The New Standard Model (NSM) [pg. 23]

"Neutrino oscillations require that neutrinos must come with different masses, implying that at least two of them must have masses that are not zero. This discovery constitutes the first change in several decades in our understanding of the fundamental laws that govern the elementary constituents of all matter, namely the Standard Model (see Box 1.1). It opens new questions, the most profound of which are the determination of the average neutrino mass and the source of their mass and the determination of whether neutrinos are their own antiparticles. Concerted efforts to answer these and other questions are now being mounted by nuclear physicists in a mutually beneficial partnership with their particle physics colleagues. "

"Physicists do not expect the appearance of neutrino masses to be the last word in the quest to understand the laws of nature at the level of elementary particles and their interactions. Our current understanding, as codified in the Standard Model, has had an extraordinary run of success in describing many phenomena, but it is incomplete. Nuclear and particle physicists are seeking a new Standard Model (NSM), which will incorporate the many successes of the Standard Model but will in addition provide an understanding of aspects of physics that are now mysterious."

Box 1.1 from pages 24-25 of *Exploring the Heart of Matter*

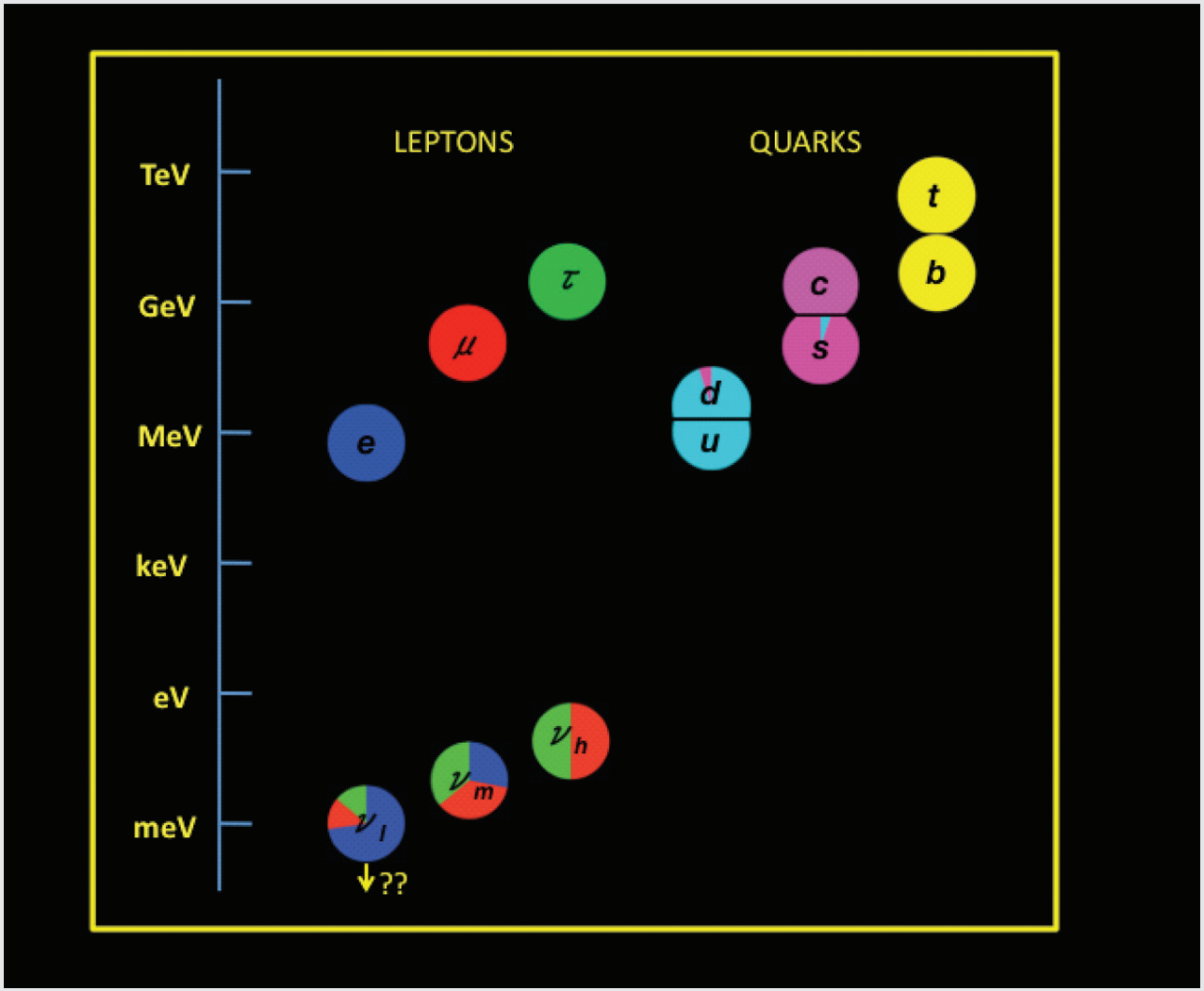

FIGURE 1.1.1 The masses of particles. The vertical scale is the particle mass in electron-volts, with each tick representing a 1,000-fold increase. SOURCE: Courtesy of R.G. Hamish Robertson, University of Washington.

Box 1.1 from pages 24-25 of *Exploring the Heart of Matter*

"The three neutrinos have different masses and so, when labeled by their masses as in this figure, they can be called "light," "medium," and "heavy." The pattern of neutrino masses shown is one of the possibilities suggested by the recent discovery of neutrino oscillations, captured in the pie chart for each neutrino. The three colors reflect the flavors of the electron, muon, and tauon charged leptons. They show that the only way to construct a neutrino that is the exact partner of the electron (called an "electron neutrino," it is blue in this diagram) is to combine neutrinos with differing masses in a certain way. Nuclear reactions in the sun produce electron neutrinos. And, all Standard Model processes in which a neutrino is made produce the exact partner of one of the charged leptons. The fact that these are combinations of neutrinos with differing masses is what causes the neutrino to oscillate as it flies through space. (Quarks also show this mixing property but to a much lesser degree.) "

"Although the discovery of neutrino oscillations has given us good information about the differences between the three neutrino masses, the mass of the lightest neutrino is not known precisely; it could even be zero. Ongoing nuclear physics experiments seeking to measure the average neutrino mass directly, not via oscillations, will help. But we do not yet have any fundamental understanding of the pattern of the masses of the 12 Standard Model matter particles, in particular of why the neutrinos are millions of times lighter than any of the other particles."