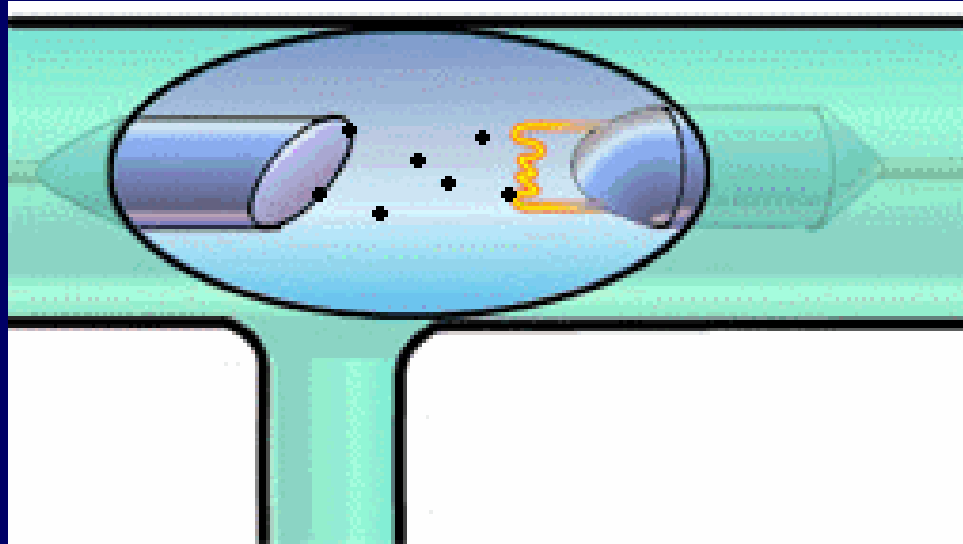


End-of-semester info

- **Final exam info:**
 - A1: Friday, Dec. 20, 8:00-11:00am
 - A2: Tuesday, Dec. 17, 7:00-10:00pm
 - Approximately 50 questions
 - Cumulative (all material from semester covered evenly)
- **CHECK GRADEBOOK!**
 - Missing iClicker points? – you need to show me proof you were in class!
- **Online ICES evaluation!**
- **James Scholar projects**
 - Due Thursday, Dec. 5 by email (ychemla@illinois.edu)

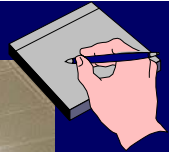
Physics 102: Lecture 26

X-rays





X-Rays



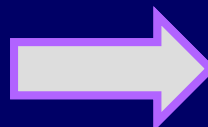
Photons with energy in approx range **100eV to 100,000eV**.

This large energy means they mostly go right through you (except for your bones and some soft tissue).

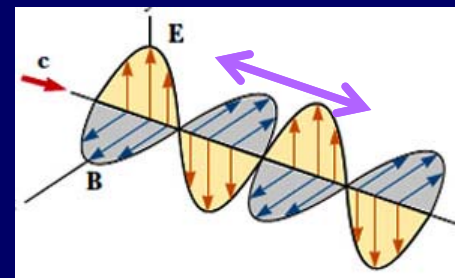
What are the wavelengths?

$$\lambda = \frac{hc}{E} = \frac{1240 \text{ eV} \cdot \text{nm}}{E}$$

$$\frac{1240 \text{ eV} \cdot \text{nm}}{100000 \text{ eV}} \approx .01 \text{ nm}$$

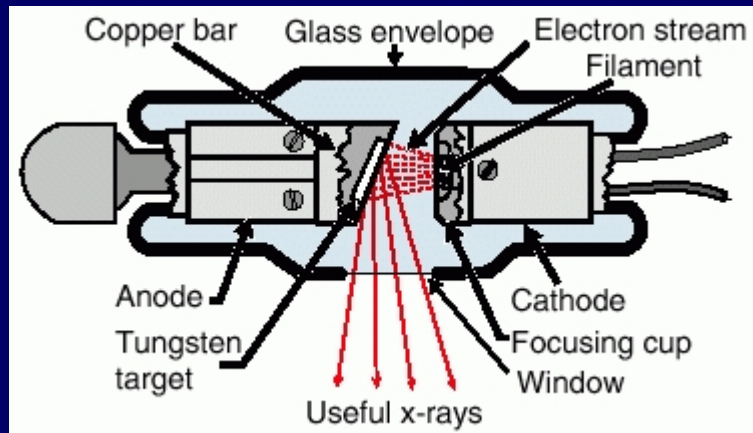


0.01 nm to 10 nm



$$\frac{1240}{100} \approx 10 \text{ nm}$$

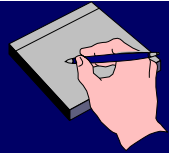
From Electrons to X-Rays



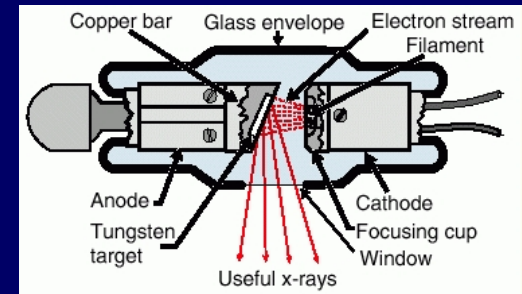
- Take high energy electrons and slam them into a target (any heavy element, usually tungsten)

Example

Electron Tubes



- **Electron** is accelerated through a voltage difference (from - “cathode” to + “anode”) to give it some energy...



An electron is accelerated through a potential difference of 70,000 V. How much energy does it emerge with?

