QUANTUM PHYSICS.

Study of matter and energy in the form of particles. This means energy, charge and such physical quantities take discrete values and not continuous values.
Eg: Charge comes as 1e, 2e, not 1.5e, 1.6e ...

Both light and matter exhibit properties of both waves and particles. This wave-particle duality is the basis of quantom mechanics.

Photon

- Max Planck – the energy carried by EM radiation might exist as discrete packets of energy called quanta
- with water as example, when a tap is leaking drops, the drops are particlutate nature of light while a smooth laminar flow with no discrete drops is wave nature

- A particle or quantum (a discrete energy packet) of electromagnetic radiation is known as photon.
- The energy of photon of an EM radiation is directly proportional to the frequency of radiation.

$E = hf$, where h is Planck's constant
$h = 6.63 \times 10^{-34}$ Js.
For a wave, $c = \lambda f$

$$E = \frac{hc}{\lambda}$$

- The rest mass of a photon is 0, while the moving mass is $m = \frac{E}{c^2} = \frac{h}{c\lambda}$.
- A photon behaves like a particle when moving, its linear momentum is:
$p = mc = \frac{E}{c^2} \times c = \frac{E}{c} = \frac{h}{\lambda}$.

Electronvolt (eV) as a unit of energy.

The KE gained by an electron that is accelerated through a potential difference of 1V is called electron volt (eV).
$1 eV = 1.6 \times 10^{-19} J$.

Photoelectric effect

The process of emission of electrons from the surface of a metal when the surface is illuminated with em radiation of suitable frequency / wavelength is photoelectric effect / photoelectric emission.
The electrons emitted from surface of metal due to incident em radiations are photo electrons.

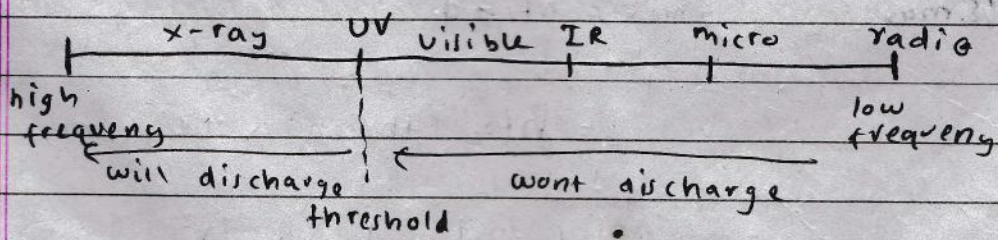
$I = \frac{E}{At} = \frac{N \times hf}{t \times A}$

Observations on photoelectric effect.

- For a given metal there is a certain minimum frequency of radiation, called threshold frequency for below which no photoelectric emission occurs.
- The wavelength corresponding to the threshold frequency is threshold wavelength λ_0.
- The no. of photoelectrons emitted per sec. is proportional to intensity of incident radiation (for a given frequency.)
- Photoelectrons are emitted with a range of KE which ranges from 0 to maximum.

Einstein's photoelectric eq^n, Quantum theory.

- The observations on process of photoelectric effect can't be explained in terms of wave theory of light.
- According to quantum theory, radiation travels in form of discrete packets of energy called photons.
- The energy of photon of em depends on frequency of radiation.



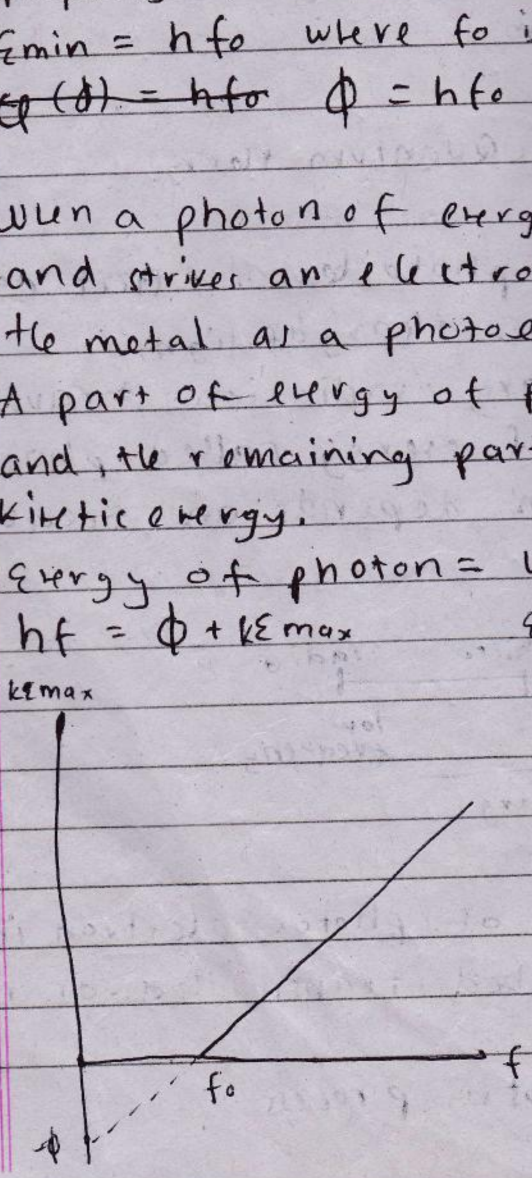
- Photoelectric effect is result of photon-electron interaction.
- Em radiation is either absorbed, transmitted or reflected from a surface.
- Photoelectric effect is absorption process.

