For example, as explained on page 14, an electron neutrino can interact with a neutron to produce a proton and an electron.

$$\nu_e + n \longrightarrow p + e^-$$

However, an electron neutrino and a neutron could not change into an antiproton and a positron.

$$\nu_e + n \not\longrightarrow \bar{p} + e^+$$

By assigning +1 to a lepton and –1 to an antilepton and 0 for any non-lepton, we can see that the total lepton number is unchanged in the permitted change above.

The first equation has a lepton number of +1 before the change and a lepton number of +1 after the change. So this equation is permitted.

The second equation has a lepton number of +1 before the change and a lepton number of –1 after the change. So this change is not permitted.

2 **In muon decay**, the muon changes into a muon neutrino. In addition, an electron and an electron antineutrino are created to conserve charge.

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

However, a muon cannot decay into a muon antineutrino, an electron and an electron antineutrino even though charge is conserved.

$$\mu^- \not\longrightarrow e^- + \bar{\nu}_e + \bar{\nu}_\mu$$

The first equation has a lepton number of +1 before the change and a lepton number of +1 (= +1 – 1 + 1) after the change. So this equation is permitted.

The second equation has a lepton number of +1 before the change and a lepton number of – 1 (= +1 – 1 – 1) after the change. So this change is not permitted.

In any change, the total lepton number before the change is equal to the total lepton number after the change. In other words, **the lepton number is conserved in any change**.

A weak puzzle

Consider the following possible change for a muon decay.

$$\mu^- \overset{?}{\longrightarrow} e^- + \nu_e + \bar{\nu}_\mu$$

It obeys the lepton conservation law and conservation of charge but it is never seen. The reason is that the muon can only change into a muon neutrino. The above decay can't happen because a muon can't change into a muon antineutrino and an electron can only be created with an electron antineutrino. So we need to apply the rule above separately to each branch of leptons, namely:

- the electron branch consisting of electrons, electron neutrinos and their antiparticles
- the muon branch consisting of muons, muon neutrinos and their antiparticles.
- The lepton number is +1 for any lepton, –1 for any antilepton and 0 for any non-lepton.
- Leptons are in two branches, the electron branch and the muon branch.
- The lepton number for each branch is conserved in any change.

Summary questions

1 State one similarity and one difference between

a an electron and a muon,

b an electron neutrino and a muon neutrino.

2 **a** What type of interaction occurs when

i two protons collide and create π mesons?

ii a beta particle is emitted from an unstable nucleus?

iii a muon decays?

b The muon decays into an electron, a neutrino and an antineutrino.

i Complete the equation below representing this decay:

$$\mu^- \longrightarrow e^- \quad + \quad +$$

ii Use the rest energy values in Table 1 on page 20 to calculate how much energy, in MeV, is removed by the neutrino and the antineutrino, if the muon and the electron have no kinetic energy.

3 **a** What is the charge of **i** a muon neutrino, **ii** an antimuon, **iii** a positron, **iv** an electron antineutrino?

b What is the lepton number of each of the above leptons?

4 State whether or not each of the following reactions is permitted, giving a reason if it is not permitted.

a $\nu_e + p \longrightarrow n + e^-$

b $\bar{\nu}_e + p \longrightarrow n + e^+$

c $\nu_e + p \longrightarrow n + e^+$

d $\bar{\nu}_e + p \longrightarrow n + \mu^+$