Recall from Lecture 3: $EPE = V q$

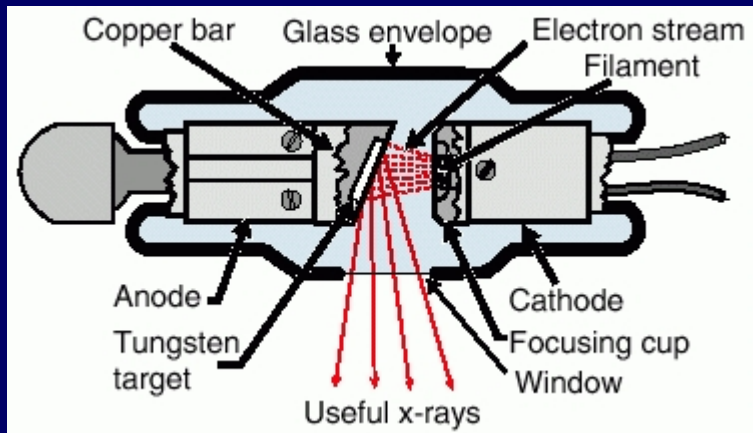
$$KE = EPE = (70,000 \text{ V}) (1 e^-) = 70,000 \text{ eV}$$

$$= 1.6 \times 10^{-19} \text{ C}$$

$$= 11.2 \times 10^{-14} \text{ J}$$

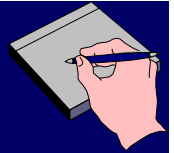
EPE of voltage gap becomes K.E. for electron!

From Electrons to X-Rays

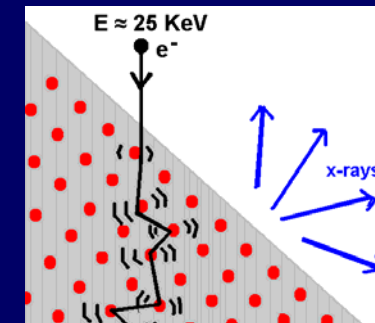
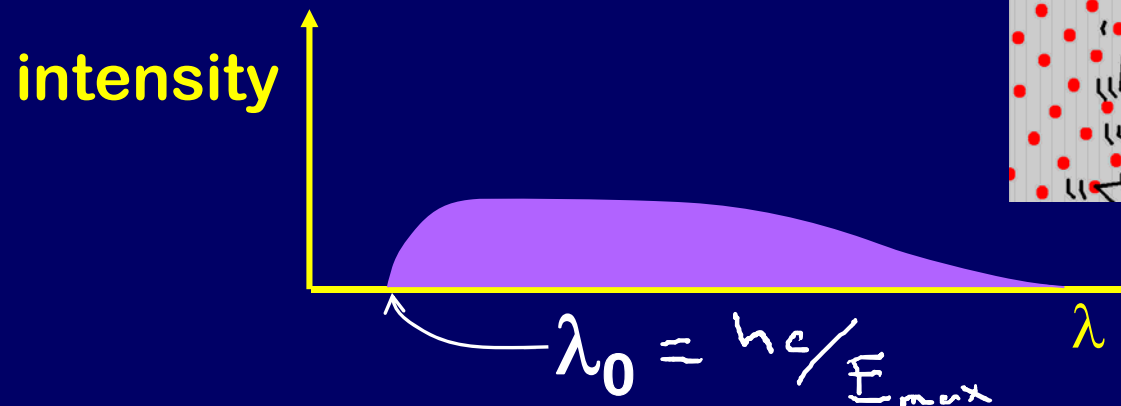
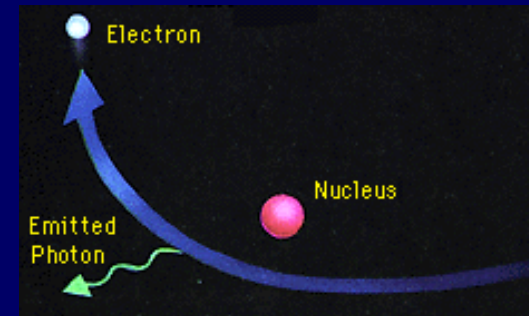


- Take high energy electrons and slam them into a target (any heavy element, usually tungsten)
- 2 kinds of X-Rays are produced:
 - “Bremsstrahlung” German = “braking radiation”
 - “Characteristic”

Bremsstrahlung X-Rays



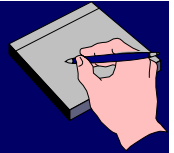
- **Electron hits atom and slows down, losing kinetic energy.**
 - Energy emitted as photon
- **Electron hitting atom makes many photons (X-Rays), all with different energy.**
 - Many different wavelengths.



- **If all of electron's energy is lost to a single photon, photon has maximum energy (minimum wavelength).**
 - Minimum X-Ray wavelength = λ_0 .

Example

Bremsstrahlung Practice

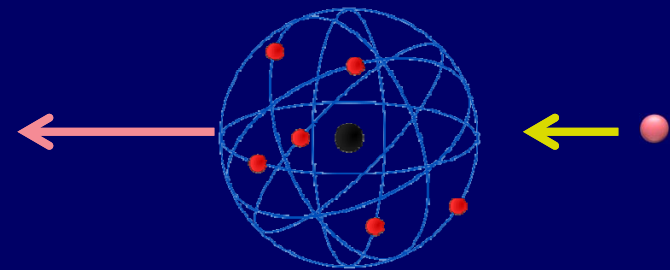


An electron is accelerated through 50,000 volts

What is the minimum wavelength photon it can produce when striking a target?

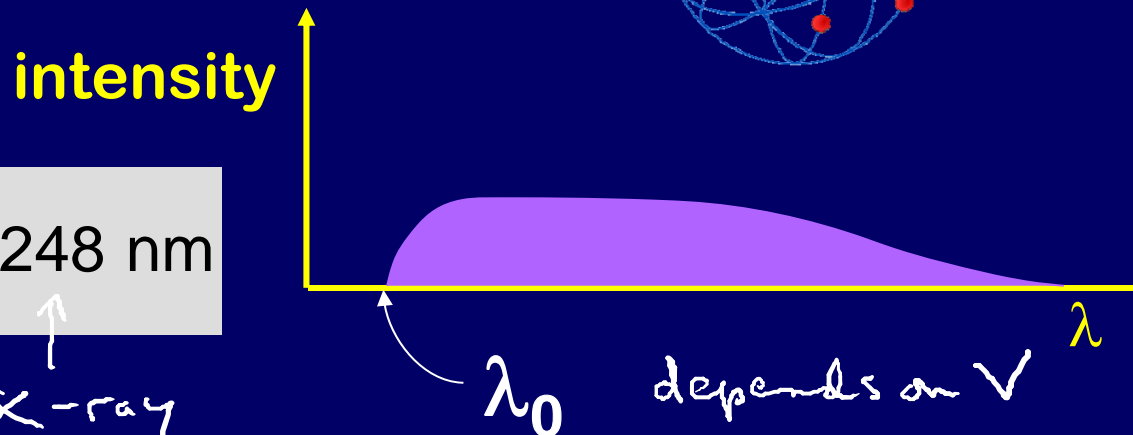
Minimum wavelength \longleftrightarrow Maximum energy