The electron ~~is ab~~ absorbs the energy of the photon. If this energy is enough to emit it from the surface, photoelectric emission takes place.

The min. amount of work / energy necessary to take a free electron out of a metal against the attractive forces of surrounding +ve ions is the work function (ϕ) of the metal.

~~For~~ Threshold frequency is frequency of wave but is a property of metals.
$\varepsilon_{min} = hf_0$ where f_0 is threshold frequency.
$\therefore$ ~~$E_p(\phi) = hf_0$~~ $\phi = hf_0$

When a photon of energy hf is incident on the metal and strikes an electrons that electron is emitted from the metal as a photoelectron.
A part of energy of photon is used to emit the electron and, the remaining part is taken by the electron as kinetic energy.
Energy of photon = work function + max. kinetic energy of photoelectron
$hf = \phi + KE_{max}$ $\quad\quad \varepsilon_{max} = hf - \phi$



$\phi = hf_0$ (threshold frequency)

$$hf = \phi + \frac{1}{2}m(v_{max})^2$$

Einstein's photoelectric eqn.

Even if intensity is increased, it just increases the no. of photons but graph of $KE_{max} - f$ remains same

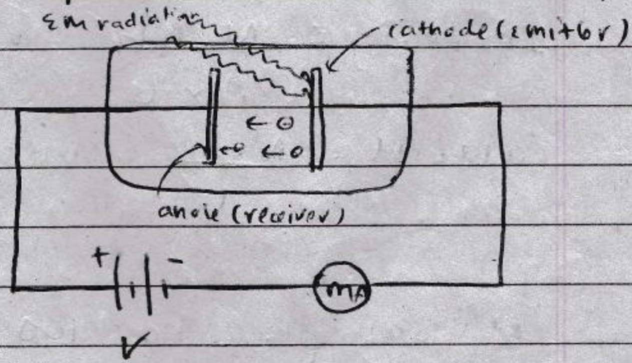
Electrons from deep inside the surface have used some energy to get to the surface, so will have a less KE_{max}.
The KE_{max} is of the electrons in the surface.

Photoelectric current and stopping potential.

Current due to photoelectrons is photoelectric current

$I = \frac{Ne}{t}$, where N is number of electrons emitted

$\therefore I = n_e e$, where n_e is no. of photoelectrons emitted per se



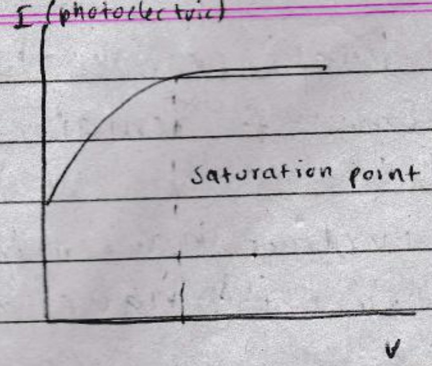
$hf = hf_0 + E_{max}$
$\therefore hf = \phi + \frac{1}{2} m v_{max}^2$

