# Nuclear and Radiation Physics (PHY2005)

*Lecture 6*

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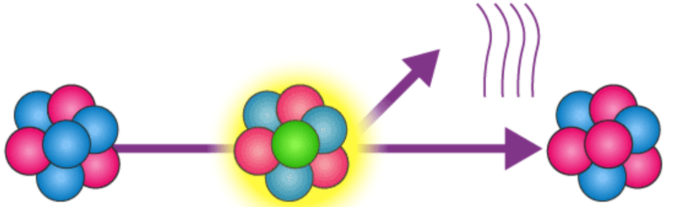
*2021-2022*

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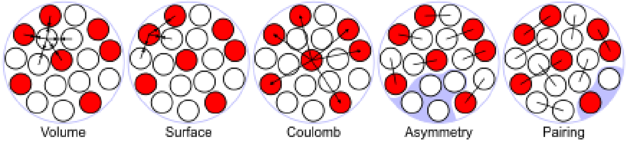
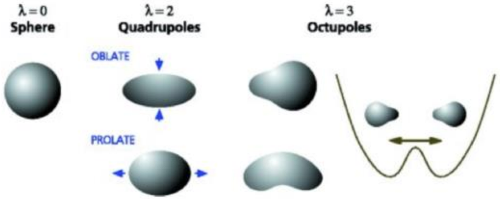
# Recap & Learning Goals

**Summary of Lecture 5** *(Chap.3)*

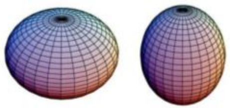
- The Liquid Drop Model
  - ✓ Semi-empirical mass formula
- The Collective Model
  - ✓ Nuclear vibrations *(A<150)*
  - ✓ Nuclear rotations *(150<A<190 A>220)*
  - ✓ Magnetic quadrupole moment




$$M_{Z,A} = f_0(Z,A) + f_1(Z,A) + f_2(Z,A) + f_3(Z,A) + f_4(Z,A) + f_5(Z,A)$$




$$\mu(I) = I\frac{Z}{A}\mu_N$$



oblate deformation (β<0) prolate deformation (β>0)

$$E = \frac{\hbar^2}{2\mathfrak{I}}I(I+1)$$

**Learning goals of of Lecture 6** *(Chap.4)*

- Knowing the terminology and notation of the *nuclear decay law*
- Understanding physical reasoning behind the *nuclear decay law*

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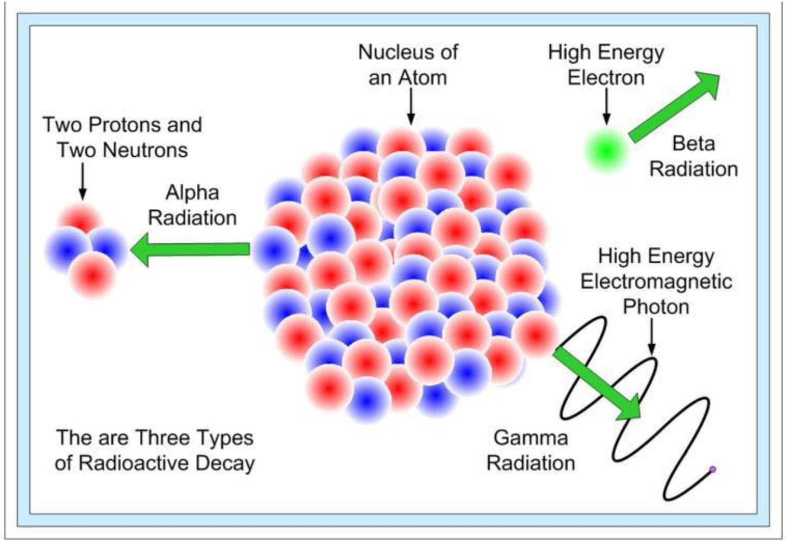
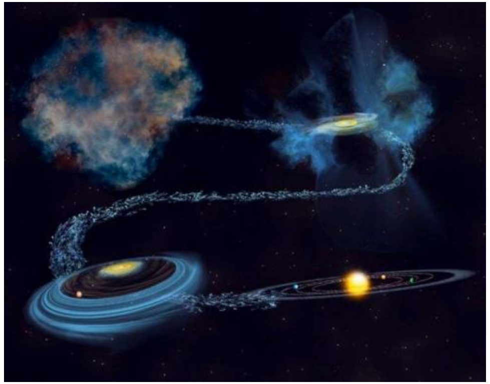
**Nuclear decays** *(categories)*