Electron loses ALL of its energy in one collision and emits one photon.



$$\lambda_0 = \frac{hc}{E} = \frac{1240}{50,000} = .0248 \text{ nm}$$

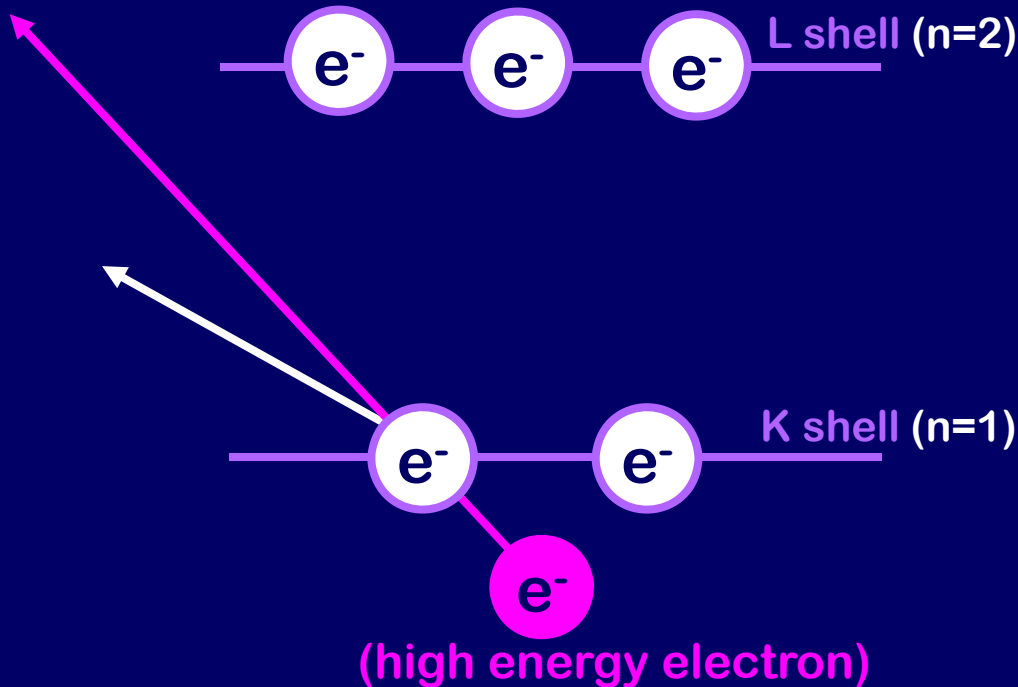
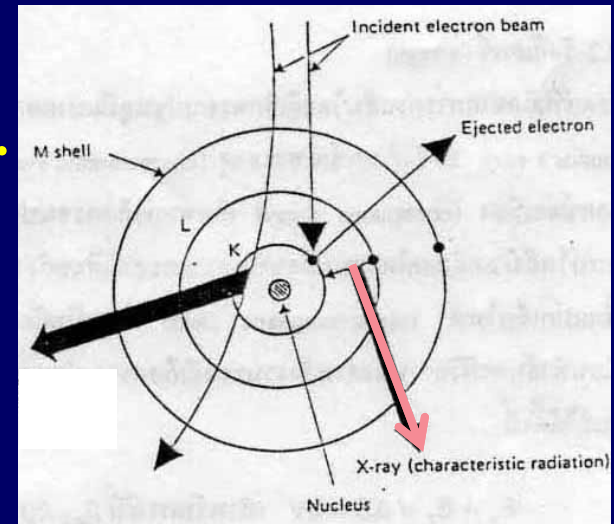
↑
X-ray



Characteristic X-Rays

Electron knocks one of the two K shell (ground state) electrons out of an atom.

L (n=2) or higher shell electron falls down to K shell (ground state) and x-ray photon is emitted



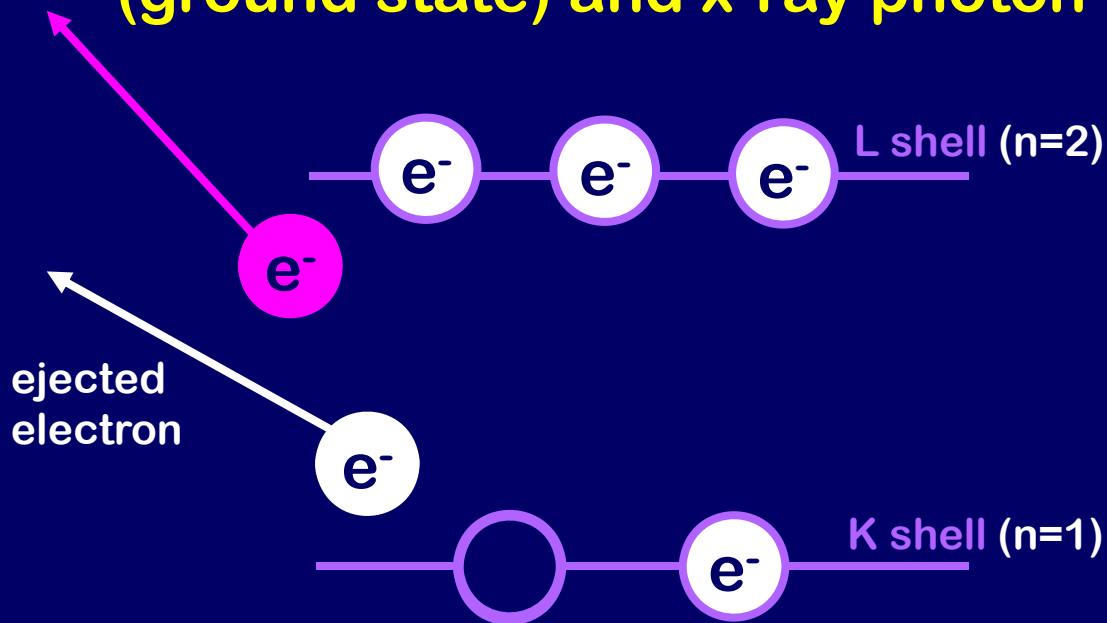
Characteristic x-ray nomenclature

n=1	“K shell”
n=2	“L shell”
n=3	“M shell”

