# Course Introduction

ICPY473 Nuclear Physics

MUIC, Thrid Trimester 2020-21

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April 26, 2021

# Introduction

As a life of young physics student, you will be trained to learn the subjects of basic quantum mechanics and its applications. They are atomic and molecular physics, and nuclear and particle physics. Both of them are different in dimension and energy scale.

# From atoms down to atomic nuclei

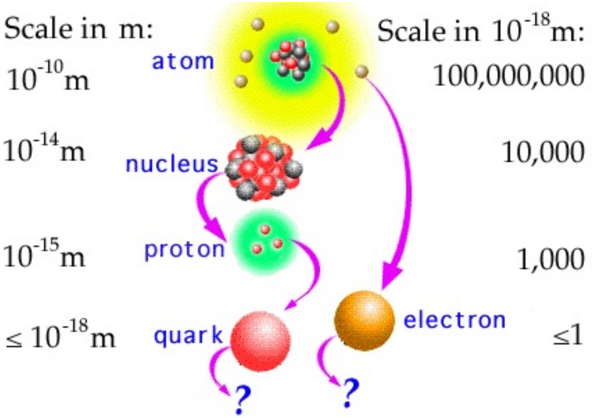
In atomic physics, you have to learn about the structure of atoms based Schrodinger quantum mechanics. The size of atom is around one angstrom, and energy range is around a few $eV$. Overlap of atomic orbitals produce molecules, its size is around a few angtrom upto a hundred nanometer and its energy range is $meV$. You can learn both of them in the same course, but the determination of emission spectra are quite different.

# From nucleus down to nuclear particles

In nuclear physics subject, you will learn about the bulk of atomic nucleus., i.e., its stability, decay and emission of radiations. When you go down into the nucleus, you will face with many problems, i.e., how nuclear particle stay together, how they can emit some radiations, and finally you will find that nuclear particles are composite. The size of the nucleus is around a few *fm*, and its energy range is around a few $MeV$.

When you try to looking for something inside the nuclear particles, the energy range is going up to a thousand $MeV$, according to de Brogilie hypothesis of particle wave, i.e., $\lambda = h/p$. This is the area of elementary particle physics, we cannot estimate its size since its energy range go up to a million of $MeV$.

No more tiny thing will be learned, since it is limit by our observation, see Figure (1.1).



# Units

The length and time will be stated in SI unit, except energy will be stated in electron Volt or $MeV$, in which

$$1.0eV = 1.6 \times 10^{-19}\ J \tag{1}$$

According to special relativity, the mass is stated in unit of $MeV/c^2$ and the momentum is stated in unit of $MeV/c$. (You need not divide the stated number with $c = 3 \times 10^8 m/s$ and $M$ means *mega* or $10^6$.)

# The essential of special relativity

A short cut to special relativity can be done by first define the 4-position $x^\mu = (ct, \vec{x})$ as a vector in 4-dimensional Minkowski space $\mathcal{M}_4$. The Lorentz transformation is then written in the form

$$x^\mu \to x'^\mu = \Lambda^\mu{}_\nu x^\mu \tag{2}$$

where the tensor indices $\mu, \nu = 0, 1, 2, 3$ and repeated index means summation is understood. For example of Lorentz boost in x-direction, we will have

$$\Lambda^\mu{}_\nu = \begin{pmatrix} \gamma & -\gamma\beta & 0 & 0 \\ -\gamma\beta & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{3}$$

where $\beta = v_x/c$ is relative speed and $\gamma = 1/\sqrt{1-\beta^2}$.

You can derive expression of the time dilation and length contraction, with the aid of *simultaneity*, respectively as

$$dt = \gamma d\tau \qquad dx = \frac{1}{\gamma} dx_0 \tag{4}$$

where $d\tau$ is a proper time and $dx_0$ is a proper length.
Now we can determine particle kinematics by first defining 4-velocity as

$$v^\mu = \frac{dx^\mu}{d\tau} = \gamma \frac{dx^\mu}{dt} = \gamma(c, \vec{v}), \quad \text{with} \quad \vec{v} = \frac{d\vec{x}}{dt} \tag{5}$$

Then we define 4-momentum as

$$p^\mu = mv^\mu = (\gamma mc, \gamma m\vec{v}) = (E/c, \vec{p}), \quad \text{where } \vec{p} = \gamma m\vec{v} \tag{6}$$

and $E = \gamma mc^2 = K + mc^2$ is the relativistic energy, and $K$ is the kinetic energy.

From (6), you can derive a famous expression of relativistic energy momentum relation

$$E^2 = \vec{p}^2 c^2 + m^2 c^4 \tag{7}$$

This shows that $[E] = MeV, [\vec{p}] = MeV/c$ and $[m] = MeV/c^2$. Note that $x^\mu, v^\mu, p^\mu$ are Lorentz vectors, they will transformed by Lorentz transformation as in (0.2). A useful information for the Lorentz transformation are

$$\vec{v}/c = \vec{\beta} = \frac{\vec{p}/c}{E} \qquad \gamma = \frac{E}{mc^2} \tag{8}$$

# Basic Quantum Mechanics

We need time-independent Schrodinger quantum mechanics, with quantum equation

$$\left(-\frac{\hbar^2}{2m}\nabla^2 + V(\vec{r}) - E\right)\varphi(\vec{r}) = 0 \tag{9}$$

$$\rightarrow \left(\nabla^2 + \frac{2m}{\hbar^2}(E - V(\vec{r}))\right)\varphi(\vec{r}) = 0 \tag{10}$$