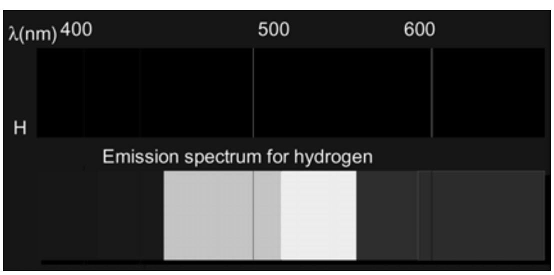
Orientation

- Previously, we considered detection of photons.
- Next, we develop our understanding of photon generation
- We need to consider atomic structure of atoms and molecules

Line Emission Spectra

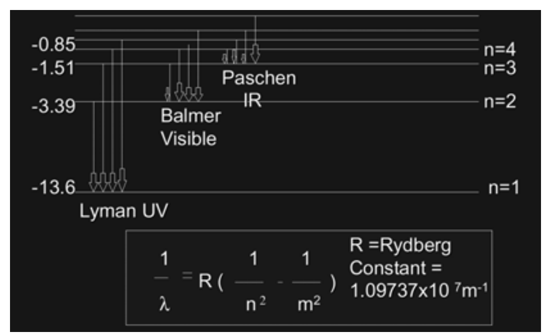
- The emission spectrum from an exited material (flame, electric discharge) consists of sharp spectral lines
- Each atom has its own characteristic spectrum.
- Hydrogen has four spectral lines in the visible region and many UV and IR lines not visible to the human eye
- The wave picture of electromagnetic radiation completely fails to explain these lines (!)

Atomic Physics/Line Spectra

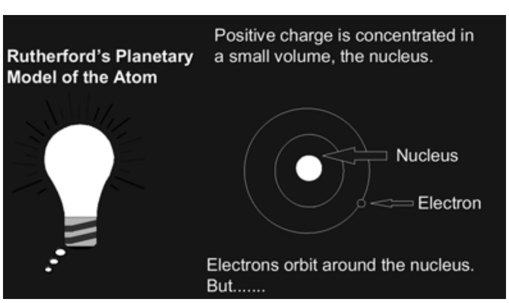


The absorption spectrum for hydrogen: dark absorption lines occur at the same wavelengths as emission lines.

Atomic Physics/Line Spectra

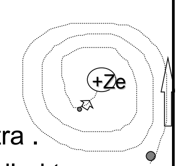


Rutherford's Model



Fatal problems !

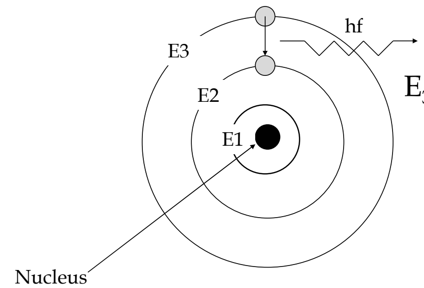
- **Problem 1:** From the Classical Maxwell's Equation, an accelerating electron emits radiation, losing energy.
- This radiation covers a continuous range in frequency, contradicting observed line spectra .
- **Problem 2**: Rutherford's model failed to account for the stability of the atom.



Bohr's Model

- Assumptions:
  - Electrons can exist only in stationary states
  - Dynamical equilibrium governed by Newtonian Mechanics
  - Transitions between different stationary states are accompanied by emission or absorption of radiation with frequency $\Delta E = hf$

Transitions between states



$E_3 - E_2 = hf$

How big is the Bohr Hydrogen Atom?

$R_n = a_0 n^2/Z^2$

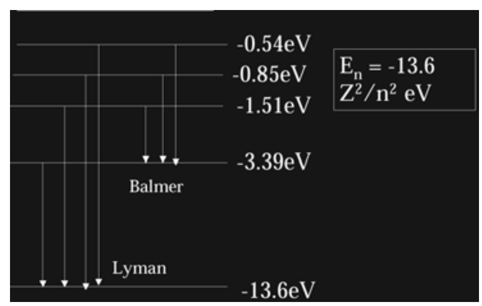
R_n=radius of atomic orbit number n

a_0=Bohr radius = 0.0629 nm

Z=atomic numner of element

Exercise: What is the diameter of the hydrogen atom?

