Particle Physics Concept Inventory

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PLEASE READ THE INSTRUCTIONS!

Do not turn the page until instructed otherwise.

Dear participant!

This test is part of a study trying to improve the teaching and learning of the basic concepts of particle and nuclear physics. It is vital that you take the test seriously and do the best you can in it.

Thank you for your contribution and for your time!

- **No other equipment** is allowed **except for pens** and the test itself. You can use the free space around the questions for your calculations. In problems requesting a number, as a result, it is sufficient to do approximate calculations without a calculator.
- Answer directly into the test by making a circle around the letter of your selected choice.
- Each question has **one correct answer**. If you think that there are more partly correct answers, select the one you consider the most accurate.
- If you do not know the answer at all, do not answer. If you have some idea about it and you are sure that some answers are not correct, you can make an educated guess.
- The problems are **not ordered by the difficulty**. Since you have limited time, if you do not know the answer quickly, skip it and return later.
- The test is still under development. We welcome your comments written in the free space.
- You will have **30 minutes** for **31 questions**.

Name, surname: ______________________________

Course/school: ______________________________

Experiences with nuclear and particle physics: ______________________________

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e.g., a study of literature, watching videos, lectures, study visit in CERN, ...

A few constants that might or might not be useful for solving the problems

Constant	Value
Coulomb constant	$k_e = 8.99 \cdot 10^9\,\mathrm{N{\cdot}m^2 \cdot C^{-2}}$
Gravitational constant	$G = 6.67 \cdot 10^{-11}\,\mathrm{m^3{\cdot}kg^{-1} \cdot s^{-2}}$
Speed of light in vacuum	$c = 3.00 \cdot 10^8\,\mathrm{m \cdot s^{-1}}$

Particle	Invariant mass
Electron	$m_\mathrm{e} = 511\,\mathrm{keV/c^2}$
Photon	$m_\mathrm{f} \equiv 0\,\mathrm{keV/c^2}$
Positron	$m_\mathrm{e} = 511\,\mathrm{keV/c^2}$
Proton	$m_\mathrm{p} = 0.938\,\mathrm{GeV/c^2}$
Neutrino	$m_\nu \leq 18\,\mathrm{MeV/c^2}$
Neutron	$m_\mathrm{n} = 0.940\,\mathrm{GeV/c^2}$
Quark u	$m_\mathrm{u} = 2.3 \pm 1.2\,\mathrm{MeV/c^2}$

Isotope	Invariant mass
$^{4}_{2}\mathrm{He}$	$3.73\,\mathrm{GeV/c^2}$
$^{12}_{6}\mathrm{C}$	$11.1\,\mathrm{GeV/c^2}$
$^{56}_{26}\mathrm{Fe}$	$52.1\,\mathrm{GeV/c^2}$
$^{95}_{36}\mathrm{Kr}$	$88.4\,\mathrm{GeV/c^2}$
$^{139}_{56}\mathrm{Ba}$	$129\,\mathrm{GeV/c^2}$
$^{208}_{82}\mathrm{Pb}$	$194\,\mathrm{GeV/c^2}$
$^{234}_{90}\mathrm{Th}$	$218\,\mathrm{GeV/c^2}$
$^{235}_{92}\mathrm{U}$	$219\,\mathrm{GeV/c^2}$
$^{238}_{92}\mathrm{U}$	$222\,\mathrm{GeV/c^2}$

1. Select the radiation, which changes neither the nucleon nor the proton number of the particle after its emission.

   A Alpha radiation
   B Beta radiation
   C Gamma radiation
   D Neutron radiation
   E There is no such type of radiation.

2. Select the radiation, which decreases the nucleon number of the particle by 4 and proton number by 2 after its emission.

   A Alpha radiation
   B Beta radiation
   C Gamma radiation
   D Neutron radiation
   E There is no such type of radiation.

3. Select the radiation, which increases the proton number by 1, and the nucleon number stays the same after its emission.

   A Alpha radiation
   B Beta radiation
   C Gamma radiation
   D Neutron radiation
   E There is no such type of radiation.

4. Are we able to observe individual quarks?

   A Yes, they are observable in nature.
   B Yes, we can observe them directly, but only using artificial radioactivity.
   C No, we are only able to observe them indirectly through products of their interaction.
   D No, it is not even possible to prove their existence.