- $\alpha$-decay → spontaneous emission of an $\alpha$-particle ($^4$He nucleus) from a nucleus with a large *A* *(upper limit on the atomic numbers of the chemical elements)*
- $\beta$-decay → spontaneous emission (or absorption) of an electron (or a positron) by a nucleus
- $\gamma$-decay → spontaneous emission of high-energy photons *(transitions from a nucleus in an excited state)*



*radioactivity in meteorites (origin of heaviest elements in our solar system)*



**Decay law**

- unstable nuclei *(natural events)* → radioactive nuclei
- nuclear decay process → radioactive decay *(or radioactivity)*
- radioactive decays → origin of the universe

- let's consider a system with *N(0)* nuclei at some initial condition (*zero*) and a nuclear decay rate *R*
- … and *N* undecayed nuclei at a time *t*

$$\boxed{N(t) = N(0)e^{-Rt}}$$

***nuclear decay law***

## *4.1 Decay law II*

*number of undecayed nuclei at the time t*

*decay rate*

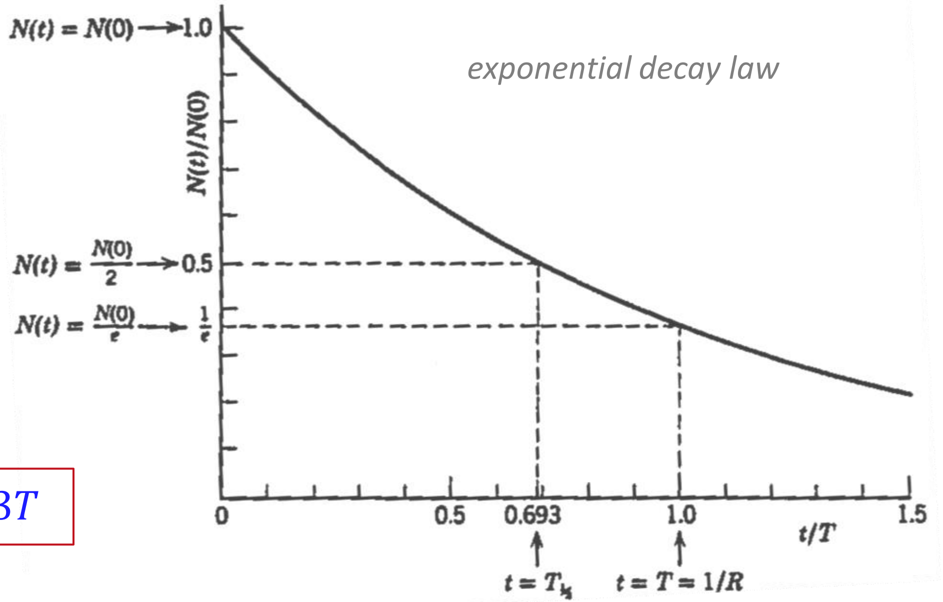
$$\boxed{N(t) = N(0)e^{-Rt}}$$

*number of undecayed nuclei at the initial time 0*

$$\boxed{T = \frac{1}{R} \rightarrow N(T) = N(0)/e}$$

$$\boxed{T_{1/2} = (\ln 2)T = 0.693T}$$

*exponential decay law*




**Decay law** *(characteristics)*

- ***T*** → <u>lifetime</u> *(average time a nucleus survives before it decays)*
- ***$T_{1/2}$*** → <u>half-life</u> *(required time for undecayed nuclei to decrease by a factor of 2)*
- calculations involve probabilities → results are correct only in the average

