The Wu Experiment: Parity Violation in Weak Interactions

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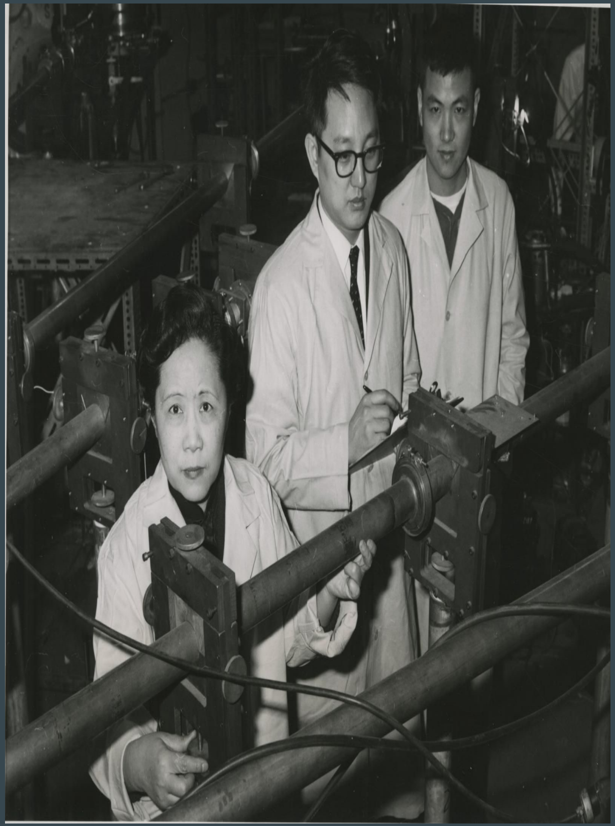
The Life and Accomplishments of Chien Wu:

- Born in Shanghai, China in 1912.
- Attended the University of Shanghai for undergrad.
- Received her PhD in physics at Berkeley.
- Joined the faculty at Columbia and Smith College.

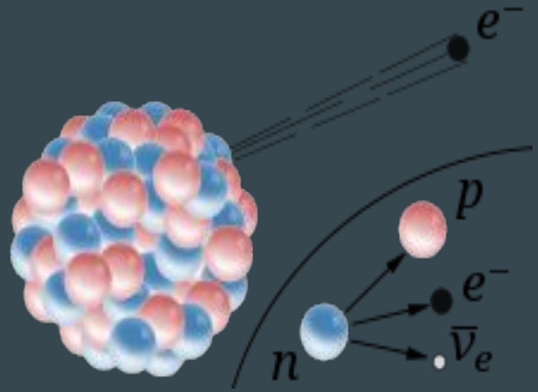
The Life and Accomplishments of Chien Wu:

- Joined the Manhattan Project in 1944.
- Worked on Beta decay at Columbia after WWII.
- Began working with Tsung Lee and Chen Yang on parity violation in 1956.
- Lee and Yang Awarded the Nobel Prize in 1957 for work done by Wu.
- Continued to do research in physics and biology and won many awards later on in her career.



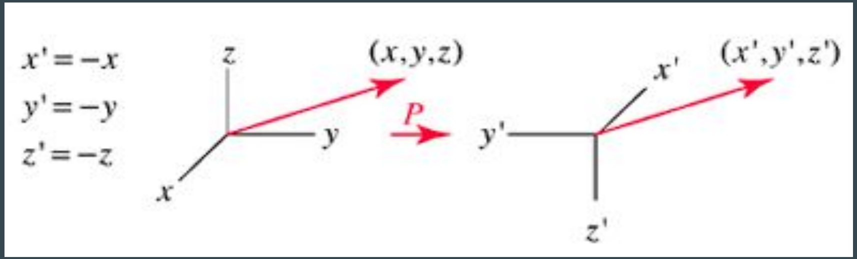
Weak Interactions:

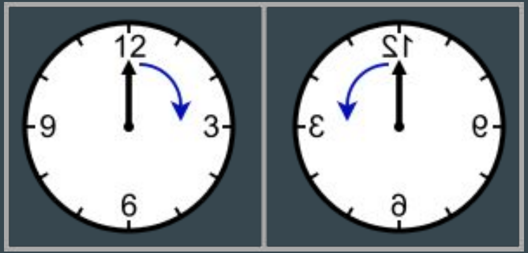
- One of the four fundamental forces.
- Mechanism of subatomic interaction responsible for radioactive decay.
- Six types (flavours) of Quarks make up composite particles like neutron/proton.
- Weak interaction allows these Quarks to change their ‘flavour’ by exchanging force-carries, namely W+, W-, and Z Bosons.
- Example: In Beta Decay, down quark turns into up quark, thus changing neutron into proton and resulting in emission of electron and electron antineutrino.



Parity Conservation and P-symmetry:

- The current world and its mirror image would behave in the same way, but left and right are reversed.
- In 1927, Eugene Wigner (Not Dr. Strange!) formalised this principle of conservation of parity.
- Parity transformation changes a right-handed coordinate system into a left-handed one.
- It’s a reasonable supposition that nature shouldn’t care about whether the coordinate system is right-handed or left-handed. This is the concept of P-conservation.



