

Forms of radiation

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Radiation

emission or transmission (of energy) in the form of **waves** or **particles** through space or through a material medium



Moving elemental particles or waves

Radiation

emission or transmission (of energy) in the form of waves or particles through space or through a material medium

Questions:

- Tell me some examples of the radiation
- Can a human body detect any radiation?
- Is there a difference between waves and particles?



Is there a difference between waves and particles?

Wave–particle duality in quantum mechanics:

- a particle may be partly described in terms not only of particles, but also of waves
- a wave may be also described in terms of particle

Is there a difference between waves and particles?

Wave–particle duality in quantum mechanics:

- a **particle** may be partly described in terms not only of particles, but also of **waves**
- a **wave** may be also described in terms of **particle**

Radiation types

- **electromagnetic radiation**, such as radio waves, microwaves, visible light, X-rays, and gamma radiation (γ)
- **particle radiation**, such as alpha radiation (α), beta radiation (β), neutron radiation, neutrinos (particles of non-zero rest energy)
- **acoustic radiation**, such as ultrasound, sound, and seismic waves (dependent on a physical transmission medium)
- **gravitational radiation**, radiation that takes the form of gravitational waves, or ripples in the curvature of spacetime

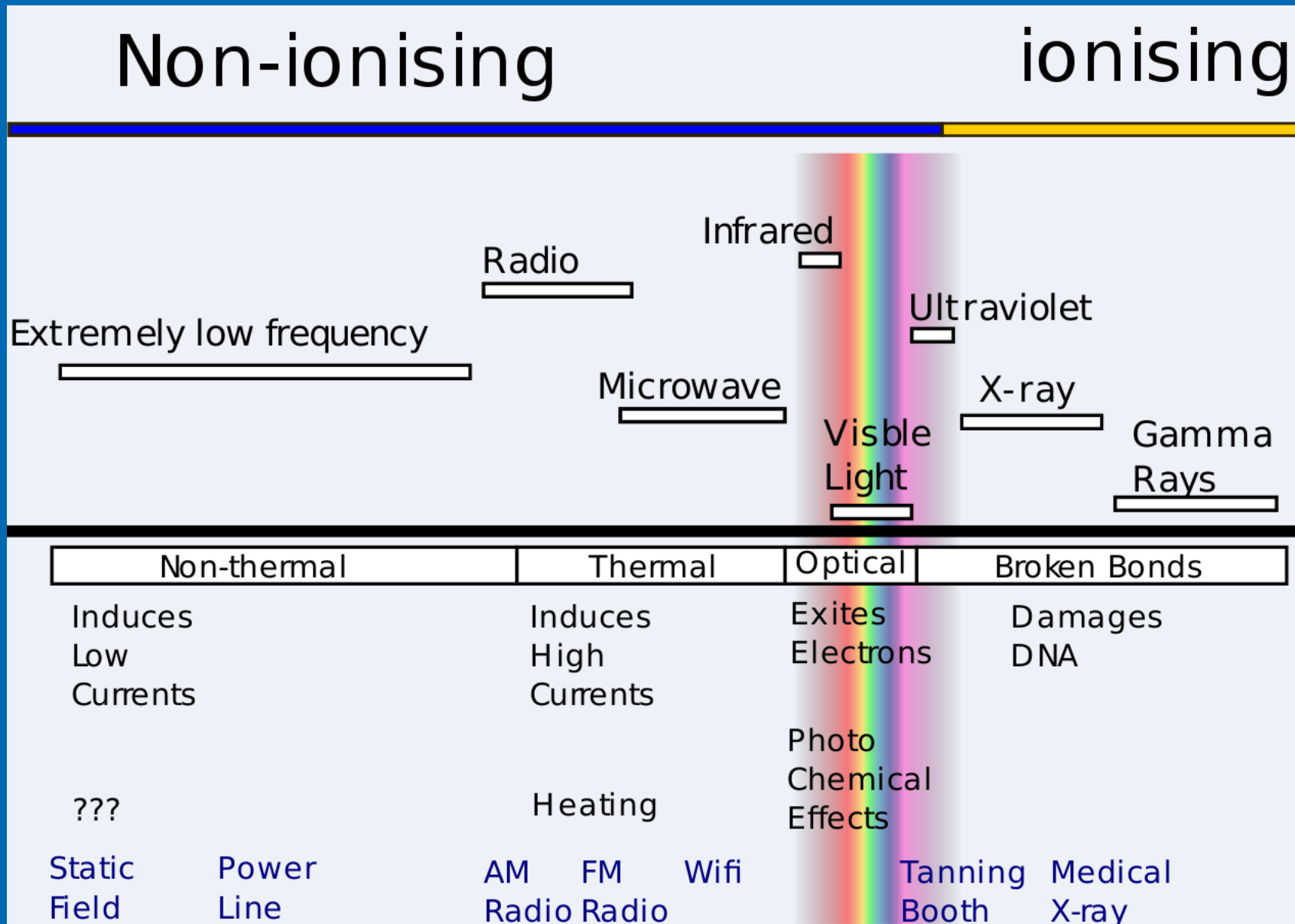
Effects of Radiation

energy higher than 10 eV can ionize atoms and break chemical bonds

ionizing radiation is harmful to living organisms

- radioactivity – α , β , γ
- cosmic rays - muons, mesons, positrons, neutrons and other particles
- X-rays
- neutrons (indirectly)
- neutrinos – but they do not really react

Effects of electromagnetic Radiation

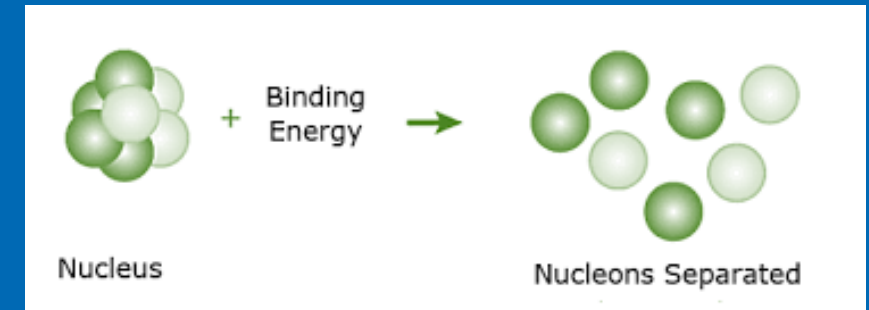
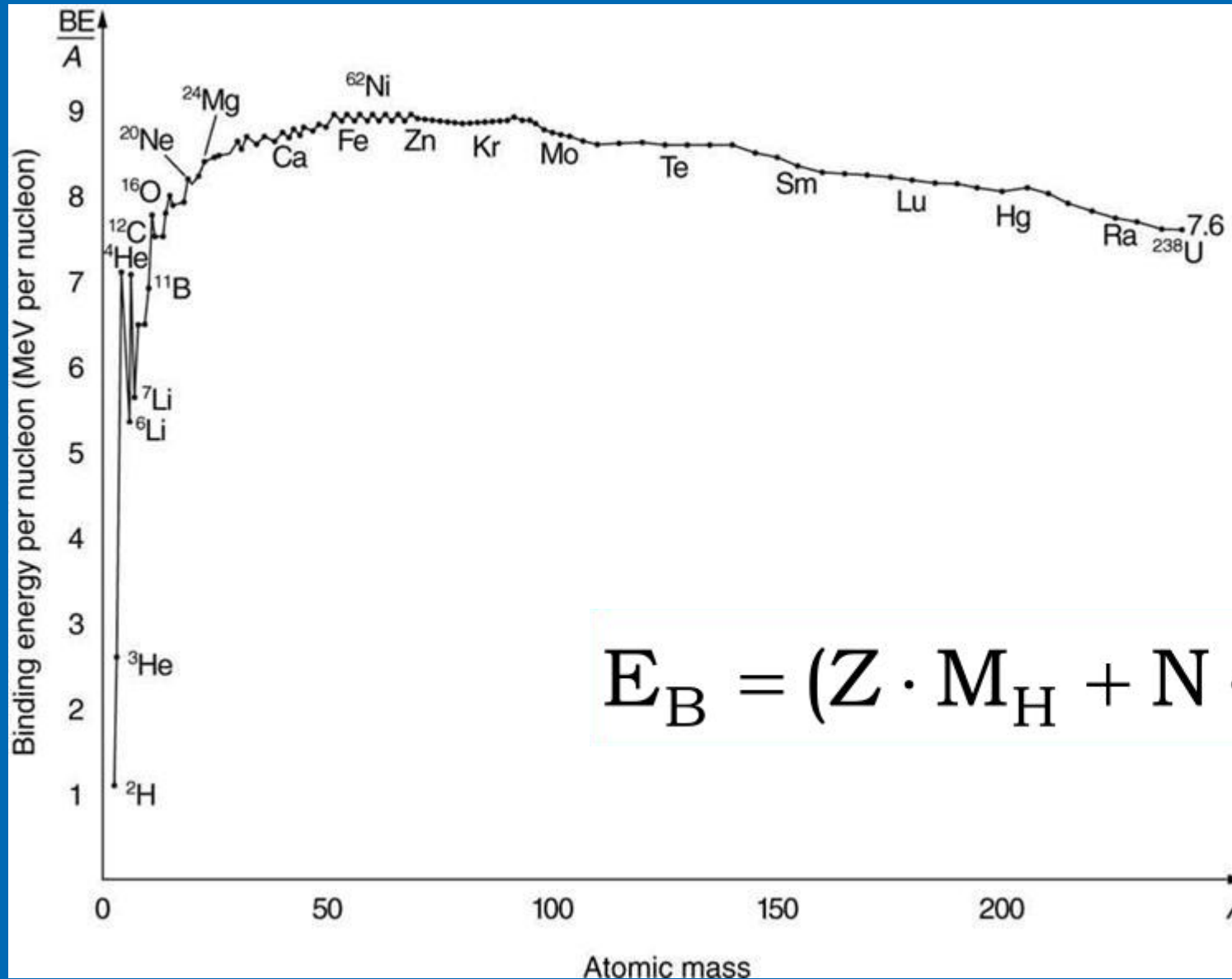


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Ionizing Radiation sources

- radioactive decay - α , β , γ
- fission
- (other) nuclear reactions (by cosmic rays, neutrons)
- atomic changes – X-rays