5. Which combination of the “colour charges” of quarks is **not allowed** in a compound particle?

   A Blue and green
   B Red and anti-red
   C Red, blue and green
   D Red, blue, green, blue, anti-blue

6. How many neutrons are released in the following reaction?

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{139}_{56}\mathrm{Ba} + ^{95}_{36}\mathrm{Kr} + x \cdot ^{1}_{0}\mathrm{n}$$

A $x = 0$

B $x = 1$

C $x = 2$

D $x = 3$

E $x \geq 4$

7. The K-capture is a type of radioactivity when an electron from a K-electron shell is captured by the nucleus (K-electron shell is the closest shell to the nucleus). In the nucleus, the electron interacts with a proton and the product of this reaction is a neutron. Which kind of radiation are we able to detect in the vicinity of such radioactive element?

A Electrons or positrons

B Photons

C Helium nuclei

D Muons

E Neutrons

8. Why does the atomic nucleus hold together since there are only positive protons and neutral neutrons?

A They are so close that the gravity is stronger than the electromagnetic force.

B The particles are held by the strong nuclear force.

C The protons and neutrons get in proximity strongly polarised, and the electromagnetic force can hold them.

D The electromagnetic force is universally attractive on short distances.

9. Where is the more significant portion of the mass of the atom?

A The mass of the electron shell is by more than one **order lower** than the mass of the atomic nucleus.

B The mass of the electron shell is **slightly lower** than of the atomic nucleus but by less than one order.

C The mass of the electron shell is **the same** as of the atomic nucleus.

D The mass of the electron shell is **slightly greater** than of the atomic nucleus but by less than one order.

E The mass of the electron shell is by more than one **order greater** than the mass of the atomic nucleus.

10. Which part of the atom occupies larger space and determines the major part of the atomic size?

A The size of the electron shell is by more than one **order lower** than the size of the atomic nucleus.

B The size of the electron shell is **slightly lower** than of the atomic nucleus but by less than one order.

C The size of the electron shell is **the same** as of the atomic nucleus.

D The size of the electron shell is **slightly greater** than of the atomic nucleus but by less than one order.

E The size of the electron shell is by more than one **order greater** than the size of the atomic nucleus.

11. Each proton consists of three quarks (up, up and down). What is the relation between the masses of these quarks and the mass of the proton.

A The mass of the proton is by more than one **order lower** than the mass of the three quarks.

B The mass of the proton is **slightly lower** than of the three quarks but by less than one order.

C The mass of the proton is **the same** as of the three quarks.

D The mass of the proton is **slightly greater** than of the three quarks but by less than one order.

E The mass of the proton is by more than one **order greater** than the mass of the three quarks.

12. A nucleus of the ${}^{238}_{92}\mathrm{U}$ undergoes a natural decay. The products are ${}^{234}_{90}\mathrm{Th}$, and alpha radiation (${}^{4}_{2}\mathrm{He}$). In this process, some energy is released in the form of the kinetic energy of the products. What part of the total kinetic energy is taken by the alpha particle? Suppose that the ${}^{238}_{92}\mathrm{U}$ was at rest and the only two non-negligible products of the decay are these two nuclei.

   A No energy

   B Some part of the total energy, less than one half

   C Exactly one half of the total energy

   D More than one half of the energy, but not all of it

   E All the energy

13. One of the known types of radioactivity is neutron radiation. In a nuclear reactor, we want to slow neutrons down to increase the probability of their interaction with another nucleus. Which of the following materials is the most suitable for moderation? We are interested in the highest velocity decrease after the same number of collisions. Suppose that the moderation is done by perfectly elastic collisions.

   A Water

   B Graphite (carbon)

   C Lead

   D Uranium

14. We have a material that undergoes beta decay. We also have a detector which can measure beta particles and determine the basic information about their direction and energy. Could we discover using such equipment, that another unobserved particle is emitted? (Not a proton, antiproton, electron or positron; namely neutrino or antineutrino which cannot be measured.)

   A Yes, from the spatial distribution of the beta radiation particles.

   B Yes, from the various kinetic energies of the emitted particles.

   C Yes, from the time fluctuation of the sample activity.

   D Yes, from the beta radiation polarisation.

   E No.

15. Large Hadron Collider in CERN is known as the largest particle accelerator in the world. The length of the longest circle is approx 27 km, and the particles are accelerated to the highest velocities available at the energy of 6.5 TeV. How many times does a bunch of particles go around the circle in one second? Suppose that the particles are led in order not to collide with anything.

