

Exercise 3.4 More symmetries of Riemann

```
1 {a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w#}::Indices(position=independent).
2
3 \partial{#}::PartialDerivative.
4
5 g_{a b}::Symmetric.
6 g^{a b}::Symmetric.
7
8 \Gamma^{a}_{b c}::TableauSymmetry(shape={2}, indices={1,2}).
9 \Gamma_{a b c}::TableauSymmetry(shape={2}, indices={1,2}).
10
11 GammaU := \Gamma^{a}_{b c} -> 1/2 g^{a d} ( \partial_{b}{g_{d c}}
12                                     + \partial_{c}{g_{b d}}
13                                     - \partial_{d}{g_{b c}}). # cdb(Gamma.000,GammaU)
14
15 GammaD := \Gamma_{a b c} -> 1/2 ( \partial_{b}{g_{a c}}
16                                     + \partial_{c}{g_{b a}}
17                                     - \partial_{a}{g_{b c}}). # cdb(Gamma.010,GammaD)
18
19 Rabcd := R_{a b c d} -> \partial_{c}{\Gamma_{a b d}}
20                       - \partial_{d}{\Gamma_{a b c}}
21                       + \Gamma_{e a d} \Gamma^{e}_{b c}
22                       - \Gamma_{e a c} \Gamma^{e}_{b d}. # cdb(Rabcd.000,Rabcd)
```

Exercise 3.4 Antisymmetry on first pair of indices

```
1  expr := R_{a b c d} + R_{b a c d}.    # cdb(ex-0304.101,expr)
2
3  substitute      (expr, Rabcd)         # cdb(ex-0304.102,expr)
4  substitute      (expr, GammaU)        # cdb(ex-0304.103,expr)
5  substitute      (expr, GammaD)        # cdb(ex-0304.104,expr)
6  distribute      (expr)                # cdb(ex-0304.105,expr)
7  product_rule    (expr)                # cdb(ex-0304.106,expr)
8  sort_product    (expr)                # cdb(ex-0304.107,expr)
9  rename_dummies  (expr)                # cdb(ex-0304.108,expr)
10 canonicalise    (expr)                # cdb(ex-0304.109,expr)
```

$$R_{abcd} + R_{bacd} = \partial_c \Gamma_{abd} - \partial_d \Gamma_{abc} + \Gamma_{ead} \Gamma_{bc}^e - \Gamma_{eac} \Gamma_{bd}^e + \partial_c \Gamma_{bad} - \partial_d \Gamma_{bac} + \Gamma_{ebd} \Gamma_{ac}^e - \Gamma_{ebc} \Gamma_{ad}^e \quad (\text{ex-0304.102})$$

$$\begin{aligned} &= \partial_c \Gamma_{abd} - \partial_d \Gamma_{abc} + \frac{1}{2} \Gamma_{ead} g^{ef} (\partial_g g_{fc} + \partial_g g_{bf} - \partial_g g_{bc}) - \frac{1}{2} \Gamma_{eac} g^{ef} (\partial_g g_{fd} + \partial_g g_{bf} - \partial_g g_{bd}) + \partial_c \Gamma_{bad} - \partial_d \Gamma_{bac} \\ &\quad + \frac{1}{2} \Gamma_{ebd} g^{ef} (\partial_g g_{fc} + \partial_g g_{af} - \partial_g g_{ac}) - \frac{1}{2} \Gamma_{ebc} g^{ef} (\partial_g g_{fd} + \partial_g g_{af} - \partial_g g_{ad}) \end{aligned} \quad (\text{ex-0304.103})$$

$$\begin{aligned} &= \partial_c \left(\frac{1}{2} \partial_g g_{ad} + \frac{1}{2} \partial_g g_{ba} - \frac{1}{2} \partial_g g_{bd} \right) - \partial_d \left(\frac{1}{2} \partial_g g_{ac} + \frac{1}{2} \partial_g g_{ba} - \frac{1}{2} \partial_g g_{bc} \right) + \frac{1}{2} \left(\frac{1}{2} \partial_g g_{ed} + \frac{1}{2} \partial_g g_{ae} - \frac{1}{2} \partial_g g_{ad} \right) g^{ef} (\partial_g g_{fc} + \partial_g g_{bf} - \partial_g g_{bc}) \\ &\quad - \frac{1}{2} \left(\frac{1}{2} \partial_g g_{ec} + \frac{1}{2} \partial_g g_{ae} - \frac{1}{2} \partial_g g_{ac} \right) g^{ef} (\partial_g g_{fd} + \partial_g g_{bf} - \partial_g g_{bd}) + \partial_c \left(\frac{1}{2} \partial_g g_{bd} + \frac{1}{2} \partial_g g_{ab} - \frac{1}{2} \partial_g g_{ad} \right) \\ &\quad - \partial_d \left(\frac{1}{2} \partial_g g_{bc} + \frac{1}{2} \partial_g g_{ab} - \frac{1}{2} \partial_g g_{ac} \right) + \frac{1}{2} \left(\frac{1}{2} \partial_g g_{ed} + \frac{1}{2} \partial_g g_{be} - \frac{1}{2} \partial_g g_{bd} \right) g^{ef} (\partial_g g_{fc} + \partial_g g_{af} - \partial_g g_{ac}) \\ &\quad - \frac{1}{2} \left(\frac{1}{2} \partial_g g_{ec} + \frac{1}{2} \partial_g g_{be} - \frac{1}{2} \partial_g g_{bc} \right) g^{ef} (\partial_g g_{fd} + \partial_g g_{af} - \partial_g g_{ad}) \end{aligned} \quad (\text{ex-0304.104})$$

