Subatomic Physics I: exam (exercises)

July 2, 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: Collision kinematics (2p)

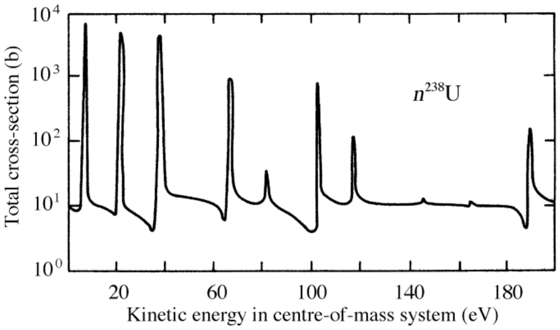
Question: Particle A with an energy E_A collides into a stationary particle B, and as a result of this collision, several particles C_1, C_2, ..., C_n. are produced (i.e. $A+B \rightarrow C_1+C_2+...+C_n$).

(a) Calculate the minimum energy of particle A in the lab frame for this reaction to take place, as a function of the involved particle masses (i.e. m_A, m_B, m_{C_1}, ..., m_{C_n}).

(b) Using this result, calculate the minimum pion energy required for the reaction $\pi^- + p \rightarrow K^0 + \Sigma^0$ (where the proton is initially at rest).

Exercise 2: Neutron-uranium reaction (2.5p)

Question: The total cross-section data for the reaction between a neutron and a ^{238}U-nucleus is shown below:



There is a resonance R at the neutron kinetic energy (in the center-of-mass frame) of $E_n = 10$ eV with a width of 10^{-2} eV. The peak cross-section for this resonance production is $\sigma = 9\times10^3$ barn (as can be seen in the figure as well). Use this information to find the partial widths Γ_n and Γ_γ, relevant for the decay channels $R \rightarrow n+^{238}U$ and $R \rightarrow \gamma+^{239}U$ respectively. Assume there are no other decay channels. The spin of ^{238}U (in the ground state) is 0. while the spin of the R resonance is measured to be 1/2.

Exercise 3: Lambda decay rate (2p)

Question: Draw a feynman diagram at the quark level for the decay $\Lambda^0 \rightarrow p + \pi^-$. If nature were to double the weak coupling constant and decrease the mass of the W-boson by a factor of four, what would be the effect on the decay rate $\Gamma(\Lambda^0 \rightarrow p + \pi^-)$? You can neglect the momentum transferred by the W-boson in the process with respect to its (on-shell) rest mass. The quark content of the Λ^0 is uds.

Exercise 4: The shell model (1.5p)

Question: What is the shell-model configuration of the nucleus $^7_3$Li? What are its spin, parity and magnetic moment (in units of nuclear magnetons)? Give the two most likely configurations for the first excited state.

Exercise 5: Spin-orbit potential (2p)

Question: From experiments with lead and thallium, the following table of nuclear states with their spin properties and excitation energies could be derived:

Nucleus	J^P	E_X (MeV)
${}^{207}_{82}\mathrm{Pb}$	$1/2^-$	0
	$5/2^-$	0.5696
	$3/2^-$	0.8977
	$7/2^-$	2.340
${}^{207}_{81}\mathrm{Tl}$	$1/2^+$	0
	$3/2^+$	0.35
	$5/2^+$	1.67

With this data, derive three estimates for the magnitude and sign of the expectation value of the spin-orbit potential $< V_{ls}(r) >$ in the nuclear potential and compare the results. What can you conclude about the shell model?