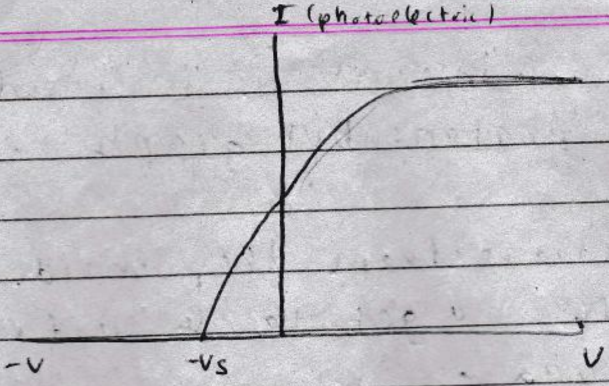
$E = \frac{V}{d}$

$\therefore F = Eq$
$\therefore a = \frac{Eq}{m_e}$

$I = q/t = Ne/t$
where N/t is rate of electron emission

If a is decreased, rate of ~~elect~~ flow of charge is less, because electrons travel slower and thus current 'I' is also decreased.





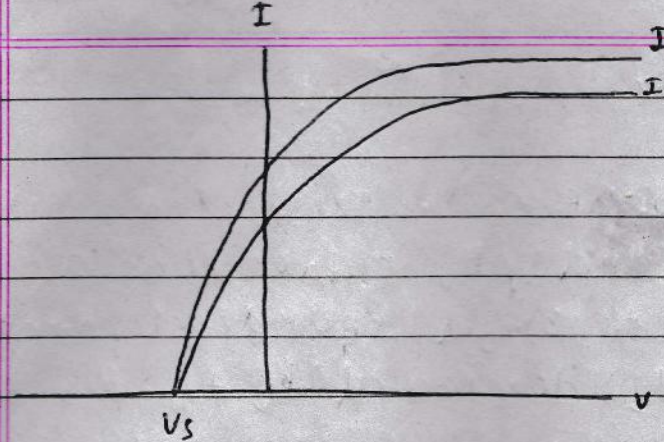
when potentials are reversed and now emitter is ~~made~~ +ve while collector is made negative (-ve), I decreases as electrons experience force in opposite direction. If electrons have enough KE however it can overcome the force of repulsion coming from receiver but as this force is increased by increasing (-V), the electrons slow down

Vs is known as the stopping potential.

$$\text{Intensity} = \frac{N \times hf}{A \times t}$$ when N is number of photons

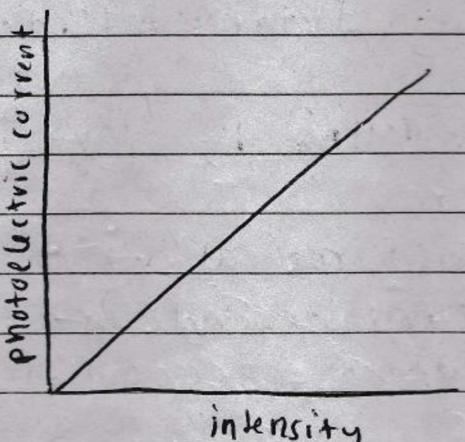
$$\text{Current} = \frac{N \times e}{t}$$ where N = N (photon no. = electron no.)

Let's say plate has 100 e^-, First on photon collision let's say 60 e^- are emitted, some don't have enough KE, so we increase V to pull 25 e^-, this increases I, again 15 e^- can't come so we increase V more and I also increases. This is saturation point. Now as all e^- are finished, no matter how much we increase V, I will remain same as $\frac{N}{t}$, t remains constant due to constant EM radiation and N is also constant at 100 e^- $I_{max} = \frac{N_{total} \times e}{t}$



In constant frequency when we increase intensity to I2, more photons strike and more electrons are emitted.
$I2 > I1$

As KE max is same, f is constant, KE max is same and as $KE = eV_s$, V_s remains same.



$I_p = \frac{Ne}{t}$

$\text{Intensity} = \frac{N \times hf}{t \times A}$

$\therefore \frac{N}{t} = \text{Intensity} \times \frac{A}{hf}$

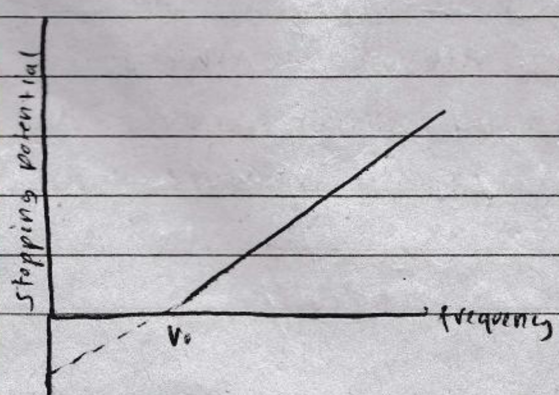
$\therefore I_p = \frac{Ae}{hf} \times \text{intensity}$

$hf = \phi + KE_{max}$

$hf = hf_0 + eV_s$

or, $eV_s = hf - hf_0$

$\therefore V_s = \frac{h}{e} f - \frac{h}{e} f_0$



If a graph of V_s against f is plotted and it comes straight, Einstein's photoelectric theory is verified.

