Neutrinoless double-beta decay

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Beta decay vs double-beta decay

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Beta-decay

Originally thought of as the process

$$(A, Z) \to (A, Z+1) + e\,.$$

Problems:

1. Energy and momentum are not conserved. Electron spectrum is continuous.
2. Angular momentum is not conserved.
3. Lepton number is not conserved. (The concept came later)

Pauli's solution solved all three problems:

$$(A, Z) \to (A, Z+1) + e + \overline{\nu}_e\,.$$

Double beta decay

One possibility: two successive beta decays.

$$\begin{aligned}(A,Z) \rightarrow\ & (A,Z+1)\ + e + \overline{\nu}_{\mathbf{e}}\,, \\ & (A,Z+1)\ \rightarrow (A,Z+2) + e + \overline{\nu}_{\mathbf{e}}\,.\end{aligned}$$

This is not of any primary interest.

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If the first one is prohibited by energy consideration:

then the double decay can happen in a single step:

$$(A,Z) \to (A,Z+2) + e + e + \overline{\nu}_{\mathbf{e}} + \overline{\nu}_{\mathbf{e}}\,.$$

This process has been observed.

Neutrinoless?

Is it possible to have the process without neutrinos?

$$(A, Z) \to (A, Z+2) + e + e\,.$$

At the nucleon level, it would be the process

$$n + n \to p + p + e + e\,.$$

At the quark level, the process would be

$$d + d \to u + u + e + e\,.$$

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What happens to the problems with conservation laws?

Energy-momentum: No problem.

Angular momentum: No problem.

Lepton number: Will be violated.

Categories of conservation laws

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Various conservation laws of the Standard Model.

Category	$E, \mathbf{p}$	Ang. Mom.	Charge	L	B	CPT
Spacetime/Internal	ST	ST	Int	Int	Int	ST
Discrete/Continuous	Cont.	Cont.	Cont.	Cont.	Cont.	Disc.
Gauged?	No	No	Yes	No	No	—
Anomalous?	—	—	No	Yes	Yes	—

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Caste system of conservation laws:

Breadking spacetime conservation laws would require new theory from scratch.

Gauge symmetries govern the dynamics of interactions, and are therefore noble.

Global symmetries are accidental: one can easily contemplate situations where they are not conserved. Lepton number symmetry falls in this category.

Lepton and baryon number violation?

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In the standard model, both are accidental symmetries.

They are consequences of the particle content and renormalizability of the Lagrangian.

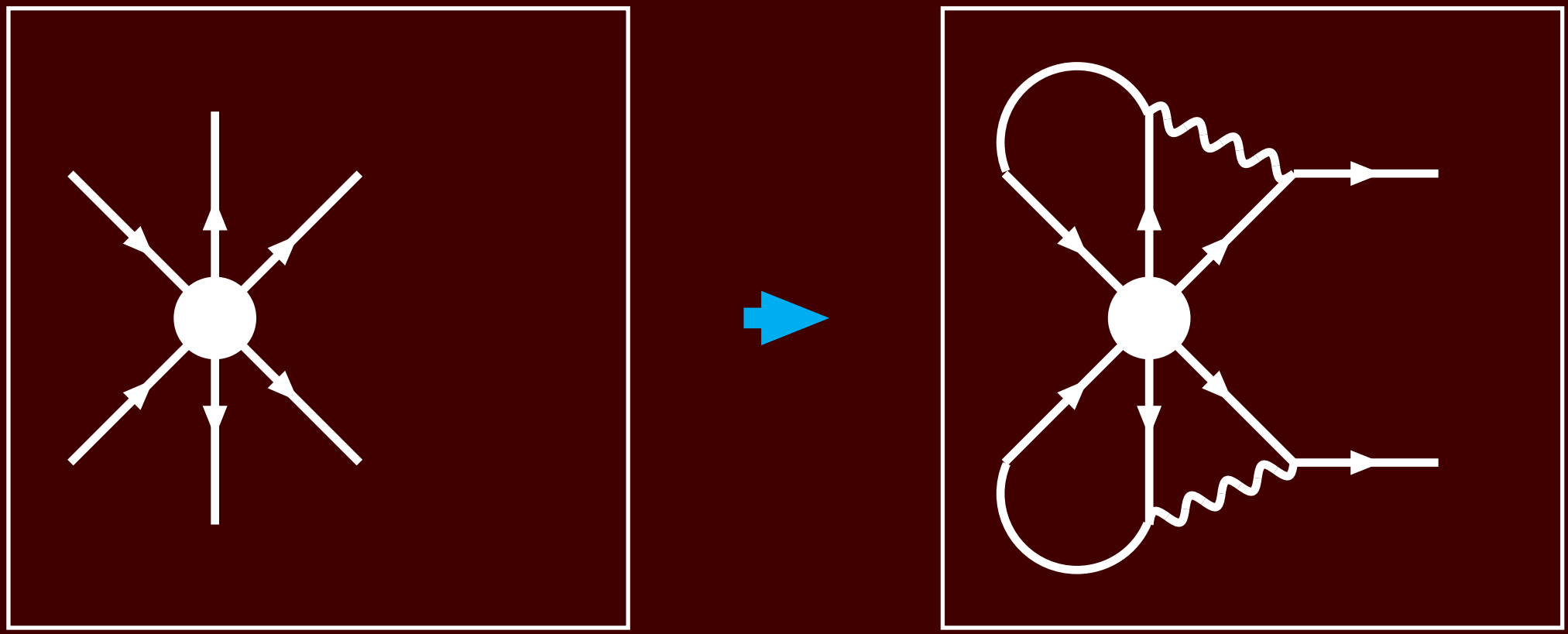
From energy considerations, the following processes can occur:

B- and L- violating: Proton decay. Simplest channels: $\mathrm{p} \to e^+\pi^0$, $\mathrm{p} \to e^+\mathrm{K}^0$.

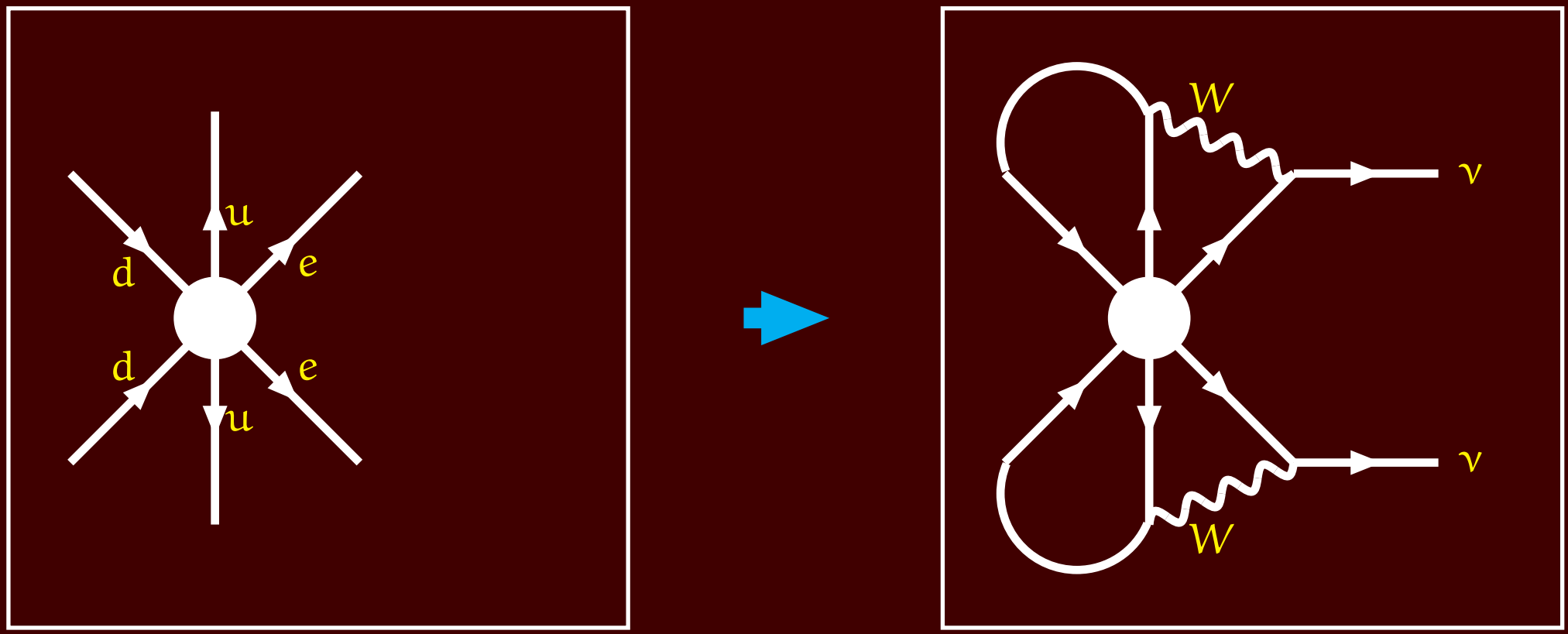
B-violating: Neutron-antineutron oscillation.

