Homework VIII

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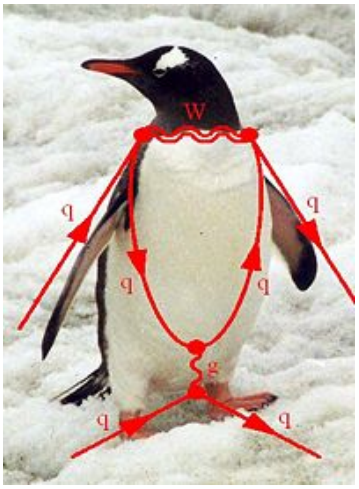
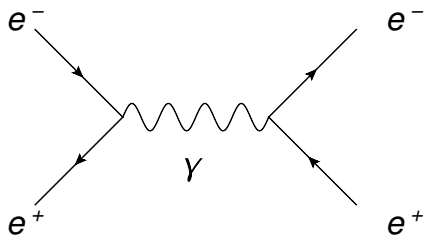
Take $c = 1$ in this assignment. Particle physicists almost never make c explicit. Also, here is a penguin diagram:



Problem 1 Virtual particles

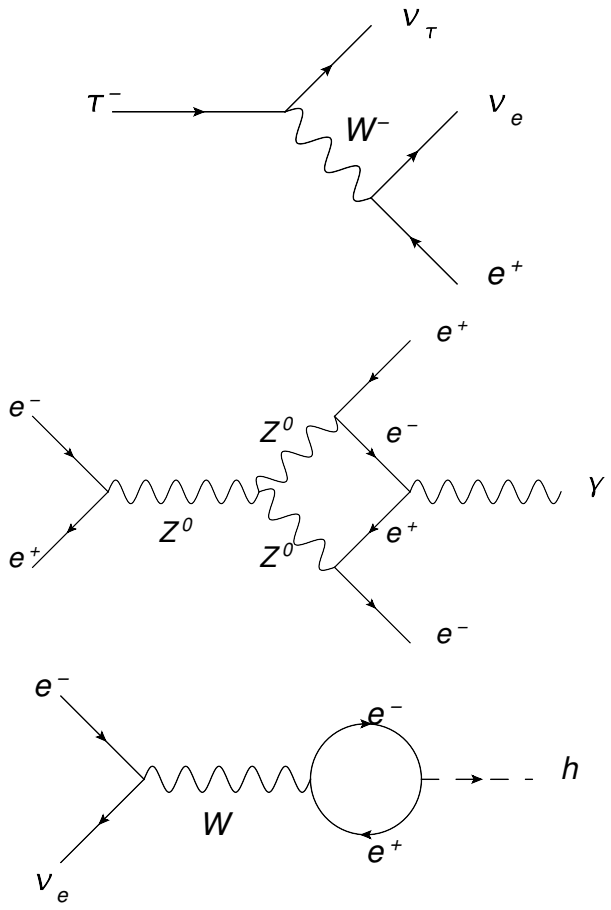
We learned in class that $\Delta E \Delta t \geq \hbar/2$. This means that particles with finite lifetime have an uncertainty in their mass, and that the virtual particles may not satisfy $p_\mu p^\mu = -m^2$[1]. Show that the invariant mass squared of the photon is nonzero in the following diagram:



[1] A particle that does not satisfy the momentum relation is called *off shell* (short for on mass shell), while one that does is called *on shell*.

Problem 2 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 3 Nonclassical photon effects

The diagram I drew at the end of class on Day 7 corresponds to an effect called *Schwinger pair production*. Essentially, strong electromagnetic fields will suddenly start converting their energy to $f\bar{f}$ pairs.

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 the Feynman diagrams for 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 4 Antihydrogen

I mentioned that 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 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 Reading

Read chapters 8 and 9 of Oerter. Also check out the news article I linked, Fermilab just announced the observation of a new particle today!