

# Particles and the Universe

Examples of exam questions for academic year 2016/17

## Questions for lecture 1

- When was the first elementary particle discovered? What particle was it?
- How did Einstein explain the photoelectric effect?
- What was the idea of the Compton experiment?
- How was the natural radioactivity discovered?
- What particles are emitted in three types of natural radioactivity?
- What was the idea of the Rutherford experiment?
- How were cosmic rays discovered?
- What particles constitute most of the primary cosmic rays?
- What particles constitute most of the secondary cosmic rays at Earth surface?
- When was the proton discovered, when a positron?
- Name three particles discovered in the cosmic rays?

## Questions for lecture 2

- Who introduced energy quanta to physics and what for?
- What did Einstein receive the Nobel Prize for?
- What did De Broigle postulate?
- What does Pauli exclusion principle say?
- What did Einsteins assume about the speed of light?
- How was existence of antimatter predicted?
- Who formulated the first theory of weak interactions?
- When were quarks introduced to particle physics and why?
- When was the existence of the Higgs boson predicted?

## Questions for lecture 3

- What interactions are important at macro scales? And at micro scales?
- How do we explain different ranges of electromagnetic and weak interactions?
- Compare the strength of gravitational and electrostatic interactions of two protons.
- How many elementary particles do we know today? How many fundamental particles?
- What is the difference between the fundamental and the elementary particle?
- What is the mass of the proton (in energy units)?
- What is the lightest particle of matter?
- Who introduces a concept of neutrino and why?
- What are the two most stable elementary particles?
- What fundamental particles are needed to explain the structure of "ordinary" matter?
- Is muon decay fast or slow?
- What is the resonant production?
- Is the  $d$  quark heavier than the  $u$  quark?
- When were strange particles discovered?
- What is strange in strange particles?

- What is the strangeness of  $J/\psi$  particles?
- When was the  $b$  quark discovered?
- How many times is the  $b$  quark heavier than the proton?
- What are hadrons?
- Meson baryon number is equal to?
- What is the muon number of the tau antineutrino?

#### Questions for lecture 4

- What are the possible sources of high energy cosmic rays?
- What energies can be obtained in electrostatic accelerators?
- How do linear accelerators work?
- Who built the first cyclotron?
- What elements are used to build a circular accelerators?
- Why is beam focusing important for accelerator performance?
- Why do most high energy accelerators work in collider mode?
- What is the maximum beam energy at LHC? What particles are accelerated?
- What limits the energy we can obtain at the LHC (pp collider)?
- Why can't we built a circular  $e^+e^-$  collider with energy in TeV range?

#### Questions for lecture 5

- Why does classical mechanics fail to describe particle interactions?
- Is it possible to observe particles without making them interact?
- What are the three physical phenomena used for particle detection?
- What is the process of ionization?
- How is a Geiger-Muller counter built? How does it work?
- Why is charge multiplication crucial in gas detectors, how is it obtained?
- Can a digital camera be used to detect particles?
- What is scintillation? How can we measure it?
- What is the condition for Cherenkov radiation by charged particle?
- What is measured in the calorimeter?
- What happens to the particle measured in the calorimeter?
- Name at least three parts of the universal detector at particle colliders.
- What part of the universal detector at collider is placed closest to the beam interaction point?
- How can we measure momentum of the charged particle in the tracking detector?
- How are quarks observed in collider experiments?
- How are electrons identified in the universal detector at particle collider (eg. LHC)?
- How muons are identified in the universal detector at particle collider (eg. LHC)?
- How do we know that a neutrino was produced in a high energy collision?
- Why do we need a trigger system at LHC?
- How many collisions are observed at LHC per second? How many can we reconstruct and store?

#### Questions for lecture 6

- How many different spin states has massive particle with spin  $s$ ?
- Does exist an elementary particle with spin  $7/2$  ?
- Does exist a right neutrino in the Standard Model ?

