Midterm

NAME: ____ **SCORE:** ______________

Subject: Introduction to Nuclear and Particle Physics
Date: Tuesday 24 January 2023
Duration: 120 minutes
Credits: 40 points. Each question is worth 1 point.

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

1. ${}^{A}_{Z}X_{N}$ What is the name of A and Z in the expression? What do A, N, Z signify?

A - atomic mass number (number of protons + neutrons)
Z - atomic number (number of protons)
N - is the number of neutrons

2. What are Fermions?

Elementary particles with spin = $\frac{1}{2}$

3. What are hadrons? Which are the two types of hadrons? Briefly explain what they are.

Hadrons are composit particles, made of bound quarks and anti quarks.
Two types: mesons — have an equal number of quarks and antiquarks
baryons : - made from 3 quarks

4. What are bosons?

Elementary particles that are the force carriers. They have integer spin: 1 or 0

5. What is the difference between the mean radius and the skin thickness?

The mean radius defines the central part of the nucleus, while the skin thickness refers to where the ~~intensity~~ density drops from 90% to 10% and is an indicator for the outher part of the nucleus

6. Name 3 methods to measure the nuclear matter distribution of an atomic nucleus.

- high energy scattering experiments
- radioactive decay
- π mesonic X-rays

7. What is the X-ray isotope shift?

The energy emitted from an e^- transitioning from one level to another ($L \rightarrow K$ shell) changes for different isotopes of a certain element.

8. What parameter does the nuclear radius depend on? How is the radius proportional to this parameter?

→ depends on the atomic mass number A

$$R \propto A^{1/3}$$

9. What are two methods to measure the mass of a nucleus?

- mass spectrometer
- nuclear reactions, nuclear decay

10. With what method can we produce energy from elements heavier than iron (Fe)?

→ Fission

11. What do the terms in the semi-empirical mass formula represent? Briefly explain the terms.

$$\boxed{M(Z,A) = Zm_p + Nm_n - B(Z,A)/c^2}$$

→ mass of the protons

→ mass of the neutrons

→ binding energy:

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

- density distribution – density distribution is even in most nuclei in the centre
- surface term – binding E on the surface depends on the number of nucleons
- Coulomb term – depends on the number of protons – Coulomb repulsion
- symmetry term – small nuclei have ~~the~~ almost the same number of p^+ and n^0
- odd-even pairing term → change in binding E if nucleons are paired or unpaired

12. Why is the calculated magnetic dipole moment different from the measured magnetic moment for heavy elements?

→ the nucleus of heavy elements is not sperically symmetric → distorted shape → change in magnetic momentum
→ the distorted nuclei also have rotational modes

13. What does the cross section describe in nucleon-nucleon scattering experiments?

The probability of the scattering happening

14. What do the following terms represent in the nucleon-nucleon force: 1) repulsive at short distances, 2) nearly charge independent?

1) → nucleons are at certain distances from one another, the density in the centre is not very large
2) the n-p scattering is slightly different from the n-n and p-p scattering → related to the mass difference in π^0 and π^- and π^+

15. What is the exchange force model?

A model that explains the nuclear force as an exchange of particles. The exchanged particles are the π mesons

16. The shell model and the liquid drop model can explain most observed properties of nuclei. Name a property that the liquid drop model can not explain and a property that the shell model can not explain. Also mention the reason.

Liquid drop model can not explain how the valance nucleons and the unfilled shells change the properties of the nuclei. For example the odd-even term in the nuclear binding energy formula

The shell model can not explain the rotational and vibrational energy levels or the magnetic dipole moment of heavy nuclei

17. Do heavy nuclei A > 40 have rotational modes? Shortly explain your answer.

Yes. They are deformed → rotation is possible.

18. What is the definition of half-life?

The time it takes for half the nuclei in a radioactive sample to decay.

19. What happens to the released energy in decays?

The decay products carrie away the released energy in the form of kinetic energy.