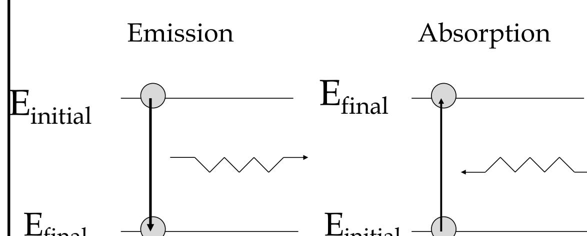
What energy Levels are allowed?



Exercise

- A hydrogen atom makes a transition between the n=2 state and the n=1 state. What is the wavelength of the light emitted?
- Step1: Find out the energy of the photon:
  - E_1=13.6 eV E_2=13.6/4=3.4 eV
  - hence the energy of the emitted photon is 10.2 eV
- Step 2: Convert energy into wavelength.
  - E=hf, hence $f=E/h = 10.2*1.6\times10^{-19}/6.63\times10^{-34} = 2.46\times10^{15}$ Hz
- Step 3: Convert from frequency into wavelength:
  - $\lambda = c/f = 3\times10^{8}/2.46\times10^{15}$ = 121.5 nm

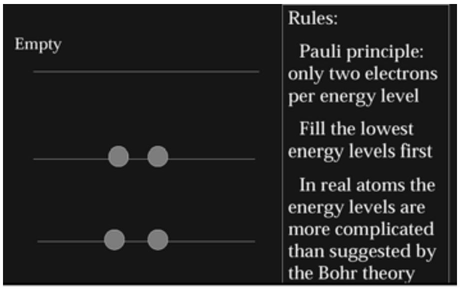
Emission versus absorption



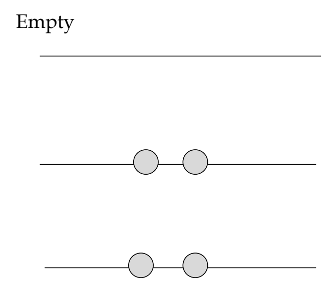
$hf = E_{final} - E_{initial}$ $hf = E_{final} - E_{initial}$

Explains Hydrogen spectra

What happens when we have more than one electron?



What happens when we have more than one electron?

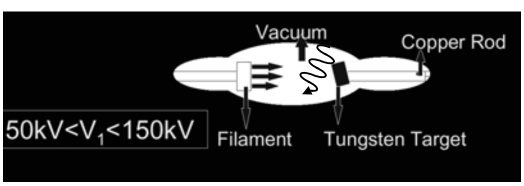


Apply rules:

- Pauli principle: only two electrons per energy level
- Fill the lowest energy levels first
- In real atoms the energy levels are more complicated than suggested by the Bohr theory

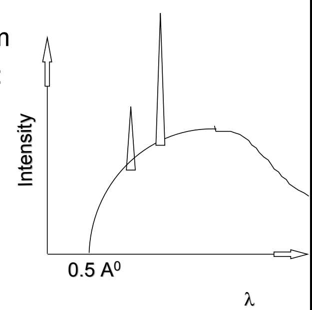
Atomic Physics – X-rays

- How are X-rays produced?
  - High energy electrons are fired at high atomic number targets. Electrons will be decelerated emitting X-rays.
  - Energy of electron given by the applied potential (E=qV)



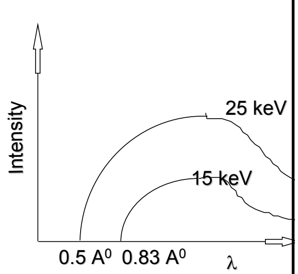
X-rays

- The X-ray spectrum consists of two parts:
  1. A continuous spectrum
  2. A series of sharp lines.



