NTNU **Institutt for fysikk**

Contact during the exam:
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Exam in FY3403 PARTICLE PHYSICS

Friday December 2, 2011
09:00–13:00

Allowed help: Alternativ **C**
Standard calculator
K. Rottman: *Matematisk formelsamling* (all languages).
Schaum's Outline Series: *Mathematical Handbook of Formulas and Tables.*

Det finnes også en norsk utgave av dette oppgavesettet.

This problem set consists of 3 pages.

Problem 1. Quark model for baryons

Give a qualitative description of how one in the quark model assumes that baryons are made of quarks. In particular try to explain

a) how many quarks and antiquarks the baryons are made of,

b) which spin S the total baryon system may have,

c) which isospin I the total baryon system may have,

d) why there are no baryons with charge -2 (in units of the positron charge),

Problem 2.

The normalized spin/flavor wave function for Δ^{++} with spin $S_z = \frac{3}{2}$ is given by

$$|\Delta^{++}\ \tfrac{3}{2}\rangle = |u\uparrow\rangle|u\uparrow\rangle|u\uparrow\rangle.$$

a) Find the normalized spin/flavor wave function for Δ^{+} with spin $S_z = \frac{3}{2}$.

b) Find the normalized spin/flavor wave function for Δ^{+} with spin $S_z = \frac{1}{2}$.

c) The magnetic moment of a baryon with spin/flavor wave function $|\Psi\rangle$ is defined as

$$\mu_z = \langle\Psi\,|\sum_i \frac{e\,\boldsymbol{Q}_i}{2\boldsymbol{m}_i}\,\boldsymbol{S}_{iz}\,|\,\Psi\rangle,$$

where the sum is over the three positions in the wave function. (Note that $\boldsymbol{Q}_i$, $\boldsymbol{m}_i$ and $\boldsymbol{S}_{iz}$ is *operators* which take different values depending on the states they act on.) Find the magnetic moment of Δ^{++} with spin $S_z = \frac{3}{2}$. Assume that $m_u = m_d$.

d) Find the magnetic moment of Δ^{+} with spin $S_z = \frac{1}{2}$. Assume that $m_u = m_d$.

Hint to point a–b): Use the ladder operators.

Problem 3. Interaction processes and Feynman diagrams

Draw lowest order Feynman diagrams for the following interaction processes (if the process is possible)

a) $e^- + \mu^- \longrightarrow e^- + \mu^-$

b) $e^- + \mu^+ \longrightarrow e^- + \mu^+$

c) $e^- + \mu^+ \longrightarrow e^+ + \mu^-$

d) $e^- + e^+ \longrightarrow \mu^+ + \mu^-$

e) $e^- + e^+ \longrightarrow e^+ + e^-$

f) $e^- + \nu_\mu \longrightarrow e^- + \nu_\mu$

g) $e^- + \nu_\mu \longrightarrow \nu_e + \mu^-$

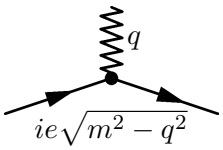
h) $\tau^- \longrightarrow \mu^- + x$ (replace x by some possible set of particles)

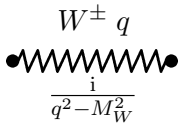
i) $\nu_e + \nu_\mu \longrightarrow \nu_\mu + \nu_e$

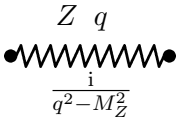
j) $n \longrightarrow p + x$ (replace x by some possible set of particles)

Problem 4. Elastic $\nu_e + e^- \to \nu_e + e^-$ scattering

Assume Feynman rules as *indicated* below, where m is the mass of the heaviest fermion involved in the interaction vertex and q is the four-momentum of the virtual messenger particle.







a) Draw all lowest order Feynman diagrams for the process.

b) Write down the corresponding algebraic expressions for the scattering amplitude $\mathcal{M}_{fi}$.

c) Find the total scattering cross-section. You may assume that $|q^2| \ll M_W^2$ and $|q^2| \ll M_Z^2$ to simplify expressions.

