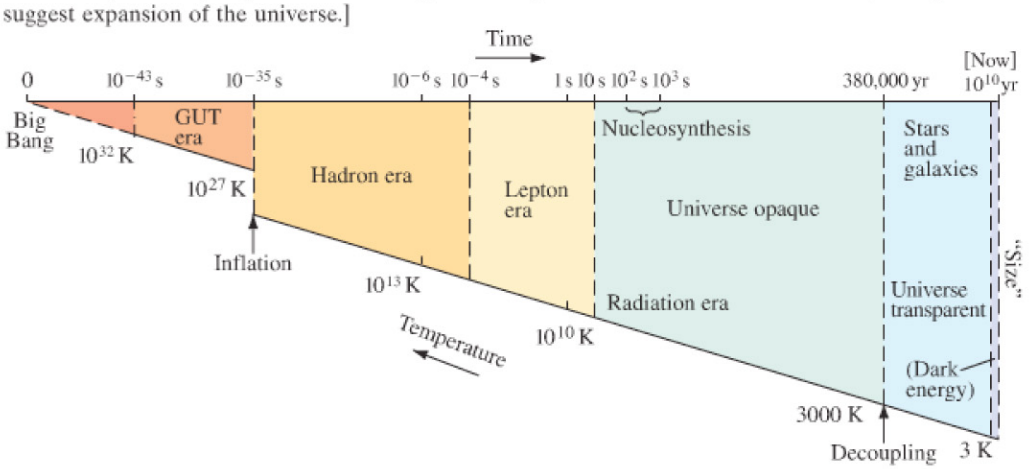
33–7 The Standard Cosmological Model: the Early History of the Universe

In the last decade or two, a convincing theory of the origin and evolution of the universe has developed, now called the **standard cosmological model**, or (sometimes) the *concordance model*. Part of this theory is based on recent theoretical and experimental advances in elementary particle physics. Indeed, cosmology and elementary particle physics have cross-fertilized to a surprising extent.

Let us go back to the earliest of times—as close as possible to the Big Bang—and follow a standard model scenario of events as the universe expanded and cooled after the Big Bang. Initially we talk of extremely small time intervals as well as extremely high temperatures, far beyond anything in the universe today. Figure 33–25 is a compressed graphical representation of the events, and it may be helpful to consult it as we go along.

FIGURE 33–25 Compressed graphical representation of the development of the universe after the Big Bang, according to modern cosmology. [The time scale is mostly logarithmic (each factor of 10 in time gets equal treatment), except at the start (there can be no $t = 0$ on a log scale), and just after $t = 10^{-35}$ (to save space). The vertical height is a rough idea of the size of the universe, mainly to suggest expansion of the universe.]



The History

Modern cosmology "scenario" of the history of the universe after the Big Bang

We begin at a time only a minuscule fraction of a second after the Big Bang, 10^{-43} s. This is an unimaginably short time, and predictions can be only speculative. Earlier, we can say nothing because we do not yet have a theory of quantum effects on gravity which would be needed for the incredibly high densities and temperatures then. It is thought that prior to 10^{-35} s, perhaps as early as 10^{-43} s, the four forces in nature were unified—there was only one force. The temperature would have been about 10^{32} K, corresponding to particles moving about every which way with an average kinetic energy KE of 10^{19} GeV (see Eq. 13–8):

All four forces unified

$$\text{KE} \approx kT \approx \frac{(1.4 \times 10^{-23}\,\text{J/K})(10^{32}\,\text{K})}{1.6 \times 10^{-19}\,\text{J/eV}} \approx 10^{28}\,\text{eV} = 10^{19}\,\text{GeV}.$$

(Note that the factor $\frac{3}{2}$ in Eq. 13–8 is usually ignored in such order of magnitude calculations.) At $t = 10^{-43}$ s, a kind of "phase transition" is believed to have occurred during which the gravitational force, in effect, "condensed out" as a separate force. This, and subsequent phase transitions, are analogous to the phase transitions water undergoes as it cools from a gas, condenses into a liquid, and with further cooling freezes into ice.† The symmetry of the four forces was broken, but the strong, weak, and electromagnetic forces were still unified, and the

Symmetry broken (gravity condensed out)

†It may be fun to note that our story of origins here bears some resemblance to ancient accounts that mention the "void," "formless wasteland," "abyss," "divide the waters" (possibly a phase transition?), not to mention the sudden appearance of light.