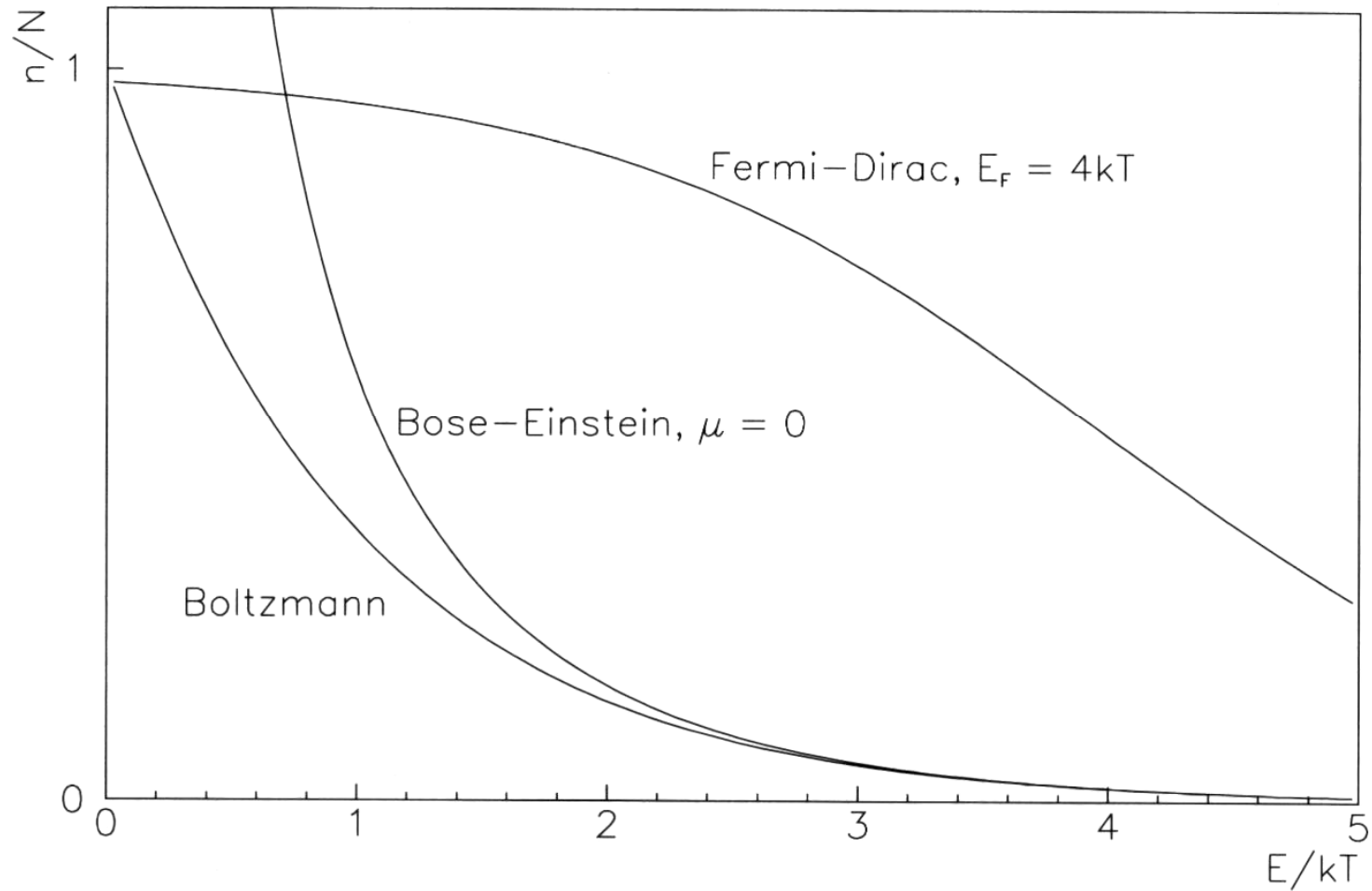

Chapter 4

Thermodynamics of the Universe

