3.3 particles waves

so we can describe an electron as a wave. analogously to a photon where we have an electric field $E(x,t)$ and teh intensity on a screen is $\propto |E(x,t)|^2$. so Bohr said the same was true for a particle. The probability of finding an electron between x and $x+dx$ at time t is $|\Psi(x,t)|^2 dx$.

so its detected as a particle, at point x,t but this is determined by the wavefunction probability $|\Psi(x,t)|^2$ at that point.

we see the double slit experiement - electrons are detected as single particles, and even if we dim the electron rate down so that only one electron is in the apparatus at any one time we still get an interference pattern on the screen - built up from individual particle hits!!

electrons are not like little billiard balls. they have some wavelike properties. in the macroscopic world 'things' are either waves or particles but not both. so electrons are not really like anything we experience in the macroscopic world. the thing they are most like is like light!

actually ALL particles are not like little billiard balls. they are wavy, with wavyness $\lambda = h/p = h/(mv)$ if non relativisitic. so smaller mass particles are more obviously wavy! but bigger ones have smaller wavelength so their wavines is only apparent on smaller scales.

eg a proton is accelerated though a potential of 54V - what is its wavelength? compare this to an electron accelerated through the same potential

$\lambda = h/p$ and we are non-relativisitic so $K = eV = p^2/2m$

for electrons $K = 1.6\times10^{-19}54 = 8.6\times10^{-18}$ so $p = \sqrt{2mK} = 3.9\times10^{-24}$ kg/m/s so $\lambda = h/p = 1.66\times10^{-10}$m

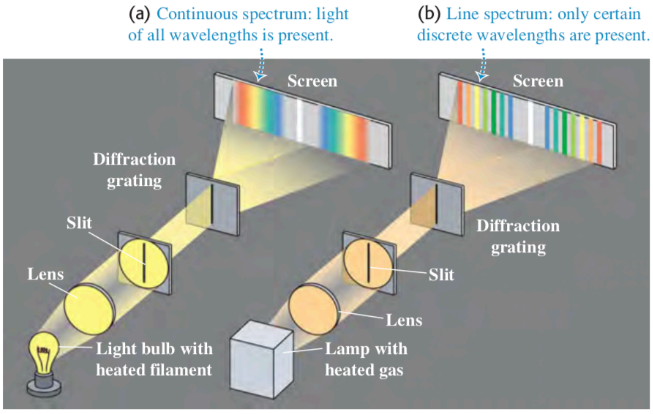
for protons, m is 1840x bigger so p is $42\times$ bigger and λ is 42x smaller

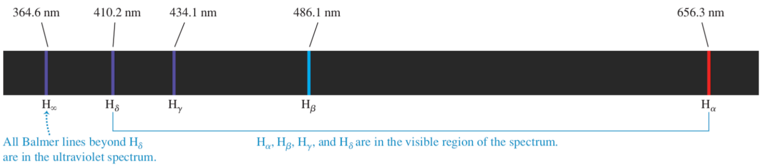
3.4 Atomic spectra and the structure of the atom

Experiemnts on gas excited by an electrical discharge showed that the heated gas produced monochromatic lines!! not blackbody continuum - unless the gas was very dense.

for hydrogen, Balmer found that these lines had a well defined wavelength $\lambda = 364.5[n^2/(n^2-4)]$ nm for $n \geq 3$ integer! so n=3 gives 654nm, n=4 is 468, n=5 is 433nm, as observed!

BUT WHY???? nobody knew.





3.5 Models of atoms

Thomson discovered the electron in 1897 and proposed a plum pudding model of the atom - uniformly +ve charged object with electrons dotted around to make it electrically neutral with size 5×10^{-10} m.

Rutherford did some experiements. used a narrow beam of alpha particles (Helium nuclei) on gold foil target. mass of electron is 1840x less than proton and alpha particle has 2 protons and 2 neutrons so mass is 7300x larger. the +ve charge is diffuse so it can't deflect the alpha particles much, and electrons cannot appreciably deflect an alpha particle either as its momentum is huge in comparison. but some alpha particles were deflected by almost 180 degrees!

suppose the +ve charge is very localised, so not distributed on the atmo dimensions of 10^{-10} m but on much smaller scales. then it acts like a point charge down to small distances so the electrostatic potential is much larger $V(r) = qQ/(4\pi\epsilon_0 r$. fitting to the distribution of alpha particle scattering showed that needs a radius of 7×10^{-15} m in gold any larger and there is not enough large angle scattering!