Atom and its binding energy



$$E_B = (Z \cdot M_H + N \cdot m_n - \frac{A}{Z}M) \cdot c^2$$

Atom and its binding energy

The Liquid Drop Model

$$E_B = a_V A - a_S A^{2/3} - a_A \frac{(A-2Z)^2}{A^{1/3}} - a_C \frac{Z(Z-1)}{A^{1/3}} + \delta(A, Z)$$

Volume
term

Surface
term

Asymmetry
term

Coulomb
term

Pairing
term

For pairing term:

$$\delta(A, Z) = \begin{cases} +\delta_o & A, Z \text{ even} \\ 0 & A \text{ odd} \\ -\delta_o & A, Z \text{ odd} \end{cases}$$

where

$$\delta_o = \frac{a_p}{A^{1/2}}$$

Coefficients:

$$a_V = 15.85 \text{ MeV}$$

$$a_S = 18.34 \text{ MeV}$$

$$a_A = 23.21 \text{ MeV}$$

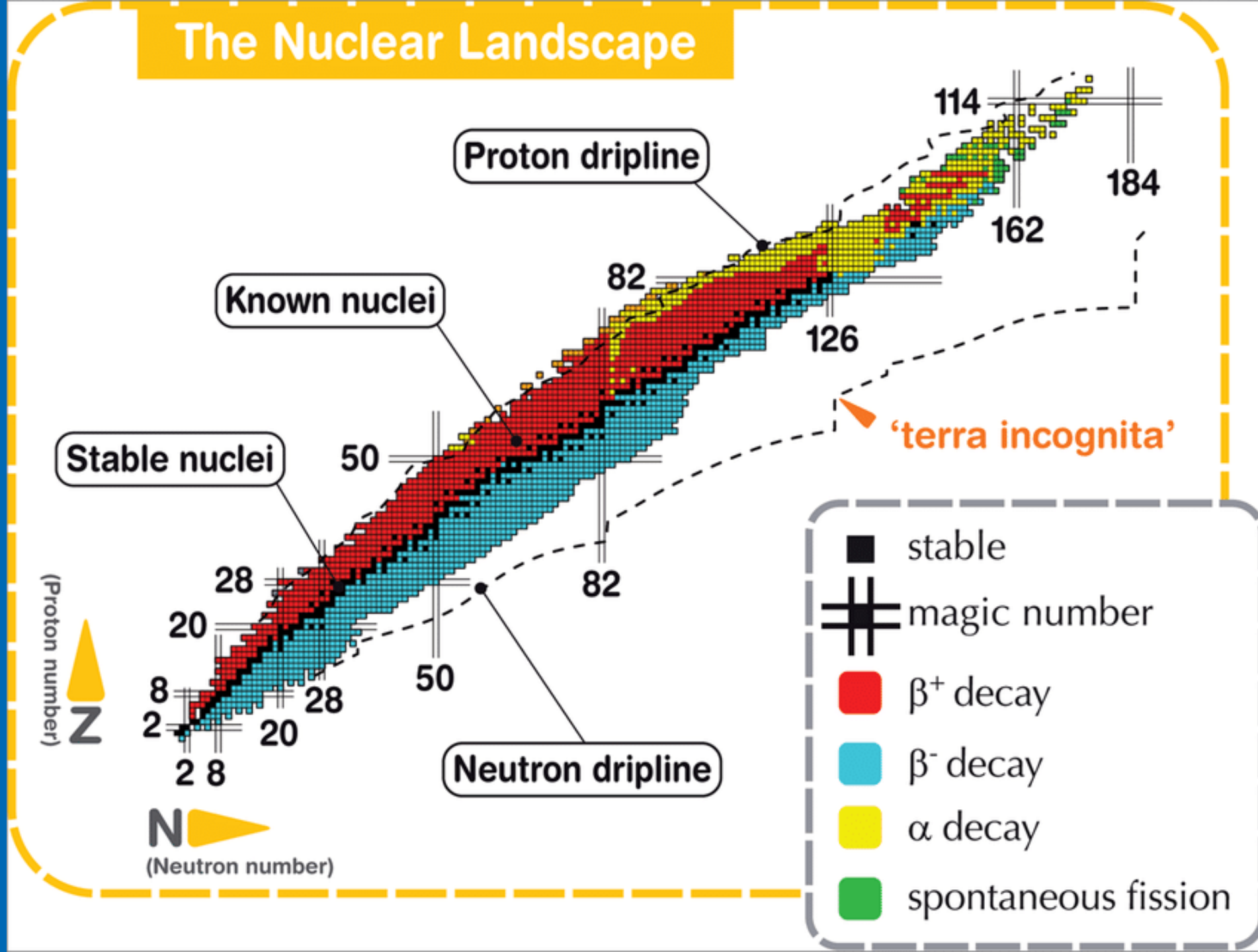
$$a_C = 0.714 \text{ MeV}$$

$$a_p = 12.00 \text{ MeV}$$

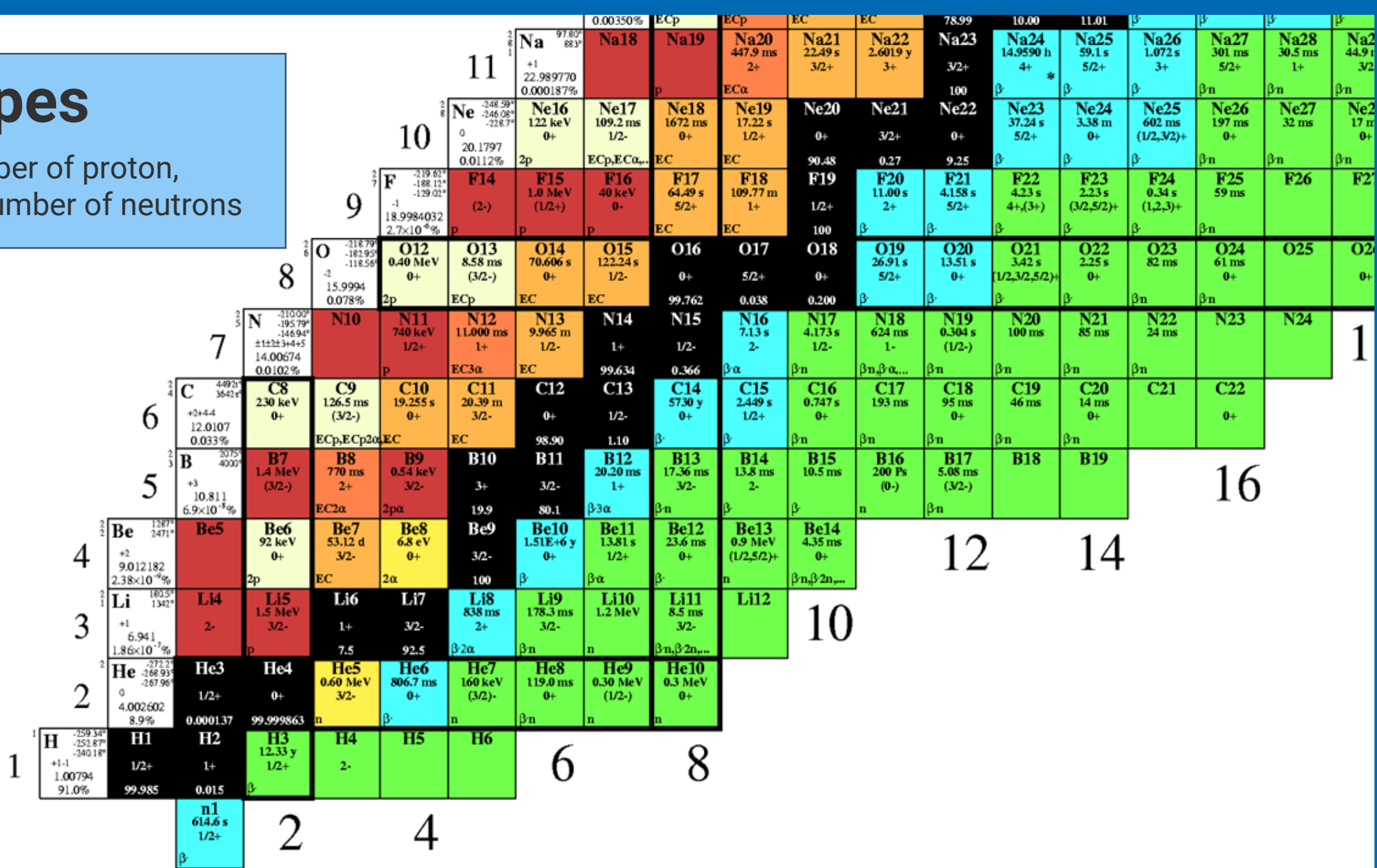
Isotopes

Isotopes shown here in black are stable.

Radioisotopes are unstable.