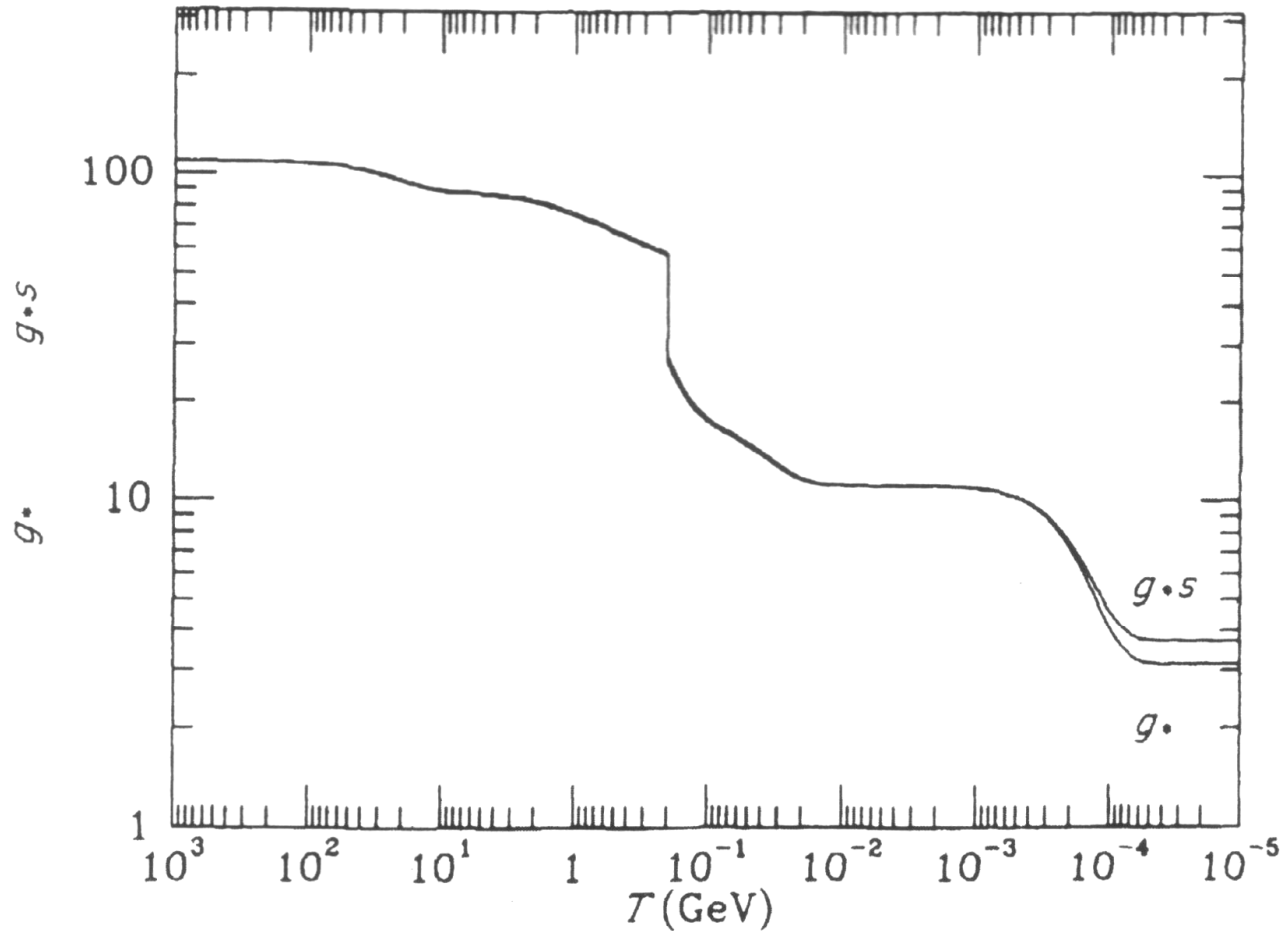
Quantum statistics: distribution functions