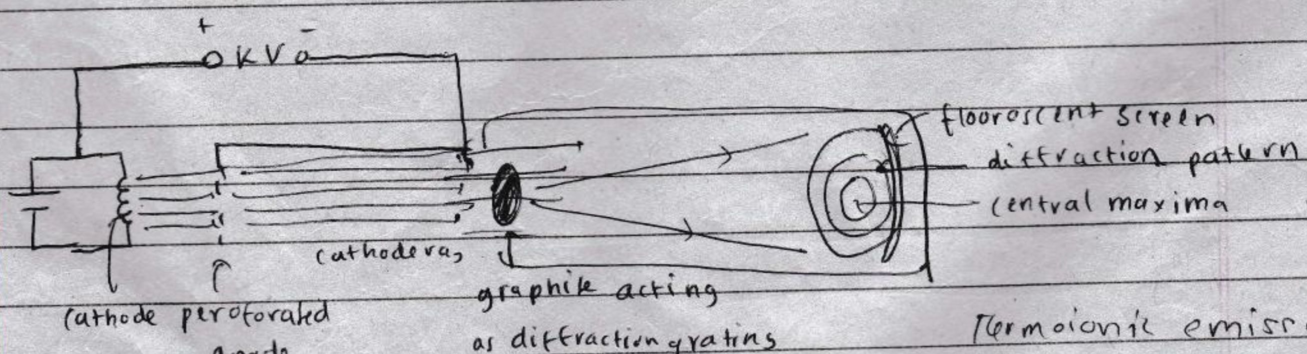
QUANTUM PHYSICS...

When metal is exposed to light, either electrons are emitted immediately or not at all. This does not support wave theory of light but supports particle /quantum theory as wave theory suggests light is continuously supplying energy and if this were true, the electron would take some time then eventually emit. But from particle theory we know, photons are discrete packets of energy, so electrons ~~et~~ gain the same energy from discrete photons and if it is more than work function it is emitted, else not.

Wave-Particle Duality

Photoelectric effect provides evidence for particulate (discrete packets) nature of em radiation while phenomena like interference, diffraction suggest its wave nature.

Louis de Broglie suggested that moving particle also behaves like waves which was proved by electron diffraction experiment.



Thermoionic emission

e^- → Thermions

As e^- are also experiencing diffraction, it suggested for particle nature of e^-

$d\sin\theta = n\lambda$ (constructive interference)

where $d\sin\theta$ is path difference between waves.

The e^- are diffracted at different angles and thus follow,
$d\sin\theta = n\lambda$, where central maxima is $n=0$.
Thus, fast moving e^- behave like waves.

Moving mass of photon,

$E = mc^2 = hf$ $\qquad E/c = mc$

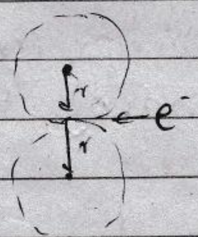
$\therefore m = \frac{hf}{c^2}$ $\qquad p = hf/c$

$\therefore p = h/\lambda$ // (Formula for de Brogile wavelength)

$\lambda = \frac{h}{mv}$

de Brogile relation states that $\lambda = h/p$.

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2E}{m}}} = \frac{h}{\sqrt{m^2\times\frac{2E}{m}}} = \frac{h}{\sqrt{2mE}}$$



To be best diffracted ~~2r = mos~~ $\lambda = 2r$ of electron, as nucleus is very small.
So when λ = diameter of diffracting atom, best diffraction is obtained.

