

IMPORTANT ERRATA for A GENERAL RELATIVITY WORKBOOK (1st Printing)
(last updated 1/12/2018)

- Inside front cover, under “Useful Formulae,” left side for Riemann tensor in a LIF should be $R_{\alpha\beta\mu\nu}$, not $R^{\alpha}_{\beta\mu\nu}$.
- Page 4, figure 1.2, label under point B : “ $t_B = c(0.02 \text{ s})$ ” should be “ $ct_B = c(0.02 \text{ s})$ ”.
- Page 10, P1.5, 3rd line from the bottom: “ $(1+x)^n = 1+nx$ ” should be “ $(1+x)^n \approx 1+nx$ ”.
- Page 14, section about defining inertial reference frames: In general relativity, technically one can use the described method to define a *locally* inertial reference frame (that is, a frame that is inertial to a specified accuracy within a sufficiently small region of space and time).
- Page 38, equation 3.32: change \mathbf{p}_{if} to \mathbf{p}_{rf} .
- Page 40, line immediately following equation 3.37, p^x should be \mathbf{p}_x .
- Page 42, problem P3.3, second line: “ $(v \leq 135 \text{ MeV})$ ” should be “ $(m_\pi = 135 \text{ MeV})$ ”.
- Page 51, line between equations 4.29 and 4.30: “left” should be “right” and vice versa.
- Page 54, second line above equation 5.1: should be “neighboring point Q ” not “neighboring point P ”.
- Page 58, seventh line: “we define a vector ds ” should be “we define a vector \mathbf{e}_θ ”.
- Page 60, figure 5.4, the basis vector \mathbf{e}_θ should be \mathbf{e}_ρ .
- Page 62, second line of equation 5.30: $(-\gamma\beta)^2$ should be simply $(\gamma\beta)^2$.
- Page 62, Exercise 5.2.1 should be numbered 5.5.1.
- Page 64, problem P5.4, part b, 2nd line: change “coordinates in the cartesian” to “components in the cartesian”.
- Page 64, problem P5.4, part e: ∂x should be \mathbf{e}_q .
- Page 64, problem P5.6, 5th line from the problem’s end: replace θ with r .
- Due to a computer glitch, the page numbers in chapter 6 are out of sequence: they should read 65-76 instead of 81-92. This means that pages having numbers in the range 81-92 appear in chapter 6 and also in chapters 7 and 8. Index entries for items in chapter 6 point you to the correct (misnumbered) page in chapter 6. For example, “Covector” in the index points you to pages 82-86, but it means the pages with those numbers in chapter 6, not the pages with the same numbers in chapter 7.
- Page 79, equations 7.4b and 7.4c: Technically, the x , y , and z subscripts should be superscripts.
- Page 79, 2nd line from the bottom: change “But the left” to “But the right”.
- Page 80, between equations 7.7 and 7.8, $m^2 = -p^\mu p_\mu$, not $p^\mu p_\mu$.
- Pages 88, 354, 360-362, 364, 365, 368, 373, 377, 384, 390, 408, 412, 471, often several times per page: “Lorentz gauge” should be “Lorenz gauge”, after Ludwig Lorenz, not Hendrik Lorentz. (This error appears in many books.)
- Page 91: equation 8.11 got all screwed up somehow. The correct equation should look like this

$$0 = \frac{d}{d\sigma} \left[-g_{\alpha\mu} \frac{dx^\mu}{d\tau} \right] + \frac{1}{2} \frac{\partial g_{\mu\nu}}{\partial x^\alpha} \frac{dx^\mu}{d\tau} \frac{dx^\nu}{d\sigma}$$

- Page 93, Figure 8.2: points A and B and the worldline of the free particle should all lie on the t axis.
- Page 94, equation 8.22 should read

$$\tau_{AB} \equiv \int_0^1 L(\sigma) d\sigma \quad \text{where} \quad L = \sqrt{-g_{\mu\nu} \dot{x}^\mu \dot{x}^\nu}$$

