Answers are given after problem 10 where you also find tables with particle data that you may need. Such tables will be available at the exam.

1. A neutral π-meson, π^0, decays at rest according to:

$$\pi^0 \rightarrow \gamma + \gamma$$

Calculate the total energy, the kinetic energy and the monentum for each of the two photons.

2. All the reactions below are forbidden. Check which conservation rules are violated. We assume that conservation of energy and momentum are fulfilled.

$$p + \bar{p} \rightarrow \mu^+ + e^-$$
$$\pi^- + p \rightarrow p + \pi^+$$
$$p + p \rightarrow p + \pi^+$$
$$p + p \rightarrow p + p + n$$
$$\gamma + p \rightarrow n + \pi^0$$

3. A Λ^0–baryon at rest decays according to:

$$\Lambda^0 \rightarrow p + \pi^-$$

Calculate the kinetic energy for the decay products.
What is the quark content of the Λ^0–baryon?

4. Calculate the highest possible kinetic energy of the electron in the decay:

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

The muon is assumed to be at rest when it decays.

5. One way for the K^+ meson to decay is:

$$K^+ \rightarrow e^+ + \nu_e + \pi^0$$

Calculate the maximum total energy of the π-meson and the positron in the rest frame of the kaon. What is the quark content of the K^+-meson?

6. What is the Q-value for the two reactions?

$$\pi^- + p \rightarrow K^0 + \Lambda^0$$
$$K^- + p \rightarrow \pi^0 + \Lambda^0$$

Interpret the results in words.

7. The following reactions violate one or more conservation rules. Check which rules are broken. We assume that energy and momentum are conserved.

$\nu_e + p \rightarrow n + e^+$
$p + p \rightarrow p + n + K^+$
$p + p \rightarrow p + p + \Lambda^0 + K^0$
$\pi^- + n \rightarrow K^- + \Lambda^0$
$K^- + p \rightarrow n + \Lambda^0$

8. Use the Heisenberg uncertainty principle to calculate the mass of the exchange particle if we estimate that an average range for the force in the nucleus is 0.7fm (about half of the maximum range). Which particle in the table is the most likely candidate.

9. Determine the kinetic energy of the two decay products if the decay takes place with the mother particle at rest in the laboratory system.

$\Omega^- \rightarrow \Lambda^0 + K^-$

Make both a non-relativistic and a relativistic calculation and compare the results. What is the quark content of the three hadrons. Which of the four forces must be responsible for the decay.

10. Which conservation rules are violated in the following decays.

$\pi^+ \rightarrow e^+ + \gamma$
$\Lambda^0 \rightarrow p + K^-$
$\Lambda^0 \rightarrow \pi^- + \pi^+$
$\Sigma^0 \rightarrow p + \gamma$
$\mu^- \rightarrow e^- + \gamma$

Answers:

1: 67.5MeV, 67.5MeV, 67.5MeV/c
2: lepton (e and μ), charge, baryon,baryon,charge
3: 5.4 and 32.3MeV
4: 52.3MeV
5: 265.3MeV and 228.4MeV
6: -535.3 and 181.4MeV
7: lepton, strangeness, baryon, strangeness,baryon. In weak interactions strangeness does not have to be conserved. But since these are collisions with a very short interaction time and not decays, weak interaction is extremely unlikely.
8: 140MeV/c^2
9:43.9MeV and 19.4MeV
10: lepton,energy,baryon,charge,lepton (e and μ)

The properties of the lightest quarks.

	Q Charge (e)	B Baryon number	S strangeness
u	2/3	1/3	0
d	-1/3	1/3	0
s	-1/3	1/3	-1

The lightest leptons.

$m_e = 0.511 MeV/c^2$
$m_\mu = 105.4 MeV/c^2$
The neutrinos have negligible mass for kinematic calculations.
The negatively charged leptons are particles.

Properties of a selection of hadrons.

		particle	Charge (e)	Mass (MeV/c^2)	Strange-ness	Mean life-time (s)
Hadrons	Baryons	p	+1	938.3	0	stable
		n	0	939.6	0	~900
		Λ	0	1115,6	-1	$2.63 \cdot 10^{-10}$
		Σ^+ Σ^0 Σ^-	+1 0 -1	1189.4 1192.5 1197.4	-1 -1 -1	$0.80 \cdot 10^{-10}$ $7.4 \cdot 10^{-20}$ $1.48 \cdot 10^{-10}$
		Ξ^0 Ξ^-	0 -1	1314.9 1321.3	-2 -2	$2.90 \cdot 10^{-10}$ $1.64 \cdot 10^{-10}$
		Ω^-	-1	1672.5	-3	$0.82 \cdot 10^{-10}$
	Mesons	π^+ π^0	+1 0	139.6 135.0	0	$26.0 \cdot 10^{-9}$ $8.4 \cdot 10^{-17}$
		K^+ K^0	+1 0	493.7 477.6	1 1	$12.3 \cdot 10^{-9}$ $0.89 \cdot 10^{-10}$ (K^0 short) $5.2 \cdot 10^{-8}$ (K^0 long)
		η	0	547.5	0	$<10^{-22}$

Notes about the four types of intercations

interaction	Field particle	Mass of field particle	Range	Relative strength	Typical live time	Conserved numbers	Acts on particles	example	comment
Strong in nucleus btw p,n									
Strong in hadron btw quarks									
Weak									
Electromagnetic									
Gravity									