Characteristic X-Rays

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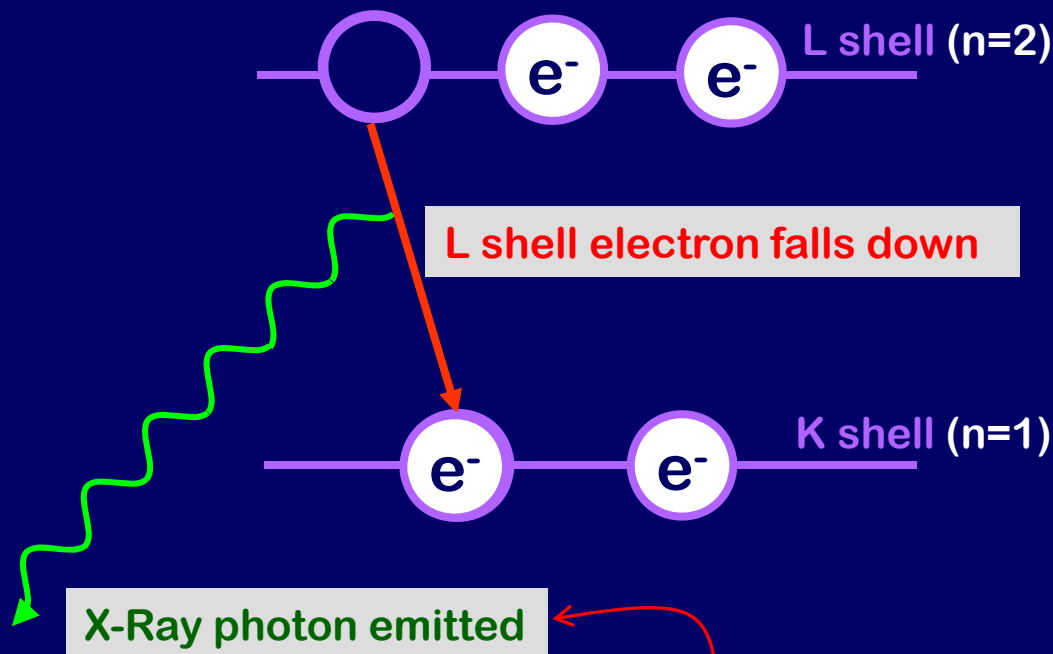
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Characteristic X-Rays

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Characteristic x-ray nomenclature

n=1	"K shell"
n=2	"L shell"
n=3	"M shell"

"K_α X-ray" ($n=2 \rightarrow n=1$ transition)

Example

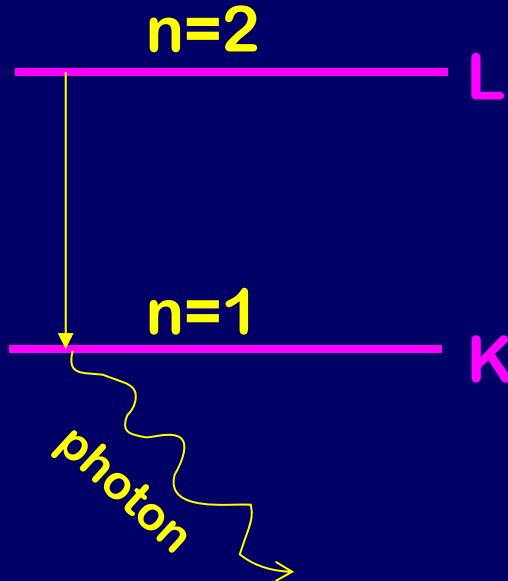
protons

K_α X-Rays

Estimate the energy of K_α X-rays off of a silver (Ag) target (Z=47).

Better formula for
Carefully the formula
inner-shell electrons
in multi-electron
atoms assumed a *single electron* bound
to just a positive nucleus.

$$E_n = \frac{(-13.6)(Z-1)^2}{n^2}$$



$$E_L = -13.6\text{eV}(47-1)^2 \frac{1}{2^2} = -7.2\text{keV}$$

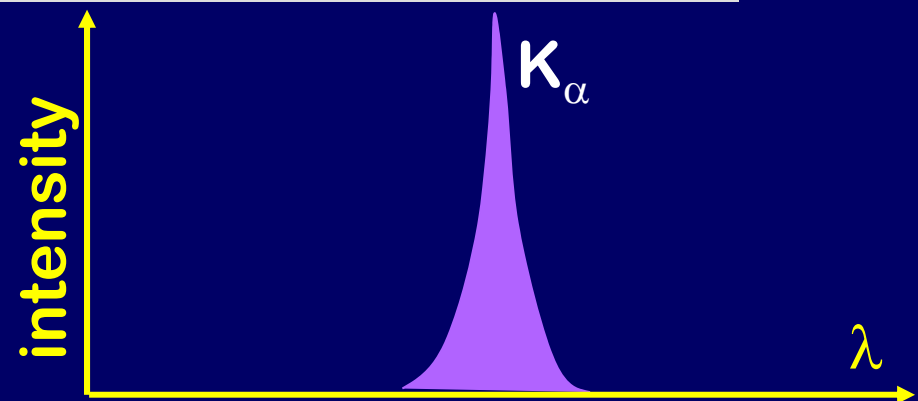
$$E_K = -13.6\text{eV}(47-1)^2 \frac{1}{1^2} = -28.8\text{keV}$$

$$E(K_\alpha) = E_L - E_K = 21.6\text{keV}$$

(vs. 21.7 keV Expt)

Not bad!

