Relativistic Dynamics

Basic Problems

1. A photon can decay into an electron and a positron (*pair creation*). Calculate the photon's minimum energy for this process.
2. During the last billion years the sun emitted radiation at a more or less constant rate of $3.8 \cdot 10^{26}$ W. Calculate the percentage decrease of its mass.
3. Calculate the mass defect in the fusion reaction ${}^2_1\mathrm{H} + {}^2_1\mathrm{H} \rightarrow {}^3_2\mathrm{He} + \mathrm{p}$.
4. Calculate the binding energy of a lead nucleus.
5. Why is iron considered to be the most stable element?
6. Two particles of identical mass m and with equal kinetic energies $E_{kin} = 2 \cdot m \cdot c^2$ collide and form a new particle. What is the maximum mass of the new particle?
7. An electron is accelerated to 0.999 c. Calculate its kinetic energy.
8. An object with mass 1 g moves at 90 % of the speed of light. Calculate its rest energy, total energy and kinetic energy.
9. Calculate the speed of an α-particle with a kinetic energy of 5 MeV.
10. Calculate the kinetic energy of protons moving at 90 % of the speed of light.
11. A particle is accelerated from 90 % to 91 % of the speed of light. Calculate the percentage change of the particles momentum. What is the result for an acceleration from 98 % to 99 % of the speed of light?
12. Calculate the momentum of 20 keV protons.

Additional Problems

13. Newton's Second Law is correct in relativity if force is defined as the *derivative of momentum with respect to time*. Show that for a force acting on a particle parallel to its motion the force can be written as

$$F = \gamma^3 \cdot m \cdot \frac{dv}{dt}.$$

14. In the particle accelerator DESY (*Deutsches Elektronen-Synchrotron*) near Hamburg, electrons are accelerated to 0.999 999 997 c. Calculate the total acceleration voltage.
15. The nuclear power station in Leibstadt has an average output power of 1 GW at an efficiency of about 30 %.
    a) Calculate the mass equivalent to the energy produced per day. Where does this mass "disappear"?
    b) The fuel elements become also lighter when they are contained in a gas-tight container. Give a reason for this phenomenon. Can this effect be measured?
16. A deuterium (${}^2_1\mathrm{H}$) and a tritium (${}^3_1\mathrm{H}$) nucleus combine in a fusion reactor to form a helium nucleus (${}^4\mathrm{He}$), leaving one excess neutron. Using the binding energies or the nuclear masses, calculate the energy set free in this reaction.

Solutions to Basic Problems: 1. 1.022 MeV; 2. $6.7 \cdot 10^{-3}$ %; 3. $-7.2 \cdot 10^{-30}$ kg; 4. -1.6 GeV; 6. $6 \cdot m$; 7. 11.4 MeV; 8. 90 TJ, 206 TJ, 116 TJ; 9. 0.052 c; 10. 1.2 GeV; 11. 1.06, 1.43; 12. 6 MeV/c