FYS3500 Problem set 4

Problem 1

a) From M&S 1.1.3: The Standard Model of particle physics aims to describe all phenomena of particle physics, except those due to gravity, in terms of the properties and interactions of a small number of elementary particles. The elementary particles are separated into the matter particles (quarks and leptons, each consisting of three generations) which are fermions, and the force carrying particles, which are bosons S=1 (also called gauge bosons), and then the Higgs particle (S=0).

b) The four fundamental forces are the strong force, the electromagnetic force, the weak force, and gravity. The Standard Model solely describes the first three forces. Among the fermions, solely the quarks feel the strong force. All particles with charge interact electromagnetically, and so the quarks and the charged leptons feel the EM force. All the fermions feel the weak force. This means that the neutral leptons (aka the three neutrinos) only interact weakly.

c) According to the Standard Model, interactions take place as an exchange of a force carrying boson. (Also called gauge boson). These are virtual particles, as the boson does not appear as a real particle in the final state.

The strong interaction is mediated by the gluon, the EM by the photon, and the weak by either the Z0 or the W+/-.

Problem 2

a) Feynman diagrams are used as a visualization of how particles interact; they help us to see how an interaction takes place, which force that mediated the interaction, and determining the probability for the reaction to occur. (There are also mathematical rules associated with them, which we won't delve too deeply into)

b) Basic rules:

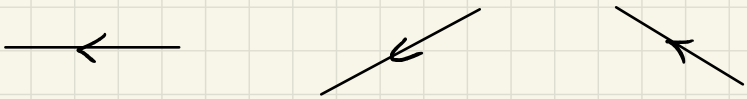
- Initial-state particles on the left, and final-state particle on the right (aka arrow of time: $\longrightarrow$)

- Virtual particles are connected in a vertex on both sides

- Spin-1/2 fermions are drawn like this:

with arrow always pointing in positive time direction

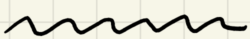
- spin-1/2 anti-fermions are drawn like this:



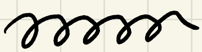
with arrow pointing in negative time direction

NB: not direction of motion!

- spin-1 bosons, aka γ, Z^0, $W^\pm$ are drawn like:



exception: gluons are drawn as:



- spin-0 boson (Higgs) drawn as:

- Some quantum numbers, like e.g. charge, must be conserved in each vertex. We will later learn more q.nrs that must be conserved.

c) The virtual particles have vertices on either side in the Feynman diagram, while the real particles only have it on one side.

d) The order of the Feynman diagram is the number of vertices in the diagram, and lower-orden interactions are generally more probable than higher-order interactions.

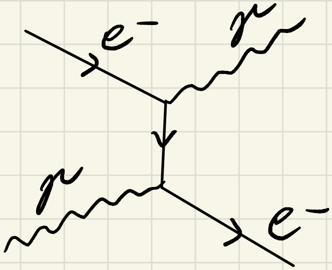
e) The leptons (l^-) should have arrows pointing to the right, and the anti-leptons (l^+) should have arrows pointing to the left...

Problem 3

a) An electron and a positron annihilate into a photon which then again produces an electron-positron pair. Photon mediator $\Rightarrow$ EM force

b) Two electrons interact via the exchange of a photon. (Like repulsion due to same charge!)

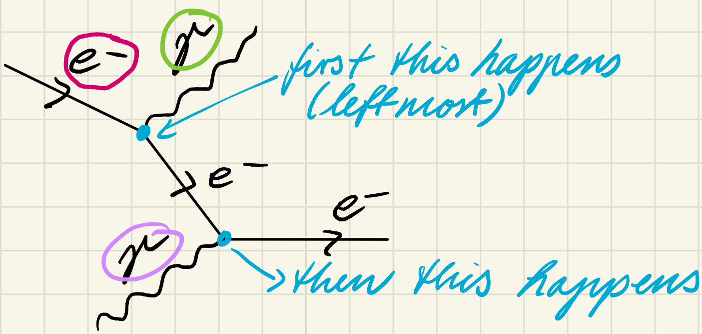
c) This one:



is when you have $e^- + \gamma \to e^- + \gamma$; a photon and an electron bounce off each other, aka Compton scattering.

