Discrete Symmetries (in Particle Physics)

\[ \{ P, C, T \} \]

- Parity, \( P \)
- Charge conjugation, \( C \)
- Time reversal, \( T \)

What are they?
Are these symmetries observed?

So \( g \) could be \( C, P, T \) or \( CPT \)

First:
All examples of \( \mathbb{Z}_2 \): \( \{ I, g \} \) where \( g^2 = I \)
   a) closure \( I \cdot I = I \), \( I \cdot g = g \cdot I = g \), \( g \cdot g = I \)
   b) Identity \( g \cdot g = g \)
   c) Inverse \( g \cdot g = E \Rightarrow g = g^{-1} \)
   d) Associativity Can be faithfully represented by \( \mathbb{Z}_2, \mathbb{Z}_3 \) with
      multiplication and this is obviously associative.

**Parity**

\[ \text{rotation on vectors} \]

Recall \( O(3) = SO(3) \times \mathbb{Z}_2 \)

- Inversion of coordinates \( (P) \)

\[ SO(3): \{ n \} \text{ such that } n^T n = I, \text{ det } n = 1 \]
\[ O(3): \{ n \} \text{ such that } n^T n = I, \text{ det } n = \pm 1 \]

Can get any element of \( O(3) \) by combining an \( \in SO(3) \) with \( P \).

Some call parity “mirror” symmetry:

\[ \begin{array}{c}
\text{This would be true if we defined } \\
\text{as } P: \{ I, (-I) \}, \text{ but } \\
\text{this treats } x \text{ preferentially.}
\end{array} \]

Instead we will work with \( P: \{ I, (-I) \} \) which sends \( x \rightarrow -x, y \rightarrow y, z \rightarrow z \) (all on equal footing)

But remember that to get the “other” 1 signs we can invert \( x \), then do a 180° in the
\( y-z \) plane:

\[ \text{Note that you can't get the result of } P \text{ by } \\
\text{rotating alone!} \]

**NOTE:** In many cases we will just reflect in \( x \) to make visualization easier!
Okay, so we know that physics over small length scales is invariant under rotations (actually under the Lorentz group).

Is it invariant under $P$? For a long time the assumed answer was yes.

2 ways to answer:

a) Consider all SM processes and their parity transformed versions. If all quantities (lifetimes, reaction rates, etc.) are the same then $P$ is "good." If any differ then $P$ is "bad."

b) Assign a "parity" label to particles and see if processes "conserve" parity.

Answer: Nope! The SM violates $P$.
We will see evidence in both ways.
Experimental test suggested by Lee & Yang and carried out by “dragon lady” Wu.

Cadmium 60 decay: \(^{60}\text{CO} \rightarrow ^{60}\text{Ni} + e + \overline{\nu}\)

Nuclear spin picks out a preferred direction
(N+5 poles of magnetic dipole moment)

\(\uparrow N \quad \downarrow N\)
\(\uparrow S \quad \downarrow S\)
\(\uparrow e \quad \downarrow e\)

The electron always emerges opposite the nuclear spin.

Now let’s consider the \(P\)-transformed version of this:

\(\uparrow P_x \quad \downarrow P_y \quad \uparrow e\)

So in the \(P\)-transformed version of this process, the electron emerges along the nuclear spin.

This is never observed to happen!!

Okay so maybe \(P\)-violation only occurs in this one single interaction. But wait...