$$\begin{aligned} &= \frac{1}{2} \partial_c g_{ba} - \frac{1}{2} \partial_d g_{ba} + \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{fc} + \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{bf} - \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{bc} + \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{fc} + \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{bf} - \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{bc} \\ &\quad - \frac{1}{4} \partial_g g_{ad} g^{ef} \partial_g g_{fc} - \frac{1}{4} \partial_g g_{ad} g^{ef} \partial_g g_{bf} + \frac{1}{4} \partial_g g_{ad} g^{ef} \partial_g g_{bc} - \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{fd} - \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{bf} + \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{bd} - \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{fd} \\ &\quad - \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{bf} + \frac{1}{4} \partial_g g_{ae} g^{ef} \partial_g g_{bd} + \frac{1}{4} \partial_g g_{ac} g^{ef} \partial_g g_{fd} + \frac{1}{4} \partial_g g_{ac} g^{ef} \partial_g g_{bf} - \frac{1}{4} \partial_g g_{ac} g^{ef} \partial_g g_{bd} + \frac{1}{2} \partial_c g_{ab} - \frac{1}{2} \partial_d g_{ab} + \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{fc} \\ &\quad + \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{af} - \frac{1}{4} \partial_g g_{ed} g^{ef} \partial_g g_{ac} + \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{fc} + \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{af} - \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{ac} - \frac{1}{4} \partial_g g_{bd} g^{ef} \partial_g g_{fc} - \frac{1}{4} \partial_g g_{bd} g^{ef} \partial_g g_{af} \\ &\quad + \frac{1}{4} \partial_g g_{bd} g^{ef} \partial_g g_{ac} - \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{fd} - \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{af} + \frac{1}{4} \partial_g g_{ec} g^{ef} \partial_g g_{ad} - \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{fd} - \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{af} + \frac{1}{4} \partial_g g_{be} g^{ef} \partial_g g_{ad} \\ &\quad + \frac{1}{4} \partial_g g_{bc} g^{ef} \partial_g g_{fd} + \frac{1}{4} \partial_g g_{bc} g^{ef} \partial_g g_{af} - \frac{1}{4} \partial_g g_{bc} g^{ef} \partial_g g_{ad} \end{aligned} \quad (\text{ex-0304.105})$$

