# Atomic Parity Violation and Fundamental Physics

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Glashow-Salam-Weinberg theory of electroweak interactions predicts that electron and nucleus exchange Z boson. This effectively adds to the potential energy of the one-particle relativistic Hamiltonian the term

$$H_{\mathrm{EW}} = \frac{G_\beta}{2^{3/2}} \rho_W(\vec{r}) \gamma_5 \,,$$

where $\gamma_5$ is the fifth Dirac matrix, $G_\beta$ is Fermi coupling constant determined from neutron lifetime. The "weak charge density" $\rho_W$, is given in terms of the proton and neutron densities, $\rho_p$ and $\rho_n$, respectively, as

$$\rho_W(\vec{r}) = \rho_p(\vec{r})(1 - 4\sin^2\vartheta) - \rho_n(\vec{r}) \,,$$

where $\vartheta$ is weak mixing angle, the fundamental quantity of EW theory.

Let us summarize the main features of the interaction $H_{\mathrm{EW}}$.
First, it is parity violating, that is, it mixes states of different parity, namely $s$-state and a $p_{1/2}$ state.
Second, the interaction $H_{\mathrm{EW}}$ is really weak. Changing to atomic units, $r = r_A/(m_e Z\alpha)$, we find that the interaction is proportional to

$$Q_W G_\beta m_e^3 (Z\alpha)^4 \simeq m_e (Z\alpha)^2 \left[10^{-5} \left(\frac{m_e}{m_p}\right)^2 \alpha^2\right] Q_W Z^2 \,,$$

where we substituted $G_\beta \simeq 1 \times 10^{-5} m_p^{-2}$. The factor in the square brackets on the rhs is of the order $10^{-15}$. However, given that $Q_W \approx Z$, we see that for heavy atoms there is an enhancement of the interaction strength by the factor $Z^3$.

# Why it is important?

Comparison of measurement (Gilbert at al, PRL **24**, 2680 (1985), Wood et al, Science 275, 1759 (1997)) and theory (Porsev et al, Phys. Rev. D **82**, 036008 (2010)) for parity violating transition amplitude in the cesium atom reads

$$\sin^2\vartheta = 0.2356(20)\,.$$

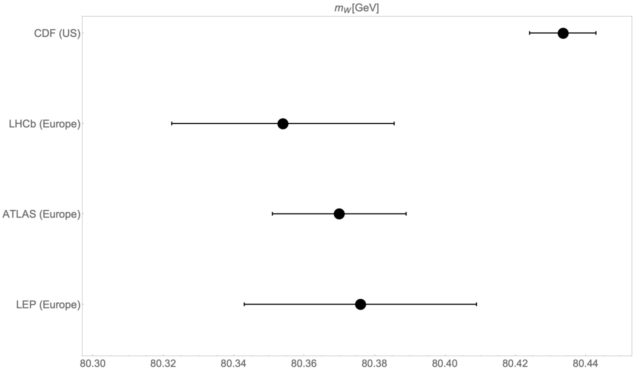
This is the "weighting" of the $W$ and $Z$ bosons; up to corrections of the order $\alpha \simeq 1/137.036$ (few percents)

$$m_W = \sqrt{\frac{\alpha\pi}{\sqrt{2}G_\beta \sin^2\vartheta}} \simeq 79\,\mathrm{GeV}$$

$$m_Z = m_W/\cos\vartheta \simeq 90\,\mathrm{GeV}\,.$$

# Why it is important?

The masses of the $W$ and $Z$ bosons are determined from the position of resonances in high-energy collider experiments but there are discrepancies...



# What are we trying to do

The necessary input is accurate theoretical determination of atomic structure. We develop methods and codes for accurate atomic structure calculations to improve the theoretical predictions for measured parity violation interactions.

At the present time the accuracy of theory and experiments on atomic parity violation is as follows (see B.M. Roberts, et al, Annu. Rev. Nucl. Part. Sci., **65**, 63 (2015) )

| Atom | Theory[%] | Experiment[%] |
|---|---|---|
| Cs | 0.9 | 0.3 |
| Yb | 10 | 15 |
| Tl | 2.5 | 1.1 |
| Pb | 8 | 1.2 |
| Bi | 10 | 2 |

One can see that with exception of Yb, the accuracy of experiments surpasses the accuracy of theory.

# Home take message

Abstract theories of fundamental interactions can be brought "down to the earth", to the very small momentum transfers. Their low-energy consequences can be verified or disproved by atomic measurements and calculations.

Atomic physics confirms the validity of SM and rules out speculative BSM theories.

We are certainly not at the end of our possibilities, neither theoretical nor experimental, so we can look forward into the future.