In these works, Wigner laid the foundation for the theory of [symmetries](https://en.wikipedia.org/wiki/Symmetry_in_physics) in [quantum mechanics](https://en.wikipedia.org/wiki/Quantum_mechanics).[20] [Wigner's theorem](https://en.wikipedia.org/wiki/Wigner%27s_theorem) proved by Wigner in 1931, is a cornerstone of the [mathematical formulation of quantum mechanics](https://en.wikipedia.org/wiki/Mathematical_formulation_of_quantum_mechanics). The theorem specifies how physical [symmetries](https://en.wikipedia.org/wiki/Symmetries) such as rotations, translations, and [CPT symmetry](https://en.wikipedia.org/wiki/CPT_symmetry) are represented on the [Hilbert space](https://en.wikipedia.org/wiki/Hilbert_space) of [states](https://en.wikipedia.org/wiki/Quantum_state). According to the theorem, any symmetry transformation is represented by a [linear and unitary](https://en.wikipedia.org/wiki/Unitary_transformation) or [antilinear and antiunitary](https://en.wikipedia.org/wiki/Antiunitary_operator) transformation of Hilbert space. The representation of a symmetry group on a Hilbert space is either an ordinary [representation](https://en.wikipedia.org/wiki/Representation_%28group_theory%29) or a [projective representation](https://en.wikipedia.org/wiki/Projective_representation).[21][22]

Wigner and [Hermann Weyl](https://en.wikipedia.org/wiki/Hermann_Weyl) were responsible for introducing group theory into quantum mechanics. The latter had written a standard text, *Group Theory and Quantum Mechanics* (1928), but it was not easy to understand, especially for younger physicists. Wigner's *Group Theory and Its Application to the Quantum Mechanics of Atomic Spectra* (1931) made group theory accessible to a wider audience.[19]

Wigner was awarded the [Nobel Prize in Physics](https://en.wikipedia.org/wiki/Nobel_Prize_in_Physics) in 1963 "for his contributions to the theory of the [atomic nucleus](https://en.wikipedia.org/wiki/Atomic_nucleus) and the [elementary particles](https://en.wikipedia.org/wiki/Elementary_particles), particularly through the discovery and application of fundamental symmetry principles".[1] The prize was shared that year, with the other half of the award divided between [Maria Goeppert-Mayer](https://en.wikipedia.org/wiki/Maria_Goeppert-Mayer) and [J. Hans D. Jensen](https://en.wikipedia.org/wiki/J._Hans_D._Jensen).[1]

In 1929, Weyl proposed a fermion for use in a replacement theory for relativity. This fermion would be a massless [quasiparticle](https://en.wikipedia.org/wiki/Quasiparticle) and carry electric charge. An electron could be split into two Weyl fermions or formed from two Weyl fermions. [Neutrinos](https://en.wikipedia.org/wiki/Neutrino) were once thought to be Weyl fermions, but they are now known to have mass. Weyl fermions are sought after for electronics applications to solve some problems that electrons present. Such quasiparticles were discovered in 2015, in a form of crystals known as Weyl semimetals, a type of topological material.[27][28][29]

In 1927, [Eugene Wigner](https://en.wikipedia.org/wiki/Eugene_Wigner) formalized the principle of the conservation of [parity](https://en.wikipedia.org/wiki/Parity_%28physics%29) (*P*-conservation),[2] the idea that the current world and one built like its mirror image would behave in the same way, with the only difference that left and right would be reversed (for example, a clock which spins clockwise would spin counterclockwise if you built a mirrored version of it).