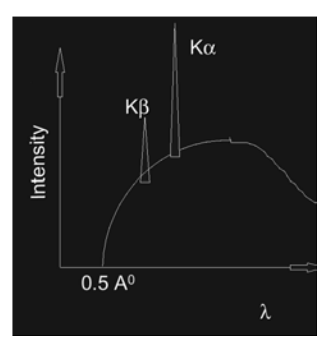
X-rays

- The continuous spectrum depends on the voltage across the tube and does not depend on the target material.
- This continuous spectrum is explained by the decelerating electron as it enters the metal



Atomic Physics/X-rays

- The characteristic spectral lines depend on the target material.
- These Provides a unique signature of the target's atomic structure
- Bohr's theory was used to understand the origin of these lines

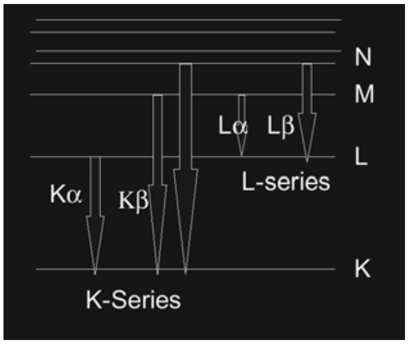


Atomic Physics – X-rays

The K-shell corresponds to n=1

The L-shell corresponds to n=2

M is n=2, and so on

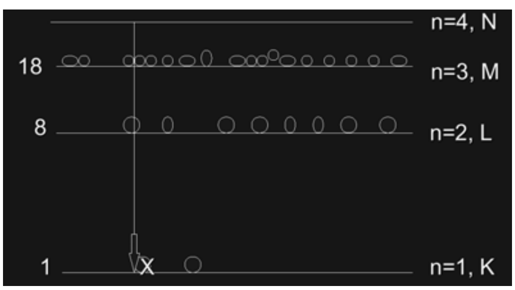


Atomic Spectra – X-rays

Example:

Estimate the wavelength of the X-ray emitted from a tantalum target when an electron from an n=4 state makes a transition to an empty n=1 state ($Z_{tantalum}$ =73)

Emission from tantalum



Atomic Physics – X-rays

The X-ray is emitted when an e from an n=4 states falls into the empty n=1 state

E_i= $-13.6Z^2/n^2$ = $-(73)^2(13.6 \text{ eV})/ 4^2$

= -4529 eV

E_f= $-13.6(73)^2/1^2$ = -72464 eV

hf = E_i- E_f= 72474-4529= 67945 eV = 67.9 keV

What is the wavelength?

Ans = 0.18 Å

Using X-rays to probe structure

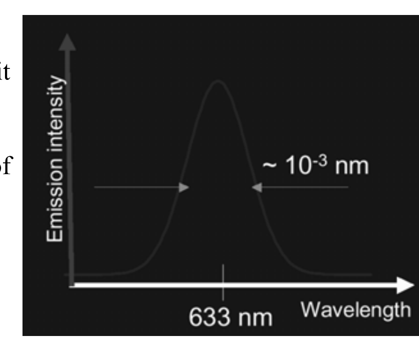
- X-rays have wavelengths of the order of 0.1 nm. Therefore we expect a grating with a periodicity of this magnitude to strongly diffract X-rays.
- Crystals have such a spacing! Indeed they do diffract X-rays according to Bragg's law

$$2d\sin\theta = n\lambda$$

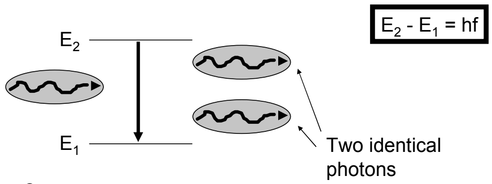
- We will return to this later in the course when we discuss sensors of structure

Line Width

- Real materials emit or absorb light over a small range of wavelengths
- Example here is Neon



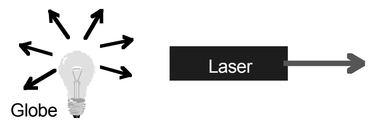
Stimulated emission



Same
- frequency
- direction
- phase
- polarisation

Lasers

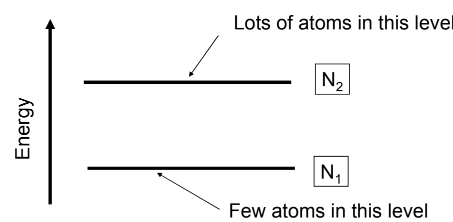
- LASER- acronym for
  - Light Amplification by Stimulated Emission of Radiation
  - produce high intensity power at a single frequency (i.e. monochromatic)