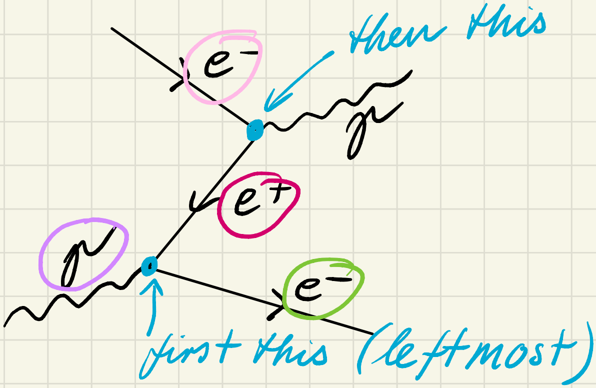
There are two ways this can happen:

1)



The electron emits a photon, and then bounces off a incoming photon.

2)



The incoming photon pair produces e^+ e^-, the e^+ annihilates with the incoming electron, and a photon is produced

$\Rightarrow$ The outcome is the same in both Feynman diagrams:

$$e^- + \gamma \to e^- + \gamma$$

We say 1) & 2) have different time orderings

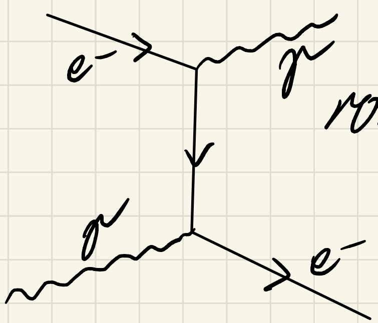
Problem 4

M&S 1.10

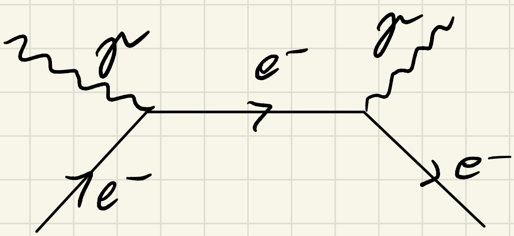
Topologically distinct: not only different time orderings; changing the order of events doesn't give same digram (unlike 1) & 2) in the previous exercise)

Easiest way: rotate 90°:

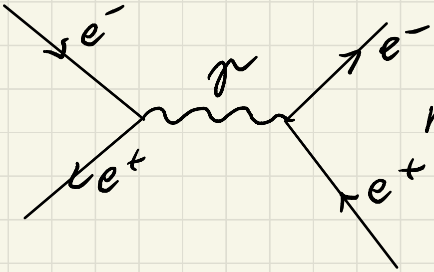
a) $\gamma + e^- \to \gamma + e^-$



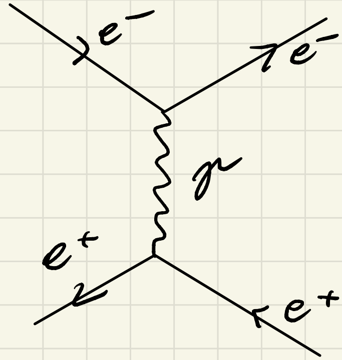
rotate:



b) $e^+ + e^- \to e^+ + e^-$

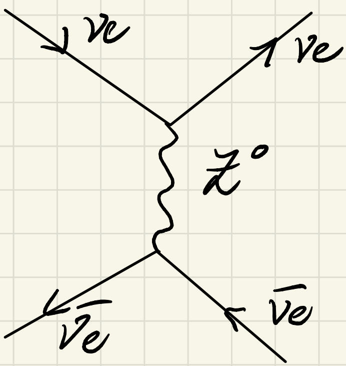


rotate

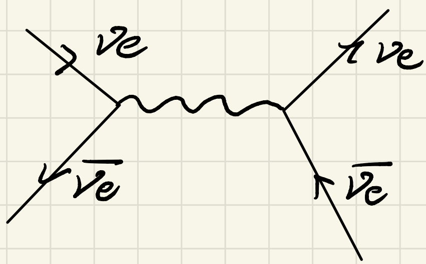


c) $\nu_e + \overline{\nu_e} \to \nu_e + \overline{\nu_e}$

Neutrino: must be weak interaction



rotate:

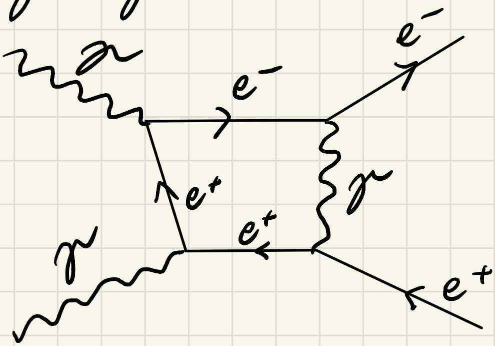


(Charge must be conserved at each vertex)

Problem 5

1.11 in M&S 2019

a) $\gamma + \gamma \rightarrow e^+ + e^-$



b) $e^+ + e^- \rightarrow e^+ + e^-$