



Figure 16
The four fundamental interactions of nature were indistinguishable during the early moments of the big bang.

The evolution of the four fundamental interactions from the big bang to the present is shown in **Figure 16**. During the first 10^{-43} s, it is presumed that the strong, electroweak (electromagnetic and weak), and gravitational interactions were joined together. From 10^{-43} s to 10^{-32} s after the big bang, gravity broke free of this unification while the strong and electroweak interactions remained as one. This was a period when particle energies were so great (greater than 10^{16} GeV) that very massive particles that are now rare, as well as quarks, leptons, and their antiparticles, existed.

Then the universe rapidly expanded and cooled, the strong and electroweak interactions parted, and the grand unification was broken. About 10^{-10} s after the big bang, as the universe continued to cool, the electroweak interaction split into the weak interaction and the electromagnetic interaction.

Until about 7×10^5 years (2×10^{13} s) after the big bang, most of the energy in the universe was in the form of radiation rather than matter. This was the era of the radiation-dominated universe. Such intense radiation prevented matter from forming even single hydrogen atoms. Matter did exist, but only in the form of ions and electrons. Electrons are strong scatterers of photons, so matter at this time was opaque to radiation. Matter continuously absorbed and reemitted photons, thereby ensuring thermal equilibrium of radiation and matter.

By the time the universe was about 380,000 years (1×10^{13} s) old, it had expanded and cooled to about 3000 K. At this temperature, protons could bind to electrons to form hydrogen atoms. Without free electrons to scatter photons, the universe suddenly became transparent. Matter and radiation no longer interacted as strongly, and each evolved separately. By this time, most of the energy in the universe was in the form of matter. Clumps of neutral matter steadily grew: first atoms, followed by molecules, gas clouds, stars, and finally galaxies. This period, referred to as the matter-dominated universe, continues to this day.

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