$$\begin{aligned}
R_{abcd} + R_{bacd} = & \frac{1}{2} \partial_{ca} g_{ba} - \frac{1}{2} \partial_{dc} g_{ba} + \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_{\mathfrak{H}fc} + \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_{\mathfrak{G}bf} - \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_{\mathfrak{F}bc} + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{H}fc} + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{G}bf} - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{F}bc} \\
& - \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_{\mathfrak{H}fc} - \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_{\mathfrak{G}bf} + \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_{\mathfrak{F}bc} - \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_{\mathfrak{H}fd} - \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_{\mathfrak{G}bf} + \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_{\mathfrak{F}bd} - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{H}fd} \\
& - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{G}bf} + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_{\mathfrak{F}bd} + \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_{\mathfrak{H}fd} + \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_{\mathfrak{G}bf} - \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_{\mathfrak{F}bd} + \frac{1}{2} \partial_{ca} g_{ab} - \frac{1}{2} \partial_{dc} g_{ab} + \frac{1}{4} \partial_{\mathfrak{H}ed} g^{ef} \partial_a g_{fc} \\
& + \frac{1}{4} \partial_{\mathfrak{H}ed} g^{ef} \partial_a g_{af} - \frac{1}{4} \partial_{\mathfrak{H}ed} g^{ef} \partial_{\mathfrak{F}ac} + \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_a g_{fc} + \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_a g_{af} - \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_{\mathfrak{F}ac} - \frac{1}{4} \partial_{\mathfrak{G}bd} g^{ef} \partial_a g_{fc} - \frac{1}{4} \partial_{\mathfrak{G}bd} g^{ef} \partial_a g_{af} \\
& + \frac{1}{4} \partial_{\mathfrak{G}bd} g^{ef} \partial_{\mathfrak{F}ac} - \frac{1}{4} \partial_{\mathfrak{H}ec} g^{ef} \partial_a g_{fd} - \frac{1}{4} \partial_{\mathfrak{H}ec} g^{ef} \partial_a g_{af} + \frac{1}{4} \partial_{\mathfrak{H}ec} g^{ef} \partial_{\mathfrak{F}ad} - \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_a g_{fd} - \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_a g_{af} + \frac{1}{4} \partial_{\mathfrak{G}be} g^{ef} \partial_{\mathfrak{F}ad} \\
& + \frac{1}{4} \partial_{\mathfrak{G}bc} g^{ef} \partial_a g_{fd} + \frac{1}{4} \partial_{\mathfrak{G}bc} g^{ef} \partial_a g_{af} - \frac{1}{4} \partial_{\mathfrak{G}bc} g^{ef} \partial_{\mathfrak{F}ad} \quad (\text{ex-0304.106}) \\
= & \frac{1}{2} \partial_{ca} g_{ba} - \frac{1}{2} \partial_{dc} g_{ba} + \frac{1}{4} \partial_a g_{ed} \partial_{\mathfrak{H}fc} g^{ef} + \frac{1}{4} \partial_a g_{ed} \partial_{\mathfrak{G}bf} g^{ef} - \frac{1}{4} \partial_a g_{ed} \partial_{\mathfrak{F}bc} g^{ef} + \frac{1}{4} \partial_{\mathfrak{H}fc} \partial_a g_{ae} g^{ef} + \frac{1}{4} \partial_{\mathfrak{G}bf} \partial_a g_{ae} g^{ef} - \frac{1}{4} \partial_a g_{ae} \partial_{\mathfrak{F}bc} g^{ef} \\
& - \frac{1}{4} \partial_{\mathfrak{H}fc} \partial_a g_{ad} g^{ef} - \frac{1}{4} \partial_{\mathfrak{G}bf} \partial_a g_{ad} g^{ef} + \frac{1}{4} \partial_a g_{ad} \partial_{\mathfrak{F}bc} g^{ef} - \frac{1}{4} \partial_a g_{ec} \partial_{\mathfrak{H}fd} g^{ef} - \frac{1}{4} \partial_a g_{ec} \partial_{\mathfrak{G}bf} g^{ef} + \frac{1}{4} \partial_a g_{ec} \partial_{\mathfrak{F}bd} g^{ef} - \frac{1}{4} \partial_{\mathfrak{H}fd} \partial_a g_{ae} g^{ef} \\
& - \frac{1}{4} \partial_a g_{ae} \partial_{\mathfrak{G}bf} g^{ef} + \frac{1}{4} \partial_a g_{ae} \partial_{\mathfrak{F}bd} g^{ef} + \frac{1}{4} \partial_{\mathfrak{H}fd} \partial_a g_{ac} g^{ef} + \frac{1}{4} \partial_{\mathfrak{G}bf} \partial_a g_{ac} g^{ef} - \frac{1}{4} \partial_a g_{ac} \partial_{\mathfrak{F}bd} g^{ef} + \frac{1}{2} \partial_{ca} g_{ab} - \frac{1}{2} \partial_{dc} g_{ab} + \frac{1}{4} \partial_a g_{fc} \partial_{\mathfrak{H}ed} g^{ef} \\
& + \frac{1}{4} \partial_{\mathfrak{H}ed} \partial_a g_{af} g^{ef} - \frac{1}{4} \partial_{\mathfrak{H}ed} \partial_{\mathfrak{F}ac} g^{ef} + \frac{1}{4} \partial_a g_{fc} \partial_{\mathfrak{G}be} g^{ef} + \frac{1}{4} \partial_a g_{af} \partial_{\mathfrak{G}be} g^{ef} - \frac{1}{4} \partial_{\mathfrak{G}be} \partial_{\mathfrak{F}ac} g^{ef} - \frac{1}{4} \partial_a g_{fc} \partial_{\mathfrak{G}bd} g^{ef} - \frac{1}{4} \partial_a g_{af} \partial_{\mathfrak{G}bd} g^{ef} \\
& + \frac{1}{4} \partial_{\mathfrak{G}bd} \partial_{\mathfrak{F}ac} g^{ef} - \frac{1}{4} \partial_a g_{fd} \partial_{\mathfrak{H}ec} g^{ef} - \frac{1}{4} \partial_{\mathfrak{H}ec} \partial_a g_{af} g^{ef} + \frac{1}{4} \partial_{\mathfrak{H}ec} \partial_{\mathfrak{F}ad} g^{ef} - \frac{1}{4} \partial_a g_{fd} \partial_{\mathfrak{G}be} g^{ef} - \frac{1}{4} \partial_{\mathfrak{G}be} \partial_a g_{af} g^{ef} + \frac{1}{4} \partial_{\mathfrak{G}be} \partial_{\mathfrak{F}ad} g^{ef} \\
& + \frac{1}{4} \partial_a g_{fd} \partial_{\mathfrak{G}bc} g^{ef} + \frac{1}{4} \partial_a g_{af} \partial_{\mathfrak{G}bc} g^{ef} - \frac{1}{4} \partial_{\mathfrak{G}bc} \partial_{\mathfrak{F}ad} g^{ef} \quad (\text{ex-0304.107})
\end{aligned}$$

