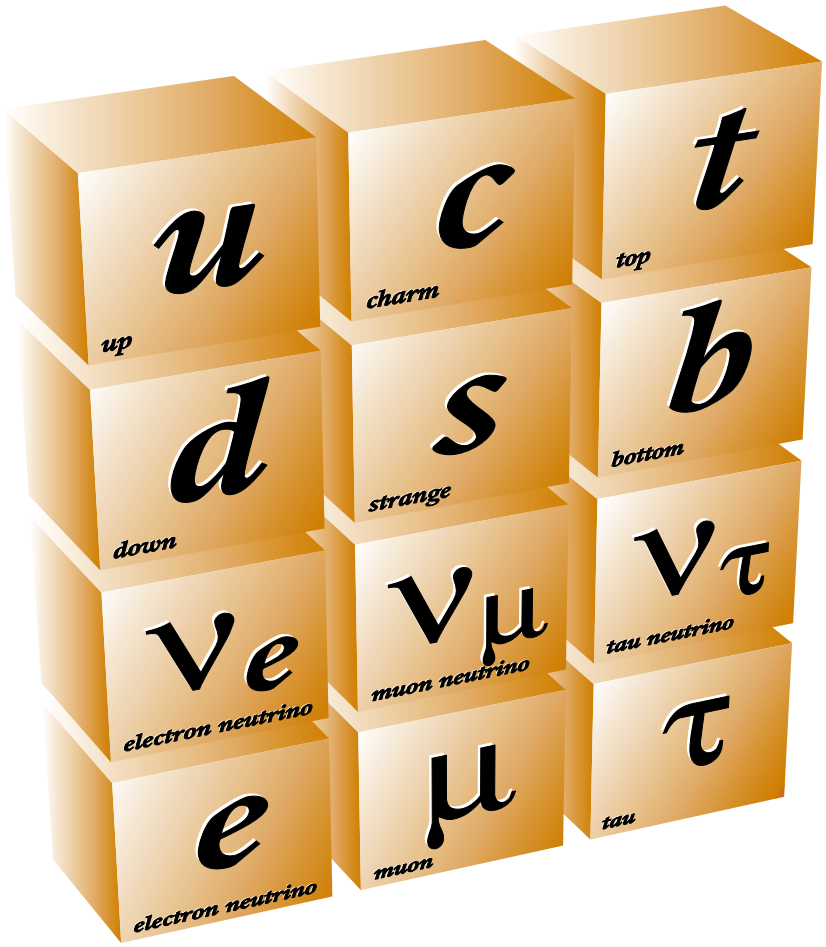
gluon fields. In this field theory pions and nucleons are elementary, though nuclei are not. When we use a field theory in this way, we are simply invoking the general principles of relativistic quantum theories, together with any relevant symmetries; we are not really making any assumption about the fundamental structures of physics.

From this point of view, we are entitled only to say that the quarks and gluons are more elementary than nucleons and pions, because their fields appear in a theory, the Standard Model, that applies over a much wider range of energies than the effective field theory that describes nucleons and pions at low energy. We cannot reach any final conclusion about the elementarity of the quarks and gluons themselves. The Standard Model itself is probably only an effective quantum field theory, which serves as an approximation to some more fundamental theory whose details would be revealed at energies much higher than those available in modern accelerators, and which may not involve quark, lepton, or gauge fields at all.

One possibility is that the quarks and leptons and other particles of the Standard Model are themselves composites of more elementary particles. The fact that we see no structure in the quarks and leptons only tells us that the energies involved in their binding must be quite large—larger than several trillion electron volts. But so far no one has worked out a convincing theory of this sort.

We will not be able to give a final answer to the question of which particles are elementary until we have a final theory of force and matter. When we have such a theory, we may find that the elementary structures of physics are not particles at all. Many theorists think that the fundamental theory is something like a superstring theory, in which quarks, leptons, etc. are just different modes of vibration of the strings. It seems impossible in principle to identify one set of strings as truly elementary, because, as recently realized, different string theories with different types of strings are often equivalent.

There is a lesson in all this. The task of physics is not to answer a set of fixed questions about Nature, such as deciding which particles are elementary. We do not know in advance what are the right questions to ask, and we often do not find out until we are close to an answer.



Elementary particles today. There are three known families of quarks and leptons in the Standard Model.