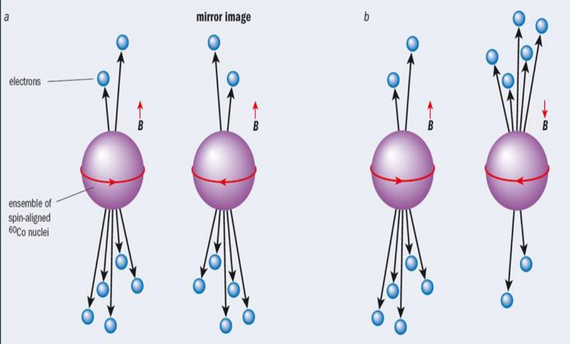


Parity Violation & Motivation of The Experiment:

- Parity conservation was tested and confirmed for electromagnetic and strong interactions
- Based on mass and lifetime, two particles τ and θ, appeared to be the same, but based on spin and intrinsic parity analysis of its decay products, they were different.
- Intrinsic parity of a pion is P = -1, and since parity is a multiplicative quantum number, θ has P = +1, while τ has P = -1.
- This is known as the τ-θ problem.
- In 1956, Lee and Yang proposed that this will be solved if parity was violated in weak interaction, which would mean τ and θ are the same particle with two different decay modes. They also proposed experimental ideas on testing this theory.

$$\theta^{+} \rightarrow \pi^{+} + \pi^{0}$$

$$\tau^{+} \rightarrow \pi^{+} + \pi^{+} + \pi^{-}$$



Experimental Design: $^{60}_{27}Co \rightarrow ^{60}_{28}Ni + e^{-} + \bar{\nu} + 2\gamma$

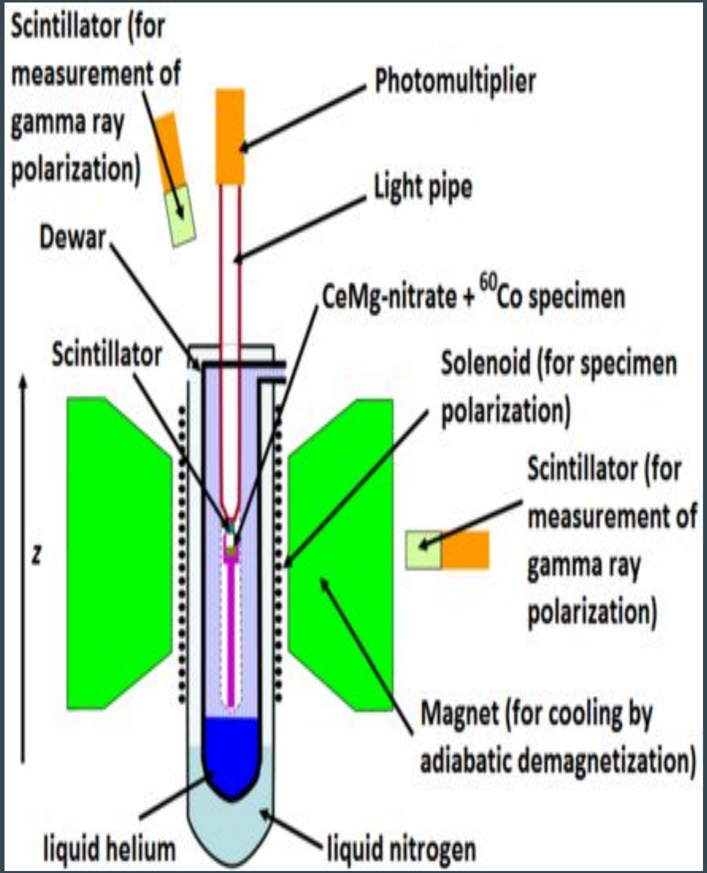
- The goal was to experimentally confirm parity violation in weak interactions.

- Wu proposed the idea to observe the decay of Cobalt-60 for its beta decay and gamma ray production.

- Observing additional processes that were known to obey parity conservation served as a control for the experiment.

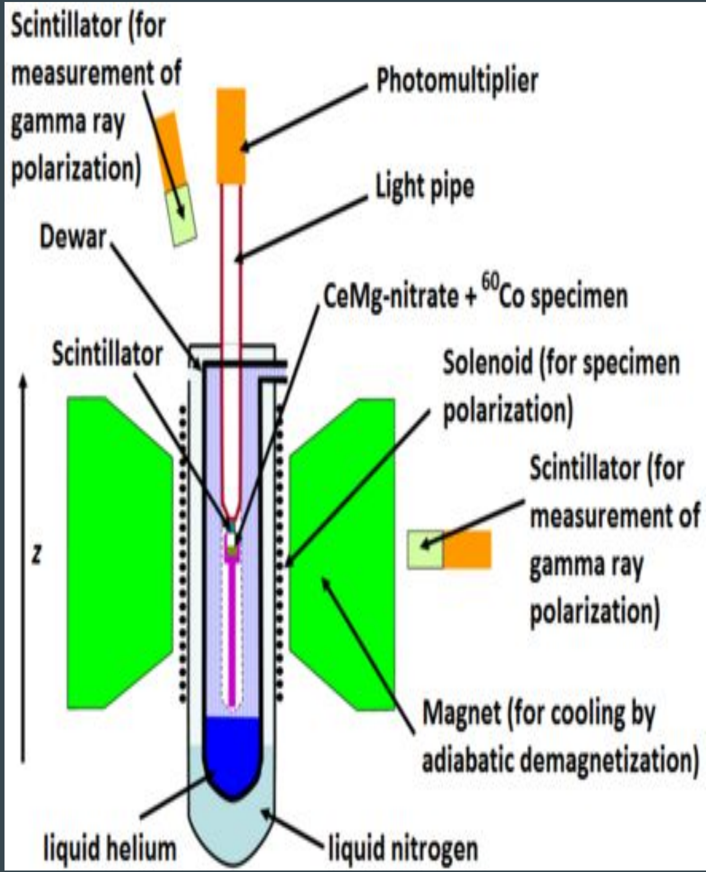
Experimental Design:

- Wu planned to observed the emission rates of the gamma rays and beta particles.
- In principle this concept was simple, but it was a bit challenging in practice.
- The most difficult aspect was achieving a high polarization of the Cobalt Nuclei.
- To do this, they needed extremely low temperatures coupled with a large magnetic field.



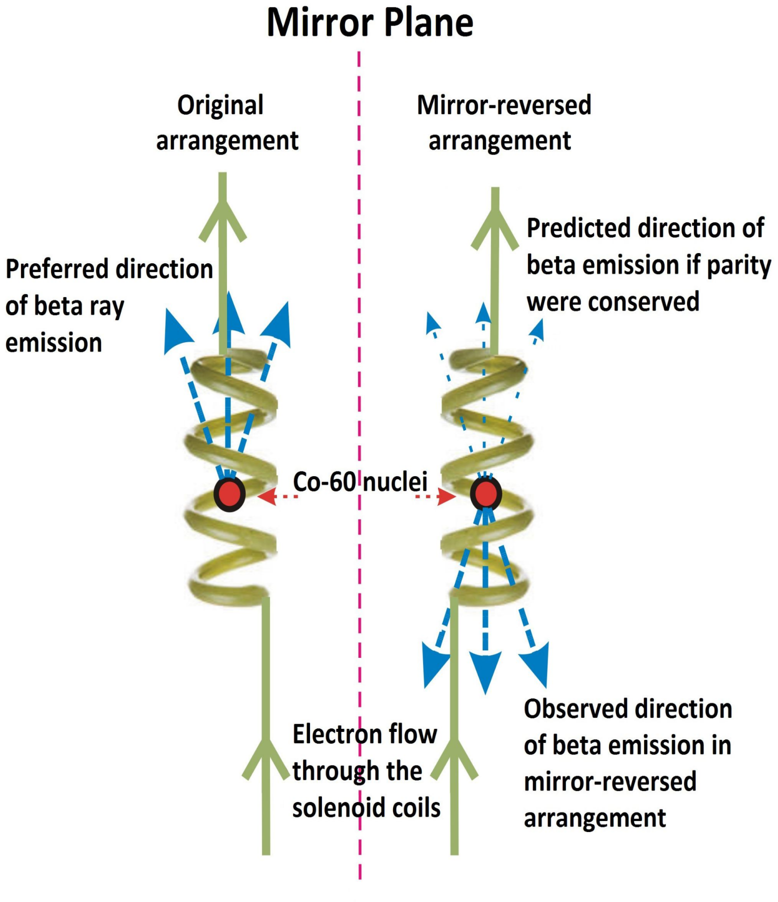
Experimental Design:

- These low temperatures were achieved using liquid helium and adiabatic demagnetization.
- The magnetic material cerium magnesium nitrate (a paramagnetic salt).
- CeMg-nitrate was chosen for its high Landé g-factor.
- The salts were magnetized along the high g-factor axis.



Experimental Results:

- Wu observed the gamma ray anisotropy to be ~0.6.
- Interestingly, the electron anisotropy was greater than that of the gammas.
- It was also observed that the electrons favored the direction opposite of the nuclear spin, thus confirming the violation of parity conservation.



Impacts of The Experiment:

- Huge shock - the universe can tell in between right and left!!!
- This lead people to test CP(Charge & Parity)-symmetry on weak interactions.
- But surprisingly, even CP-symmetry was also violated in weak interactions.
- This was a huge deal in particle and nuclear physics as well as cosmology (matter > antimatter).
- Finally, CPT(charge, Parity & Time)-symmetry was conserved - however, this is very weak theory in terms of symmetry conservation.
- There is still a lot of research going on in this field.

What made the experiment successful?

- In conclusion, we believe this was a big case of genius and out-of-box thinking at work!
  - Thinking of parity violation as a solution to τ-θ problem was radical.
  - Coming up with experimental design of testing parity violation was quite clever.
- Without the collaboration between two theorists, Lee and Yang, and an experimentalist, Wu, this would not have been achieved.
- Furthermore, hard work is always important in setting up such experiments.

Sources:

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