Principles of Lasers

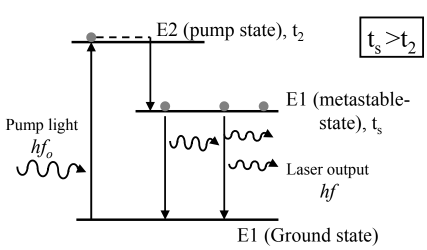
- Usually have more atoms in low(est) energy levels
- Atomic systems can be *pumped* so that more atoms are in a higher energy level.
  - Requires input of energy
  - Called *Population Inversion:* achieved via
    - Electric discharge
    - Optically
    - Direct current

Population inversion



Want $N_2 - N_1$ to be as large as possible

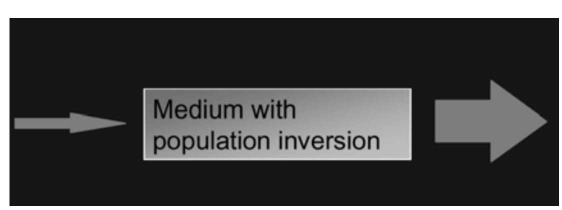
Population Inversion (3 level System)



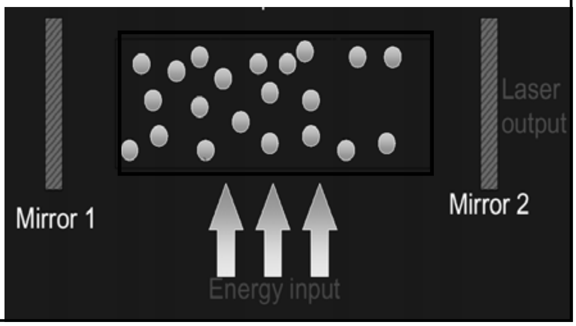
Light Amplification

Light amplified by passing light through a medium with a population inversion.

- Leads to stimulated emission



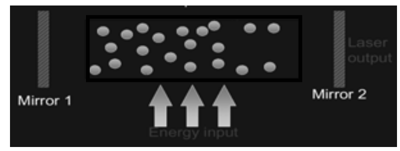
Laser



Laser

Requires a cavity enclosed by two mirrors.

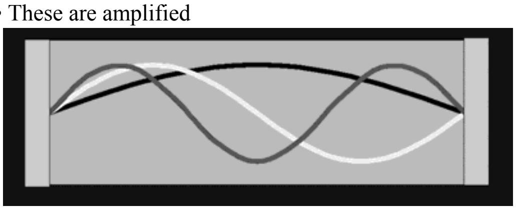
- Provides amplification
- Improves spectral purity
- Initiated by "spontaneous emission"



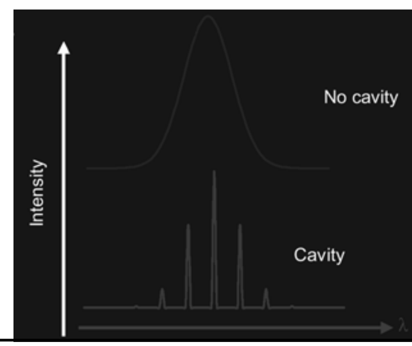
Laser Cavity

Cavity possess modes

- Analagous to standing waves on a string
- Correspond to specific wavelengths/frequencies
- These are amplified



Spectral output



Properties of Laser Light.

- Can be monochromatic
- Coherent
- Very intense
- Short pulses can be produced

Types of Lasers

Large range of wavelengths available:

- Ammonia (microwave) MASER
- CO_2 (far infrared)
- Semiconductor (near-infrared, visible)
- Helium-Neon (visible)
- ArF – excimer (ultraviolet)
- Soft x-ray (free-electron, experimental)