L-violating: Neutrinoless double beta decay.

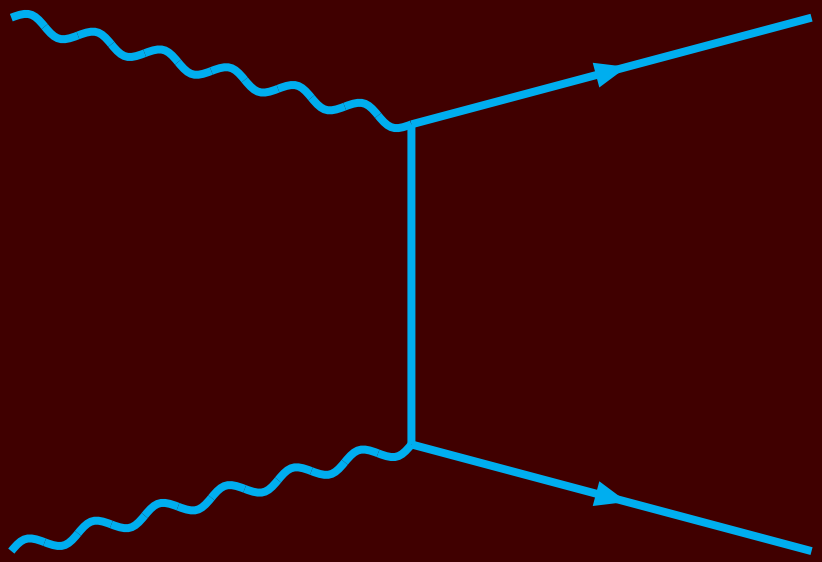
Relation with neutrino mass



Relation with neutrino mass



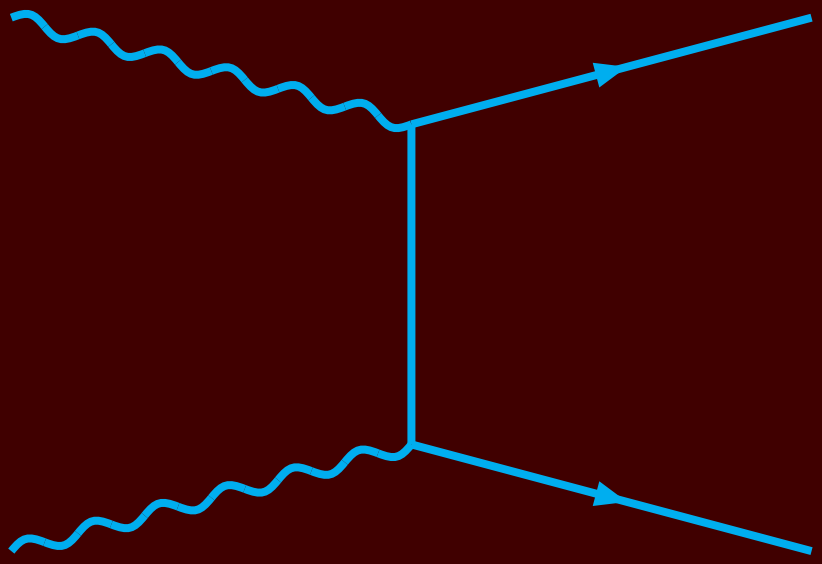
The amplitude



The amplitude

The important part of the process is

$$W^- + W^- \to e^- + e^- .$$



$$\text{Amplitude} \propto L \, \frac{\gamma^\mu q_\mu + m_\nu}{q^2 - m_\nu^2} \, L$$

Only the mass term contributes.

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- Lepton number is violated. This is not a great loss, since the symmetry is global and anomalous.
- Neutrinos are Majorana particles, i.e., are their own antiparticles. This information cannot be obtained, e.g., from neutrino oscillation experiments.
- The scale of neutrino masses. Neutrino oscillation experiments give only differences in eigenvalues, not the actual values.