$$\begin{aligned}
R_{abcd} + R_{bacd} = & \frac{1}{2} \partial_{ca} g_{ba} - \frac{1}{2} \partial_{dc} g_{ba} + \frac{1}{4} \partial_a g_{ed} \partial_b g_{fc} g^{ef} + \frac{1}{4} \partial_a g_{ed} \partial_b g_{bf} g^{ef} - \frac{1}{4} \partial_a g_{fd} \partial_b g_{bc} g^{fe} + \frac{1}{4} \partial_b g_{ec} \partial_a g_{af} g^{fe} + \frac{1}{4} \partial_b g_{be} \partial_a g_{af} g^{fe} - \frac{1}{4} \partial_a g_{af} \partial_b g_{bc} g^{fe} \\
& - \frac{1}{4} \partial_b g_{fc} \partial_a g_{ad} g^{ef} - \frac{1}{4} \partial_b g_{bf} \partial_a g_{ad} g^{ef} + \frac{1}{4} \partial_a g_{ad} \partial_b g_{bc} g^{ef} - \frac{1}{4} \partial_a g_{ec} \partial_b g_{fd} g^{ef} - \frac{1}{4} \partial_a g_{ec} \partial_b g_{bf} g^{ef} + \frac{1}{4} \partial_a g_{fc} \partial_b g_{bd} g^{fe} - \frac{1}{4} \partial_b g_{ed} \partial_a g_{af} g^{fe} \\
& - \frac{1}{4} \partial_a g_{ac} \partial_b g_{bf} g^{ef} + \frac{1}{4} \partial_a g_{af} \partial_b g_{bd} g^{fe} + \frac{1}{4} \partial_b g_{fd} \partial_a g_{ac} g^{ef} + \frac{1}{4} \partial_a g_{bf} \partial_b g_{ac} g^{ef} - \frac{1}{4} \partial_a g_{ac} \partial_b g_{bd} g^{ef} + \frac{1}{2} \partial_{ca} g_{ab} - \frac{1}{2} \partial_{dc} g_{ab} + \frac{1}{4} \partial_a g_{ec} \partial_b g_{fd} g^{fe} \\
& + \frac{1}{4} \partial_b g_{ed} \partial_a g_{af} g^{ef} - \frac{1}{4} \partial_b g_{fd} \partial_a g_{ac} g^{fe} + \frac{1}{4} \partial_a g_{ec} \partial_b g_{bf} g^{fe} + \frac{1}{4} \partial_a g_{ae} \partial_b g_{bf} g^{fe} - \frac{1}{4} \partial_a g_{bf} \partial_b g_{ac} g^{fe} - \frac{1}{4} \partial_a g_{fc} \partial_b g_{bd} g^{ef} - \frac{1}{4} \partial_a g_{af} \partial_b g_{bd} g^{ef} \\
& + \frac{1}{4} \partial_a g_{bd} \partial_b g_{ac} g^{ef} - \frac{1}{4} \partial_a g_{ed} \partial_b g_{fc} g^{fe} - \frac{1}{4} \partial_b g_{ec} \partial_a g_{af} g^{ef} + \frac{1}{4} \partial_b g_{fc} \partial_a g_{ad} g^{fe} - \frac{1}{4} \partial_a g_{ed} \partial_b g_{bf} g^{fe} - \frac{1}{4} \partial_a g_{be} \partial_b g_{af} g^{ef} + \frac{1}{4} \partial_a g_{bf} \partial_b g_{ad} g^{fe} \\
& + \frac{1}{4} \partial_a g_{fd} \partial_b g_{bc} g^{ef} + \frac{1}{4} \partial_a g_{af} \partial_b g_{bc} g^{ef} - \frac{1}{4} \partial_a g_{bc} \partial_b g_{ad} g^{ef} \tag{ex-0304.108}
\end{aligned}$$

