Karlsruher Institut für Technologie

Institute for Theoretical Physics (ITP)
Karlsruhe Institute of Technology (KIT)

General Relativity II

Lecturer: Prof. Dr. Frans R. Klinkhamer
Assistant: Dr. Viacheslav A. Emelyanov

- Handing-in: Monday, 15.05.2017; Discussion: Wednesday, 17.05.2017
- All up-to-date information related to the course can be found under the link: https://www.itp.kit.edu/~slava/relativitaetstheorie_ss_17.html

Name: _____ Points: _____

Exercise Sheet 3

Exercise 3.1: Redshift (6 points)

(a) Suppose a monochromatic electromagnetic wave of duration $\Delta\eta$ is sent at η_{em} from $\chi = \chi_{\text{em}}$ in an FRW universe (see Exercise 2.1.a). Determine the physical wavelength λ_{obs} of this wave at η_{obs} with $\chi = \chi_{\text{obs}} = 0$. Compare your result with that of Exercise 1.2.b.

(b) Determine how the peculiar velocity v of a particle, i.e. a velocity of the particle with respect to the Hubble flow, depends on cosmic time. How does the temperature of a non-relativistic gas depend on cosmic time?

Exercise 3.2: Local thermodynamic equilibrium (6 points)

(a) Derive the distribution function of an ideal boson/fermion gas of total energy E placed in a volume V, assuming that the gas is in a local-equilibrium (maximal-entropy) state.

(b) Suppose that electrons and positrons are in local equilibrium with each other and with photons, i.e. $e^- + e^+ \rightleftarrows \gamma + \gamma$. Determine how the chemical potential μ_{e^-} of electrons is related to the chemical potential μ_{e^+} of positrons. Find these chemical potentials for a neutral electron-positron plasma.

(c) One can show that the entropy density s satisfies the following equation:

$$s = \frac{\rho + P - \mu n}{T}\,. \tag{1}$$

Verify this formula for ultra-relativistic bosons with $T \gg \mu$ and $T \gg m$.

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