Homework X

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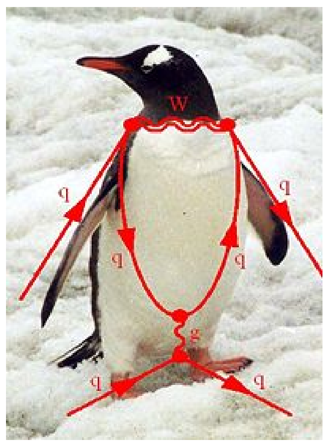
Here is a penguin diagram for your amusement:



Problem 1 Where are the particles?

This problem is taken from *Introduction to Elementary Particles* by David Griffiths.

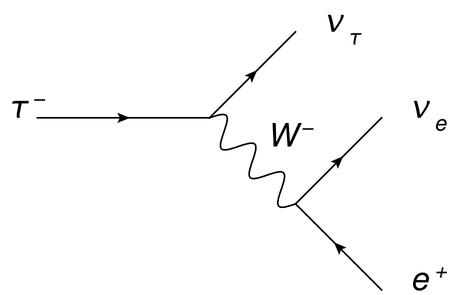
> Your roommate is a chemistry major. She knows all about protons, neutrons, and electrons, and she sees them in action every day in the laboratory. But she is skeptical when you tell her about positrons, muons, neutrinos, W bosons, and quarks. Explain to her why none of these plays any direct role in chemistry. (For instance, in the case of the muon a reasonable answer might be 'They are unstable, and last only a millionth of a second before disintegrating.')

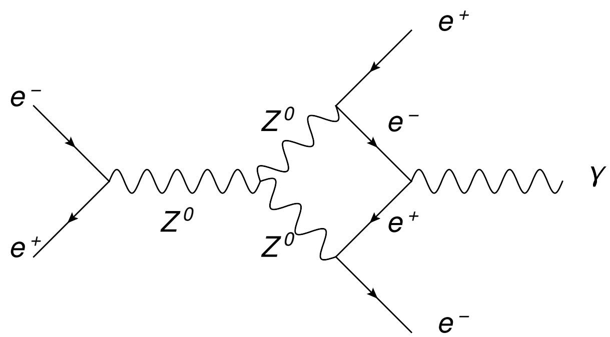
Problem 2 Elastic scattering diagrams

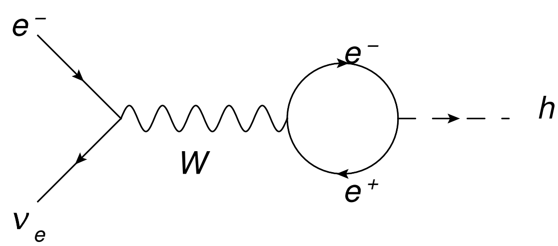
Draw all of the diagrams from QED with two or four vertices that contribute to the elastic scattering process $e^+e^- \to e^+e^-$.

Problem 3 Conservation laws

Which of the following diagrams are impossible due to violation of conservation laws? Do any have a threshold energy (a minimum energy in the center of momentum frame for the initial state, below which the process can't happen)?







Problem 4 Nonclassical photon effects

When electromagnetic fields become very strong, QED predicts a process called *Schwinger pair production.* Essentially, the electromagnetic fields will suddenly start converting their energy to $f\bar{f}$ pairs. Draw a tree level Feynman diagram for this process.

QED contains diagrams corresponding to two other non-classical effects. The first of these is elastic light-by-light scattering, i.e. the scattering of two photons to two photons. There is also a diagram for a single photon to decay into two photons. Draw Feynman diagrams for each of these processes.

Note: If the photon splitting bothers you, don't worry. Remember how the Feynman diagrams really represent numbers? The $\gamma \to 2\gamma$ diagram is actually equal to zero!

Problem 5 Feynman's aliens

The following is a famous quote from Feynmans' *Lectures on Physics*:

> ...image we were talking to a Martian, or someone very far away, by telephone. We are not allowed to send him any actual samples to inspect... Now we want to tell him all about us. Of course, first we start defining numbers, and say, "Tick, tick, *two*, tick, tick, tick, *three*...," so that gradually he can understand a couple of words, and so on. After a while we may become very familiar with this fellow, and he says, "What do you guys look like?" We start to describe ourselves, and say, "Well, we are six feet tall." He says, "Wait a minute, what is six feet?" Is it possible to tell him what six feet is? Certainly! We say, "You know about the diameter of hydrogen atoms-we are 17,000,000,000 hydrogen atoms high!" ...So we start to describe the various organs on the inside, and we come to the heart, and we carefully describe the shape of it, and say, "Now put the heart on the left side." He says, "uhhh-the left side?" Now our problem is to describe to him which side the heart goes on without his ever seeing anything that we see, and without ever sending any sample to him of what we mean by "right"-no standard right-handed object. Can we do it?

Answer Feynman's question with either an explanation of how it may be done or why it can't be!

Problem 6 Antihydrogen

Physicists have successfully produced and trapped antihydrogen at CERN. Read `http://athena-positrons.web.cern.ch/ATHENA-positrons/wwwathena/hbar.html` for information on why this is interesting, and `http://athena-positrons.web.cern.ch/ATHENA-positrons/wwwathena/overview.html` for more info on how they do it.

Problem 7 Reading

Read chapters 8 and 9 of Oerter.