X-ray



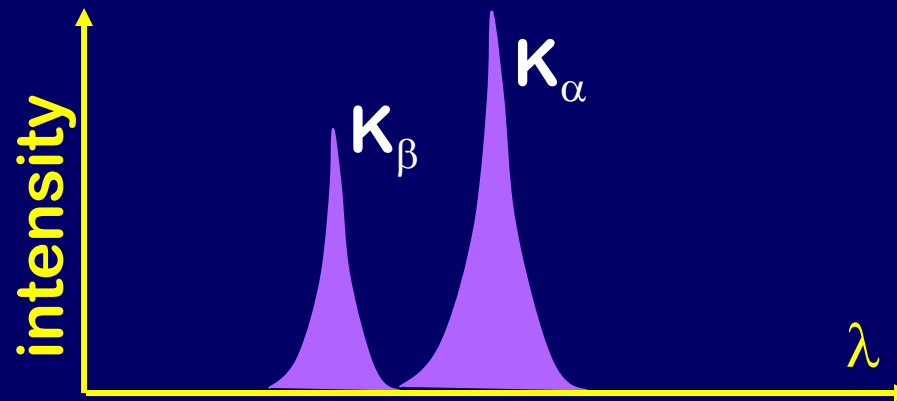
K_β X-Rays

K_α X-rays come from $n=2 \rightarrow n=1$ transition.

What about $n=3 \rightarrow n=1$ transition?

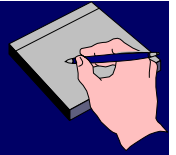
Not as likely, but possible. Produces K_β X-Rays!

K_β X-Rays are higher energy (lower λ) than K_α .
(and lower intensity)

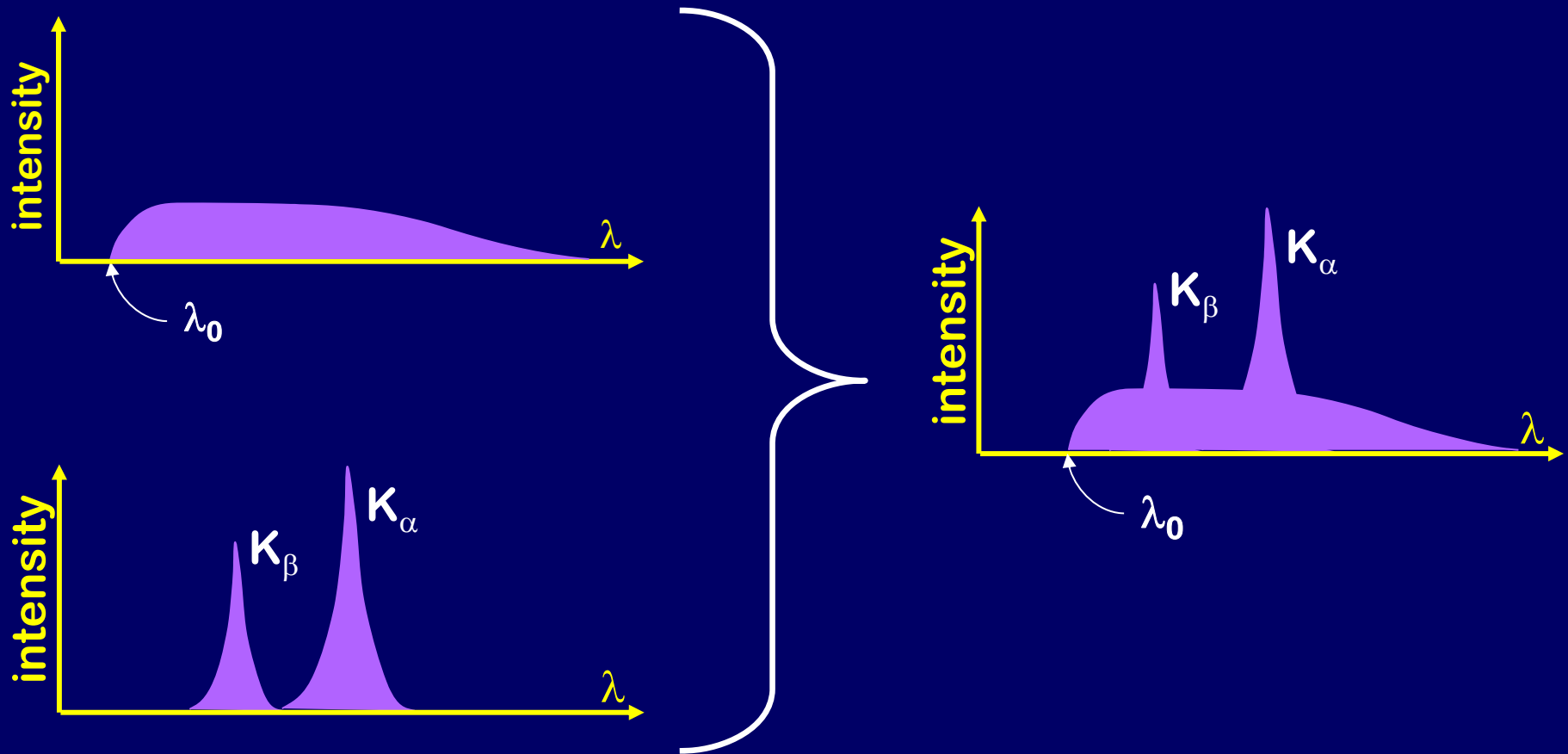


Different elements have different Characteristic X-Rays

All Together Now...

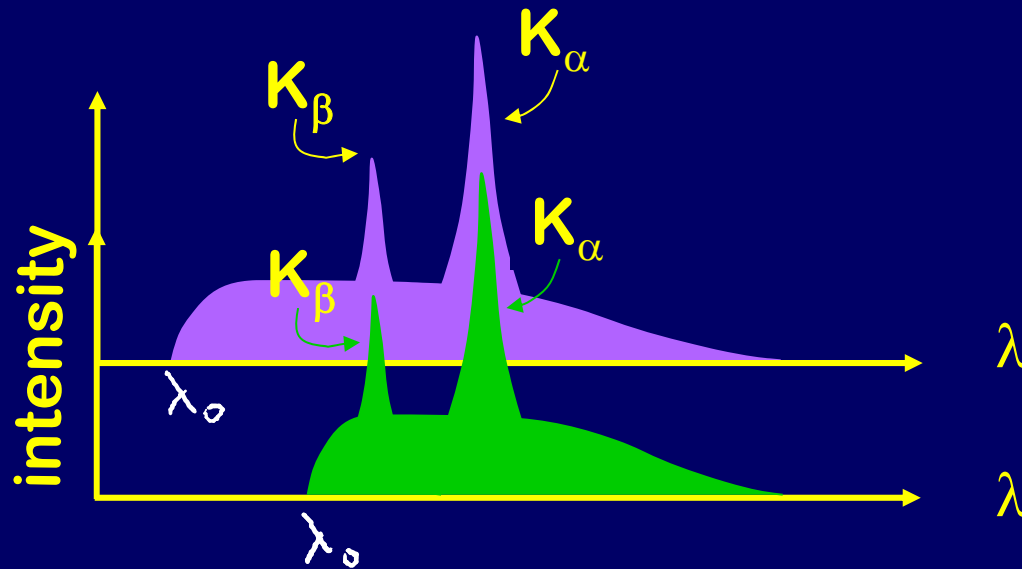


Bremsstrahlung **X-Rays** and Characteristic **X-Rays** both occur at the same time.





