PHYSICS 1020

Homework set 18

2 April 1997

[**18.1**] What is the evidence, in reference to Figure 18.8(a), that each pair consists of two oppositely charged particles?
Answer:
The picture shows tracks of electron-positron pairs created from a photon in a bubble chamber. A magnetic field exerts a force on charged particles, thus causing their trajectory to be circular. The direction of curvature depends on the sign of the charge of the particle. Since the two tracks of each pair have opposite sense of curvature, one can conclude that they are oppositely charged.

[**18.2**] In Figure 18.8(a), which of the two pairs has the faster moving particles? How do you know?
Answer:
When charged particles are deflected in a magnetic field, the radius of the trajectory depends on the momentum — the larger the momentum, the larger the radius of the circle (i.e. smaller curvature). In the picture, the tracks of the lower pair have less curvature, so they must have higher momentum.

[**18.5**] Making estimates. Suppose that a proton-antiproton pair, at rest, annihilate and create two photons. Using the data from the preceding exercise (i.e. exercise 18.4), estimate the frequency of each photon. A proton is nearly 2000 times more massive than an electron.
Answer:
The energy of photons generated in the annihilation of an electron-positron pair is equal to the total mass energy that is converted into photon energy. The mass energy of an electron is about 0.511 MeV, so this is on the average the energy of each of the two photons. Using $E = hf$, with $h = 4.16 \times 10^{-21}$MeVs, we find for the frequency

$$f = \frac{E}{h} = \frac{0.511\text{MeV}}{4.16 \times 10^{-21}\text{MeVs}} = 1.23 \times 10^{22}\text{Hz}$$

Since protons are about 2000 times (more precisely 1836 times) more massive than electrons, the photons from the annihilation of a proton/antiproton pair will have a frequency about 2000 times as high.

[**18.6**] Of the 10 electroweak particles (see table 18.1), which ones travel at (or near) light-speed?
Answer:
Strictly speaking, only particles without restmass (with rest mass = 0) can travel at the speed of light. If the total particle energy is large compared to the rest energy, the speed of the particle can be rather close to the speed of light. The lighter (less massive) a particle is, the easier it is to have energy much larger than rest energy. So we expect the photon always to travel at the speed of light, and the neutrinos close to the speed of light. (In fact, measurement of the speed of neutrinos has not shown any evidence for deviations from the speed of light).

[**18.7**] Of the 10 electroweak particles (see table 18.1), which ones can feel the electric force? Which can exchange photons?

Answer:

The particles which have electric charge can feel the electric force, i.e. the electron, muon, tauon, W, Z. These same particles can also exchange photons, because this is just the way particles "feel" the electric force – by emitting and absorbing photons.

[**18.9**] In what ways are the W and Z particles similar to photons? In what ways are they different?

Answer:

Similarities: They are all exchange particles – "gauge bosons" which play a role as mediators of interactions; they all have spin 1.

Differences: the photon is massless (zero rest mass), while the W and Z are massive; the photon always travels at lightspeed, while the W and Z don't; the photon and Z are neutral, while the W's are charged.

[**18.10**] In what ways are gluons similar to photons? In what ways are they different?

Answer:

Both gluons and photons are neutral and massless, and move at lightspeed.

Both gluons and photons are "gauge bosons" of spin 1, and they play a role as mediators of interactions. The gluons are the mediators of the strong interaction (force), while the photon is the mediator of the electromagnetic interaction.

Unlike the photon which is electrically neutral and does not "feel" the electromagnetic interaction which it mediates, the gluons carry "color charge" and therefore feel the strong interaction.

As a consequence, gluons can interact with each other by the strong interactions, while photons cannot interact with each other.

[**18.11**] In what ways are quarks similar to electrons? In what ways are they different?

Answer:

Similarities:

Both quarks and electrons are fermions, i.e they have half-integer spin; they both are matter particles, i.e. they are the basic constituents of material objects.

They both are "massive", i.e. their rest mass is non-zero (i.e. they move at less than lightspeed).

They both appear to be "point-like", i.e. there is no evidence for them to have any substructure (but this may just mean that we haven't yet looked close enough).

Differences:

Quarks have fractional electric charges (1/3, 2/3), while electrons have integer charge (in terms of proton charges).

Quarks carry color charge, i.e. they feel the strong interaction, while electrons don't.

[18.12] Give at least one specific reason (other than a general belief in unity) why scientists believe that there is probably a single theory that can unite the electroweak and the strong force into a single grand unified force.

Answer:

According to our present understanding, the weak, electromagnetic and the strong interactions are mediated by the exchange of "gauge bosons" whose existence can be derived from the assumption that there be a group of certain transformations (called "local gauge transformations") under which the laws of physics are invariant. In the past, there have been steps of unification in which it was shown that forces that previously had been thought to be very different, were in fact different aspects of the same force: Newton unified "heavenly" and "earthly" motions by showing that they were all due to the same principles, and that the same force was responsible for the motion of the moon around the earth as for the falling of the apple form the tree.

A further step of unification was made by Maxwell in the 19th century who showed that electric and magnetic forces were really two different aspects of "electromagnetism."

Another big step in the direction of unification was made in the 1970's and 1980's when it was shown that the weak and the electromagnetic interactions were different aspects of the "electroweak" interaction.

Given the fundamental similarity between the strong and the electroweak interaction, it seems plausible that a more general theory than the standard model could be found in which the strong and electroweak forces become unified.

[18.14] In what ways was the emergence of the four different fundamental forces during the big bang similar to the change of state of water from liquid to solid?

Answer:

As the temperature dropped (i.e the average energy decreased), each one of the fundamental forces (gravitational, strong, weak, electromagnetic) "froze out" and manifested itself as a separate, distinct force. This process involved a loss of symmetry, similar to the loss of symmetry when water (which is the same in all directions, or symmetric) freezes and turns into ice (which has a crystal lattice and so is not the same in all directions).