   A Approximately once

   B 110 times

   C 11 000 times

   D 1 100 000 times

   E Infinitely many times

16. The usual range of alpha particles from radioactive sources in the air is approximately 6 cm. What would be the range of the same particles in an ideal vacuum?

   A 0 cm (They cannot propagate in the vacuum.)

   B 6 cm

   C More than 6 cm, but a few meters at maximum

   D Infinite

   E The answer depends on the particular alpha source.

17. We send one particle towards a plate. From the previous experiments, we know that a plate with the same thickness of the same material absorbs three-quarters of the particles and one quarter goes through. We have a detector right behind the plate, which certainly detects the particle if it goes through. What should we expect as a result of our experiment?

    A We will certainly not measure the particle.

    B We will measure the particle with 25 % probability.

    C We will measure one-fourth of the particle.

    D We will certainly measure the particle.

18. We receive a radioctive sample with a half-life of 5 years. What is the expected state of the sample after 10 years?

    A All the particles are decayed.

    B Three-quarters of the particles are decayed.

    C Half of the particles are decayed.

    D It is not possible to determine from the available information.

19. We have a sample of 10 000 radioactive nuclei. Their half-life is 10 minutes. How many particles decay most probably during the first minute?

    A 341

    B 500

    C 670

    D 1 000

20. Suppose we have a radioctive material with the activity $A = 1\,000\,\mathrm{Bq} = 1\,000\,\mathrm{s}^{-1}$. How many radioactive decays should we expect during one second? (We are interested in the ideal situation. The products are not radioactive. Disregard the imperfection of detectors.)

    A Precisely 1 000

    B Surely $1\,000 \pm 10$

    C With the probability of 98 % to the $1\,000 \pm 10$ decays

    D With the probability of 68 % to the $1\,000 \pm 32$ decays

21. How does the radiocarbon dating method, which uses organic samples, work? How is the age of the sample determined?

    A It is determined by weighing the concurrent mass of the carbon and other elements in the sample. The age is determined from their ratio.

    B It is determined from the ratio of radioactive and stable isotopes of carbon.

    C The age is calculated from the count of radioactive transformations per second.

    D The individual age of the particles is tracked.

22. Which conservation law **does not** work at small scales?

    A Conservation of probability

    B Conservation of energy

    C Conservation of angular momentum

    D Conservation of electric charge

    E Conservation of invariant mass

23. We are interested in the experiment where a neutron is flying towards an oxygen nucleus. What is the elastic cross section of this interaction in the centroid system? (Vaguely spoken, how large is the interaction area/space?) For simplicity, we consider that neutron and the oxygen nucleus are balls with diameters 1.1 fm and 2.9 fm.

A Infinite
B $50\,\mathrm{fm}^2$
C $16\,\mathrm{fm}^2$
D 4.0 fm
E None of the previous answers is correct.

24. Which of the following results of nuclear reactions is **not possible** if the two protons entered into the reaction? The proton is p; the neutron is n, and the pion is π.

A $3\mathrm{p}^+ + \bar{\mathrm{p}}^-$
B $\mathrm{p}^+ + \pi^+ + \mathrm{n}^0$
C $\mathrm{p}^+ + \pi^+ + 42\pi^0 + \mathrm{n}^0$
D $\mathrm{p}^+ + \pi^0 + \mathrm{n}^0$