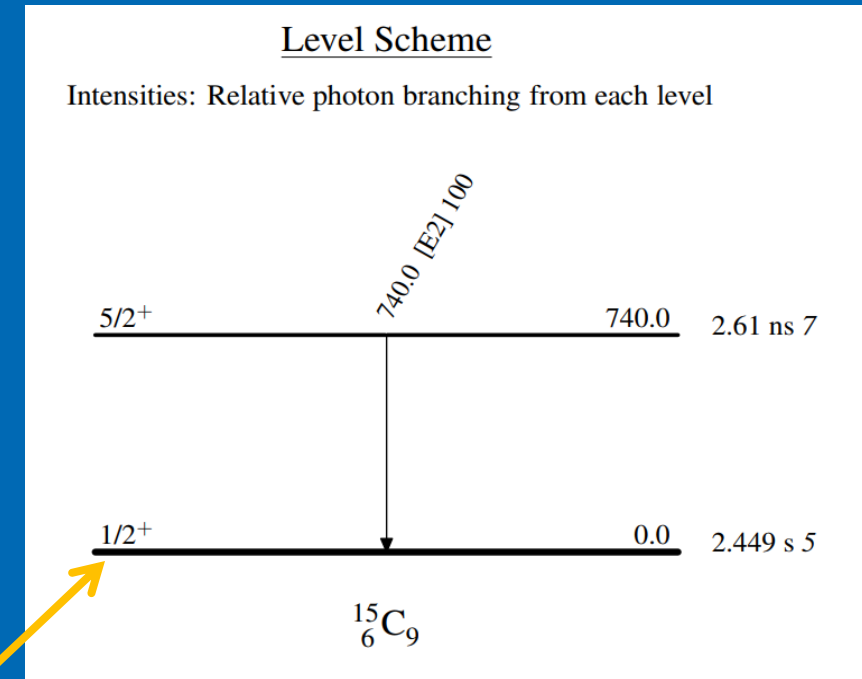
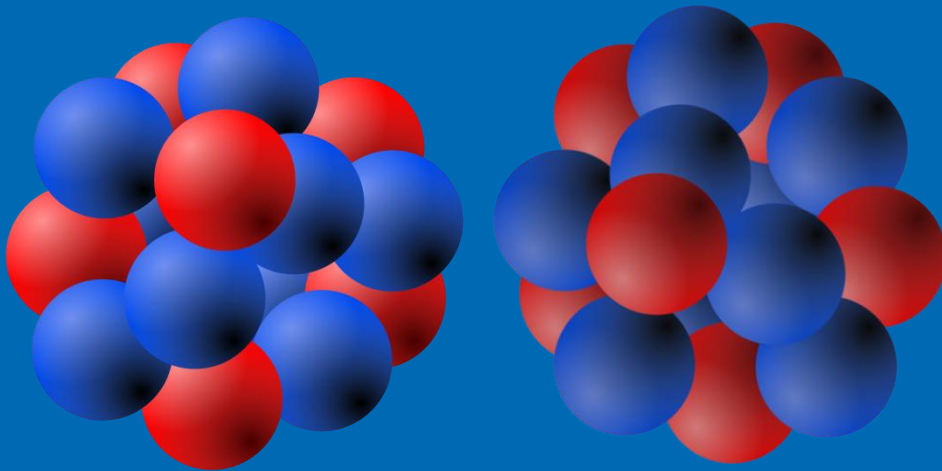


Same number of proton,
different number of neutrons



Nucleus and its excited states

^{15}C – different states, different energies

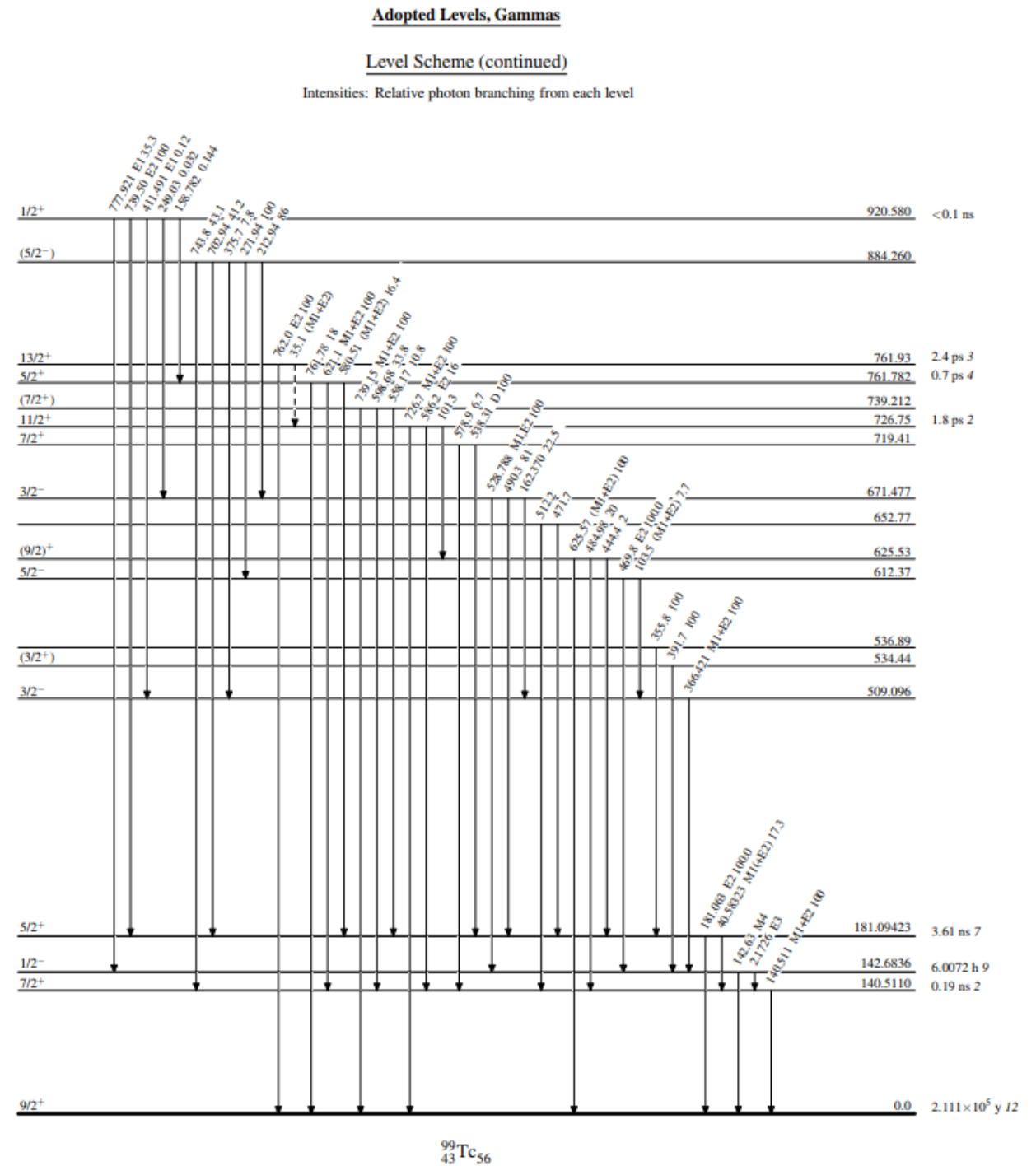


The lowest state – ground state

Nucleus and its excited states

Isomeric state

181.09423	3.61 ns 7
142.6836	6.0072 h 9
140.5110	0.19 ns 2
Excitation energy [keV]	Half-life
0.0	2.111×10^5 y 12



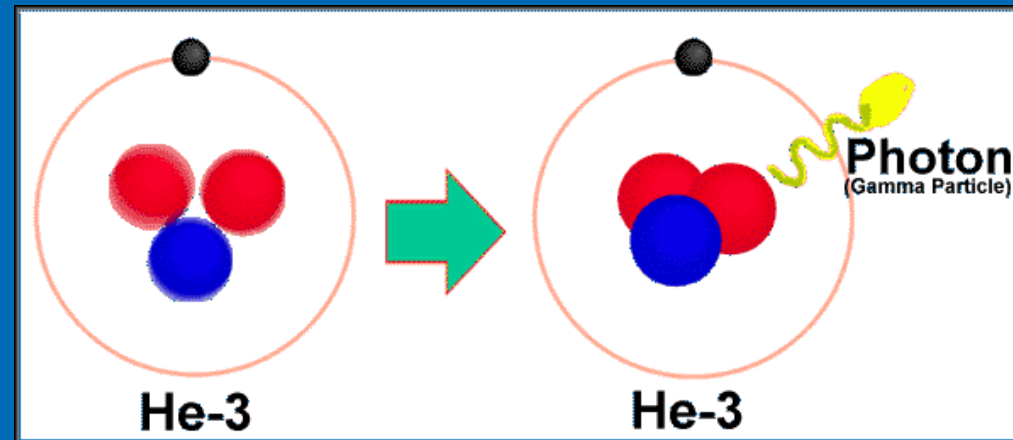
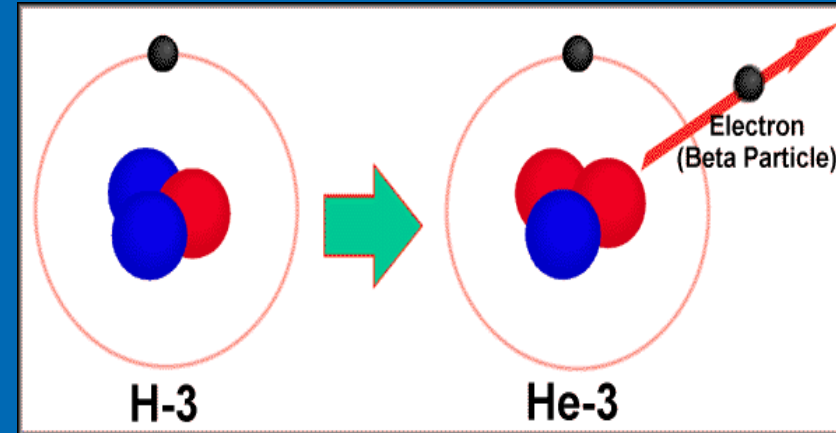
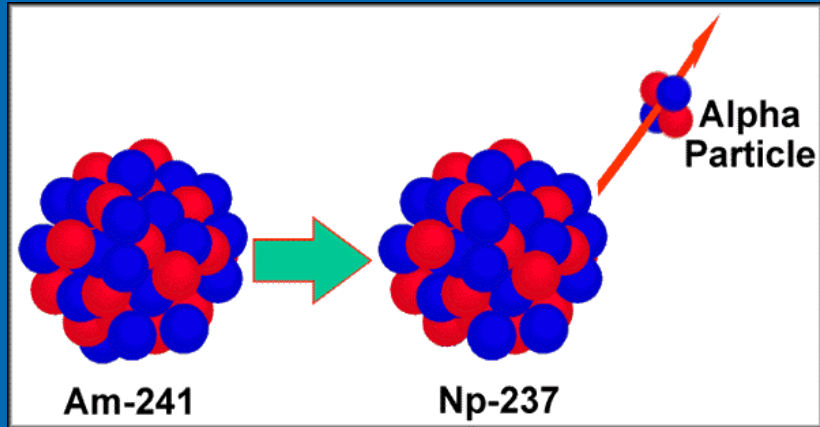
What do we mean by Radioactivity?

Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting radiation in the form of **particles or electromagnetic waves**.

