Recap!

- Vector current splits into L-chiral + R-chiral "sectors"

$$j^\mu = \bar{\Psi}_L \gamma^\mu \Psi_L + \bar{\Psi}_R \gamma^\mu \Psi_R$$

- Assumed true for all interactions, but weak interaction violate parity conservation

  - W^+ ~~coupes~~ couples to L-chiral particles, R- " antiparticles

$$j^{\mu\,\text{weak}} = \bar{\Psi}_L \gamma^\mu \Psi_L$$

  - no RH particle sector
  - no RH neutrino because of current

- Parity operator: γ^0

- Showed: Time component of $\bar{\Psi}\gamma^\mu\Psi$ unchanged by a parity transformation

  Spatial components change sign...

So $\bar{\Psi}\gamma^\mu\Psi$ violates parity conservation (!?)

BUT: We observe probabilities, not currents, so we should see Parity violating effects in the probabilities.

Schematically. Prob $\propto$ V V V = vector current

Timelike: $V^0 V^0 \xrightarrow{\hat{P}} V^0 V^0$

Spacelike: $V^i V^i \xrightarrow{\hat{P}} (-V^i)(-V^i) = V^i V^i$

Probabilities are not affected by a parity transformation

ie. Vector current <u>conserves</u> parity

We need to add something to the vector current to form the weak current

$$j^{\mu, \text{weak}} = j^{\mu, V} + ?$$

What are the choices? Bilinear Covariants

$\bar{\Psi}\Psi$ Scalar Current S

$\bar{\Psi}\gamma^5\Psi$ Pseudoscalar Current P

$\bar{\Psi}\gamma^\mu\Psi$ Vector " V

$\bar{\Psi}\gamma^\mu\gamma^5\Psi$ Axial Current A

$\bar{\Psi}\frac{i}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)\Psi$ Tensor T

$j^{\mu,V}$ is a vector quantity, so <u>dimensionally</u> the only quantity I can add is A

$$j^{\mu,weak} = j^{\mu,V} - j^{\mu,A}$$

$$= \bar{\psi}\gamma^{\mu}\psi - \bar{\psi}\gamma^{\mu}\gamma^{5}\psi$$

$$= \bar{\psi}\gamma^{\mu}(1-\gamma^{5})\psi$$

$$= 2\cdot\bar{\psi}\gamma^{\mu}\cdot\frac{1}{2}(1-\gamma^{5})\psi$$

$$= 2\cdot\bar{\psi}\gamma^{\mu}P_L\psi$$

$$= 2\cdot\bar{\psi}\gamma^{\mu}\psi_L$$

$$= 2\,\bar{\psi}_L\gamma^{\mu}\psi_L$$

We are left with a weak current which violates parity as we've removed the R-chiral bit of the vector current.

The current $\bar{\psi}\gamma^{\mu}(1-\gamma^{5})\psi$ is called the **V-A current**

Why does this work? Consider probabilities again

$$\text{Prob} \propto (V-A)(V-A) \simeq VV + AA - 2AV$$

Under parity: $A^0 \to A^0$, $A^i \to A^i$

$$\text{Prob}: VV + AA - 2AV \xrightarrow{\hat{P}} (-V)(-V) + AA - 2A(-V)$$
$$= VV + AA + 2AV$$

The interference between A and V generates the parity violation we observe.

Incidentally: $S \pm P$ would also work but didn't agree with experiment. V−A works.

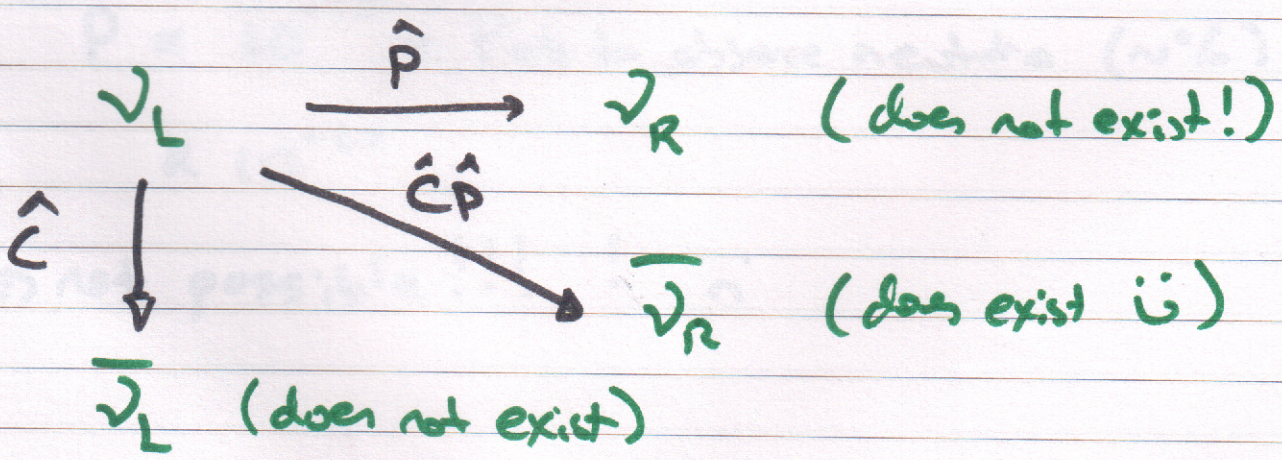
The appearance of parity violation was a great shock. Physicists scrambled to "save" the theory

- Perhaps what we mean by "parity" is not what the universe means.

Charge conjugation symmetry, C

Charge conjugation changes particles to anti-particles

$$\hat{C}\,|p\rangle = C\,|\bar{p}\rangle \qquad p \equiv \text{particle}$$



The idea is that the universe meant "CP" and not just P [invert the spatial dimensions, yes, but you also need to change all the charges]

Clearly the universe is symmetric under $\hat{C}\hat{P}$

Unhappily, no! :(

Shortly experimental evidence in the weak decays of K^0 showed that CP was also violated in weak interactions.

One of the big questions is: is do neutrinos violate CP as well as quarks.

OK: neutrinos have L-chirality and mass - so there must be a R-helical neutrino out there

Prob (L-chirality and R-helicity) $\propto \left(\frac{m}{E}\right)^2$

For ν: $m \simeq 10^{-3}$ eV , $E \simeq 100$ keV

$P \propto 10^{-18} \times$ Prob to observe neutrino ($\sim$%)

$\propto 10^{-20}$

$\Rightarrow$ not possible!!! ! :(