Subatomaire Fysica 1

Derde Bachelor Fysica en Sterrenkunde 5 juni 2020

Theorie [1]

1. Which of these reactions is not possible and why? And which one only through W exchange? Which one only through Z exchange? And which one is possible through both W exchange and Z exchange?

$$e^- + \nu_\mu \to \mu^- + \nu_e$$
$$\nu_\mu + e^- \to e^- + \nu_\mu$$
$$\nu_\tau + e^- \to \mu^- + \nu_e$$
$$\nu_e + e^- \to e^- + \nu_e$$

   (a) Draw the Feynman diagrams.

2. Explain the graph.

   (a) What do the peaks represent?

   (b) Identify one electric transition and one magnetic transition.

   (c) Which one of these can be formed through e^+e^- scattering: 1^1S_0 (η meson) or 1^3S_1 (J/ψ)?

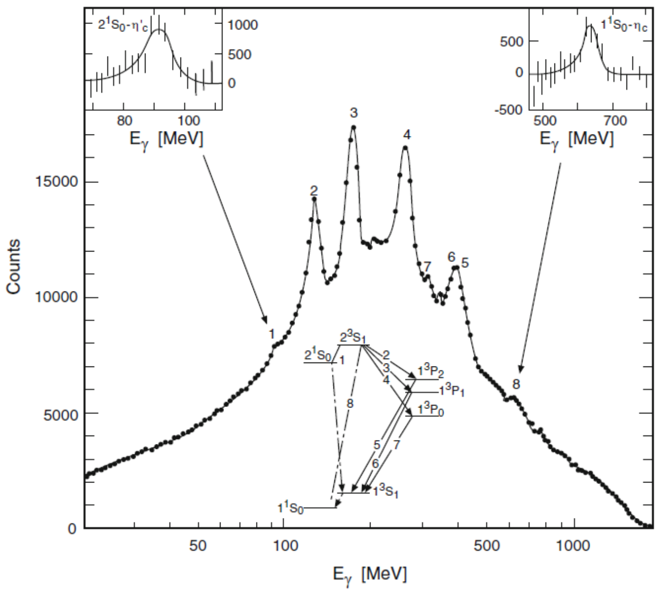
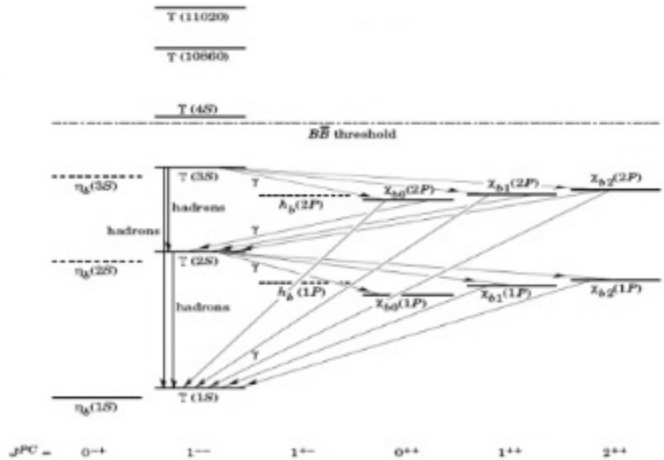


Fig. 14.6 The photon spectrum in the decay of ψ (2^3S_1), as measured in a crystal ball, and a sketch of the so extracted charmonium energy levels. The strong peaks in the photon spectrum represent the so numbered transitions in the sketch. The *continuous lines* in the sketch represent parity changing electric dipole transitions and the *dashed lines* denote magnetic dipole transitions which do not change parity [3]

Bonus: Draw the Feynman diagram for $\tau \to \pi^- + \nu_\tau$ ($\pi^- = d\bar{u}$).

[1] theorie (mondeling) gesloten boek, oefeningen (hieronder) open boek (+slides)

1. **(3p)** In the figure below one finds the masses and several decay channels of $b\bar{b}$ mesons.
   a) Which of these mesons can be formed directly in $e^+ e^-$ annihilations
   b) Why are the (upsilon) more massive than the η_b?
   c) Why are the masses of the χ_b mesons not equal?



2. **(3p)** Discuss the four fundamental forces/interactions known to us presently. What are the characteristic length and/or energy scales where they are significant? What are similarities and differences with respect to for example the type of charges between which they interact, the type of particles which are subjected to them, the existence of bound states, etc.

3. **(Bonus 1p)** Draw the lowest order Feynman diagram for the following interaction:

$$\tau^- \rightarrow e^- + \bar{\nu}_e + \nu_\tau$$

Subatomic Physics I: exam (exercises)

June 5, 2020

Note: book and theory lecture slides are allowed.