There are several types of radioactive decay. The general idea:

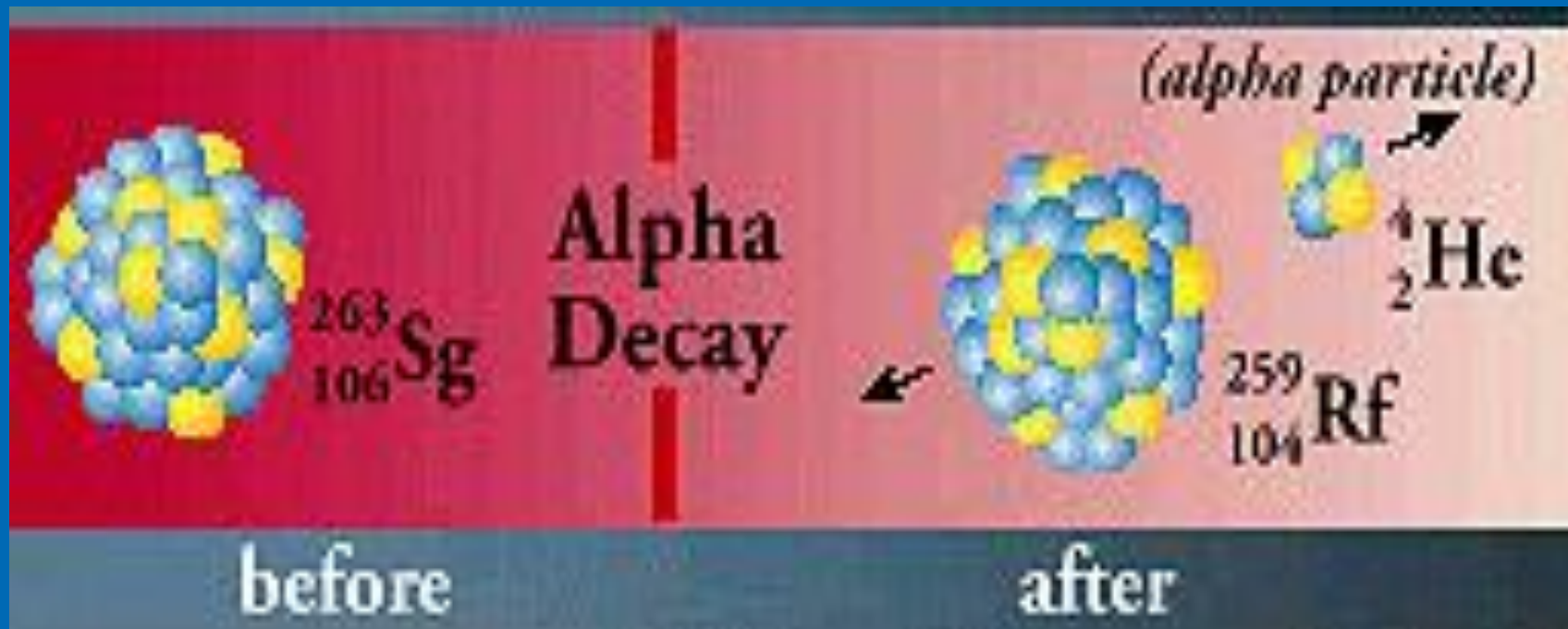
An unstable nucleus releases energy to become more stable

Radioactivity



Alpha Radioactivity

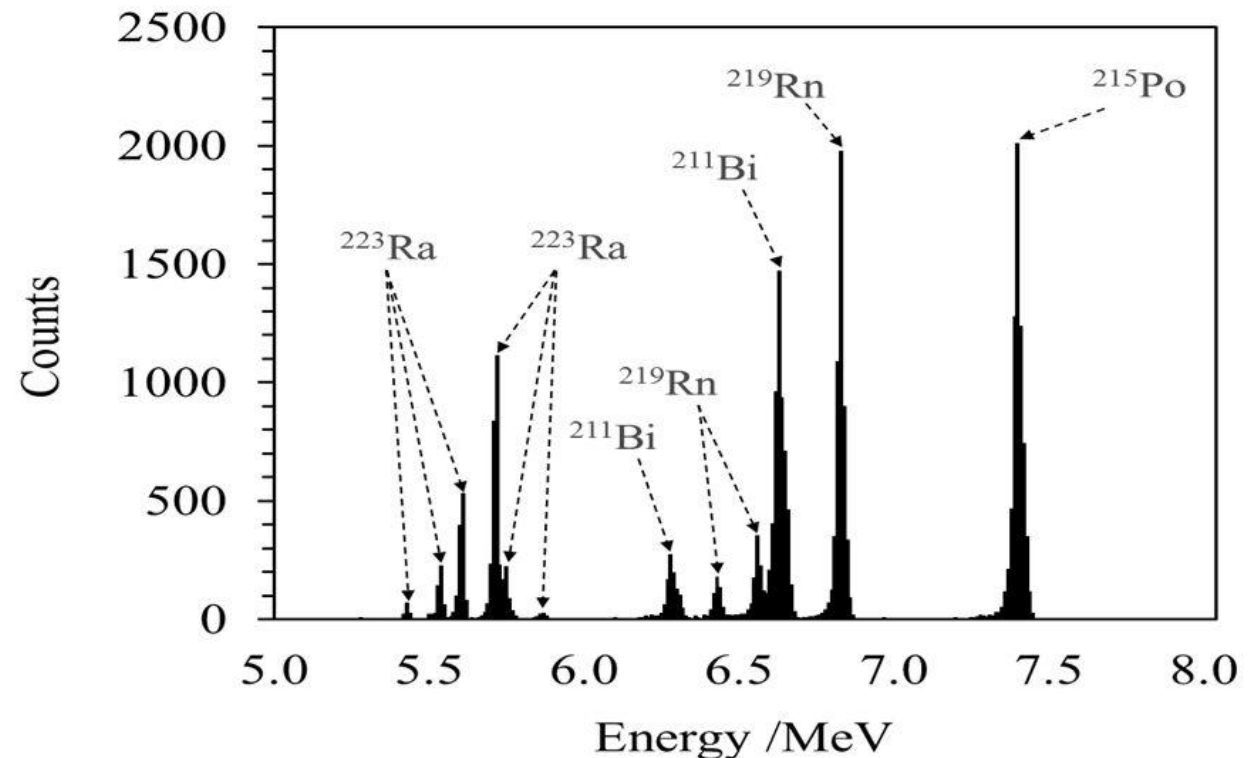
Alpha Decay: 2 neutrons and 2 protons leave the nucleus
They travel short distances, have large mass
Only a hazard when inhaled



Alpha Radioactivity

Energy of the alpha – **discrete** difference in binding energies

Alpha decay spectrum of ^{223}Ra and daughters
(courtesy Sean Collins, NPL).



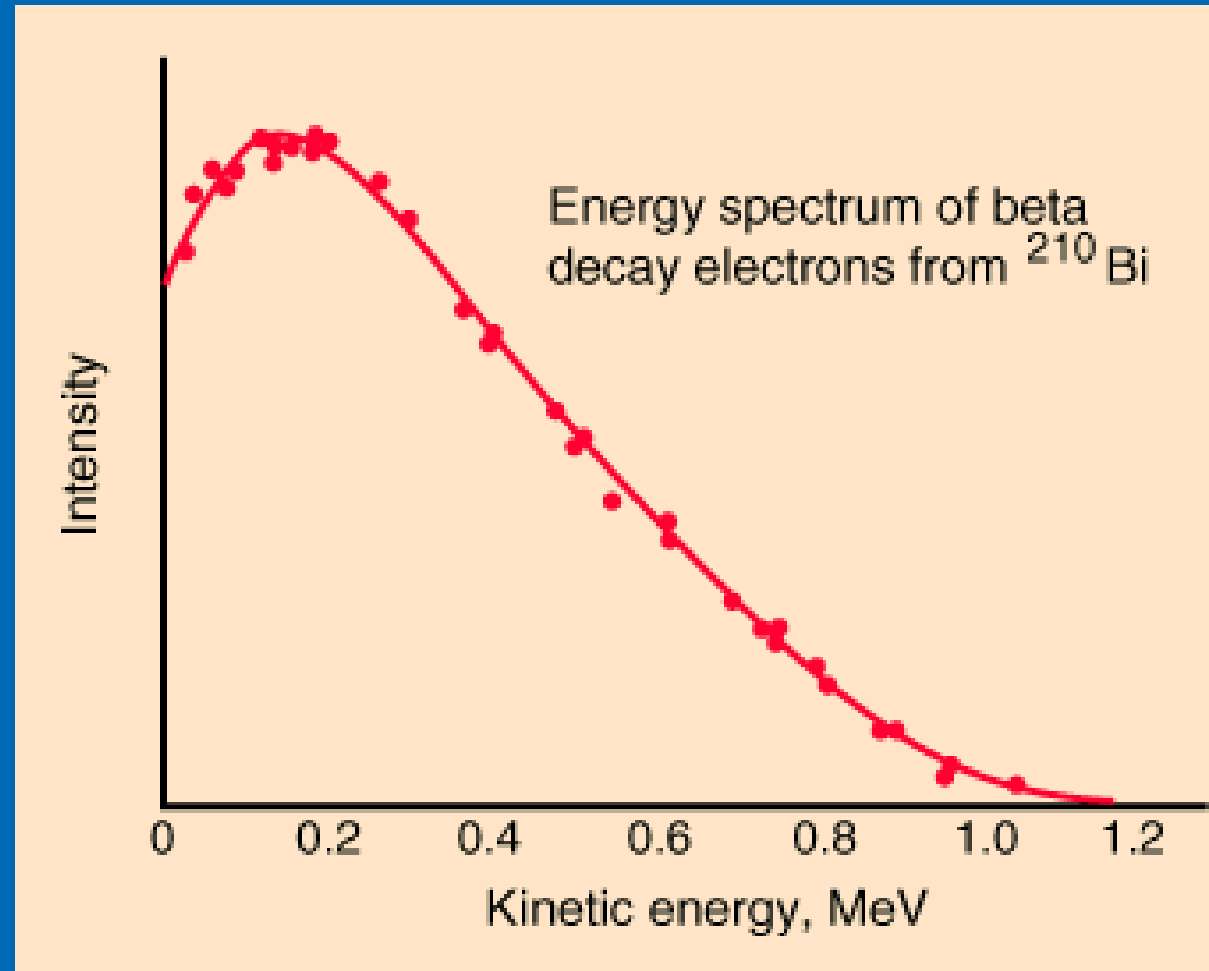
Beta Radioactivity

Beta Decay: Electrons and antineutrinos form when a neutrons transform into protons; positrons and neutrinos form when protons transform into neutrons



