SUM OF NEUTRINO MASSES
Revised April 1998 by K.A. Olive (University of Minnesota).

The limits on low mass \( m_\nu \lesssim 1 \text{ MeV} \) neutrinos apply to \( m_{\text{tot}} \) given by

\[
m_{\text{tot}} = \sum_\nu (g_\nu/2) m_\nu,
\]

where \( g_\nu \) is the number of spin degrees of freedom for \( \nu \) plus \( \bar{\nu} \): \( g_\nu = 4 \) for neutrinos with Dirac masses; \( g_\nu = 2 \) for Majorana neutrinos. Stable neutrinos in this mass range make a contribution to the total energy density of the Universe which is given by

\[
\rho_\nu = m_{\text{tot}} n_\nu = m_{\text{tot}} (3/11) n_\gamma,
\]

where the factor 3/11 is the ratio of (light) neutrinos to photons. Writing \( \Omega_\nu = \rho_\nu / \rho_c \), where \( \rho_c \) is the critical energy density of the Universe, and using \( n_\gamma = 412 \text{ cm}^{-3} \), we have

\[
\Omega_\nu h^2 = m_{\text{tot}} / (94 \text{ eV}).
\]

Therefore, a limit on \( \Omega_\nu h^2 \) such as \( \Omega_\nu h^2 < 0.25 \) gives the limit

\[
m_{\text{tot}} < 24 \text{ eV}.
\]

The limits on high mass \( m_\nu > 1 \text{ MeV} \) neutrinos apply separately to each neutrino type.