Given:

We use *natural units*, i.e. units where $\hbar = c = 1$. The connection between scattering amplitude $\mathcal{M}_{fi}$ and scattering cross-section is

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{S}{64\pi^2} \frac{|\mathcal{M}_{fi}|^2}{(E_1 + E_2)^2} \frac{|\boldsymbol{p}_f|}{|\boldsymbol{p}_i|}. \tag{1}$$

35. CLEBSCH-GORDAN COEFFICIENTS, SPHERICAL HARMONICS, AND d FUNCTIONS

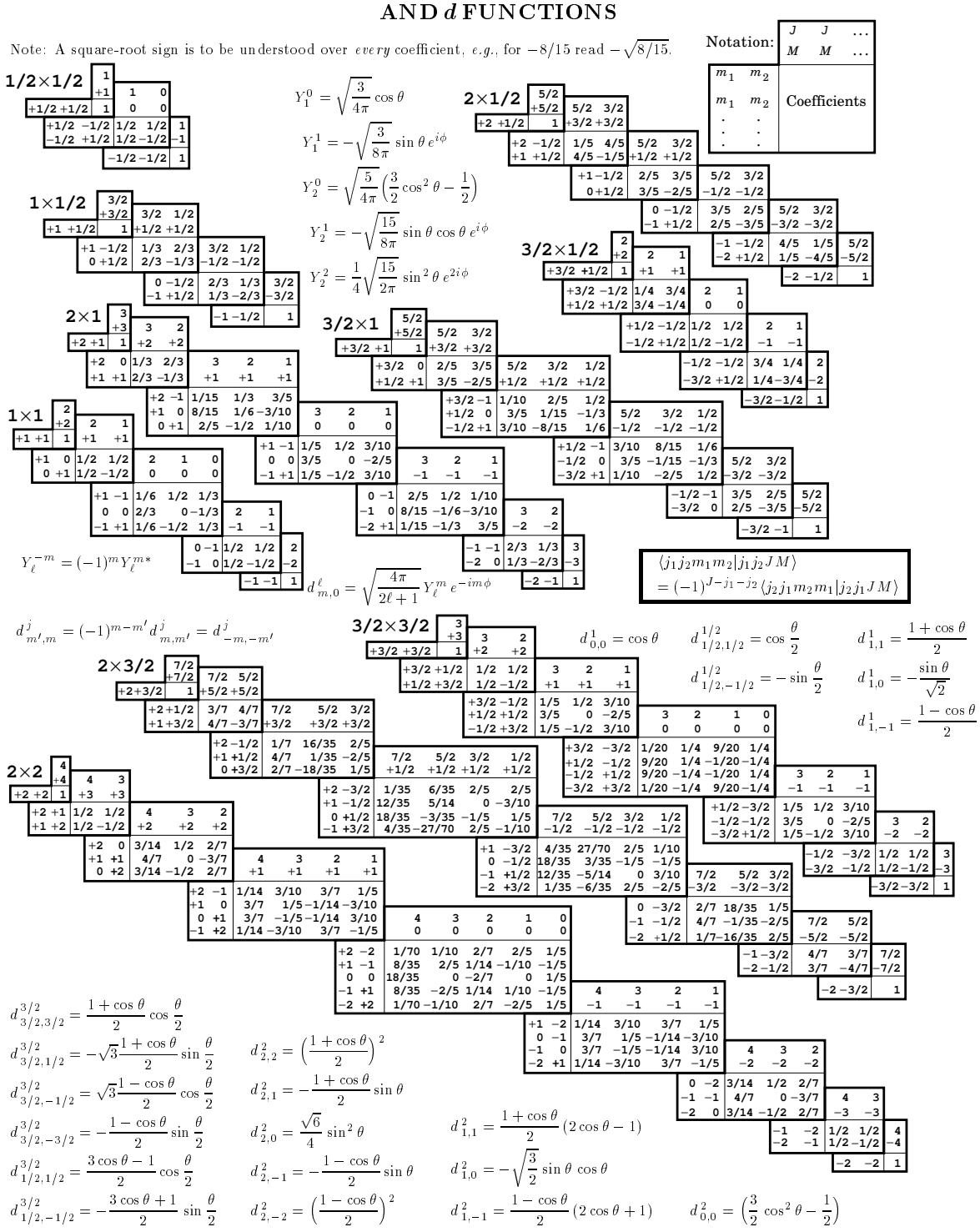


Figure 35.1: The sign convention is that of Wigner (*Group Theory*, Academic Press, New York, 1959), also used by Condon and Shortley (*The Theory of Atomic Spectra*, Cambridge Univ. Press, New York, 1953), Rose (*Elementary Theory of Angular Momentum*, Wiley, New York, 1957), and Cohen (*Tables of the Clebsch-Gordan Coefficients*, North American Rockwell Science Center, Thousand Oaks, Calif., 1974). The coefficients here have been calculated using computer programs written independently by Cohen and at LBNL.