Hallo Arbely
S2337681

Subatomic Physics 2014/20015

Re-Exam Subatomic Physics 2014/2015
Wednesday, 25 - February - 2015

70 points

Please mark your name and your student number on every sheet.
Please put consecutive page numbers on your pages.

You receive 4 A4 pages:

- pages 2 and 3 contain 5 question sets with topics from the lecture.
- page 4 gives relevant Constants, Relations and Conversion Factors
- Note: For some of the questions different approaches are possible, such that you may not necessarily need all of the given constants and equations.
- The final results are sufficient, if given correct to 2 significant figures (2 leading digits).
- Note: The exam has questions worth 70 points. They translate linearly into grades up to 10. In case your results from the homework resulted in a better grade, the averaga of the two grades will be your final grade for the course. If you have less favourite homework results recorded, we do not use them and your final grade will be from the exam only.

Groningen, 25 February, 2015
Best wishes for your exam,
Klaus Jungmann

1 Wave equations (15 points)

The Schroedinger equation is not relativistically co-variant.

(a) Which two relevant equations exist to improve on this problem? [3 pts]

(b) Which particles are described by each of the equations? [3 pts]

(c) The basic wave equations are first principles and cannot be derived from anything more fundamental, yet. Nevertheless, one can motivate them just like one can motivate the Schroedinger equation. Can you give the line of reasoning for this? [3 pts]

(c) Which wave equation would you use to describe muonic hydrogen (hydrogen atom where an electron was replaced by a negative muon) and for pionic hydrogen (hydrogen atom where an electron was replaced by a negative pion) [3 pts]

(d) When do you use the relativistic wave equations? When does the Schroedinger equation suffice? Give about 3 sentences of reasoning. Consider gross, fine and hyperfine structure. [3 pts]

2 Radioactivity (10 points)

(a) ^{64}Cu (Z=29) decays both via β^+ and β^-. Which maximum energy for the β particles can you expect in both cases ? (Assume the decay ends in the ground state of the daughter nucleus) [6 pts]

(b) The halflife time measured with the β^+ decay is 10.8h. Would the halflife time $T_{\frac{1}{2}}$ for β^- decay be larger, smaller or the same? Give one or two sentences of reasoning [2 pts]

(c) Are there other weak decay modes possible for ^{64}Cu ? Can you name them ? [2 pts]

3 Allowed and Forbidden Processes (15 points)

Which of the following processes are allowed and which are forbidden. Please give reasons for your judgment. For allowed processes please name the fundamental interaction. (Assume that the kinetic energy of the incoming particles plus their masses is high enough such that all outgoing particles could be produced.)

(a) $e^+e^- \to \Lambda^+ + \Lambda^- + \pi^0 + \pi^- + \pi^+$ [1.5 pts]

(b) $\nu_e + n \to e^- + p$ [1.5 pts]

(c) $\overline{\nu_\mu} + p \to \mu^+ + p + \pi^0$ [1.5 pts]

(d) $e^- + e^- \to \mu^- + \mu^- + \overline{p}$ [1.5 pts]

(e) $^{76}\text{Ge} \to ^{76}\text{Ge} + e^- + e^- + \nu_e + \nu_e$ [1.5 pts]

(f) $p + \pi^- \to \mu^- + e^+ + \gamma$ [1.5 pts]

(g) $e^- + e^+ \to \mu^+ + \mu^- + \pi^0$ [1.5 pts]

(h) $Ps(2^1P_1) \to Ps(1^1S_0) + 2\gamma$ (*note:* Ps:=(e^+e^-) is the positronium atom) [1.5 pts]

(i) $p + \overline{p} \to +n\overline{n} + \mu^+ + e^-$ [1.5 pts]

(h) $p +^7 \text{Li} \to^6 \text{Li} + d + e^- + \pi^+ + \pi^- + \pi^0 + \overline{\nu_e}$ [1.5 pts]

4 Fundamental Forces and Particles(15 points)

(a) Which fundamental forces do you know in physics? Give an example of a process for each of them[3 pts]

(b) Please draw a typical Feynman diagram for each of the fundamental forces. [3 pts]

(c) Which fundamental particles make up the Standard Model? How can they be grouped? How do we know that there aren't any more fundamental particles ? [3 pts]

(d) Estimate the range of the fundamental forces? Give a line of reasoning. Give one value for the range of each of the fundamental interactions. [3 pts]

(e) Where do the force carriers come from? What about energy conservation in, e.g., the helium nucleus (^{4}He), where the 2 neutrons and the 2 proton are held together by pions and the sum of the masses of the protons, the neutrons and pions together exceeds the ^{4}He mass? [3 pts]

5 Weak Interactions (15 points)

The weak eigenstates and the mass/flavour eigenstates of neutrinos are not identical.

