1 a) How fast must a particle move before its *kinetic energy*, defined as the difference between the total energy and the rest energy, equals the rest energy?

b) Consider the photoproduction of pions

$$\gamma + p \to \pi^0 + p \ ,$$

with the target proton at rest. What is the minimal energy of the photon γ for this process to take place? (Assume that the mass of the proton is 0.94 Gev, and the mass of the pion 140 Mev.) Compare the resulting frequency to that of hard X rays ($\lambda_X = 10^{-2} nm$). What will the result be if the target proton is moving in the same direction as the photon?

2 a) Show that a photon cannot spontaneously disintegrate into an electron-positron pair.

b) Find the velocity of the ZM frame of two photons of frequencies ν_1 and ν_2 that travel in the positive and negative x-directions respectively.

3 Radiation energy from the sun is received on earth at the rate of 1.94 calories per minute per square centimeter. Assuming the distance of the sun to be 150 000 000 km, find the total mass lost by the sun per second, and the force exerted by solar radiation on a black disk of the same diameter as the earth (use 12 800 km), at the location of the earth.

4 **Energieeffizienz bei der Teilchenproduktion**:
Der Energieeffizienzfaktor der Teilchenerzeugung ist definiert als die Energie, die in der tatsächlichen Erzeugung der neuen Teilchen steckt, also $\sum_i m_i$ (mal c^2 in SI Einheiten), dividiert durch die Energie die der Teilchenbeschleuniger bereitstellen musste, also die minimale kinetische Energie vor der Kollision die man fuer die Teilchenproduktion braucht. Berechne den Energieeffizienzfaktor für

$$\mathsf{p} + \mathsf{p} \to \mathsf{p} + \mathsf{p} + \pi^0 \ ,$$

wo p ein Proton und π^0 ein Pion bezeichne, fuer a) eine Kollision wo ein Proton immobil ist, b) beide Protonen stossen gegeneinander mit selben Geschwindigkeiten.

5 The *alternating tensor* $\epsilon_{\alpha\beta\gamma\delta}$ is defined by the requirement that it changes sign under the permutation of any two indices (such tensors are called *totally antisymmetric*), and

$$\epsilon_{0123} = 1 \ .$$

Does this indeed define $\epsilon_{\alpha\beta\gamma\delta}$ uniquely? *[Hint: What is the value of $\epsilon_{\alpha\beta\gamma\delta}$ when some indices coincide?]* Define $\epsilon^{\alpha\beta\gamma\delta}$ by raising the indices using the Minkowski metric:

$$\epsilon^{\alpha\beta\gamma\delta} = \eta^{\alpha\mu}\eta^{\beta\nu}\eta^{\gamma\rho}\eta^{\delta\sigma}\epsilon_{\mu\nu\rho\sigma} \ .$$

Show that $\epsilon^{\alpha\beta\gamma\delta}$ is totally antisymmetic and that

$$\epsilon^{0123} = \det \eta^{\alpha\beta} = -1 \ .$$

How can this be generalised to other dimensions? or to the Euclidean metric? How many totally antisymmetric tensors with five indices are there in dimension n, $1 \leq n \leq 7$?