$$= 0 \tag{ex-0304.109}$$

Exercise 3.4 Symmetric on swapping first and second pair of indices

```
1  expr := R_{a b c d} - R_{c d a b}.    # cdb(ex-0304.201,expr)
2
3  substitute      (expr, Rabcd)         # cdb(ex-0304.202,expr)
4  substitute      (expr, GammaU)        # cdb(ex-0304.203,expr)
5  substitute      (expr, GammaD)        # cdb(ex-0304.204,expr)
6  distribute      (expr)                # cdb(ex-0304.205,expr)
7  product_rule    (expr)                # cdb(ex-0304.206,expr)
8  sort_product    (expr)                # cdb(ex-0304.207,expr)
9  rename_dummies  (expr)                # cdb(ex-0304.208,expr)
10 canonicalise    (expr)                # cdb(ex-0304.209,expr)
```

$$R_{abcd} - R_{cdab} = \partial_a \Gamma_{abd} - \partial_d \Gamma_{abc} + \Gamma_{ead} \Gamma_{bc}^e - \Gamma_{eac} \Gamma_{bd}^e - \partial_a \Gamma_{cdb} + \partial_b \Gamma_{cda} - \Gamma_{ecb} \Gamma_{da}^e + \Gamma_{eca} \Gamma_{db}^e \quad (\text{ex-0304.202})$$

$$\begin{aligned} &= \partial_a \Gamma_{abd} - \partial_d \Gamma_{abc} + \frac{1}{2} \Gamma_{ead} g^{ef} (\partial_f g_{fc} + \partial_c g_{bf} - \partial_f g_{bc}) - \frac{1}{2} \Gamma_{eac} g^{ef} (\partial_f g_{fd} + \partial_d g_{bf} - \partial_f g_{bd}) - \partial_a \Gamma_{cdb} + \partial_b \Gamma_{cda} \\ &\quad - \frac{1}{2} \Gamma_{ecb} g^{ef} (\partial_d g_{fa} + \partial_a g_{df} - \partial_f g_{da}) + \frac{1}{2} \Gamma_{eca} g^{ef} (\partial_d g_{fb} + \partial_b g_{df} - \partial_f g_{db}) \end{aligned} \quad (\text{ex-0304.203})$$

$$\begin{aligned} &= \partial_c \left(\frac{1}{2} \partial_f g_{ad} + \frac{1}{2} \partial_d g_{ba} - \frac{1}{2} \partial_a g_{bd} \right) - \partial_d \left(\frac{1}{2} \partial_f g_{ac} + \frac{1}{2} \partial_d g_{ba} - \frac{1}{2} \partial_a g_{bc} \right) + \frac{1}{2} \left(\frac{1}{2} \partial_a g_{ed} + \frac{1}{2} \partial_d g_{ae} - \frac{1}{2} \partial_e g_{ad} \right) g^{ef} (\partial_f g_{fc} + \partial_c g_{bf} - \partial_f g_{bc}) \\ &\quad - \frac{1}{2} \left(\frac{1}{2} \partial_a g_{ec} + \frac{1}{2} \partial_d g_{ae} - \frac{1}{2} \partial_e g_{ac} \right) g^{ef} (\partial_f g_{fd} + \partial_d g_{bf} - \partial_f g_{bd}) - \partial_a \left(\frac{1}{2} \partial_d g_{cb} + \frac{1}{2} \partial_b g_{dc} - \frac{1}{2} \partial_d g_{db} \right) \\ &\quad + \partial_b \left(\frac{1}{2} \partial_d g_{ca} + \frac{1}{2} \partial_d g_{dc} - \frac{1}{2} \partial_d g_{da} \right) - \frac{1}{2} \left(\frac{1}{2} \partial_d g_{eb} + \frac{1}{2} \partial_b g_{ce} - \frac{1}{2} \partial_e g_{cb} \right) g^{ef} (\partial_d g_{fa} + \partial_a g_{df} - \partial_f g_{da}) \\ &\quad + \frac{1}{2} \left(\frac{1}{2} \partial_d g_{ea} + \frac{1}{2} \partial_d g_{ce} - \frac{1}{2} \partial_e g_{ca} \right) g^{ef} (\partial_d g_{fb} + \partial_b g_{df} - \partial_f g_{db}) \end{aligned} \quad (\text{ex-0304.204})$$