Beta Radioactivity

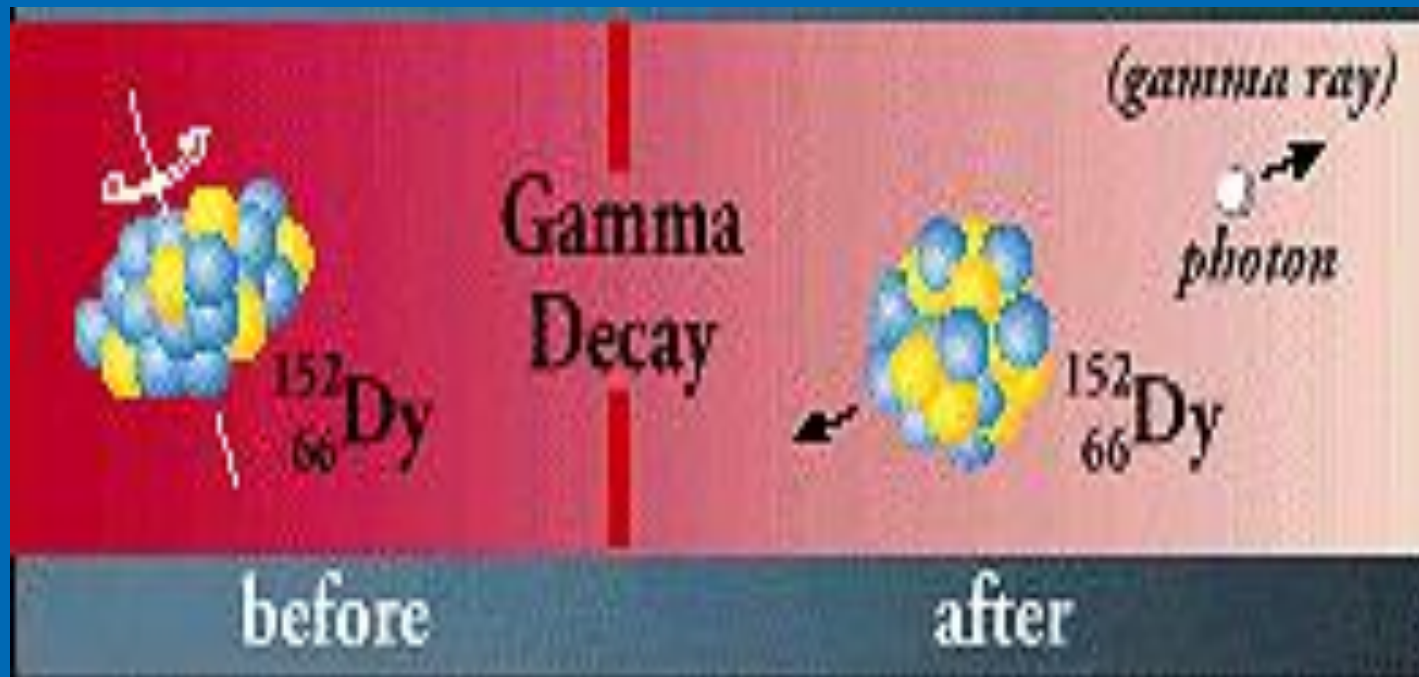
Continuous Spectrum (because of 3-body with neutrino)



Gamma Radioactivity

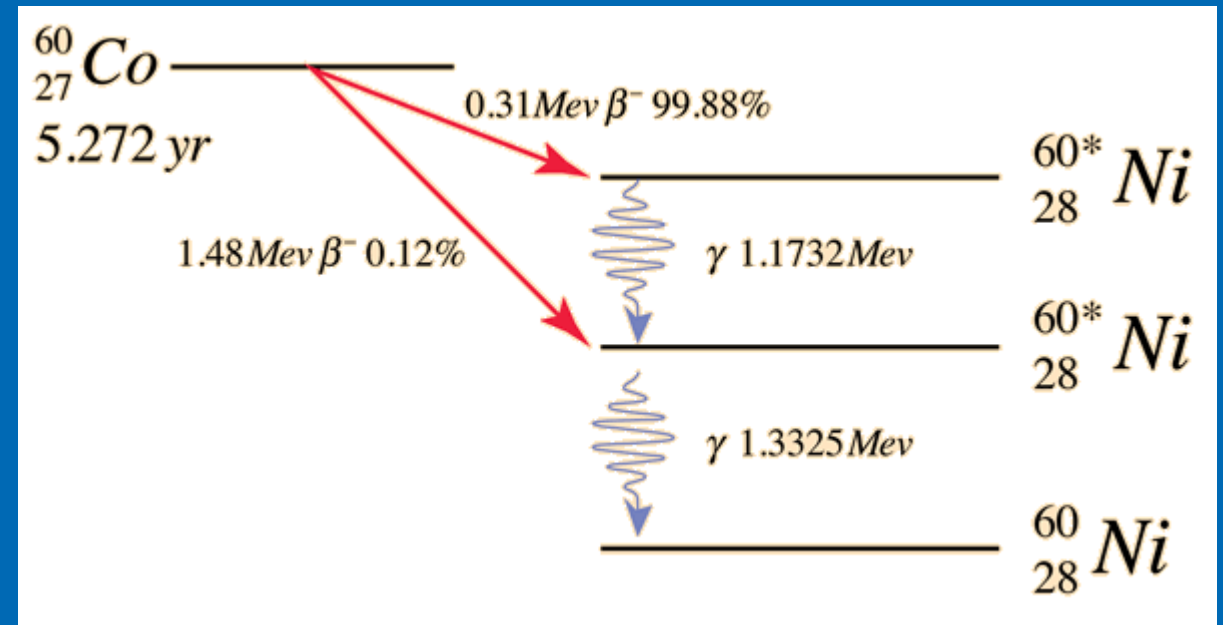
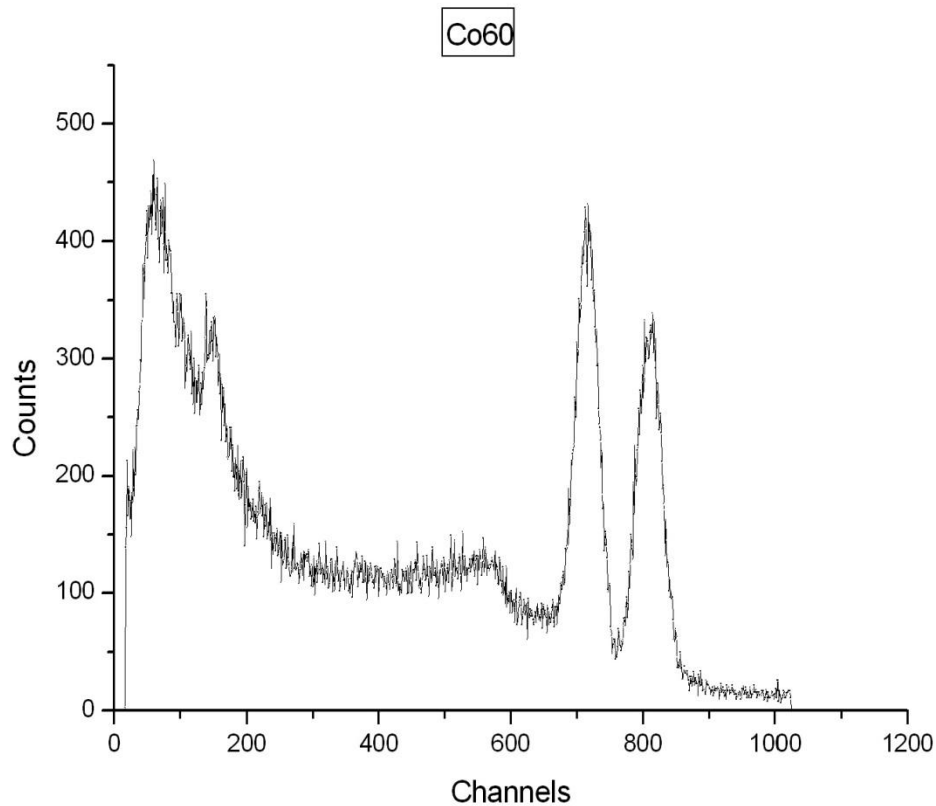
Gamma Rays (photons): Result when the nucleus releases energy, usually after an alpha, electron or positron transition

NO ISOTOPE CHANGE, ONLY STATE CHANGE



Gamma Radioactivity

Energy of the gamma – discrete difference of the state energies, but complicated process in the detector