$mv = h$

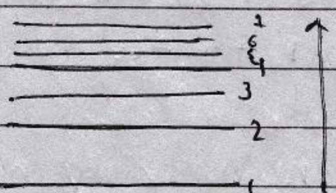
$\frac{1}{2}mv^2 = eV$ $\qquad mv = \frac{2eV}{v}$

$\lambda = \frac{h}{\sqrt{2mE}}$ or $\lambda = \frac{h}{\sqrt{2meV}}$

QUANTUM PHYSICS

Energy levels

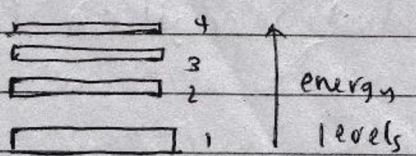
- According to nuclear model of atom, electrons can't occupy any region around nucleus
- Total energy of e^- is sum of its kinetic energy & PE.
- Diff. electrons are in different orbits corresponding to different amounts of energy known as energy levels and e^- can jump between energy levels when energy is supplied. But it can't have a energy that will keep it between two levels.
- Thus, energy of e^- in its orbit is quantized as it only takes discrete values.



Neil's Bohr said angular momentum of e^- in orbit is in integer multiple of $h/2\pi$. i.e. momentum is quantized.

As energy is quantized, functions of energy like velocity, distance are also quantized. Thus, we can say orbit is quantized.

Under high pressure (when atoms are close together), we follow band theory of energy levels which states energy inside orbit isn't quantized.



Energy level is the principal quantum number of atoms.

Energy levels (n)	Energy/eV
1	-13.58
2	-3.39
3	-1.51
4	-0.85

$E \propto \frac{1}{n^2}$

$E_1 = -13.58\ eV$

$E_2 = \frac{-13.58}{2^2} = -3.39\ eV$

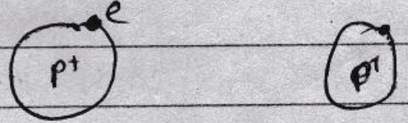
$E_3 = \frac{-3.39}{3^2} = -1.51\ eV$

An atom is said to be in its ground state if the electron is in the level of minimum energy.
An atom is said to be in excited state if electron is in higher energy levels.
Energy required to excite an atom is excitation energy.

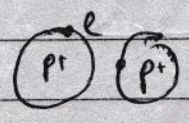
If Hydrogen atom is to be ionized, the energy required is -13.58 eV as then it reaches to 0.

Continuous and line spectra

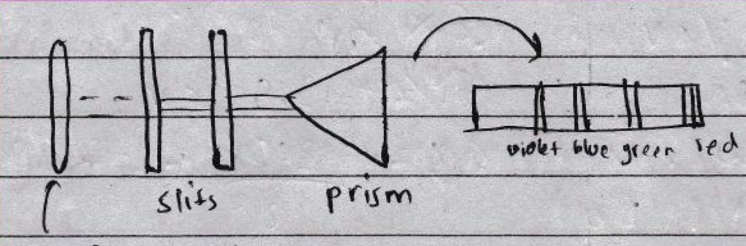
Spectrum is the group of EM radiation (light of different frequency / wavelength / color.
Continuous spectrum contains all wavelengths within a certain range while line spectrum contains only a few wavelengths.
Continuous spectrum is normally produced by hot solids, liquids and gases at high pressure.
Line spectrum is produced by gases.



At low pressure, gases are farther, so energy of e is only due to KE and PE, so it takes discrete energy values.
Line spectra



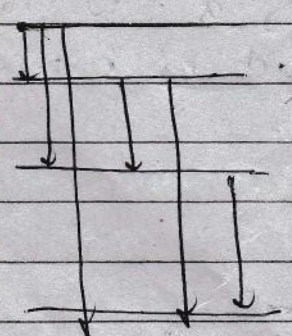
At high pressure, gases are closer so energy is continuous as ~~energy~~ e also comes closer to other e^- thus creating continuous energy variation.
Continuous spectrum



Line spectra → Emission line spectrum
Line spectra → Absorption line spectrum

Emission line spectrum

- With low energy condition (at low temp.) an atom contains e⁻ in lower energy level.
- Electrons can be excited to higher energy levels by supplying the energy like electrical and thermal energy.
- The excited state is unstable so falling to low energy level a em photon is emitted.
- When transition of no. of e⁻ takes place simultaneously, no. of photons having discrete wavelength are emitted.