$$\begin{aligned} &= \frac{1}{2} \partial_{cd} g_{ad} + \frac{1}{2} \partial_{cd} g_{ba} - \frac{1}{2} \partial_{cd} g_{bd} - \frac{1}{2} \partial_{ad} g_{ac} - \frac{1}{2} \partial_{ad} g_{ba} + \frac{1}{2} \partial_{ad} g_{bc} + \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_f g_{fc} + \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_d g_{bf} - \frac{1}{4} \partial_a g_{ed} g^{ef} \partial_f g_{bc} + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_b g_{fc} \\ &\quad + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_d g_{bf} - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_f g_{bc} - \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_b g_{fc} - \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_d g_{bf} + \frac{1}{4} \partial_a g_{ad} g^{ef} \partial_f g_{bc} - \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_b g_{fd} - \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_d g_{bf} \\ &\quad + \frac{1}{4} \partial_a g_{ec} g^{ef} \partial_f g_{bd} - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_b g_{fd} - \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_d g_{bf} + \frac{1}{4} \partial_a g_{ae} g^{ef} \partial_f g_{bd} + \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_b g_{fd} + \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_d g_{bf} - \frac{1}{4} \partial_a g_{ac} g^{ef} \partial_f g_{bd} \\ &\quad - \frac{1}{2} \partial_a g_{cb} - \frac{1}{2} \partial_a g_{dc} + \frac{1}{2} \partial_a g_{db} + \frac{1}{2} \partial_b g_{ca} + \frac{1}{2} \partial_b g_{dc} - \frac{1}{2} \partial_b g_{da} - \frac{1}{4} \partial_d g_{eb} g^{ef} \partial_a g_{fa} - \frac{1}{4} \partial_d g_{eb} g^{ef} \partial_a g_{df} + \frac{1}{4} \partial_d g_{eb} g^{ef} \partial_f g_{da} \\ &\quad - \frac{1}{4} \partial_b g_{ce} g^{ef} \partial_a g_{fa} - \frac{1}{4} \partial_b g_{ce} g^{ef} \partial_a g_{df} + \frac{1}{4} \partial_b g_{ce} g^{ef} \partial_f g_{da} + \frac{1}{4} \partial_d g_{cb} g^{ef} \partial_a g_{fa} + \frac{1}{4} \partial_d g_{cb} g^{ef} \partial_a g_{df} - \frac{1}{4} \partial_d g_{cb} g^{ef} \partial_f g_{da} + \frac{1}{4} \partial_d g_{ea} g^{ef} \partial_a g_{fb} \\ &\quad + \frac{1}{4} \partial_d g_{ea} g^{ef} \partial_b g_{df} - \frac{1}{4} \partial_d g_{ea} g^{ef} \partial_f g_{db} + \frac{1}{4} \partial_d g_{ce} g^{ef} \partial_a g_{fb} + \frac{1}{4} \partial_d g_{ce} g^{ef} \partial_b g_{df} - \frac{1}{4} \partial_d g_{ce} g^{ef} \partial_f g_{db} - \frac{1}{4} \partial_d g_{ca} g^{ef} \partial_a g_{fb} - \frac{1}{4} \partial_d g_{ca} g^{ef} \partial_b g_{df} \\ &\quad + \frac{1}{4} \partial_d g_{ca} g^{ef} \partial_f g_{db} \end{aligned} \quad (\text{ex-0304.205})$$