Degeneracy factor (=degrees of freedom)

kT	rel. Teilchen im thermischen Gleichgewicht	g_{eff}
$< 1\text{eV}$	γ	2
$< m_e c^2$	γ, e^\pm	11/2
$< m_\mu c^2$	$\gamma, e^\pm, \nu_{e,\mu,\tau}$	43/4
$< m_\pi c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm$	57/4
$< \Lambda_{QCD}$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, \pi^{\pm,0}$	69/4
$< m_s c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, g, u, \bar{u}, d, \bar{d}$	205/4
$< m_c c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}$	247/4
$< m_\tau c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}$	289/4
$< m_b c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, \tau^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}$	303/4
$< m_t c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, \tau^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}$	345/4
$< M_W c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, \tau^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}, t, \bar{t}$	387/4
$> M_Z c^2$	$\gamma, \nu_{e,\mu,\tau}, e^\pm, \mu^\pm, \tau^\pm, g, u, \bar{u}, d, \bar{d}, s, \bar{s}, c, \bar{c}, b, \bar{b}, t, \bar{t}, W^\pm, Z$	423/4

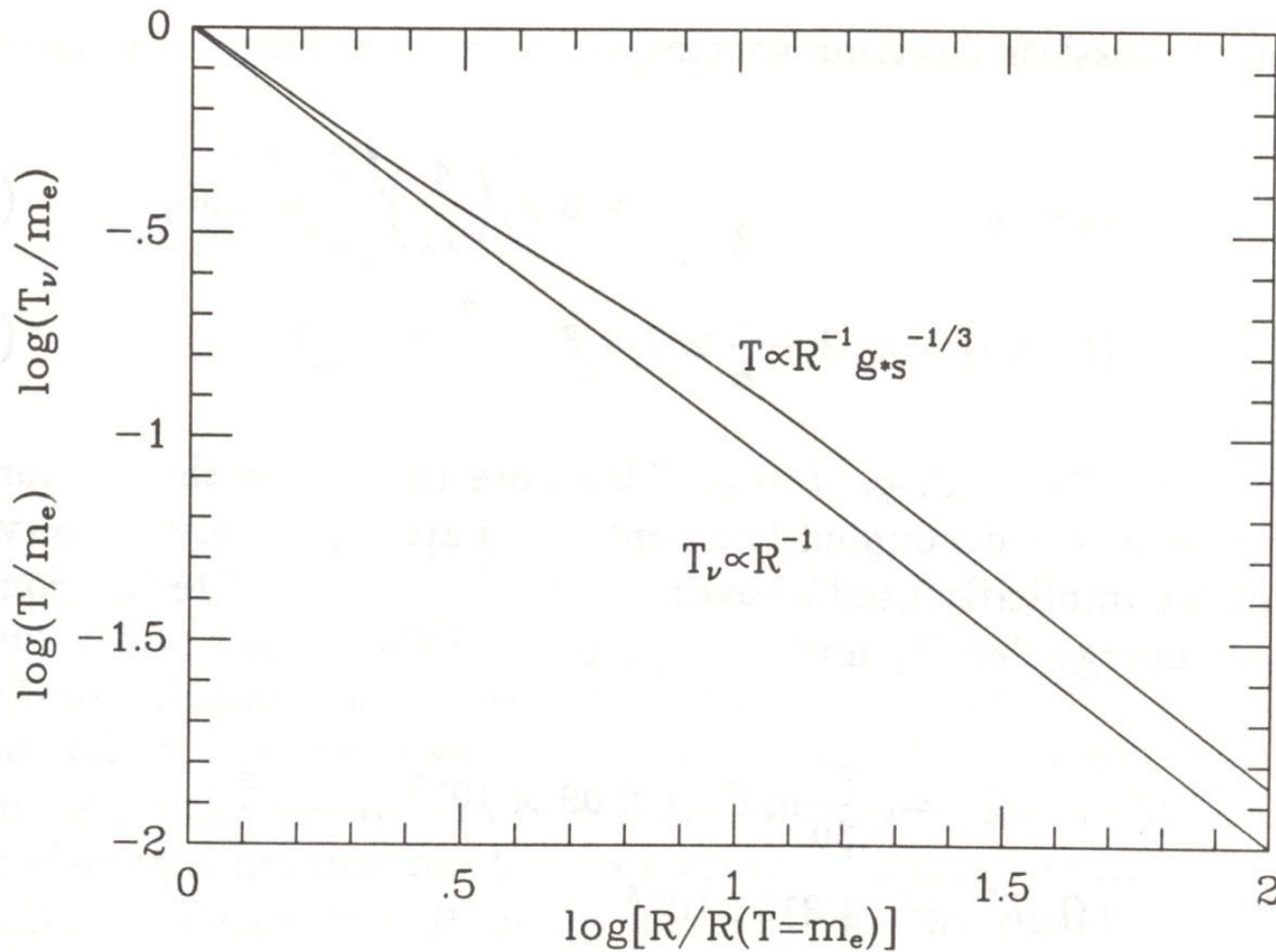
Degeneracy factor (=degrees of freedom)