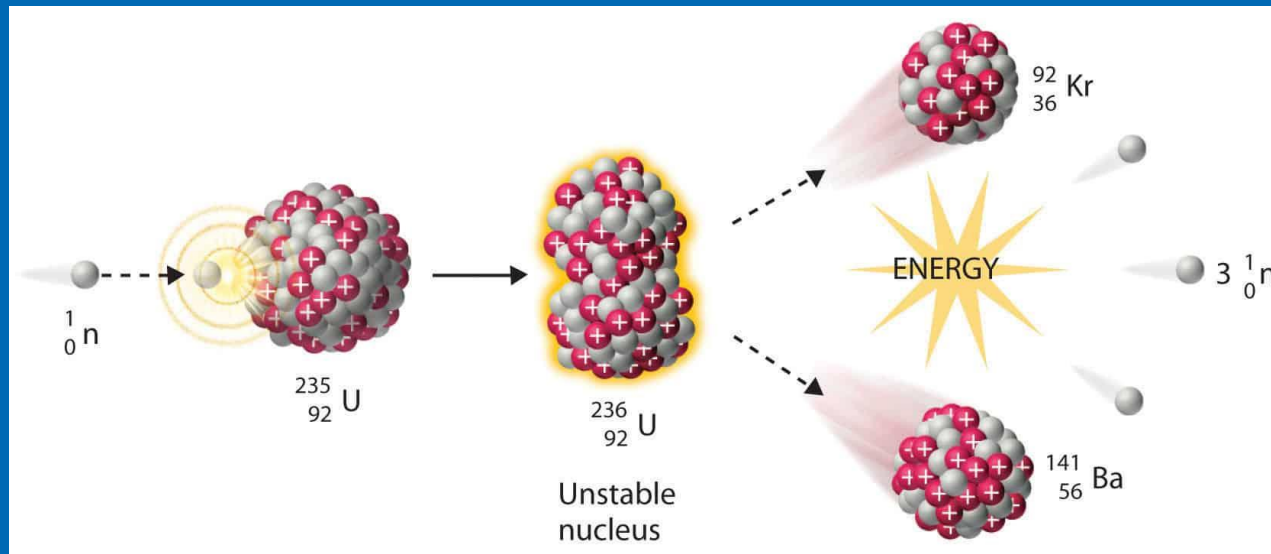
Fission

produces ions, neutrons, gammas, large energy

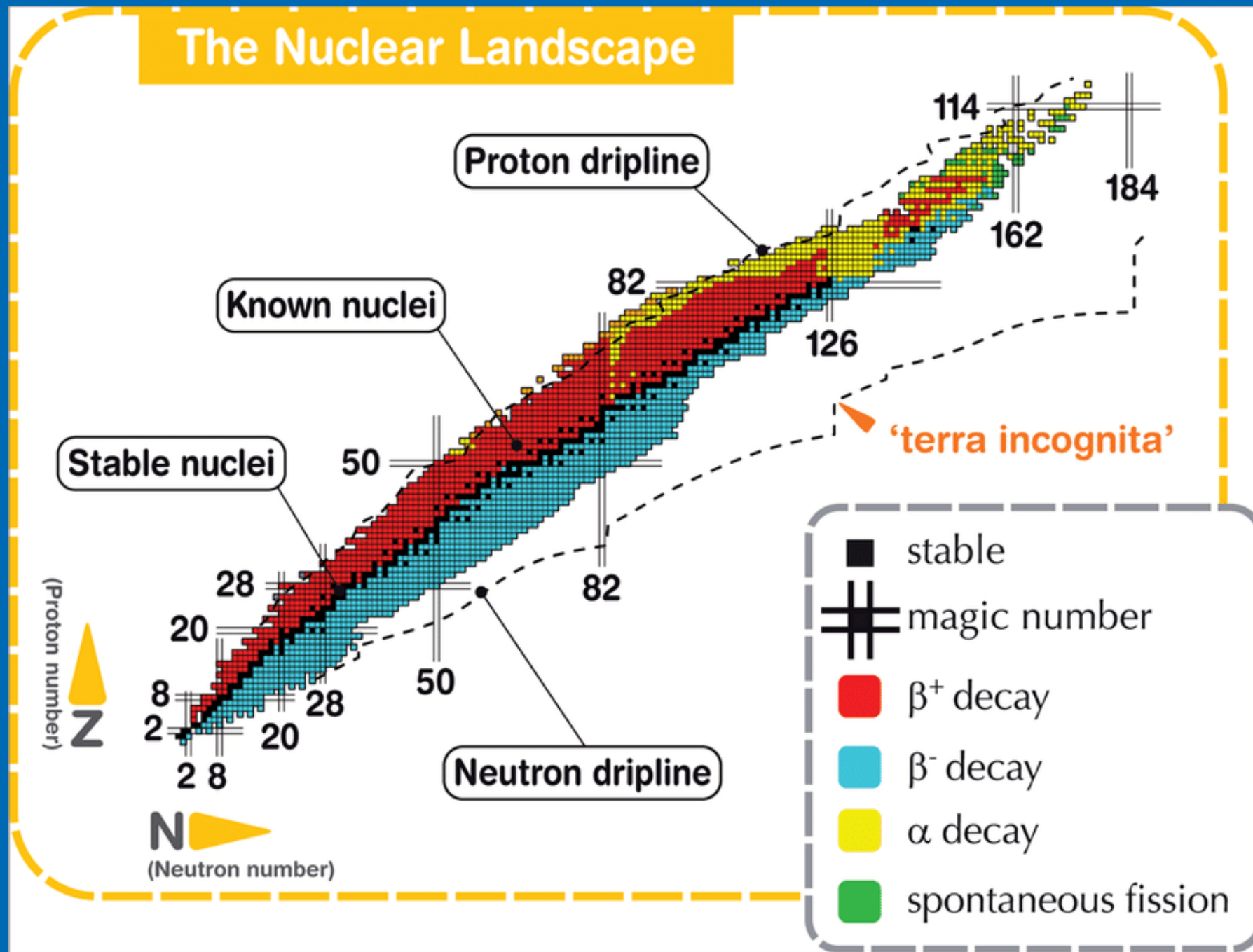
induced – usually by neutron, but also γ

spontaneous – rare, in very heavy nuclei (3% in ^{252}Cf)

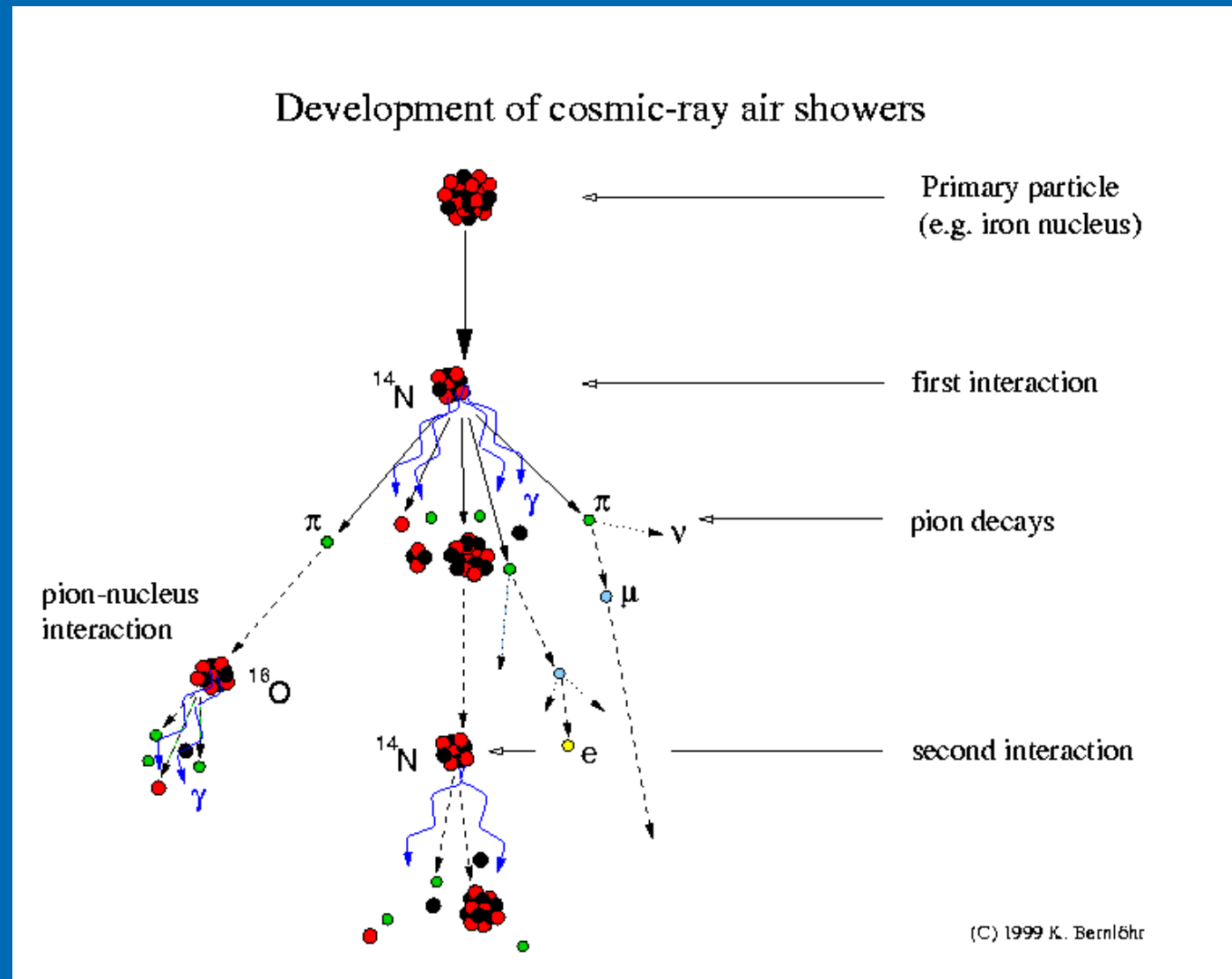
chain reaction in fission reactors, fission bombs



Decay



Reactions Of The Cosmic Rays In The Atmosphere



Natural Background Radiation

- Cosmic Radiation
- Terrestrial Radiation
- Internal Radiation

Cosmic Radiation

- The earth, and all living things on it, are **constantly** being bombarded by **radiation** from **outer space** (~ 80% protons and 10% alpha particles).
- Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of radiation.
- The amount of cosmic radiation **varies** in different parts of the world due to differences in elevation and to the effects of the earth's magnetic field.



Terrestrial Radiation

Uranium, Actinium, Thorium decay series

- Radioactive material is found throughout nature in **soil**, **water**, and **vegetation**.
- Important radioactive elements include **uranium** and **thorium** and their radioactive decay products which have been present since the earth was formed billions of years ago.
- Some radioactive material is **ingested** with food and water. Radon gas, a radioactive decay product of uranium is **inhaled**.
- The amount of terrestrial radiation **varies** in different parts of the world due to different concentrations of uranium and thorium in soil.



Internal Radiation

- People are exposed to radiation from radioactive material inside their bodies. Besides **radon**, the most important internal radioactive element is naturally occurring **K-40**, but uranium and thorium are also present as well as **H-3** and **C-14**.
- The amount of radiation from potassium-40 does not vary much from one person to another. However, **exposure from radon varies** significantly from place to place depending on the amount of uranium in the soil.
- On average, in the United States **radon** contributes **55%** of all radiation exposure from natural and man-made sources. Another 11% comes from the other radioactive materials inside the body.