$$\begin{aligned}
R_{abcd} - R_{cdab} = & \frac{1}{2} \partial_{ct} g_{ad} + \frac{1}{2} \partial_{ca} g_{ba} - \frac{1}{2} \partial_{ca} g_{bd} - \frac{1}{2} \partial_{dt} g_{ac} - \frac{1}{2} \partial_{dc} g_{ba} + \frac{1}{2} \partial_{da} g_{bc} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_c + \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c + \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_c \\
& + \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c - \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_c - \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c - \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_d - \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f \\
& + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d - \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_d - \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d + \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_d + \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d \\
& - \frac{1}{2} \partial_{ad} g_{cb} - \frac{1}{2} \partial_{at} g_{dc} + \frac{1}{2} \partial_{ac} g_{db} + \frac{1}{2} \partial_{ba} g_{ca} + \frac{1}{2} \partial_{ba} g_{dc} - \frac{1}{2} \partial_{bc} g_{da} - \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{ad} f_a - \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{ad} f + \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{fg} da \\
& - \frac{1}{4} \partial_{tg} ce g^{ef} \partial_{ad} f_a - \frac{1}{4} \partial_{tg} ce g^{ef} \partial_{ad} f + \frac{1}{4} \partial_{tg} ce g^{ef} \partial_{fg} da + \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{ad} f_a + \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{ad} f - \frac{1}{4} \partial_{g} e_b g^{ef} \partial_{fg} da + \frac{1}{4} \partial_{g} e_a g^{ef} \partial_{ad} f_b \\
& + \frac{1}{4} \partial_{g} e_a g^{ef} \partial_{ad} f - \frac{1}{4} \partial_{g} e_a g^{ef} \partial_{fg} db + \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{ad} f_b + \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{ad} f - \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{fg} db - \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{ad} f_b - \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{ad} f \\
& + \frac{1}{4} \partial_{ad} ce g^{ef} \partial_{fg} db \\
& \quad \quad \quad (\text{ex-0304.206}) \\
= & \frac{1}{2} \partial_{ct} g_{ad} + \frac{1}{2} \partial_{ca} g_{ba} - \frac{1}{2} \partial_{ca} g_{bd} - \frac{1}{2} \partial_{dt} g_{ac} - \frac{1}{2} \partial_{dc} g_{ba} + \frac{1}{2} \partial_{da} g_{bc} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_c g^{ef} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c g^{ef} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_c g^{ef} \\
& + \frac{1}{4} \partial_{g} b_f \partial_{ad} g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c g^{ef} - \frac{1}{4} \partial_{tg} f_c \partial_{ad} g^{ef} - \frac{1}{4} \partial_{g} b_f \partial_{ad} g^{ef} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_c g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{tg} f_d g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f g^{ef} \\
& + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d g^{ef} - \frac{1}{4} \partial_{tg} f_d \partial_{ad} g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{g} b_f g^{ef} + \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d g^{ef} + \frac{1}{4} \partial_{tg} f_d \partial_{ad} g^{ef} + \frac{1}{4} \partial_{g} b_f \partial_{ad} g^{ef} - \frac{1}{4} \partial_{ad} g^{ef} \partial_{fg} b_d g^{ef} \\
& - \frac{1}{2} \partial_{ad} g_{cb} - \frac{1}{2} \partial_{at} g_{dc} + \frac{1}{2} \partial_{ac} g_{db} + \frac{1}{2} \partial_{ba} g_{ca} + \frac{1}{2} \partial_{ba} g_{dc} - \frac{1}{2} \partial_{bc} g_{da} - \frac{1}{4} \partial_{g} e_b \partial_{ad} f_a g^{ef} - \frac{1}{4} \partial_{ad} f \partial_{g} e_b g^{ef} + \frac{1}{4} \partial_{g} e_b \partial_{fg} da g^{ef} \\
& - \frac{1}{4} \partial_{tg} ce \partial_{ad} f_a g^{ef} - \frac{1}{4} \partial_{ad} f \partial_{tg} ce g^{ef} + \frac{1}{4} \partial_{tg} ce \partial_{fg} da g^{ef} + \frac{1}{4} \partial_{ad} f_a \partial_{g} e_b g^{ef} + \frac{1}{4} \partial_{ad} f \partial_{g} e_b g^{ef} - \frac{1}{4} \partial_{g} e_b \partial_{fg} da g^{ef} + \frac{1}{4} \partial_{g} e_a \partial_{ad} f_b g^{ef} \\
& + \frac{1}{4} \partial_{tg} f_d \partial_{g} e_a g^{ef} - \frac{1}{4} \partial_{g} e_a \partial_{fg} db g^{ef} + \frac{1}{4} \partial_{ad} ce \partial_{ad} f_b g^{ef} + \frac{1}{4} \partial_{ad} ce \partial_{ad} f g^{ef} - \frac{1}{4} \partial_{ad} ce \partial_{fg} db g^{ef} - \frac{1}{4} \partial_{ad} f_b \partial_{ad} ce g^{ef} - \frac{1}{4} \partial_{tg} f_d \partial_{ad} ce g^{ef} \\
& + \frac{1}{4} \partial_{ad} ce \partial_{fg} db g^{ef} \\
& \quad \quad \quad (\text{ex-0304.207})
\end{aligned}$$