The **Wu experiment** was a [nuclear physics](https://en.wikipedia.org/wiki/Nuclear_physics) experiment conducted in 1956 by the [Chinese American](https://en.wikipedia.org/wiki/Chinese_American) physicist [Chien-Shiung Wu](https://en.wikipedia.org/wiki/Chien-Shiung_Wu) in collaboration with the Low Temperature Group of the US [National Bureau of Standards](https://en.wikipedia.org/wiki/National_Bureau_of_Standards).[1] The experiment's purpose was to establish whether or not conservation of [parity](https://en.wikipedia.org/wiki/Parity_%28physics%29) (*P*-conservation), which was previously established in the [electromagnetic](https://en.wikipedia.org/wiki/Electromagnetic_interaction) and [strong](https://en.wikipedia.org/wiki/Strong_interaction) [interactions](https://en.wikipedia.org/wiki/Fundamental_interaction), also applied to [weak interactions](https://en.wikipedia.org/wiki/Weak_interaction). If *P*-conservation were true, a mirrored version of the world (where left is right and right is left) would behave as the mirror image of the current world. If *P*-conservation were violated, then it would be possible to distinguish between a mirrored version of the world and the mirror image of the current world.

The experiment established that conservation of parity was violated (*P*-violation) by the weak interaction. This result was not expected by the physics community, which had previously regarded parity as a [conserved quantity](https://en.wikipedia.org/wiki/Conserved_quantity). [Tsung-Dao Lee](https://en.wikipedia.org/wiki/Tsung-Dao_Lee) and [Chen-Ning Yang](https://en.wikipedia.org/wiki/Chen-Ning_Yang), the theoretical physicists who originated the idea of parity nonconservation and proposed the experiment, received the 1957 [Nobel Prize in physics](https://en.wikipedia.org/wiki/Nobel_Prize_in_physics) for this result.

A **chiral** phenomenon is one that is not identical to its [mirror image](https://en.wikipedia.org/wiki/Mirror_image) (see the article on [mathematical chirality](https://en.wikipedia.org/wiki/Chirality_%28mathematics%29)). The [spin](https://en.wikipedia.org/wiki/Spin_%28physics%29) of a [particle](https://en.wikipedia.org/wiki/Elementary_particle) may be used to define a **handedness**, or helicity, for that particle, which, in the case of a massless particle, is the same as chirality. A [symmetry transformation](https://en.wikipedia.org/wiki/Symmetry_transformation) between the two is called [parity](https://en.wikipedia.org/wiki/Parity_%28physics%29). Invariance under parity by a [Dirac fermion](https://en.wikipedia.org/wiki/Dirac_fermion) is called **chiral symmetry**.

[An experiment](https://en.wikipedia.org/wiki/Wu_experiment) on the [weak decay](https://en.wikipedia.org/wiki/Weak_nuclear_force) of [cobalt](https://en.wikipedia.org/wiki/Cobalt)-60 nuclei carried out by [Chien-Shiung Wu](https://en.wikipedia.org/wiki/Chien-Shiung_Wu) and collaborators in 1957 demonstrated that [parity is not a symmetry](https://en.wikipedia.org/wiki/Parity_violation) of the universe.

At the [fundamental](https://en.wikipedia.org/wiki/Fundamental_particle) level (as depicted in the [Feynman diagram](https://en.wikipedia.org/wiki/Feynman_diagram) on the right), Beta decay is caused by the conversion of the negatively charged (−

1

/

3

 [e](https://en.wikipedia.org/wiki/Elementary_charge)) [down quark](https://en.wikipedia.org/wiki/Down_quark) to the positively charged (+

2

/

3

 e) [up quark](https://en.wikipedia.org/wiki/Up_quark) by emission of a [W− boson](https://en.wikipedia.org/wiki/W_boson); the W− boson subsequently decays into an electron and an electron antineutrino:

d → u + e− + ν

e.

The quark has a [left](https://en.wikipedia.org/wiki/Chirality_%28physics%29) part and a [right](https://en.wikipedia.org/wiki/Chirality_%28physics%29) part. As it walks across the spacetime, it oscillates back and forth from right part to left part and from left part to right part. From analyzing Wu experiment’s demonstration of partity violation, it can be deduced that only the left part of down quark decays and the weak interaction involves only the left part of quark and lepton(or the right part of antiquark and antilepton). The right part of the particle simply does not feel the weak interaction. If the down quark does not have mass, it would not oscillate, its right part would be quite stable by itself. Yet, because down quark is massive, it oscillates and decays.[11]

