At later times, since the energy density in radiation falls off as R^{-4} and the energy density in non-relativistic matter falls off as R^{-3}, the Universe eventually became matter dominated. The epoch of matter-radiation density equality is determined by equating the matter density at $t_{\rm eq}$, $\rho_m = \Omega_0 \rho_c (R_0/R_{\rm eq})^3$ to the radiation density, $\rho_r = (\pi^2/30)[2 + (21/4)(4/11)^{4/3}](kT_0)^4 (R_0/R_{\rm eq})^4$ where T_0 is the present temperature of the microwave background (see below). Solving for $(R_0/R_{\rm eq}) = 1 + z_{\rm eq}$ gives

$$\begin{aligned} z_{\rm eq} + 1 &= \Omega_0 h_0^2 / 4.2 \times 10^{-5} = 2.4 \times 10^4\, \Omega_0 h_0^2 \ ; \\ kT_{\rm eq} &= 5.6\, \Omega_0 h_0^2\, \mathrm{eV} \ ; \\ t_{\rm eq} &\approx 0.39 (\Omega_0 H_0^2)^{-1/2} (1 + z_{\rm eq})^{-3/2} \\ &= 3.2 \times 10^{10} (\Omega_0 h_0^2)^{-2}\, \mathrm{sec} \ . \end{aligned} \tag{3.13}$$

Prior to this epoch the density was dominated by radiation (relativistic particles; see Eq. (3.10)), and at later epochs matter density dominated. Atoms formed at $z \approx 1300$, and by $z_{\rm dec} \approx 1100$ the free electron density was low enough that space became essentially transparent to photons and matter and radiation were decoupled. These are the photons observed in the microwave background today.

The age of the Universe today (still assuming that $\Lambda = 0$) is given by

$$t_0 = H_0^{-1} \int_0^1 \left(1 - \Omega_0 + \Omega_0 x^{-1}\right)^{-1/2} dx \ . \tag{3.14}$$

Constraints on t_0 yield constraints on the combination $\Omega_0 h_0^2$. For example, $t_0 \geq 13 \times 10^9$ yr implies that $\Omega_0 h_0^2 \leq 0.25$ for $h_0 \geq 0.5$, or $\Omega_0 h_0^2 \leq 0.45$ for $h_0 \geq 0.4$, while $t_0 \geq 10 \times 10^9$ yr implies that $\Omega_0 h_0^2 \leq 0.8$ for $h_0 \geq 0.5$, or $\Omega_0 h_0^2 \leq 1.1$ for $h_0 \geq 0.4$.

The present temperature of the microwave background is $T_0 = 2.726 \pm 0.005$ K as measured by COBE [4], and the number density of photons $n_\gamma = (2\zeta(3)/\pi^2)(kT_0)^3 \approx 411\ \mathrm{cm}^{-3}$. The energy density in photons at the present epoch is $\rho_\gamma = 4.65 \times 10^{-34}\, \mathrm{g\ cm}^{-3} = 0.26\ \mathrm{eV\ cm}^{-3}$.

See the Table of Astrophysical Constants for estimates of Λ_0, h_0, Ω_0, *etc.* For full text and all references, see the full *Review.*