PARTICLE TRANSFORMATIONS
STUDENT GUIDE

To: The Particle Decay Observation Facility (PDOF) Student Research Committee (SRC)

From: Tomoko Yamada, PDOF Director

As members of PDOF, you are tasked with finding empirical rules of particle decay. Remember that a particle “decay” is the transformation of one particle into more than one. It is *not* the “breaking down” of a particle into constituents. Indeed, any one particle can have multiple decays or transformations into different particles. The Experimental Group has created a set of particle transformation (Feynman diagrams named for their creator Richard Feynman) of commonly observed decays.

Determine conservation rules that govern these transformations of all particles or of specific classes of particles. For example, we know that momentum is conserved for all particle transformations. Are some quantities conserved for all particle transformations? Are other quantities conserved only for transformations of certain classes of particles? Examine the transformations to determine what quantities are conserved.

Pool your results with other SRC members and make conclusions about conservation rules governing particle transformations. Your supervisor will validate your results and pass these on to the Theory Group to do whatever it is they do. (They already have a theory about the transformations, hence the Feynman diagrams.)

What are the research questions?

- Which quantities or characteristics are conserved for all particle transformations?
- Which quantities or characteristics are conserved only for specific classes of particle transformations? Which classes?

What tools do we need for our analysis?

You have:

- A file of one of these types of particle transformations:
  - Lepton decays
  - Meson decays
  - Gauge boson decays
  - Zoo – optional challenge examples
- A Standard Model Chart.
- A table of particles and their characteristics.
- Information found in this guide.

What will we do?

The SRC will divide into small teams. Each team will have a file of particle transformations associated with a particular class of particles. Your team will use the resources to provide evidence to support which particle properties are conserved. Each transformation diagram has a simple table in which you can write down quantities before and after the transformation. Then, the SRC will reconvene to build a consensus of the rules the committee discovered and determine when each rule applies. Your supervisor will make a final validation.

What are our claims? What is our evidence?

Use the evidence of the observed particle transformations to make claims about which quantities found in the table are conserved. Decide if the claim applies to all particles or only to certain classes of particles. Provide evidence to support your claim.

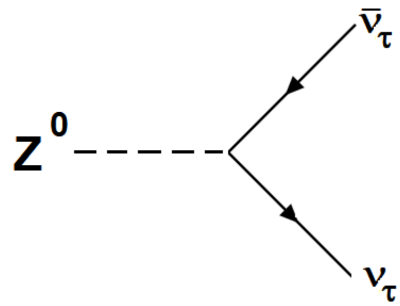
What do we know?

About the particles:

1. There are three categories of fundamental matter particles: leptons, quarks, and gauge bosons, also known as force carriers.
2. All leptons and quarks have antimatter counterparts. For example, the up quark has a counterpart of opposite electric charge, the anti-up quark. Another example: the antiparticle of the electron, a lepton, is the positron.
3. Gauge bosons are their own antiparticles. Or, to think of it another way, gauge bosons are not characterized as particle or antiparticle.
4. We will examine the decays of leptons, gauge bosons, and mesons, which are made up of quark-antiquark pairs.

About the particle transformation diagrams:

5. Particles are represented by their symbols.
6. All of the diagrams are presented with time assumed to go from left to right. Thus, the left side of the diagram will show the initial particle which transforms into the particles on the right side.
7. The lines in the diagram do not represent trajectories or paths; they just connect the particles based on the interaction.



8. Gauge bosons have dashed rather than solid lines and no arrows in our usage.
9. The arrows on the solid lines point in the direction of time for matter and opposite the direction of time for antimatter.

About numbers:

10. Every particle has an invariant mass except for gluons and photons, which have zero mass.
11. Each of the three charged leptons—electron, muon, and tau—has an associated neutrino which has zero charge and almost zero mass. The same is true for antileptons. All leptons have lepton number +1. All antileptons have lepton number -1.
12. Electron, muon, and tau are "flavors" of leptons. Each flavor of lepton or antilepton also has a +1 or -1 flavor number. For example, muons and muon neutrinos have muon number +1 while antimuons and antimuon neutrinos have muon number -1.
13. Quarks and leptons have generation numbers I, II, and III. It is traditional but not necessary to write these with Roman numerals.
14. Matter particles have electric charge that have antimatter counterparts with opposite electric charge.
15. All the numbers you need are found in the table.

Questions

1. Which quantities are conserved for meson transformations?
2. Which quantities are conserved for lepton transformations?
3. Which quantities are conserved for gauge boson transformations?
4. Which quantities are conserved for all transformations?
5. Are there any other patterns that can be observed?
6. If there is an exception to a rule, can it still be a valid rule? If so, how?