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# 4. Nuclear Decays
## 4.1 Decay law (C-14 dating)

***Carbon-14 dating*** *(application)*

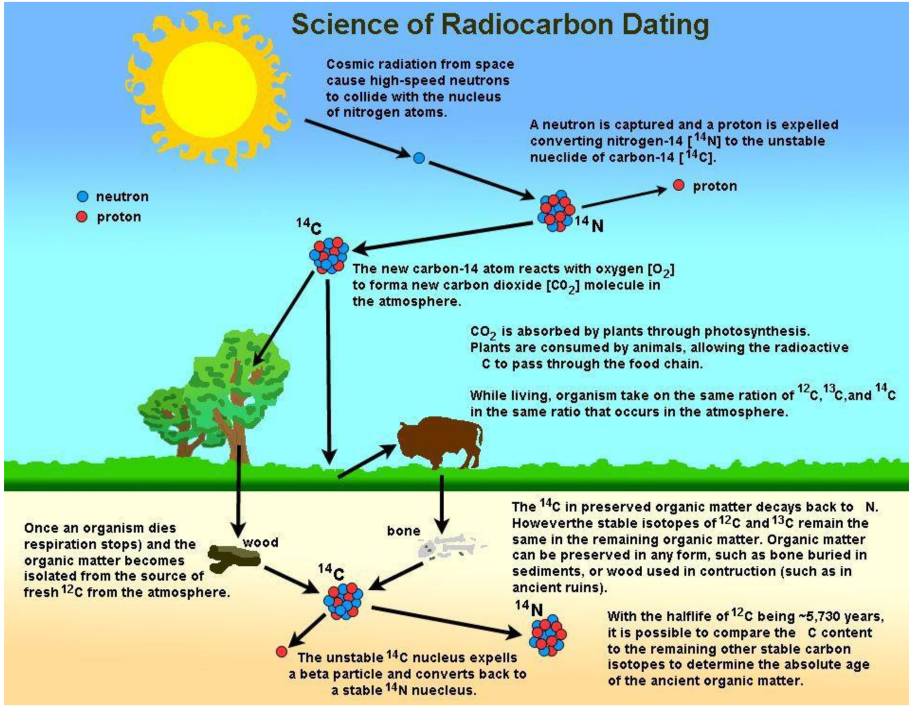
- **$^{14}$C** *(radioactive isotope of C)* undergoes β-decay:

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + e^{-} + \bar{\nu}_e $$

- biological material fossil dating *(high accuracy)*
- <u>the moment of death of the plant can be retrieved</u>:

$$ \mathrm{t} = \frac{1}{R} ln \frac{N(t)}{N(0)} = T \frac{N(t)}{N(0)} = \frac{T_{1/2}}{0.693} ln \frac{N(t)}{N(0)} $$

- *$T_{1/2}$ = 5730 years*
- the sample is assumed to have originally had the same14C/12Cas in the atmosphere *(N(0) is known)*

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**Derive the following expression:**

$$\boxed{N(t) = N(0)e^{-Rt}}$$

# 4. Nuclear Decays

## *Example 4.2*

Samples of the Dead Sea Scrolls were analysed by carbon dating. The **C-14** present had an **activity of 11 d/min.g** *(disintegrations per minute per gram)*. **Knowing that living material exhibits an activity of 14 d/min.g, calculate how old are the Dead Sea Scrolls.**

$$t = \frac{T_{1/2}}{0.693} \ln \frac{N(0)}{N(t)}$$

$T_{1/2}$ = 5730 years

*Dead Sea Scrolls (ancient Jewish religious manuscripts)*

# 4. Nuclear Decays

## *Example 4.3*

**A smoke alarm prototype is tested and shows a detector sensitivity** (smallest current detectable) **for $\alpha$-radiation of approximately 2 $\mu$A. Calculate the activity in Curie corresponding to 2 $\mu$A current of $\alpha$-particles, and explain why the result is unreasonable for a smoke alarm for home use.** *[activity of a typical Am-241 detector ~ 1 $\mu$Ci]*