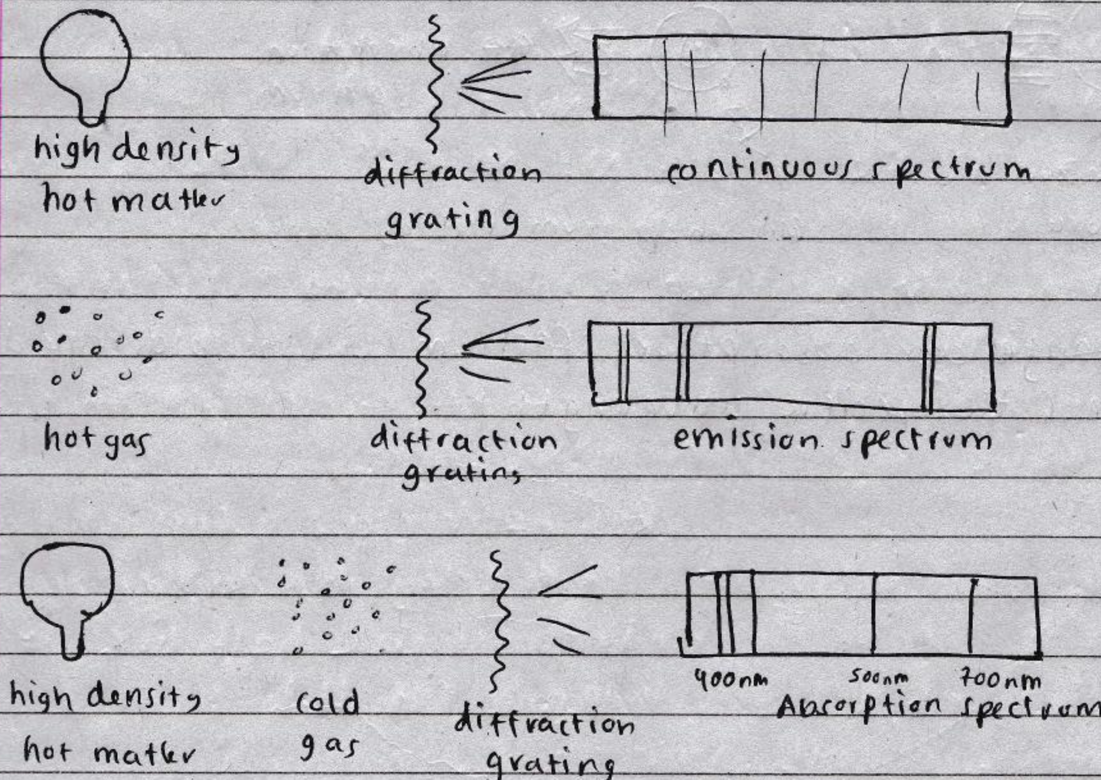


An atom with four energy levels can have six transitions so six photons are emitted. With discrete energy.

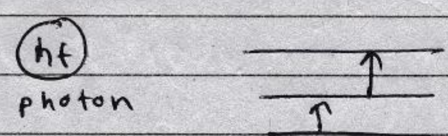
This means that differences between energy levels are unique to each element, so each gaseous element produces unique characteristic spectrum.

This spectra can be used to determine / identify the element in a particular sample.
This can be used to detect the presence of H in stars.

Absorption line spectrum

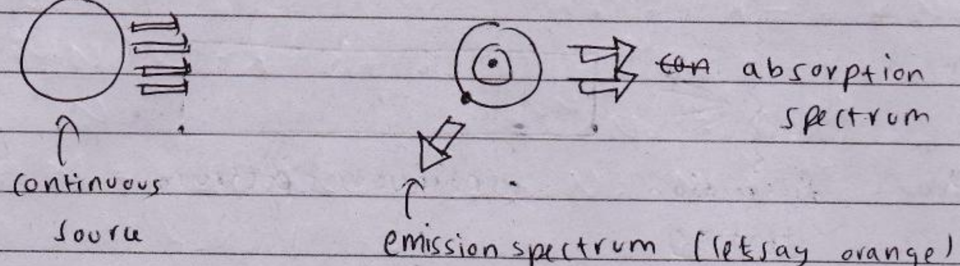


→ If the light producing a continuous spectrum is passed through a cold gas, only some photons are absorbed by the gas.



→ Only photons with $\varepsilon = hf$ enough to jump e^- between energy levels is absorbed and photons with $\varepsilon < hf$ or $\varepsilon > hf$ are not absorbed in that energy level jump.

- The continuous spectrum is modified into a new spectrum containing several dark lines.
- when a heated tungsten filament is viewed through hydrogen gas, this is absorbed.



So, ~~orange~~ our absorption spectrum will be blackened at orange (the specific wavelength)