(a) What are the reasons why physicists are convinced that neutrinos have a mass? How big is this mass at maximum? [2 pts]

(b) Can you explain why *"Electron neutrino"* mass in the list **Constants of Relevance** (Chapter 6.0.1 on the next page) is written in quotation marks? [1 pt]

(c) How are the different neutrinos related to each other? Explain briefly. [2 pts]

(d) What is the situation for charged leptons? Explain briefly. [2 pts]

(e) What would change, if somebody would observe in future the process $\mu^+ \rightarrow e^+ + \gamma$. [2 pts]

(f) Give one example each of a (i) leptonic, (ii) semileptonic and (iii) non-leptonic weak interaction process. Draw the corresponding Feynman diagrams and explain how the couplings differ, which describe the vertices. [6 pts]

6 Some Constants, Relations and Conversion Factors

6.0.1 Constants of Relevance

Speed of light	c	$2.998 \cdot 10^{8}$	m/s
Planck constant	h	$4.136 \cdot 10^{-24}$	GeVs
	$\hbar = \frac{h}{2\cdot\pi}$	$6.582 \cdot 10^{-25}$	GeV/c
Electron charge	e	$1.602 \cdot 10^{-19}$	C
Electron mass	m_e	0.510998928(11)	MeV/c^2
Proton mass	m_p	938.272046(21)	MeV/c^2
Neutron mass	m_n	939.565379(21)	MeV/c^2
Neutron lifetime	τ_n	880.3(1.1)	s
Deuteron mass	m_d	1875.61282(16)	MeV/c^2
Helium-3 mass (nucleus)	$m_{^3He}$	2808.391482(62)	MeV/c^2
α-particle mass	m_α	3727.379240(82)	MeV/c^2
α-particle binding energy	E$_\alpha$	28.3	MeV/c^2
"Electron neutrino" mass	m_{ν_e}	< 2.2	eV/c^2
Muon mass	m_μ	105.658369(9)	MeV/c^2
Charged pion mass	$m_{\pi^\pm}$	139.57018(35)	MeV/c^2
Neutral pion mass	m_{π^0}	134.9766(6)	MeV/c^2
W$^\pm$- boson mass	m_W	80.403(29)	GeV/c^2
Z^0-boson mass	m_Z	91.1876(21)	GeV/c^2

6.0.2 Relations

Mass of Atom (Bethe-Weizsäcker):

$$M(A,Z) = Nm_n + Zm_p + Zm_e - a_v A + a_s A^{2/3} + a_c \frac{Z^2}{A^{1/3}} + a_a \frac{(N-Z)^2}{4A} + \frac{\delta}{A^{1/2}}$$

with

$a_v = 15.67 MeV/c^2$

$a_s = 17.23 MeV/c^2$

$a_c = 0.714 MeV/c^2$

$a_a = 93.15 MeV/c^2$

$\delta = 0$ (odd A) or -11.2 MeV/c^2 (Z and N even) or +11.2 MeV/c^2 (Z and N odd)

6.0.3 Conversion Factors

Electronvolt	eV	$1.60217653(14) \cdot 10^{-19}$	J
Tesla	T	$0.561 \cdot 10^{30}$	MeV/(c$^2\cdot$ C $\cdot$ s)
Kilogram	kg	$5.60958896(48) \cdot 10^{35}$	eV/c^2
barn	b	$1 \cdot 10^{-28}$	m^2

Note: For some of the questions different approaches are possible, such that you may not necessarily need all of the given constants and equations. Unless differently stated, the final results are sufficient, if given to 2 significant figures (2 leading digits and order of magnitude).