Man-Made Radiation

Radioactive material is used in:

- Medicine - diagnostic (X-ray, CAT)
- Medicine - therapeutic (Co-60, Linac)
- Medical research (radio-pharmaceuticals, accel.)
- Industry - (X-ray density gauges, well logging)

Radioactive decay

Radioactivity or decay rate A is the rate of disintegration of N nuclei

$$A = -\frac{dN}{dt} = \lambda N$$

$$\frac{dN}{N} = -\lambda dt$$

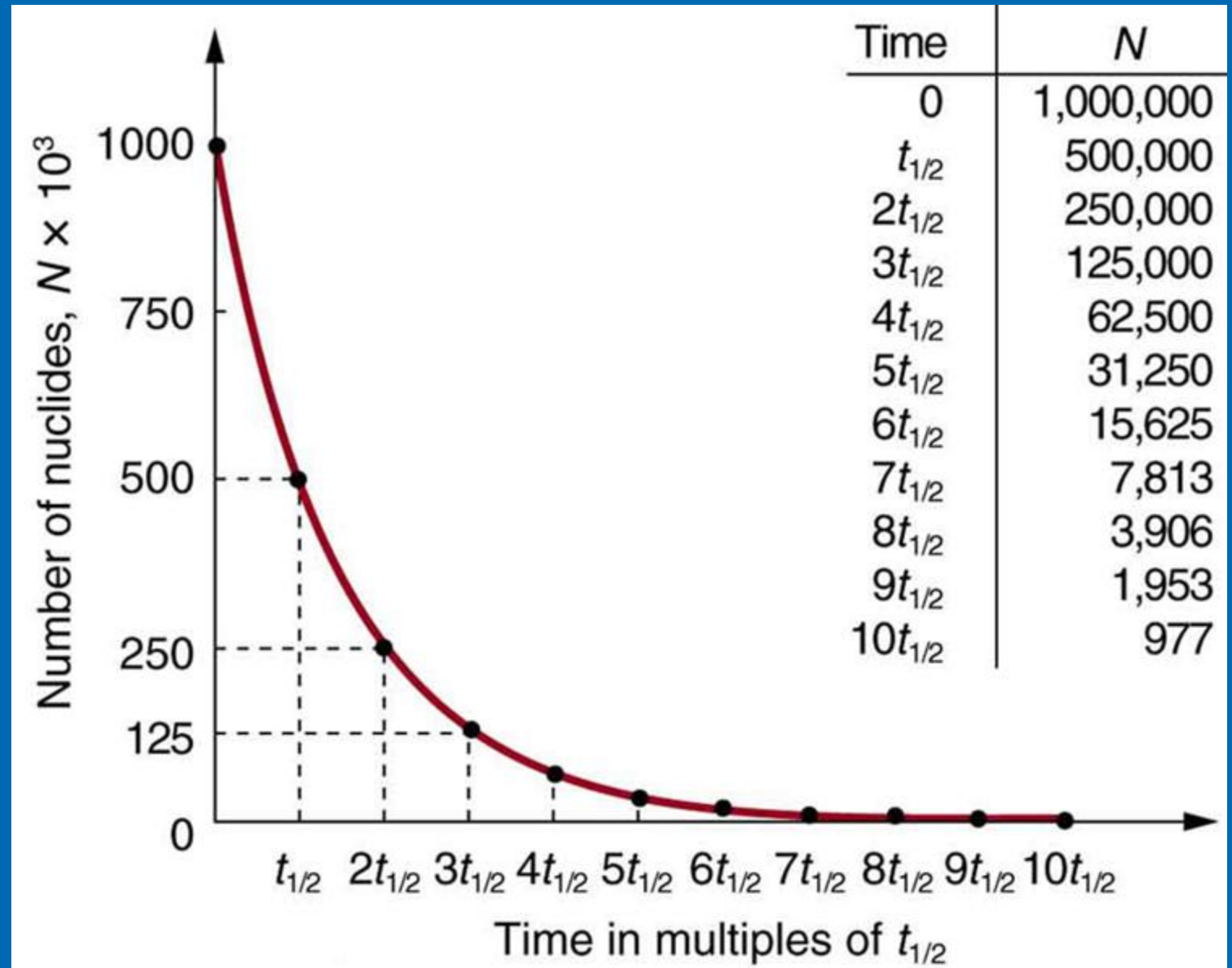
Integration gives, assuming initially we have N_0 nuclei

$$N = N_0 e^{-\lambda t}$$

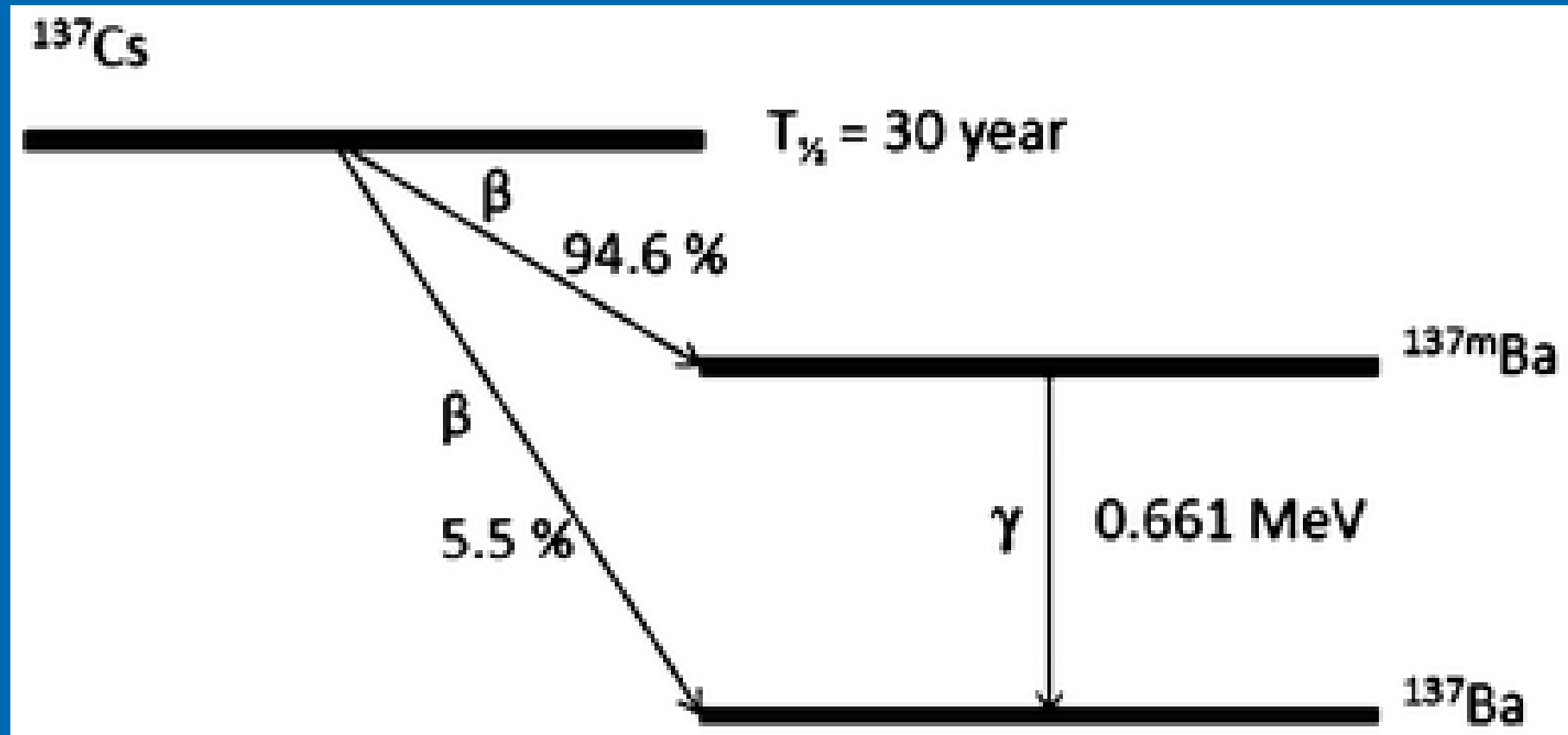
and at time t , we have N nuclei.

This rate is proportional to N , and the proportional constant is called decay constant λ .