ACT: Checkpoint 1



These two plots correspond to X-Ray tubes that:

(1) Are operating at different voltages

(2) Contain different elements

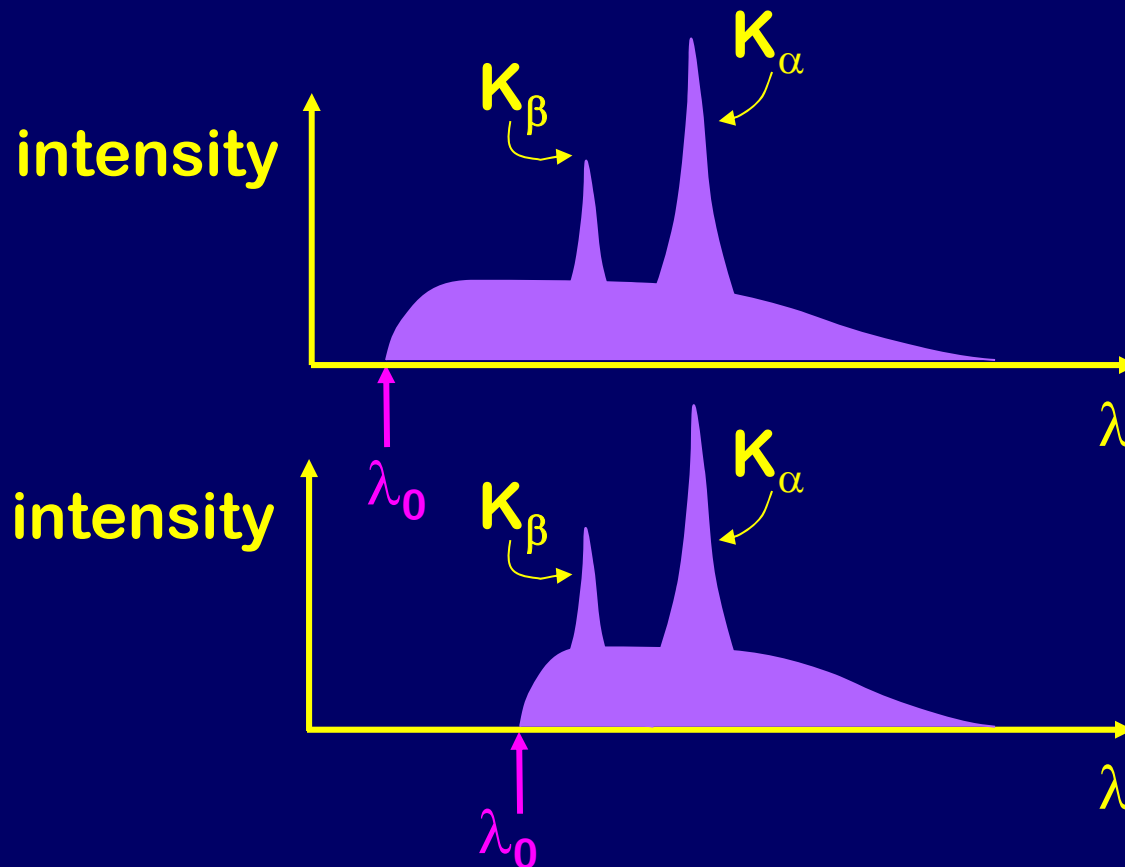
(3) Both

(4) Neither

same element
||
 K_α and K_β are the same
= different V
 λ_0 is different



ACT: X-Rays I



K_α and K_β are the same for each!

Higher voltage means higher energy x-ray photon can be produced, or smaller maximum wavelength, λ_0 .

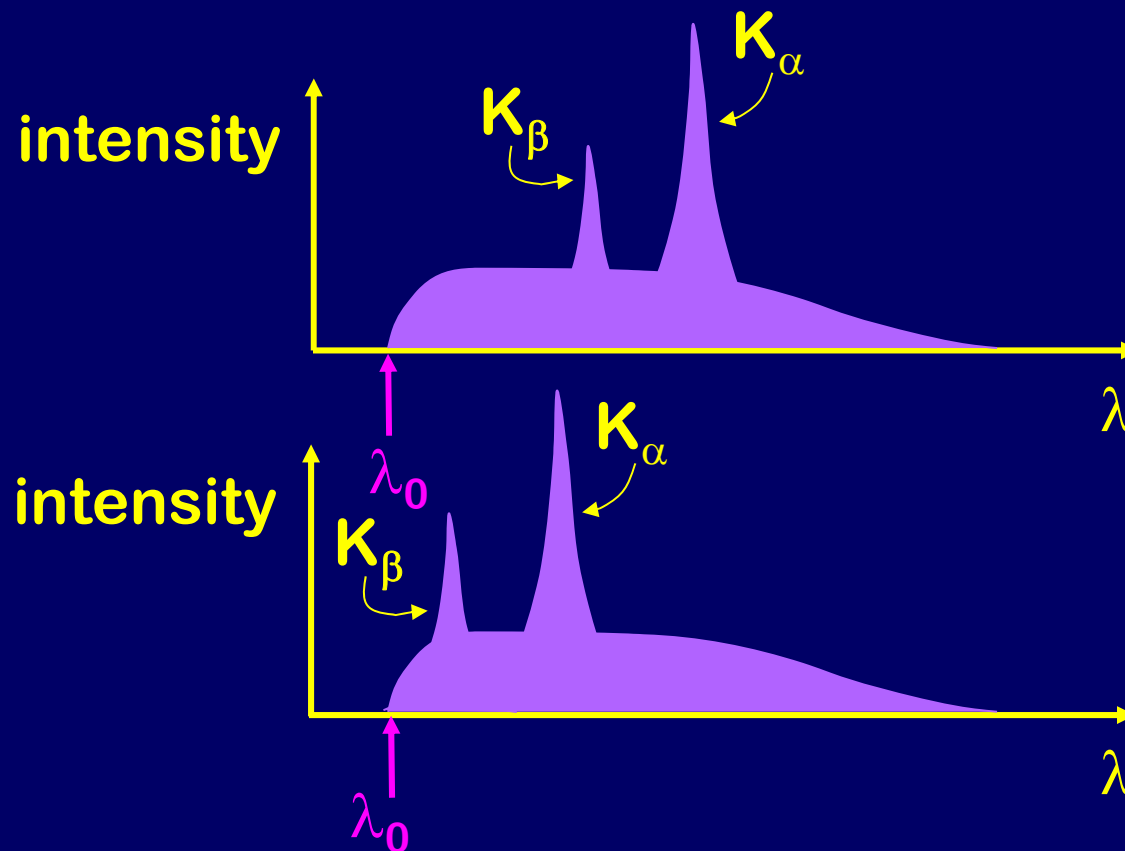
Which graph corresponds to the tube being operated at the higher voltage?