20. What is the theoretical model for α decay?

The α particle is preformed inside the nucleus and tunnels out from the nuclear potential (or trough the Coulomb barrier).

21. What can we learn from the angular distribution of the α particles in α decay? Briefly explain the reason.

→ We can learn the shape of the nucleus. A deformed nucleus have different radii for the α particle to tunnel out. The number of emitted particles in a certain direction depends on the radius of the nucleus in that direction

22. Name 3 subtypes of β decay. Also write the reaction, what particle decays into what particle(s).

β^+: $p^+ \to n^0 + e^+ + \nu_e$

β^-: $n^0 \to p^+ + e^- + \bar{\nu}_e$

electron capture: $p^+ + e^- \to n + \nu_e$

inverse β decay: $\bar{\nu} + p \to n + e^+$

$\nu + n \to p + e^-$

23. What is the difference between the energy spectrum of the electron from a β decay and from internal conversion? Briefly explain the reason.

β decay $\rightarrow$ e^- has a continous energy spectrum $\rightarrow$ energy gets devided between 3 particles

internal conversion $\rightarrow$ e^- has discrete energy spectrum – ther is no additional particle to carry the energy

24. Can unbound protons undergo β decay?

No. Unbound protons are very stable, and have a very long half life

25. How do we know about the existence of the neutrino? What do we know about the mass of the neutrino?

In β decay there needs to be an additinal particle to the daughter nucleus and the e^- (p^+). This is indicated by the continous spectrum of the e^- energies. ~~[illegible]~~ From the β decays we also know that the ν has a very small but non zero mass. Neutrino oscillation indicates the same about the mass

26. Briefly explain what is electron capture?

$p^+ + e^- \rightarrow n^0 + e^+ + \nu_e$

it is a type of β decay where a proton captures an electron and creates ~~a~~ neutron

27. Why is the double β decay important for the neutrino? Briefly explain.

If there is neutrinoless double β decay then the neutrino is its own anti particle.

28. How do we theoretically explain the β decay?

With a weak interaction

29. Which three factors does the β decay momentum distribution depend on? Briefly explain what these 3 factors represent.

(1) availability of final states for the decay : $p^2 (Q - T_e)^2$
(2) Fermi function accounting for the nuclear Coulomb field $F(Z; p)$
(3) Nuclear matrix element $|M_{fi}|^2 \to$ particular initial and final states (composition of the nucleus) and the momentum from the forbidden terms $S(p, q)$

30. What are the two types of β decay based on the alignment of the spin of the electron and the neutrino?

Gamow - Teller decay $S = 1$ parallel spin
Fermi - decay $S = 0$ anti-parallel spin

31. Briefly explain what happens during γ decay?
An excited nucleus releases a γ from the nucleus to transition into a lower energy state.

32. Approximately what energy is carried by the photon released during a γ decay?
0.1 - 10 MeV

33. What does the parity determine for γ decay?
If the electromagnetic wave is electric or magnetic in its origin.

34. Briefly explain what is the internal conversion?

in γ decay an e^- gets ejected from ~~an~~ the atom instead of a γ.
an inner e^- gets the energy from the nucleus and is ejected from the atom

35. Which one is the most damaging radiation from radioactive decays, α, β or γ radiation? Why?

γ radiation → it has the highest energy → can penetrate materials to a great distance → very damaging

36. What is the difference between a decay and a nuclear reaction?

A decay is spontaneous, nuclear reactions are induced with some energy input.

37. What is necessary for fission to start?

We need to supply the activation energy.

38. What happens to the largest fraction of energy released in nuclear fission?

The largest part of the released energy (Q) will be carried away by the fission products in the form of kinetic energy

39. How many ~~neutrinos~~ neutrons get produced during nuclear fission? Briefly explain.

We define the amount as an average of a distribution. The ~~amo~~ exact amount depends on the exact fission products.

40. What happens to the fission products after nuclear fission?

Most fission products are radioactive → they decay into other elements.