Weak Interactions

◎ $W^{\pm}$ boson interactions ("Charged Weak")

- One of the force carriers is the $W^{\pm}$ boson
  - It is charged and not its own antiparticle (ie, W^+ and W^- are each other's antiparticle)
  - It is massive (mass = M_W)

- Feynman Rules for a massive, charged $W^{\pm}$

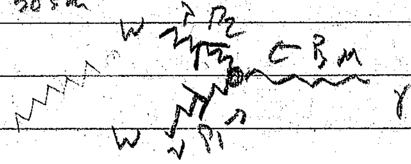
  - An external line comes with polarizations
    + Must have 4 rules
      $\vec{p}$ ~~~~• = W^+ incoming, •~~~~$\vec{p}$ = W^+ outgoing
      $\vec{p}$ ~~~~• = W^+ incoming, •~~~~$\vec{p}$ = W^+ outgoing
    + Completeness relation is modified b/c there are 3 polarizations

$$\sum_{pol} \epsilon_\mu \epsilon_\nu^* = -g_{\mu\nu} + p_\mu p_\nu / M_W^2$$

  - Propagator is

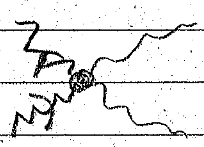
$$\bullet\!\!\sim\!\!\overset{\vec{p}}{\sim}\!\!\sim\!\!\bullet = \frac{-i\left(g_{\mu\nu} - p_\mu p_\nu / M_W^2\right)}{p^2 - M_W^2}$$

  - Vertices with photons (that is what charge means!)
    + 3-boson



$$= ie\left[g_{\nu\lambda}(p_1 - p_2)_\mu + g_{\lambda\mu}(p_2 - p_3)_\nu + g_{\mu\nu}(p_3 - p_1)_\lambda\right]$$

    + 4-boson

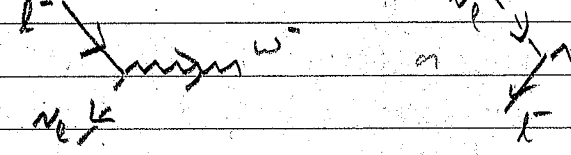


= ...

- Vertices with Fermions
  - Due to charge, the $W^{\pm}$ interactions change the particle type, ie charged lepton to neutrino

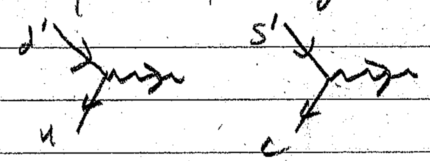
- The vertex is "vector minus axial" or "left-handed"

- The vertices for leptons are



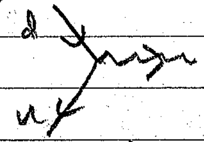
$$= \frac{-ig_w}{2\sqrt{2}} \gamma^\mu (1-\gamma^5)$$

- For quarks, they are almost within generations

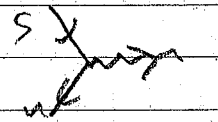
+ 

etc

+ But that's not quite right! The weak force sees "primed" negatively charged quarks. We get all 9 possible interactions



$$= \frac{-ig_w}{2\sqrt{2}} V_{ud} \gamma^\mu (1-\gamma^5)$$



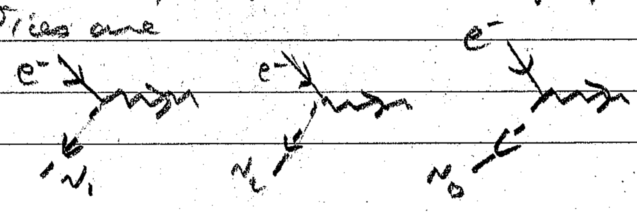
$$= \frac{-ig_w}{2\sqrt{2}} V_{us} \gamma^\mu (1-\gamma^5)$$

, etc

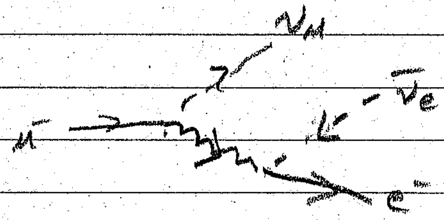
+ V_{ij} = Cabibbo-Kobayashi-Maskawa (CKM) matrix

+ This allows many weak decays, etc
+ Means that the "true" quark flavors seen as mass eigenstates, etc, are not the weak states

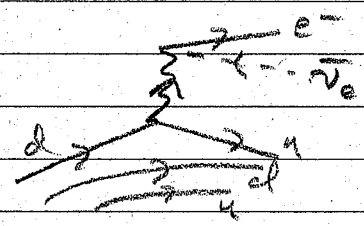
- Neutrino oscillations
  + The vertices above are not the whole story
  + In reality, the "true" neutrino mass eigenstates are ν_1, ν_2, ν_3. The "flavor" states ν_e, ν_μ, ν_τ are superpositions
  + Vertices are



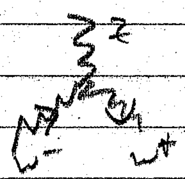
- Processes
  - Muon decay

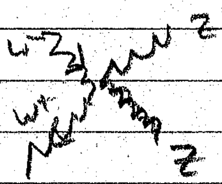


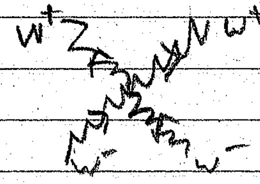
  - Neutron decay

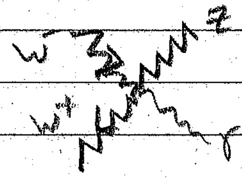


- **Neutral Weak Interactions (Z interactions)**
  - The lines look like those for $W^{\pm}$, except the Z is its own antiparticle
  - There are lots of Z + W interactions

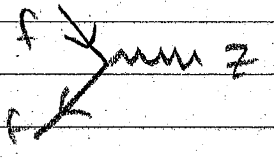








  - The Z interaction does not change fermion type



$$= \frac{-ig_z}{2}\gamma^{\mu}\left(c_V^f - c_A^f\gamma^5\right)$$

where c_V^f, c_A^f are coefficients depending on fermion type. See table 9.1