier much higher than energy of α within nucleus
      Due to nuclear attractive force and electrostatic repulsion
        - Occasionally α tunnels out of nucleus

$${}_{92}U^{238} \rightarrow {}_{90}Th^{234} + {}_{2}He^{4}$$

↑ ↑

Daughter nucleus

- Disintegration $Q = (M_U - M_{Th} - M_\alpha)c^2$.
    - Sum of products < U mass
        - $\therefore$ energy released as KE of daughter particles
    - Daughter may be in excited state
      Sudden emission of γ's
    - If consider α + Th system
        - Potential energy higher than α kinetic energy (energy of motion)
        - α's emitted with discrete energies

β decays L13p5

- ${}_6C^{14} \rightarrow {}_7N^{14} + e^-$ (?)
    - The number of nucleons constant, but atomic number changes by 1
    - But electrons not emitted with discrete (specific) energies
        - Means momentum conservation appears to not be followed!

- Neutrino suggested:
  ${}_6C^{14} \rightarrow {}_7N^{14} + e^- + \overline{\nu}$
    - Mass $m_\nu \approx 0$, $q = 0$
    - Interacts very weakly with matter: extremely Hard to detect
-
- Carbon dating
    - Cosmic rays cause nuclear reactions in upper atmosphere
    - C^{14} / C^{12} ratio constant
    - When organism dies: no longer takes in C^{14}, so ratio decreases with time $\tau \approx 5700$ years

γ decays L13p6

A nucleus can be in an excited state

- Nucleons behaving sort of like electrons in an atom, they can be moving with more or less energy within the nucleus
  - Energy leves governed by quantum mechanics
  - Because strong force is so strong, these energy levels are much more complicated than electron energy levels of an atom

- Reduce energy level by emission of γ
  - λ much shorter than visible λ's
    $\sim 10^{-6}\ \lambda_{vis}$

- no change in Z, nor A of nucleus
  - just energy level of nucleus.

    ${}_5B^{12}$ □ ${}_6C^{*12} + e^- + \bar{\nu}$.
    ${}_6C^{*12}$ □+ ${}_6C^{12} + \gamma$.

Fission & Fusion L13p7

Fission

- A heavy nucleus splits into 2 smaller nuclei
  - The combined mass of daughters < parent mass
    - Therefore, energy is released

Fusion

- when combine two atomic nuclei into one, for instance, fusing two Hydrogen nuclei to form a Helium nucleus
  - Protons must approach close enough to become He nucleus
    - Must overcome their electrostatic repulsion
  - When fusing light nuclei, the resulting nucleus is less massive than the sum of the original nuclei: therefore energy produced
- Atoms lighter than Fe
  - Can be combined to produce a more tightly bound nucleus

  - $\therefore$ Loss of mass □ release of energy

    ${}_1H^1 + {}_1H^1$ □ ${}_1H^2 + e^+ + \nu$.
    ${}_1H^1 + {}_1H^2$ □ ${}_2He^3 + \gamma$.