Quiz 1

NAME: _____ SCORE: _____

Subject: Introduction to Nuclear and Particle Physics
Date: Tuesday 22 November 2022
Duration: 60 minutes
Credits: 24 points, Type of evaluation: Quiz

This quiz consists of closed-book concept questions. Provide answers to the following items.

1. **Isotopes (4 points)**

   (a) What is an isotope?

   Elements with the same number of protons (Z) but different number of protons (N).

   (b) What is an isotone?

   Elements with the same number of neutrons (N).

   (c) What are isobars?

   Elements with the same atomic mass number (A).

   (d) Name an example for isotopes and an application where it is used.

   carbon ^{12}C and ^{14}C where ^{14}C is used in radio carbon dating

2. **Standard Model (8 points)**

   (a) What are hadrons?

   particles that are bound states of quarks.

(b) What are baryons?

particles composed of 3 quarks

(c) What are mesons?

particles composed of a quark-antiquark pair

(d) Are protons and neutrons elementary particles (can they be further subdivided)?

No, they are not elementary particles. They are made of 3 quarks each

(e) How many types of quarks are in the standard model?

6: up, down, charm, strange, top, bottom

(f) Name 3 fermions?

electron, electron neutrino, up quark etc....

all quarks, e^-, μ, τ, ν_{e^-}, ν_μ, ν_τ

(g) Name 3 of the forces that are important for nuclear physics?

strong force
electromagnetic force
wear force

(h) For which force are the gluons the force carrier particles?

strong force

3. **Basic quantum mechanics (4 points)**

(a) How do we represent particles in quantum mechanics?

particles are represented with wavepackets

(b) What is a bound-state wave function, and what important property does it have?

When a potential confines a particles into a region of space we have a bound state. The particle is permited only a set of discrete energy values. The number of energy values is determined by the depth of the potential well.

(c) What are degenerate energy states in quantum mechanics?

Degenerate states mean that the particles can have the same energy states with different wave functions

(d) What components does the total angular momentum have in quantum mechanics? (This question does not refer to the 3 spatial (x,y,z) components.)

- orbital angular momentum (l)
- spin (s)

4. **Nuclear radius (5 points)**

(a) Name 3 methods to measure the charge distribution of an atomic nucleus.

- scattering experiments (low energy)
- K X-ray energies, isotop shift
- muonic atom energy transitions
- direct measurments of Coulomb energy differences between atoms
- nuclear β-decay
- nuclear reactions

(b) What is the X-ray isotope shift?

The difference between the $2p \to 1s$ transition energies of two neighbouring isotops

(c) Name 3 methods to measure the nuclear matter (including both protons and neutrons) distribution in atoms.

- high energy scattering experiments $^4He \to {}^{197}Au$
- radiactive decay
- π mesic X-rays

(d) What parameter does the nuclear radius depend on? How is the radius proportional to this parameter?

$R = R_0 A^{1/3}$ $\to$ atomic mass number $R \propto A^{1/3}$

(e) What does the "skin thickness" refer to?

The distance over which the charge intensity drops from 90% to 10% in a nucleus

5. **Nuclear mass, binding energy (4 points)**

(a) What are two methods to measure the mass of a nucleus?

- mass spectroscopy
- nuclear reactions

(b) Name a method that can be used to separate isotopes of a certain element and briefly describe how the method works.

- mass spectroscopy: select particles at a certain velocity using an E and B field. Then use a B-field to separate isotopes with different mass.
- laser isotop separation: use 2 lasers to: 1, excite a certain isotop, 2 ionize the selected isotop and then with a B field select out the ionized isotope

(c) Which element has the highest nuclear binding energy? Is this element the heaviest known element in the periodic table?

iron Fe. No, it is not the heaviest element.

(d) What considerations are used to derive the semi-empirical mass model? (What do the terms in the formula represent?)

$$M(Z,A) = Z m(^1H) + N m_n - B(Z,A)/c^2$$

$m(^1H)$: p mass; m_n: n mass; $B(Z,A)$: binding energy

$$B = a_v A - a_s A^{2/3} - a_c Z(Z-1)A^{-1/3} - a_{sym}\frac{(A-2Z)^2}{A} + \delta$$

$a_v A$: density distribution; $a_s A^{2/3}$: surface term; $a_c Z(Z-1)A^{-1/3}$: Coulomb-term; $a_{sym}\frac{(A-2Z)^2}{A}$: symmetry; δ: odd-even pairing