

$$\begin{aligned}
 & \frac{1}{2} \left( \begin{array}{c} \text{(a)} \\ \begin{array}{c} \nu' \\ \nearrow \\ \nu \end{array} \begin{array}{c} \text{---} \alpha \text{---} \\ \nwarrow \nearrow \\ \bar{\nu} \end{array} \begin{array}{c} \bar{\nu}' \\ \nwarrow \\ \bar{\nu} \end{array} \end{array} \right) + \begin{array}{c} \text{(b)} \\ \begin{array}{c} \nu \\ \nearrow \\ \nu' \end{array} \begin{array}{c} \text{---} \alpha \text{---} \\ \nwarrow \nearrow \\ \bar{\nu}' \end{array} \begin{array}{c} \bar{\nu} \\ \nwarrow \\ \bar{\nu}' \end{array} \end{array} \right) + \\
 & \frac{1}{2} \left( \begin{array}{c} \text{(c)} \\ \begin{array}{c} \nu' \\ \nearrow \\ \nu \end{array} \begin{array}{c} \text{---} \alpha \text{---} \\ \nwarrow \nearrow \\ \bar{\nu} \end{array} \begin{array}{c} \bar{\nu}' \\ \nwarrow \\ \bar{\nu} \end{array} \end{array} \right) + \begin{array}{c} \text{(d)} \\ \begin{array}{c} \nu \\ \nearrow \\ \nu' \end{array} \begin{array}{c} \text{---} \alpha \text{---} \\ \nwarrow \nearrow \\ \bar{\nu}' \end{array} \begin{array}{c} \bar{\nu} \\ \nwarrow \\ \bar{\nu}' \end{array} \end{array} \right)
 \end{aligned}$$

The image shows four Feynman diagrams labeled (a), (b), (c), and (d), each representing a neutrino-neutrino interaction via a scalar particle  $\alpha$ . The diagrams are grouped by large parentheses and a factor of  $1/2$ .

- (a)**: Incoming  $\nu$  and  $\bar{\nu}$  meet at a vertex, producing  $\nu'$  and  $\bar{\nu}'$  at another vertex. The scalar  $\alpha$  is exchanged between the two vertices.
- (b)**: Incoming  $\nu'$  and  $\bar{\nu}'$  meet at a vertex, producing  $\nu$  and  $\bar{\nu}$  at another vertex. The scalar  $\alpha$  is exchanged between the two vertices.
- (c)**: Incoming  $\nu$  and  $\bar{\nu}$  meet at a vertex, producing  $\nu'$  and  $\bar{\nu}'$  at another vertex. The scalar  $\alpha$  is exchanged between the two vertices.
- (d)**: Incoming  $\nu'$  and  $\bar{\nu}'$  meet at a vertex, producing  $\nu$  and  $\bar{\nu}$  at another vertex. The scalar  $\alpha$  is exchanged between the two vertices.