- How many fundamental particles with spin 3/2 do exist?
- What is a difference between fermion and boson?
- Spin of boson  $Z$  is equal to ..?
- $t$  quark is in doublet with what type of quark ?
- Write antileptons of the 2<sup>nd</sup> family.
- Write the beta decay at the fundamental level?
- What is the electric charge of the photon?
- Write all intermediate gauge bosons (together with antibosons) of electromagnetic and weak interactions.
- When the first unification theory was formulated?
- In what kind of collisions was the  $Z$  boson discovered?
- How many  $Z$  bosons were produced at the LEP collider?
- What is mass and half width of the  $Z$  boson?
- What is the lifetime of the  $Z$  boson?
- How do we know that there are only 3 generations of light neutrinos?
- What is the value of the weak coupling at low energies.
- Are weak interactions weak due to large mass of  $W$  ?
- Does the Sun shine so long due to strong or weak interactions?
- How much energy is emitted in one proton cycle in the Sun?
- At what energy have electromagnetic and weak interactions the similar strength?

#### Questions for lecture 7

- Is the range of weak forces larger or smaller than the range of strong interactions?
- Which particles interact due to nuclear forces, which particles due to the color forces .
- Is gravitation important in the micro world for low energies?
- What is the value of the Planck length? What is value of the Planck mass?
- Write 3 elementary acts of interactions between particles from the first family.
- What is the value of subtle coupling constant for momentum  $p \rightarrow 0$ ? And for momentum  $p = 100 \text{ GeV}/c$  ?
- Do two electrons interact stronger or weaker for larger energies (momenta)?
- What is the value of the strong coupling constant for momentum (energy) of about 1 GeV? For which momentum is  $\alpha_s$  equal to 1/10?
- When are quarks more free: for low or large energies?
- Write two processes obtained by crossing of the scattering process  $u d \rightarrow u d$ .
- To quarks of which colour does the green-antired gluon decay ?
- What is the reason for running of coupling constants? Why is the subtle coupling constant growing while the strong coupling constant decreases with a growth of energy?

#### Questions for lecture 8

- Give two examples of continuous transformations.
- Does a global symmetry is a consequence of a local one, or vice versa?
- Is a local symmetry the same as a gauge symmetry?
- Does the symmetry dictate the dynamics?
- Noether theorem describes ...?
- Does the gauge principle apply only to the Standard Model?
- Give two examples of spontaneously symmetry breaking.
- How many spin (polarisation) states has the massive  $Z$  boson ?

- Does a right electron participate in the weak interaction ?
- What is mass and spin of the Higgs particle.
- Is Higgs particle interaction stronger with more massive particle?
- Do Higgs particles interact with themselves ?
- For what Y. Nambu got Noble prize?
- What is a Sacharow postulate?

#### Questions for lecture 09

- Does Cabibbo angle describe mixing between  $d$  and  $s$  quarks or between  $u$  and  $d$  quarks ?
- Value of Cabibbo angle is equal to ?
- Write a coupling of the  $c$  quark to  $d$  quark assuming mixing between two lighter families only. What is its sign?
- What does the Cabibbo-Kobayashi-Maskawa matrix describe?
- Do we observe a mixing between  $b$  and  $d$  quarks?
- How many parameters does the Cabibbo-Kobayashi-Maskawa matrix have?
- Did N. Cabibbo got Noble prize in 2008?
- Is a transition of the  $u$  quark to  $c$  quark:  $u \rightarrow c Z$  possible in the SM?
- How one can determine the Cabibbo angle ?
- Does the Weinberg angle describe quark mixing?
- What is the status of FCNC in the SM ?
- Is the probability of transition  $c \rightarrow s W^+$  equal to probability of transition  $\nu \rightarrow e^- W^+$  ?
- Does photon couple to neutrinos?