Info: masses and quark content of some hadrons

Symbol	quark content	mass (MeV/c^2)
Ξ^-	(dss)	1322
Ξ^0	(uss)	1314
Λ^0	(uds)	1116
Σ^-	(dds)	1197
Σ^0	(uds)	1193
π^-	$(d\bar{u})$	140
π^+	$(u\bar{d})$	140
π^0	$(u\bar{u}/d\bar{d})$	135
K^+	$(u\bar{s})$	494
K^-	$(s\bar{u})$	494
K^0	$(d\bar{s})$	498
Δ^{++}	(uud)	1232
J/Ψ	$(c\bar{c})$	3097
D_s^-	$(s\bar{c})$	1968
B^0	$(d\bar{b})$	5280
Ω^-	(sss)	1672

Exercise 1: Δ cross section (2.5p)

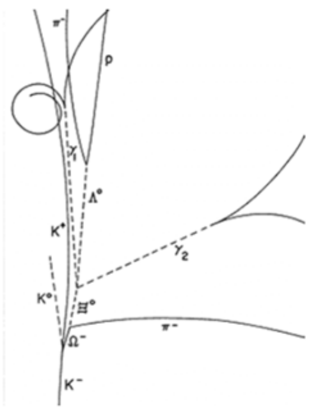
Question: Consider an experiment where positively charged pions are scattered off stationary proton targets. In such a collision, a Δ^{++} resonance can be produced which then decays back to a pion and a proton: $\pi^+ + p \to \Delta^{++} \to \pi^+ + p$. The proper lifetime of a Δ^{++} resonance is 5.5×10^{-24}s, its mass is 1232 MeV/c^2 and its spin is 3/2. The masses of the proton and the pion are 938 MeV/c^2 and 140 MeV/c^2 respectively. All other decay channels of the Δ^{++} than the one considered here have negligibly small branching fractions.

(a) Calculate the minimum pion energy (in the lab frame, where the proton is at rest) that is needed for Δ^{++} production.

(b) Calculate the total cross-section for the pion energy you found above.

Exercise 2: Omega baryon (2p)

Question: The omega baryon, Ω^-, was discovered at an experiment at Brookhaven laboratory, where first a proton beam is directed at stationary hydrogen atoms to produce K^- which then hit again a stationary proton target to produce a so called hyperon with three strange quarks. The experimental signature that led to the discovery of this baryon is shown below where charged particles lead to a track in the bubble chamber (solid lines) while neutral particles (dashed lines) are deduced from possible particle decays and kinematics.



Omega production:

$$p + p \to K^+ + K^- + p + p$$

$$\Downarrow$$

$$K^- + p \to \Omega^- + K^+ + K^0$$

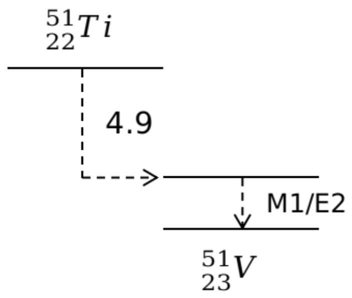
(a) What minimum energy is required for K^- to be able to produce Ω^- baryon in this way?

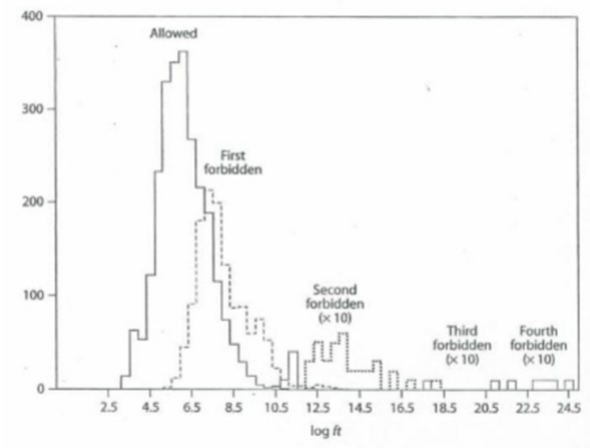
(b) Draw the feynman diagrams for the three most probable decays of Ω^- (see below). What do these diagrams have in common and what is different between them?

$$\Omega^- \to \Lambda^0 + K^-(68\%)$$
$$\Omega^- \to \Xi^0 + \pi^-(24\%)$$
$$\Omega^- \to \Xi^- + \pi^0(9\%)$$

Exercise 3: The shell model and nuclear decays (2.5p)

Question: The figure below shows some transitions between the low levels of a few $A = 51$ isobars. The number next to the β-decay line indicates its log-ft-value, while next to the electromagnetic decay its multipolarity is indicated. What is the spin and parity (J^P) of the excited state of V? Note: in this particular case, you can assume that the one-particle shell model is valid also when the valence orbital is occupied by multiple nucleons instead of one.





Exercise 4: Nuclear reaction (3p)

Question The fission of ^{235}U is induced by a neutron and the fission fragments are $^{92}_{37}$Rb and $^{140}_{55}$Cs (i.e.: n+^{235}U→$^{92}_{37}$Rb+$^{140}_{55}$Cs+4n). In this exercise, you might need the ideal gas law, $pV = nRT$ with $R = 8.314$ J/mole.K $= 0.0821$ l.atm/mole.K. Furthermore, Avogadro's constant could be useful; it is 6.022×10^{23}.

(a) Calculate the energy released per fission (in MeV). Ignore the small contribution from the pairing term.

(b) This reaction is used to power a 100 MW nuclear reactor whose core is a sphere of radius 100 cm. An average of 1 neutron from each fission escapes the core. What is the neutron flux at the outer surface of the reactor core (in units of $m^{-2}s^{-1}$)?

(c) The core is surrounded by 1.3 m^3 of an ideal gas maintained at a pressure of 0.987 atm and a temperature of 298 K. All neutrons escaping the reactor core pass through the gas. If the reaction cross section between the neutrons and the gas is 1 mb, calculate the rate of the neutron interactions in the gas.