$$\begin{aligned}
R_{abcd} - R_{cdab} = & \frac{1}{2} \partial_c \mathfrak{g}_{ad} + \frac{1}{2} \partial_{ca} \mathfrak{g}_{ba} - \frac{1}{2} \partial_{ca} \mathfrak{g}_{bd} - \frac{1}{2} \partial_{dt} \mathfrak{g}_{ac} - \frac{1}{2} \partial_{dc} \mathfrak{g}_{ba} + \frac{1}{2} \partial_{da} \mathfrak{g}_{bc} + \frac{1}{4} \partial_a \mathfrak{g}_{ed} \partial_{\mathfrak{t}f} \mathfrak{g}_{fc} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{ed} \partial_{\mathfrak{g}b} \mathfrak{g}_{f} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{fd} \partial_{\mathfrak{g}b} \mathfrak{g}_{c} g^{fe} + \frac{1}{4} \partial_{\mathfrak{t}ec} \partial_a \mathfrak{g}_{af} g^{fe} \\
& + \frac{1}{4} \partial_{\mathfrak{g}be} \partial_a \mathfrak{g}_{af} g^{fe} - \frac{1}{4} \partial_a \mathfrak{g}_{af} \partial_{\mathfrak{g}bc} g^{fe} - \frac{1}{4} \partial_{\mathfrak{t}fc} \partial_a \mathfrak{g}_{ad} g^{ef} - \frac{1}{4} \partial_{\mathfrak{g}bf} \partial_a \mathfrak{g}_{ad} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{ad} \partial_{\mathfrak{f}bc} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{ec} \partial_{\mathfrak{t}fd} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{ec} \partial_{\mathfrak{g}bf} g^{ef} \\
& + \frac{1}{4} \partial_a \mathfrak{g}_{fc} \partial_{\mathfrak{g}bd} g^{fe} - \frac{1}{4} \partial_{\mathfrak{t}ed} \partial_a \mathfrak{g}_{af} g^{fe} - \frac{1}{4} \partial_a \mathfrak{g}_{ae} \partial_{\mathfrak{g}bf} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{af} \partial_{\mathfrak{g}bd} g^{fe} + \frac{1}{4} \partial_{\mathfrak{t}fd} \partial_a \mathfrak{g}_{ac} g^{ef} + \frac{1}{4} \partial_{\mathfrak{g}bf} \partial_a \mathfrak{g}_{ac} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{ac} \partial_{\mathfrak{f}bd} g^{ef} \\
& - \frac{1}{2} \partial_a \mathfrak{g}_{cb} - \frac{1}{2} \partial_{at} \mathfrak{g}_{dc} + \frac{1}{2} \partial_a \mathfrak{g}_{db} + \frac{1}{2} \partial_{ba} \mathfrak{g}_{ca} + \frac{1}{2} \partial_{ba} \mathfrak{g}_{dc} - \frac{1}{2} \partial_{bg} \mathfrak{g}_{da} - \frac{1}{4} \partial_{\mathfrak{g}eb} \partial_a \mathfrak{g}_{fa} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{de} \partial_{\mathfrak{g}fb} g^{fe} + \frac{1}{4} \partial_{\mathfrak{g}fb} \partial_a \mathfrak{g}_{da} g^{fe} \\
& - \frac{1}{4} \partial_{\mathfrak{t}ce} \partial_a \mathfrak{g}_{fa} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{de} \partial_{\mathfrak{t}cf} g^{fe} + \frac{1}{4} \partial_{\mathfrak{t}cf} \partial_a \mathfrak{g}_{da} g^{fe} + \frac{1}{4} \partial_a \mathfrak{g}_{fa} \partial_{\mathfrak{g}cb} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{df} \partial_{\mathfrak{g}cb} g^{ef} - \frac{1}{4} \partial_{\mathfrak{g}cb} \partial_{\mathfrak{f}da} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{ea} \partial_{\mathfrak{g}fb} g^{ef} \\
& + \frac{1}{4} \partial_{\mathfrak{t}de} \partial_a \mathfrak{g}_{fa} g^{fe} - \frac{1}{4} \partial_a \mathfrak{g}_{fa} \partial_{\mathfrak{g}db} g^{fe} + \frac{1}{4} \partial_a \mathfrak{g}_{ce} \partial_{\mathfrak{g}fb} g^{ef} + \frac{1}{4} \partial_a \mathfrak{g}_{ce} \partial_{\mathfrak{t}df} g^{ef} - \frac{1}{4} \partial_a \mathfrak{g}_{cf} \partial_{\mathfrak{g}db} g^{fe} - \frac{1}{4} \partial_{\mathfrak{g}fb} \partial_a \mathfrak{g}_{ca} g^{ef} - \frac{1}{4} \partial_{\mathfrak{t}df} \partial_a \mathfrak{g}_{ca} g^{ef} \\
& + \frac{1}{4} \partial_a \mathfrak{g}_{ca} \partial_{\mathfrak{f}db} g^{ef} \tag{ex-0304.208} \\
= 0 \tag{ex-0304.209}
\end{aligned}$$