#### Questions for lecture 10

- Why was the existence of the  $c$  quark postulated?
- Can a particle of matter transform to its own anti-particle?
- Name two sources of neutrinos studied in experiments nowadays.
- When were neutrinos discovered? What was the source of these neutrinos?
- What is the probability that neutrino produced in Sun passes through the Earth without any interaction?
- What is the maximum energy of neutrinos produced in the Sun?
- How are neutrinos detected in Super-Kamiokande experiment?
- How were solar neutrinos identified in Super-Kamiokande experiment?
- What results of the Super-Kamiokande experiment pointed to neutrino oscillations?
- What does it mean that neutrinos oscillate?
- Which assumptions of the Standard Model were violated by observation of neutrino oscillations?
- Are neutrinos the only particles which oscillate?

#### Questions for lecture 11

- Does a fact of a particle decay depend on the reference frame?
- Do terms "a free particle" and "a particle on the mass shell" mean the same?
- Why can't a free positron emit a photon and remain on the mass shell?
- What does "a virtual particle" mean?
- Does QED have infinite expressions at intermediate stages of calculation?
- What is a precision we know the anomalous magnetic moment for a muon?

- When is the theory renormalizable?
- Proper high energy behaviour of the probability for EW processes demands an existence of spin 0 particle. How such a particle couples to the gauge boson  $Z$ ?
- Has the Higgs boson been discovered?

#### Questions for lecture 12

- Existence of what particles was predicted by the Weinberg-Salam model (1968)?
- When and where were the  $W^\pm$  and  $Z^0$  bosons discovered?
- How were the first  $Z^0$  bosons observed at CERN SPS?
- At which accelerator were the  $Z^0$  boson production and properties studied with highest precision?
- Why were precise measurements at LEP sensitive to top and Higgs boson masses?
- Where and when was the top quark discovered?
- What is the mass of the top quark? How well do we know it today?
- Which decay channels of the Higgs boson were used for its discovery?
- What is the mass of the Higgs boson?
- How can we verify if the particle discovered at CERN is the predicted SM Higgs boson?
- What is the collision energy at LHC Run 2 (starting 2015)?
- How long is the LHC supposed to run?

#### Questions for lecture 13

- Write 3 problems of the SM.
- What is a meaning of GUT?
- Is GUT a common (unified) description of all fundamental interaction including gravity?
- What is the energy scale of GUT?
- Has supersymmetry been discovered ?
- How many Higgs particles are predicted in the MSSM?
- Is life time of the proton predicted in the SU(5) in agreement with experiment?
- Is the baryonic number conserved in SU(5) ?
- Do models with more than 4 space-time dimensions exist?
- What is the main idea of a superstring theory?
- Does the superstring theory include gravity?

#### Questions for lecture 14

- What information can be obtained from the measured shift in the spectral lines of distant objects?
- Who was the first to notice that the escape velocity of galaxies increases with distance?
- Formulate the Hubble's Law
- What are the cosmological scales?
- How does the Universe look like according to the cosmological principle?
- How did the Big Bang started?
- What particles filled the Universe just after the Big Bang?
- How long, after the Big Bang, were the nuclei formed?
- How many years after the Big Bang were the atoms formed?
- What is the critical density of the Universe?
- What would the future of the Universe be, if its average density is higher than the critical

- density?
- What is the density of baryonic matter in the Universe (in units of critical density)?
  - How do we know there is Dark Matter in the Universe?
  - Why does Dark Matter need to be "cold"?
  - How does Dark Matter interact?

#### Questions for lecture 15

- What was the Universe made of after nuclei and electrons combined?
- When was the cosmic microwave background created?
- What is the current temperature of the cosmic microwave background ?
- What can we learn from the measured angular scales of the CMB temperature fluctuations ?
- What is the density of the Dark Energy in the Universe (in units of critical density)?
- What is the total matter+energy density of the Universe (in units of critical density)?
- What is the age of the Universe?
- What was the first evidence for existence of gravitational waves (1974)?
- What is the expected velocity of gravitational wave propagation?
- What can be the source of gravitational waves?
- What instruments can be used to detect gravitational waves?
- Have gravitational waves been discovered?