From experiments such as the Wu experiment and the [Goldhaber experiment](https://en.wikipedia.org/w/index.php?title=Goldhaber_experiment&action=edit&redlink=1), it was determined that massless neutrinos must be left-handed, while massless antineutrinos must be right-handed. Since it is currently known that neutrinos have a small mass, it has been proposed that right-handed neutrinos and left-handed antineutrinos could exist. These neutrinos would not couple with the weak [Lagrangian](https://en.wikipedia.org/wiki/Lagrangian_%28field_theory%29) and would interact only gravitationally, possibly forming a portion of the [dark matter](https://en.wikipedia.org/wiki/Dark_matter) in the universe.[12]

massless neutrinos must be left-handed. Neutrinos have travelled from the Big Bang and let us see beyond the microwave background.

http://www.nature.com/news/morphing-neutrinos-provide-clue-to-antimatter-mystery-1.20405?WT.ec\_id=NATURE-20160818&spMailingID=52085095&spUserID=OTAyMTUxOTY3MzES1&spJobID=983154956&spReportId=OTgzMTU0OTU2S0

In the 1990s, neutrinos were found1, 2 [to defy the predictions of physics' standard model](http://www.nature.com/news/morphing-neutrinos-win-physics-nobel-1.18513) — a successful, but incomplete, description of nature — by virtue of possessing mass, rather than being entirely massless. Since then, neutrino experiments have [sprouted up around the world](http://www.nature.com/news/age-of-the-neutrino-plans-to-decipher-mysterious-particle-take-shape-1.18159), and researchers are realizing that they should look to these particles for new explanations in physics, says Keith Matera, a physicist on a US-based neutrino experiment called NOvA at the Fermi National Accelerator Laboratory (Fermilab) in Batavia, Illinois. “They are the crack in the standard model,” he says.

**An odd abundance**

The excess of matter over antimatter in our Universe is extraordinary, because if the mirror-image particles were produced in equal quantities after the Big Bang, they would have annihilated each other on contact, leaving nothing but radiation. Physicists have observed differences in the behaviour of some matter particles and antimatter particles, such as kaons and B mesons — but not enough to explain the dominance of matter in the Universe.

One answer might be that super-heavy particles decayed in the early Universe in an asymmetric fashion and produced more matter than antimatter. Some physicists think that a heavyweight relative of the neutrino could be the culprit. Under this theory, if neutrinos and antineutrinos behave differently today, then a similar imbalance in their ancient counterparts could explain the overabundance of matter.´

New experiment: “Without getting into complicated mathematics, this suggests that matter and antimatter do not oscillate in the same way,” says Chang Kee Jung, a physicist at Stony Brook University in New York and a member of the T2K experiment.

**Changing flavours**

Neutrinos oscillate between flavours because they do not have a definite mass. Instead, each neutrino is a mixture — known as a quantum superposition — of three different ‘mass states’.  Different proportions of the states create the different flavours, named electron, muon and tau. (The names allude to the sister particles that are produced on the rare occasions when neutrinos interact with matter.) The waves that make up the mass states move at different speeds, separating and interfering with each other as the neutrino travels. Ultimately, this behaviour gives the neutrino a particular probability of having switched its flavour by the time it is detected.

It was the observation of neutrino oscillation in the 1990s that first implied that neutrinos had mass at all — contrary to the standard model of particle physics. That finding won Takaaki Kajita of the University of Tokyo and Arthur McDonald of Queen’s University in Kingston, Canada, [the 2015 Nobel Prize in Physics](http://www.nature.com/news/morphing-neutrinos-win-physics-nobel-1.18513). The latest T2K results — which suggest that neutrinos and antineutrinos oscillate between flavours in different ways — hint that the interference between mass states might be different between neutrino matter and antimatter.

The idea behind parity symmetry is that the equations of particle physics are invariant under mirror inversion. This leads to the prediction that the mirror image of a reaction (such as a [chemical reaction](https://en.wikipedia.org/wiki/Chemical_reaction) or [radioactive decay](https://en.wikipedia.org/wiki/Radioactive_decay)) occurs at the same rate as the original reaction. Parity symmetry appears to be valid for all reactions involving [electromagnetism](https://en.wikipedia.org/wiki/Electromagnetism) and [strong interactions](https://en.wikipedia.org/wiki/Strong_interaction).