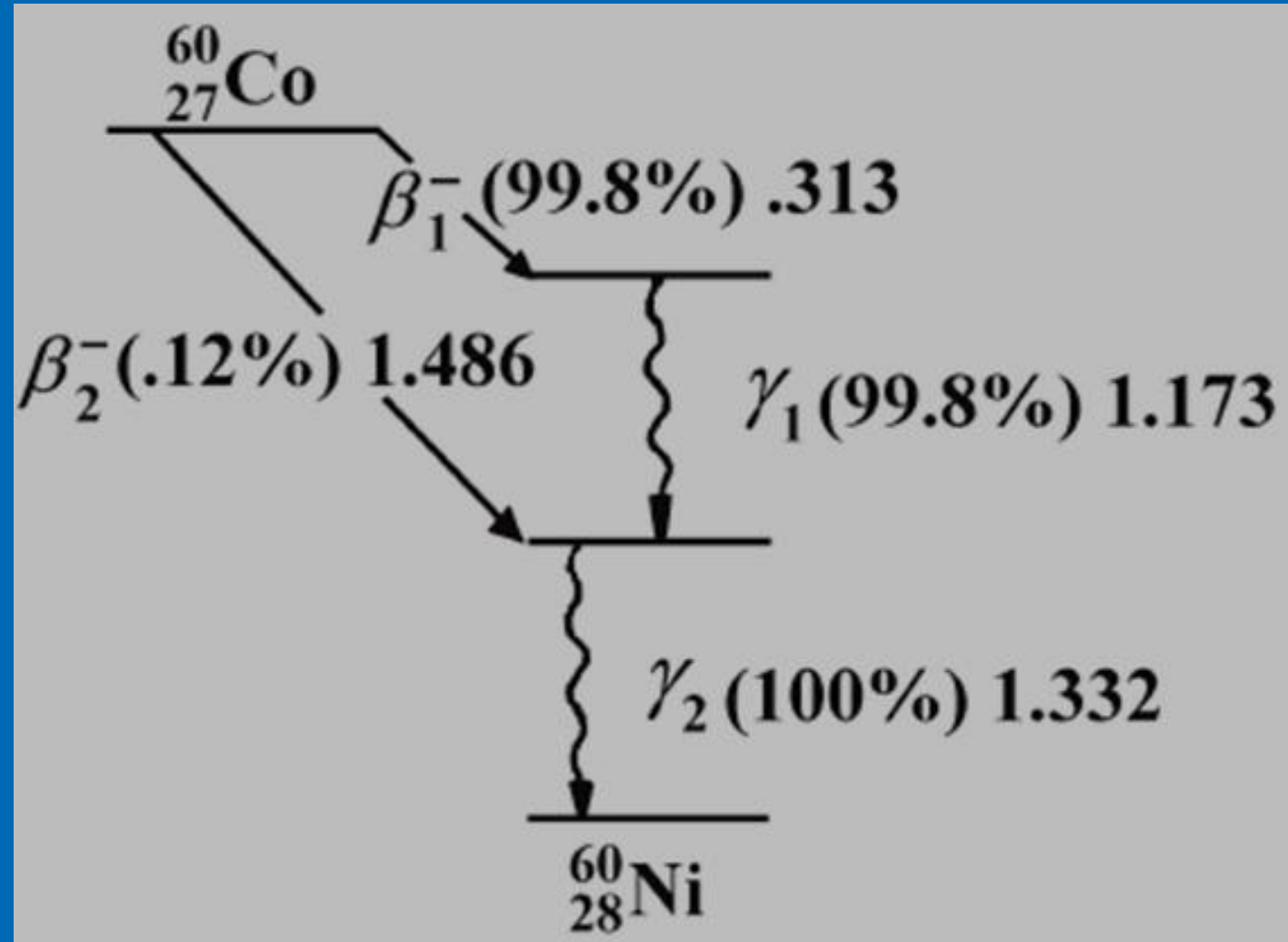
Half life



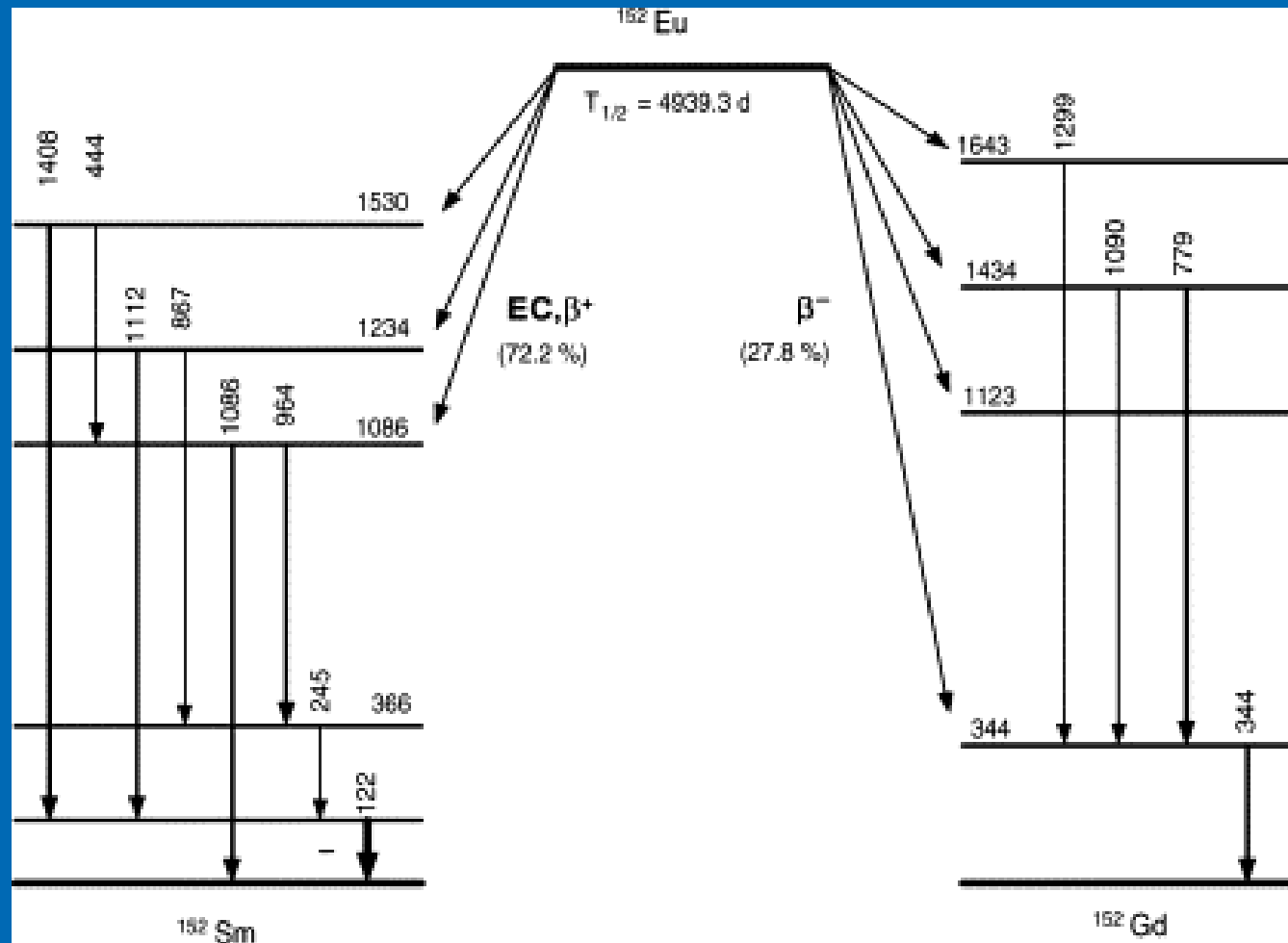
^{137}Cs



^{60}Co



^{152}Eu



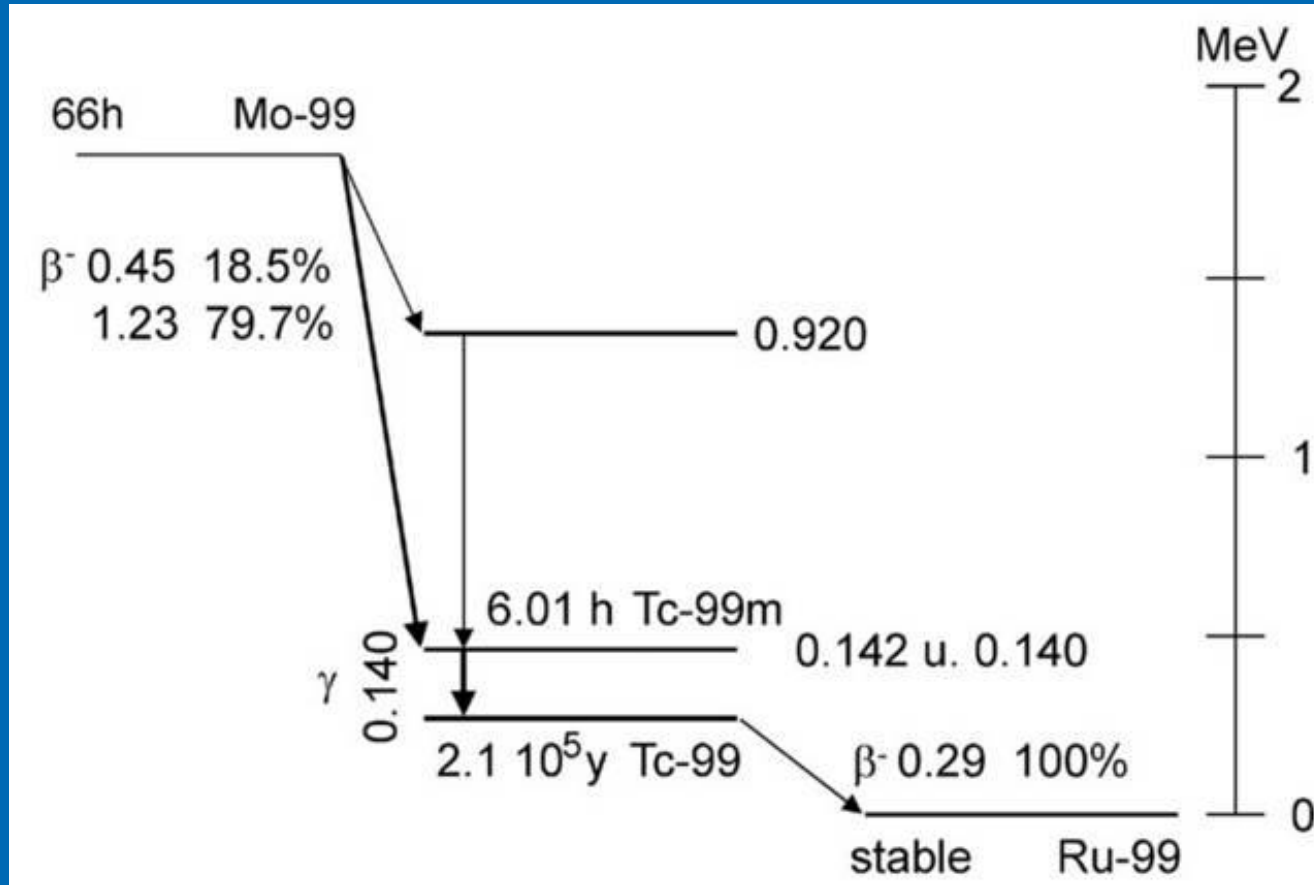
	^{152}Gd	^{153}Gd	^{154}Gd	
	1.08e+14 y 0.2% $\alpha=100\%$	240.41 d $\epsilon=100\%$	STABLE 2.18%	
	^{151}Eu 4.60e+18 y 47.81% $\alpha=100\%$	^{152}Eu 13.517 y $\epsilon+\beta^+=72.08\%$ $\beta^-=27.92\%$	^{153}Eu STABLE 52.19%	
	^{150}Sm STABLE 7.37%	^{151}Sm 94.6 y $\beta^-=100\%$	^{152}Sm STABLE 26.74%	
	^{149}Pm	^{150}Pm	^{151}Pm	



IAEA



^{99m}Tc



- ^{99m}Tc produced from ^{99}Mo
- ^{99m}Tc is metastable isomer – long-lived excited state of ^{99}Tc
- γ -decay to ^{99}Tc g.s. with a very long half-life $\rightarrow \lambda$ is very small, $A = \lambda \cdot N$
- ^{99}Tc activity is very low