CHAPTER 44
PARTICLE PHYSICS AND COSMOLOGY

Discussion Questions

Q44.1 It is possible that parts of the universe contain antimatter. Only if we detect annihilation events from the presence of both matter and antimatter or by detecting particles, such as high energy antiprotons or neutrinos that come to us from these regions could we tell. Light emitted by anti-atoms does not differ in any way from light emitted by normal atoms; there are no antiphotons. If we went there the matter in us and in anything we bring with us would annihilate with the antimatter and be converted into energy.

Q44.2 Yes. Conservation of energy can be violated for short periods of time. Empty space is not really empty. It is filled with these pairs of so-called virtual particles that individually exist for very short periods of time.

Q44.3 They have similar masses and occur with both positive and negative charges. There is a neutral pion but no neutral muon. Muons are leptons and are fundamental though unstable particles. Pions are mesons and are composed of one quark and one antiquark. Muons have spin $\frac{1}{2}$; pions have spin zero.

Q44.4 We live on the surface of a very massive object that because of its mass exerts a large enough force on objects around us to have very noticeable effects on their motion. The electrical force between a pair of fundamental particles that carry charge is much larger than the gravitational force they exert on each other. But electric charge is usually present in equal amounts of positive and negative charge and the electrical forces largely cancel out.

Q44.5 The π^0 is composed of quark-antiquark pairs. The quarks and antiquarks annihilate and their mass is converted entirely into the energy of the photons.

Q44.6 Electron decay into two photons violates conservation of charge and conservation of lepton number. The photons have zero charge and zero for all lepton numbers. Electron decay into two neutrinos also violates conservation of charge and conservation of lepton number. Neutrinos have zero charge and no pair of neutrinos has the same set of lepton numbers as an electron.

Q44.7 They both have spin $\frac{1}{2}$. Some of each are charged and some of each aren't. All baryons have mass. In the standard model the neutrino leptons have zero mass. The lightest baryons are heavier than the electron. Leptons are fundamental. Baryons are composite particles, composed of three quarks. Leptons have lepton numbers and baryons have baryon number and both these are separately conserved.

Q44.8 Both leptons and quarks are fundamental particles. Both have spin $\frac{1}{2}$. Leptons have integer Q/e; quarks have fractional Q/e. Leptons and quarks have different conserved quantities (lepton number for leptons and baryon number, strangeness, charm, bottomness and topness for quarks).

Q44.9 To obtain the quark content of an antiparticle, replace quarks by antiquarks and antiquarks by quarks in the quark composition of the particle. (a) The antineutron has quark content that consists of three antiquarks, $\boldsymbol{\bar{u}\bar{d}\bar{d}}$. (b) This is different from the quark content of the neutron and the neutron is not its own antiparticle. (c) The antiparticle of the ψ has quark content $\boldsymbol{\bar{c}c}$. This is the same as the quark content of the ψ and the ψ is its own antiparticle.

Q44.10 No. In the standard Big Bang model the universe was once in a small volume. Since then it has expanded and all points are moving away from all other points. There is no stationary center.

Q44.11 See the CAUTION statement in Section 44.6. The universe is thought to be infinite. It has no edges, so there is nothing "outside" of it and it isn't "expanding into" anything. The expansion of the universe simply means that the scale factor of the universe is increasing.

Q44.12 The cosmological principle says that the universe looks essentially the same from all observation points. If the universe had an edge it would look very different to an observer at the edge than it would to someone in the interior, far from the edge.

Q44.13 The cosmological principle requires that the universe look essentially the same from all observation points. H_0 must be constant in space so that in all directions galaxies appear to be receding from any observer anywhere in the universe. It can't be different at different places. But this does not prevent H_0 from changing in time. In fact, the most recent astronomical observations suggest that H_0 is now larger than it was in the past.