g^* effective degeneracy for energy density

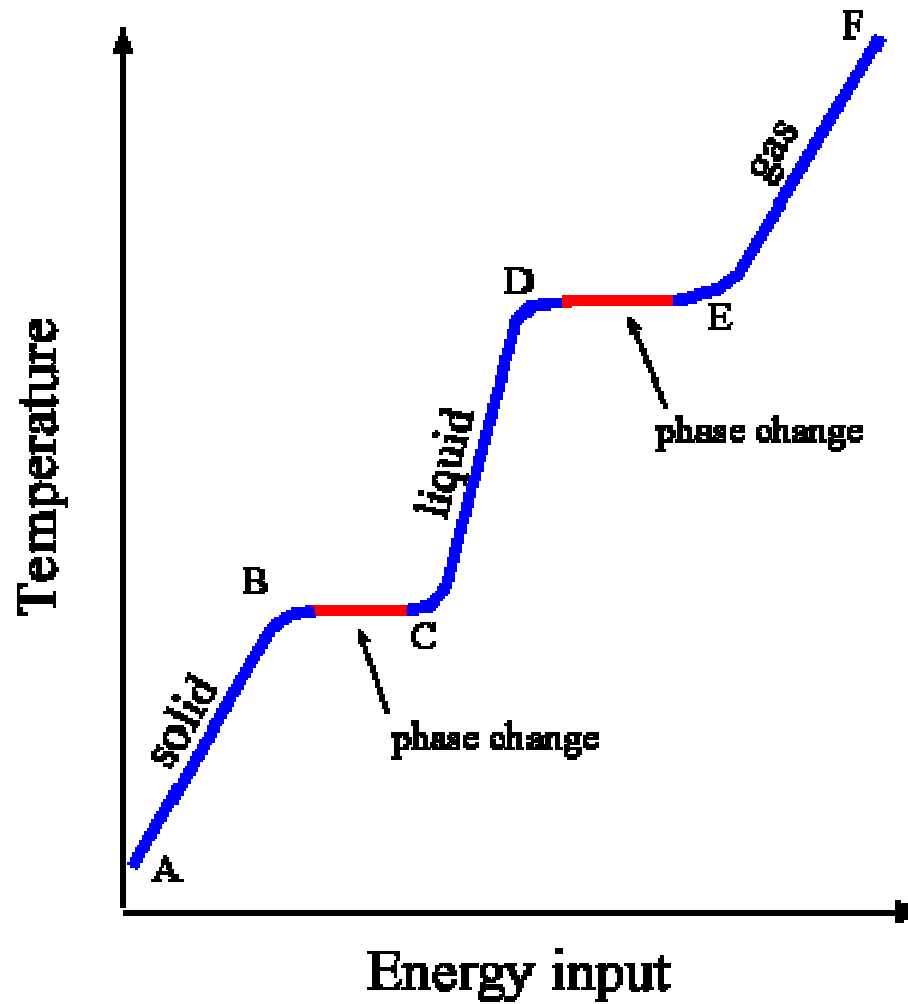
g^{*s} effective degeneracy for entropy density

"Reheating"



g^{*s} effective degeneracy for entropy density

Phase change and latent heat



Ionisation fraction versus redshift

