

## Exercise 6.8 The Kasner cosmology

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1 {t, x, y, z}::Coordinate.
2 {a,b,c,d,e,f,g,h#}::Indices(values={t, x, y, z}, position=independent).
3
4 \partial{#}::PartialDerivative.
5
6 p1::LaTeXForm("p_1").
7 p2::LaTeXForm("p_2").
8 p3::LaTeXForm("p_3").
9
10 g^{a b}::InverseMetric. # essential when using complete (gab, $g^{a b}$)
11
12 Gamma := \Gamma^{a}_{f g} -> 1/2 g^{a b} ( \partial_{g}\{g_{b f}\}
13                                         + \partial_{f}\{g_{b g}\}
14                                         - \partial_{b}\{g_{f g}\} ).
15
16 Rabcd := R^{d}_{e f g} -> \partial_{f}\{\Gamma^{d}_{e g}\}
17                      - \partial_{g}\{\Gamma^{d}_{e f}\}
18                      + \Gamma^{d}_{b f} \Gamma^{b}_{e g}
19                      - \Gamma^{d}_{b g} \Gamma^{b}_{e f}.
20
21 Rab := R_{a b} -> R^{c}_{c}_{a b}.
22
23 gab := { g_{t t} = -1,
24          g_{x x} = t**(2*p1),
25          g_{y y} = t**(2*p2),
26          g_{z z} = t**(2*p3)}. # cdb(ex-0608.101,gab)
27
28 complete (gab, $g^{a b}$) # cdb(ex-0608.102,gab)
29
30 substitute (Rabcd, Gamma)
31 substitute (Rab, Rabcd)
32
33 evaluate (Gamma, gab, rhsonly=True) # cdb(ex-0608.103,Gamma)
34 evaluate (Rabcd, gab, rhsonly=True) # cdb(ex-0608.104,Rabcd)
35 evaluate (Rab, gab, rhsonly=True) # cdb(ex-0608.105,Rab)
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$$[g_{tt} = -1, g_{xx} = t^{2p_1}, g_{yy} = t^{2p_2}, g_{zz} = t^{2p_3}] \quad (\text{ex-0608.101})$$

$$[g_{tt} = -1, g_{xx} = t^{2p_1}, g_{yy} = t^{2p_2}, g_{zz} = t^{2p_3}, g^{tt} = -1, g^{xx} = t^{-2p_1}, g^{yy} = t^{-2p_2}, g^{zz} = t^{-2p_3}] \quad (\text{ex-0608.102})$$

$$\Gamma^a_{fg} \rightarrow \square_{fg}^a \left\{ \begin{array}{l} \square_{zt}^z = p_3 t^{-1} \\ \square_{yt}^y = p_2 t^{-1} \\ \square_{xt}^x = p_1 t^{-1} \\ \square_{tz}^z = p_3 t^{-1} \\ \square_{ty}^y = p_2 t^{-1} \\ \square_{tx}^x = p_1 t^{-1} \\ \square_{zz}^t = p_3 t^{(2p_3-1)} \\ \square_{yy}^t = p_2 t^{(2p_2-1)} \\ \square_{xx}^t = p_1 t^{(2p_1-1)} \end{array} \right. \quad (\text{ex-0608.103})$$

$$R^d_{efg} \rightarrow \square_{eg}{}^d{}_f \left\{ \begin{array}{l} \square_{xx}{}^t{}_t = p_1 t^{(2p_1-2)} (p_1 - 1) \\ \square_{yy}{}^t{}_t = p_2 t^{(2p_2-2)} (p_2 - 1) \\ \square_{zz}{}^t{}_t = p_3 t^{(2p_3-2)} (p_3 - 1) \\ \square_{tx}{}^x{}_t = p_1 (p_1 - 1) t^{-2} \\ \square_{ty}{}^y{}_t = p_2 (p_2 - 1) t^{-2} \\ \square_{tz}{}^z{}_t = p_3 (p_3 - 1) t^{-2} \\ \square_{xt}{}^t{}_x = -p_1 t^{(2p_1-2)} (p_1 - 1) \\ \square_{yt}{}^t{}_y = -p_2 t^{(2p_2-2)} (p_2 - 1) \\ \square_{zt}{}^t{}_z = -p_3 t^{(2p_3-2)} (p_3 - 1) \\ \square_{tt}{}^x{}_x = p_1 (-p_1 + 1) t^{-2} \\ \square_{tt}{}^y{}_y = p_2 (-p_2 + 1) t^{-2} \\ \square_{tt}{}^z{}_z = p_3 (-p_3 + 1) t^{-2} \\ \square_{zz}{}^y{}_y = p_2 p_3 t^{(2p_3-2)} \\ \square_{zz}{}^x{}_x = p_1 p_3 t^{(2p_3-2)} \\ \square_{yy}{}^z{}_z = p_2 p_3 t^{(2p_2-2)} \\ \square_{yy}{}^x{}_x = p_1 p_2 t^{(2p_2-2)} \\ \square_{xx}{}^z{}_z = p_1 p_3 t^{(2p_1-2)} \\ \square_{xx}{}^y{}_y = p_1 p_2 t^{(2p_1-2)} \\ \square_{zy}{}^y{}_z = -p_2 p_3 t^{(2p_3-2)} \\ \square_{zx}{}^x{}_z = -p_1 p_3 t^{(2p_3-2)} \\ \square_{yz}{}^z{}_y = -p_2 p_3 t^{(2p_2-2)} \\ \square_{yx}{}^x{}_y = -p_1 p_2 t^{(2p_2-2)} \\ \square_{xz}{}^z{}_x = -p_1 p_3 t^{(2p_1-2)} \\ \square_{xy}{}^y{}_x = -p_1 p_2 t^{(2p_1-2)} \end{array} \right. \quad (\text{ex-0608.104})$$

$$R_{ab} \rightarrow \square_{ab} \left\{ \begin{array}{l} \square_{xx} = p_1 t^{(2p_1-2)} (p_1 + p_2 + p_3 - 1) \\ \square_{yy} = p_2 t^{(2p_2-2)} (p_1 + p_2 + p_3 - 1) \\ \square_{zz} = p_3 t^{(2p_3-2)} (p_1 + p_2 + p_3 - 1) \\ \square_{tt} = (-p_1^2 + p_1 - p_2^2 + p_2 - p_3^2 + p_3) t^{-2} \end{array} \right. \quad (\text{ex-0608.105})$$