1) Top

2) Bottom



ACT: X-Rays II



λ_0 is the same for each!

Energy of characteristic X-ray is proportional to $(Z-1)^2$.

Higher energy = higher Z

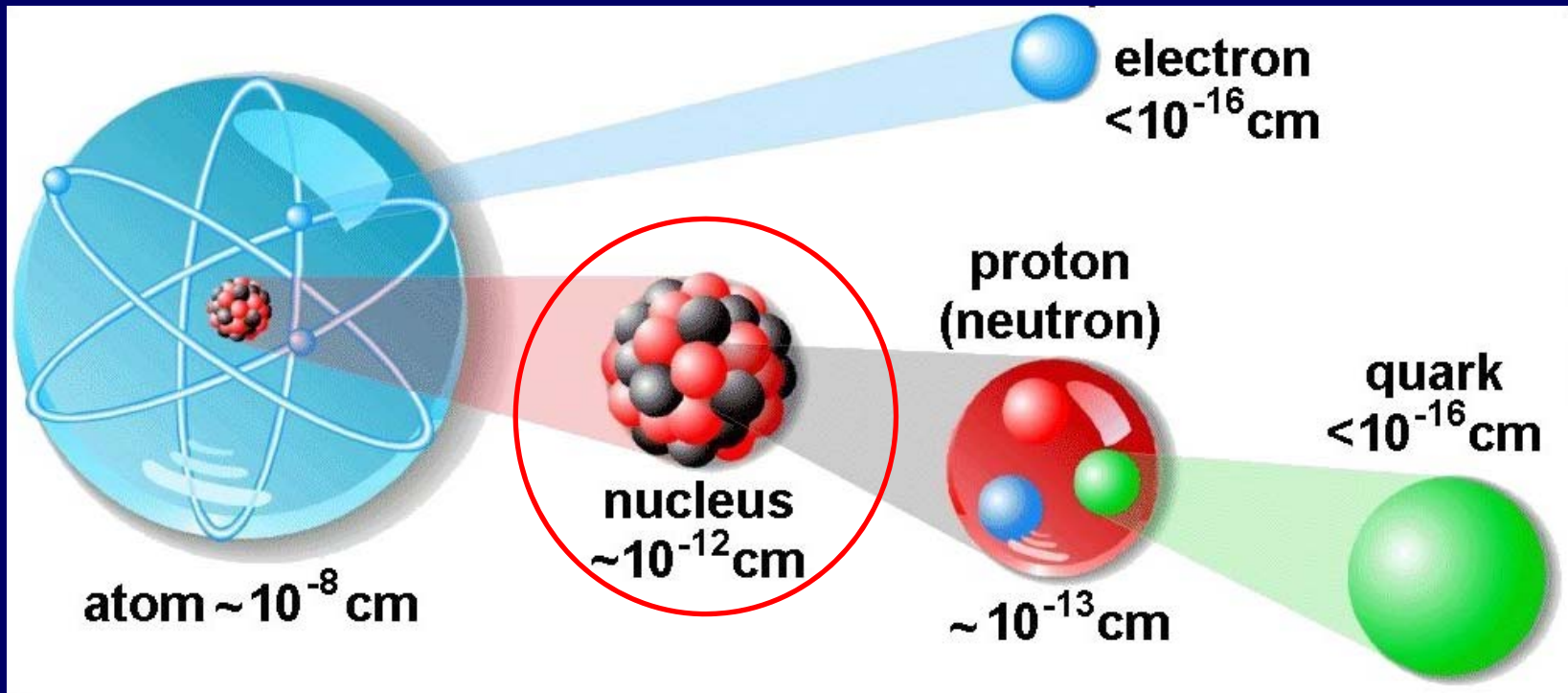
The top spectrum comes from a tube with a silver target (Ag, $Z=47$). What is the bottom target?

1) Pd, $Z=46$

2) Ag, $Z=47$

3) Cd, $Z=48$

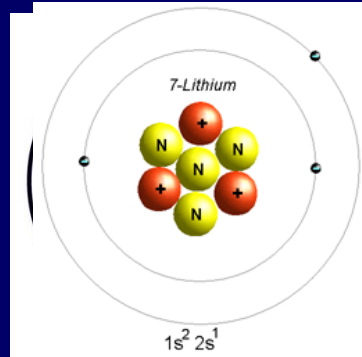
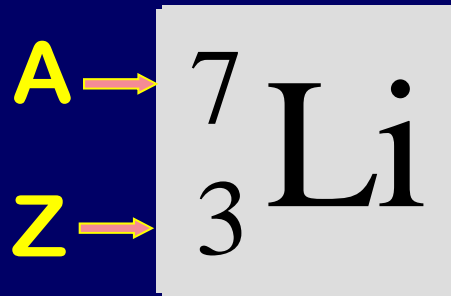
From atoms to nuclei to nucleons to quarks: The hierarchy of sizes



Rutherford
1911

Proposed 1964
Observed 1968

Nuclear Physics



Nucleus = Protons + Neutrons
nucleons

Z = proton number (“atomic number”) = *electron #*
Gives chemical properties (and name)