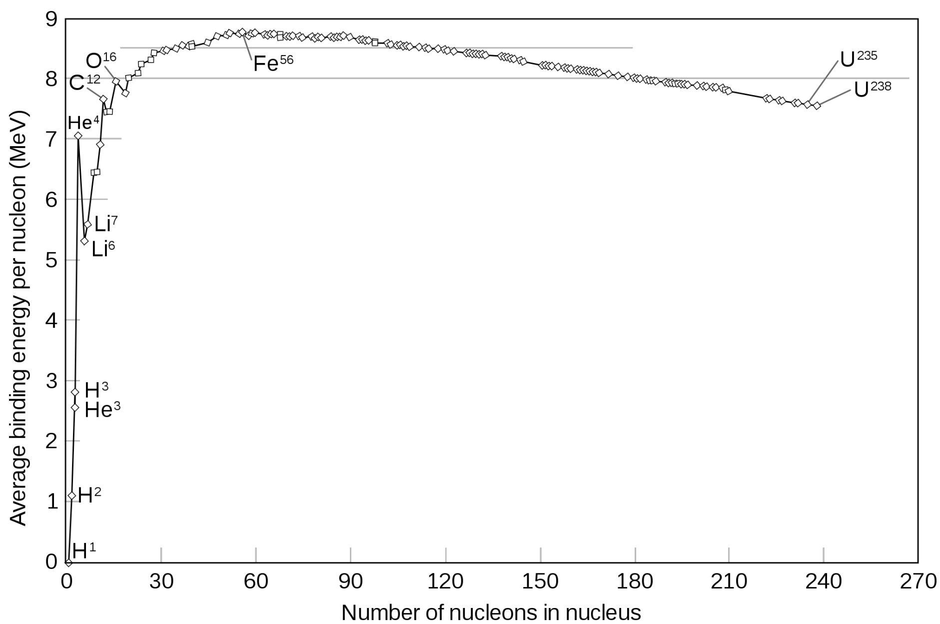


Figure 1: Hint for the problems 25. and 26.

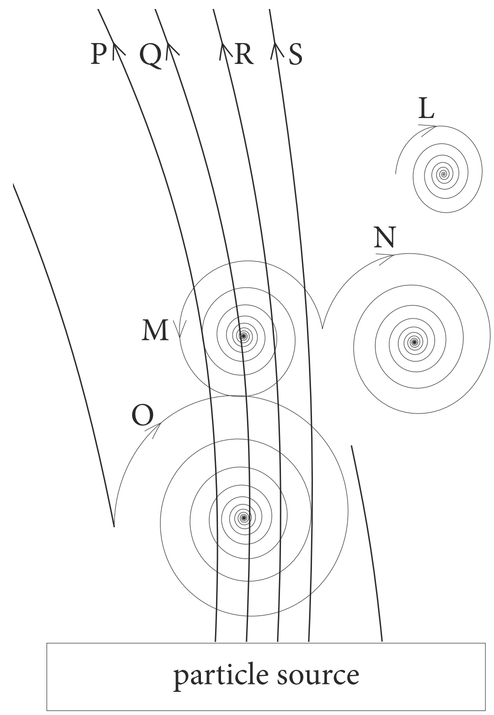
25. Which of the following elements has the highest **average** binding energy per one nucleon?

A $^{4}_{2}\mathrm{He}$ (helium)
B $^{12}_{6}\mathrm{C}$ (carbon)
C $^{56}_{26}\mathrm{Fe}$ (iron)
D $^{208}_{82}\mathrm{Pb}$ (lead)

26. Which of the following elements has the highest **total** binding energy of one nucleus?

A $^{4}_{2}\mathrm{He}$ (helium)
B $^{12}_{6}\mathrm{C}$ (carbon)
C $^{56}_{26}\mathrm{Fe}$ (iron)
D $^{208}_{82}\mathrm{Pb}$ (lead)

The following questions (from 27. to 31.) are connected to figure on the right. In the picture, there is a simplified sketch of particle tracks in a bubble chamber. The bubble chamber is a detector of ionising radiation used to observe the tracks of particles in nuclear physics. The photos taken inside were then manually processed. A homogeneous magnetic field bent the trajectories of the particles.
Presume that the particles from tracks P, Q, R and S had the same magnitude of electric charge. Likewise, the particles L, M, N and O had the same mass and the magnitude of electric charge. In the figure, there is marked the presumed direction of movement of all critical particles.



27. Which of the following particles had the lowest energy at the beginning of its track in the bubble chamber?

    A L

    B M

    C N

    D O

    E It is not possible to determine from the available information.

28. Which of the following particles had the greatest momentum at the beginning of its track in the bubble chamber?

    A P

    B Q

    C R

    D S

    E It is not possible to determine from the available information.

In the following problems assume that the particle marked as **P** has **positive charge**.

29. What was the charge of particle O?

    A Positive

    B No charge (neutral particle)

    C Negative

    D It is not possible to determine from the available information.

30. What would be the charge of the antiparticle to particle P?

    A Positive

    B No charge (neutral particle)

    C Negative

    D It is not possible to determine from the available information.

31. What would be the charge of the antiparticle to particle L?

    A Positive

    B No charge (neutral particle)

    C Negative

    D It is not possible to determine from the available information.