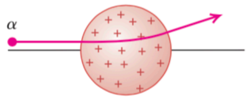
example: an alpha particle charge $+2e$ is aimed directly at a gold nucleus $(79e)$ what is the minimum KE the alpha particle must have to approach within 5×10^{-14} m

$V(r) = 79 \times 2e^2/(4\pi\epsilon_0 5 \times 10^{-14} = 7.27 \times 10^{-13}$ J which is 4.5MeV

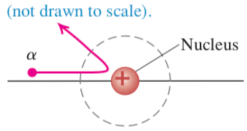
can we neglect the recoil of the atom? initial momentum of the alpha

39.12 A comparison of Thomson's and Rutherford's models of the atom.

(a) Thomson's model of the atom: An alpha particle is scattered through only a small angle.



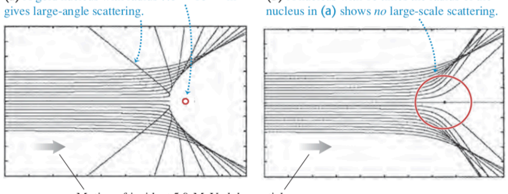
(b) Rutherford's model of the atom: An alpha particle can be scattered through a large angle by the compact, positively charged nucleus (not drawn to scale).



39.13 Computer simulation of scattering of 5.0-MeV alpha particles from a gold nucleus. Each curve shows a possible alpha-particle trajectory. **(a)** The scattering curves match Rutherford's experimental data if a radius of 7.0×10^{-15} m is assumed for a gold nucleus. **(b)** A model with a much larger radius for the gold nucleus does not match the data.

(a) A gold nucleus with radius 7.0×10^{-15} m gives large-angle scattering.

(b) A nucleus with 10 times the radius of the nucleus in **(a)** shows *no* large-scale scattering.



particle - rest mass much bigger than 4.5MeV so OK to do non-relativistic $K = p^2/2m$ so $p = \sqrt{2mK} = \sqrt{2 \times 6.64e - 27 \times 7.27 \times 10^{-13}} = 9.8 \times 10^{-20}$ kg/m/s

gold nucleus mass is 3.27×10^{-25} kg so all this is transfered so $p = mv$ and $K = p^2/2m = (9.8 \times 10^{-20})^2/(2 \times 3.27 \times 10^{-25}) = 1.5 \times 10^{-14}$ J so 0.07MeV - negligible compared to total energy of 4.5MeV

but now we have a different problem!!! if we put electrons orbiting around a nucleus - attractive potential like gravity. but circular orbits mean acceleration, so the electrons radiate EM waves and lose energy. so they spiral in! and atoms shouldn't exist.

BUT THEY DO! so the picture is WRONG. electrons are not orbiting around like little planets. electrons are not little billiard balls. they are WAVY

3.6 Bohr model of the atom

waves have wavelength - and can travel. but waves trapped in a potential interfere with themselves and set up standing waves. standing waves don't travel so don't accelerate so electrons as standing waves don't radiate!!

standing waves can only get set up at certain positions - need the wave to reinforce itself. so then there are only certain distances from the nucleus that the standing wave can exist. and these will be quantised by the number of wavelengths in the standing wave. but distance means energy as the electrostatic potential is $qQ/(4\pi\epsilon_0 r$ so quantised distances for quantised standing waves means quantised energy. and then we can explain the specific energies of emission/absorption in atoms as the photon energy required to make the transition between 2 different standing wave patterns.

so then we have $2\pi r_n = n\lambda$ and combine with $\lambda = h/p = h/(mv_n)$ so

$2\pi r_n = nh/(mv_n)$ so $mv_n r_n = nh/(2\pi) = n\hbar = L_n$ - angular momentum is quantised!!

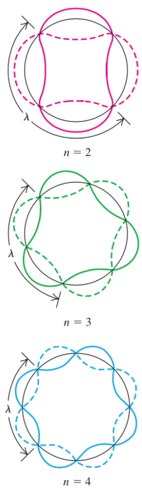
the observation that atoms are stable means that each atom has a lowest level - groud state. levels with higher energy are called excited states.

Bohr postulated that

1) electrons move in circular orbits under coulomb attraction

2) these are stable orbits where the electrons do not radiate

3) these stable orbits have angular momentum $L_n = mv_n r_n = nh/(2\pi) = n\hbar$



4) transitions from orbit of energy E_i to E_f are accompanied by emission of radiation $hf = E_i - E_f$