N = neutron number (different “isotopes”)

A = nucleon number (atomic mass number)
Gives you mass density of element

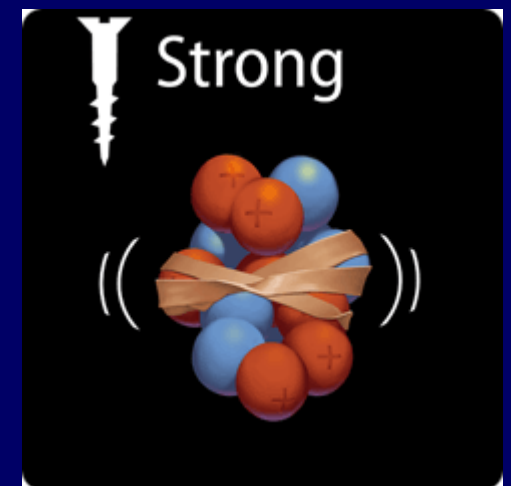
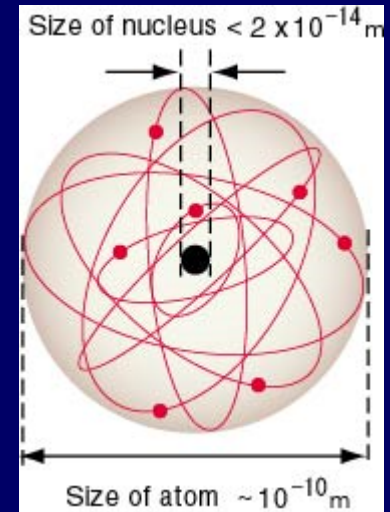
$\Rightarrow A = N + Z$

Strong Nuclear Force

- Rutherford experiment shows that all the positive charge is contained in a small nucleus
 - Size \sim few $\times 10^{-15}$ m (few fm)
- Estimate EPE of two protons separated by 1 fm

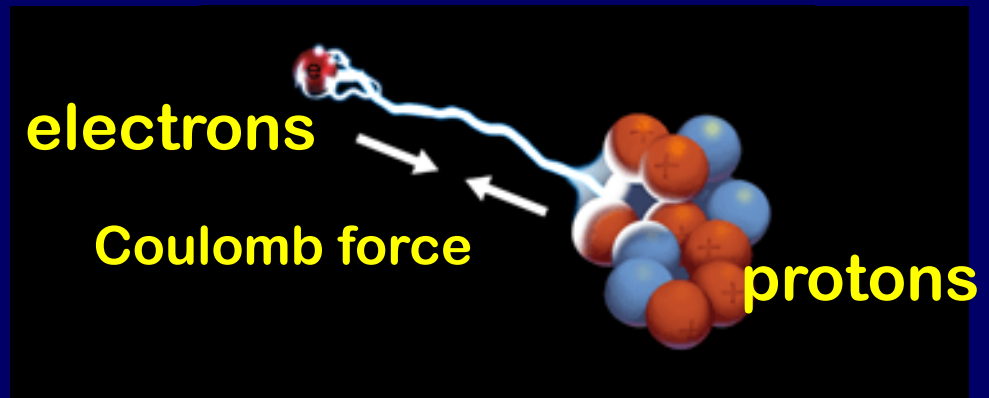
$$\begin{aligned}\text{EPE} &= kq^2/r \\ &= (9 \times 10^9)(1.6 \times 10^{-19})^2/10^{-15} \\ &= 2.3 \times 10^{-13} \text{ J} \\ &= 1.44 \times 10^6 \text{ eV} = 1.44 \text{ MeV}\end{aligned}$$

- The force that binds protons and neutrons together to form a nucleus must be very strong in order to overcome Coulomb repulsion!
- But the force acts over very short distances—of order few fm: force between atoms insignificant

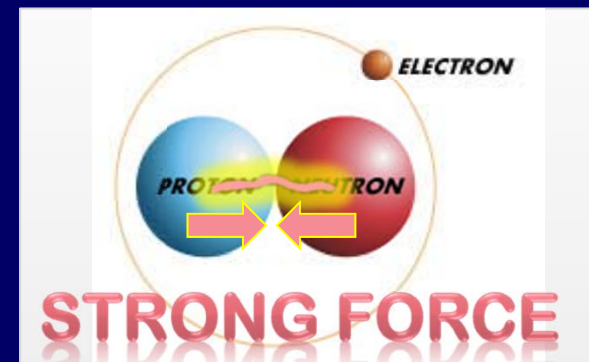


Strong Nuclear Force

Hydrogen atom:
Binding energy
=13.6eV
(of electron to nucleus)



Simplest Nucleus:
Deuteron=neutron+proton
(nucleus of deuterium, isotope of H)

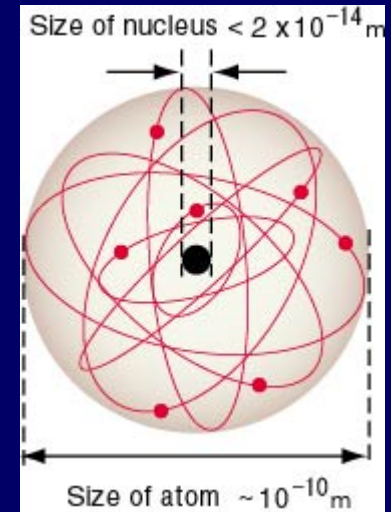


Binding energy of deuteron = $2.2 \times 10^6 \text{ eV}$ or 2.2Mev! That's around 200,000 times bigger!

Smaller is Bigger!

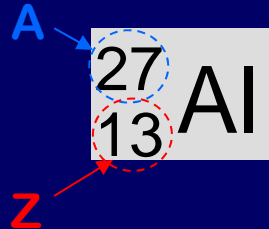
Comparing Nuclear and Atomic sizes

Hydrogen Atom: Bohr radius = $5.29 \times 10^{-11} \text{ m}$



Nucleus with nucleon number A : $r \approx A^{1/3} \cdot (1.2 \times 10^{-15} \text{ m})$

Example



has radius $r \approx 3.6 \times 10^{-15} \text{ m}$

Note the **TREMENDOUS** difference

Nucleus is 10^4 times smaller
and binding energy is 10^5 times larger!

See you next time!