- Page 107, four lines above equation 9.9 (end of the previous paragraph): h should be r_s .
- Page 109, figure 9.2: The $\Delta\tau$ labeling the interval on the left vertical worldline should be $\Delta\tau_E$.
- Page 113, 10th line: “ $t \propto h$ ” should be “ $t \approx h$ ”.
- Page 117, figure 10.1, left diagram: The horizontal line should be labeled \tilde{E} .
- Page 118, second line below equation 10.11: The r^2 should simply be r .
- Page 130, figure 11.2: The \tilde{E} label should be next to the *lower* horizontal line, and the *upper* horizontal line should be labeled with an r at its right end.
- Page 132, line following “Spatial Curvature”: change $g_{tt} = 1 - 2GM/r$ to $g_{tt} = -(1 - 2GM/r)$.
- Page 141, problem P11.4, 6th line above equation 11.33: “Darmour” should be “Damour”.
- Page 144, equation 12.5 and the line above: change “flat space” to “flat spacetime”.
- Page 149, box 12.4, title and 2nd line of exercise: change “flat space” to “flat spacetime”.
- Page 155, footnote: the link is broken: use <http://adsabs.harvard.edu/full/2001ASPC..252...21C>
- Page 165, equation 13.27: change $\sqrt{1 + \frac{2GM}{r_0 u(u+1)}}$ to $\sqrt{1 - \frac{2GM}{r_0 u(u+1)}}$
- Page 178, problem P14.8, 7th line from bottom: $2GM$ for a solar-mass black hole is about $10 \mu\text{s}$, not 40 ms .
- Page 202, 12th line from the bottom: change “coordinate differences” to “component differences”.
- Page 203, 3rd full paragraph, 3rd line from bottom: again “coordinate” should be “component”.
- Page 204, equation 17.16: the expression on the far right should have a dx^σ outside the square brackets.

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- Page 205, in the first line of equation 17.22, the lower indices of the Christoffel symbols on the far left and the far right are inconsistent with the definition in equation 17.3. (This does not matter, though, because of box 17.3.)
- Page 205, equation 17.25: Change the superscript ν index to a superscript σ index (two times).
- Page 207, line below equation 17.31: change $\partial_\mu g_{\mu\nu}$ to $\partial_\alpha g_{\mu\nu}$.
- Page 209, equation 17.38: change $\partial'_\gamma \partial'_\sigma \partial g'_{\mu\nu}$ to $\partial'_\gamma \partial'_\sigma g'_{\mu\nu}$.
- Page 226, first line of box 19.3: “and $R_{\alpha\beta\nu\mu} = -R_{\alpha\beta\mu\nu}$ ” should be “and $R_{\beta\alpha\mu\nu} = -R_{\alpha\beta\mu\nu}$ ”.
- Page 227, equation 19.17, second term in parentheses: superscript α should be σ : that is, $-\partial_\nu \Gamma_{\beta\mu}^\alpha$ should be $-\partial_\nu \Gamma_{\beta\mu}^\sigma$.
- Page 230, problem P19.8, 4th line below equation 19.28: change “metric component” to “tensor component”.
- Page 232, fourth paragraph, third line: change “last chapter” to “chapter 18”.
- Page 237, box 20.3, first line: Change “moving particles.” to “moving particles with mass m .”
- Page 237, box 20.3, second paragraph, second line: Delete “mass m and”. (The derivation in this box really only works if all particles have the same mass.)
- Page 241, problem P20.1, last line: k_B is 1.536×10^{-40} kg/K, not 1.536×10^{-49} kg/K.
- Page 251, problem 21.8a, 2nd line from end of part: $d^2x/d\tau$ should be $d^2x/d\tau^2$.
- Page 251, problem 21.8f, 2nd line from end of part: $-g^2/8\pi G$ should be $g^2/8\pi G$. There are also some sign errors in the solutions manual (from forgetting that g_{tt} is negative).
- Page 255, first paragraph, last line: Change “all objects” to “all non-rotating objects”.
- Page 256, below equation 22.9: Add (for clarity) “where \square^2 (the four-dimensional del operator) $\equiv \eta^{\alpha\mu} \partial_\alpha \partial_\mu = -\partial^2/\partial t^2 + \nabla^2$.”
- Page 257, 7th line below equation 22.14: change $-G\rho_g(\vec{r})dV$ to $-G\rho_g(\vec{r}_s)dV$.
- Page 263, P22.1, part a, fourth line: change “ h_{tt} ” to “ h_{rr} ”.
- Page 263, P22.6, part b, first and third lines: replace $\vec{\Phi}_G$ with $\vec{\nabla}\Phi_G$.
- Page 271, 5th line from the top: change $ds^2 = A(x^0)^2 + dt$ to $ds^2 = -A(x^0)^2 + dt$ (put a negative sign before A).
- Page 277, P23.5, line before part a: replace $R_{\mu\nu} = T_{\mu\nu} - \frac{1}{2}g_{\mu\nu}T$ with $R_{\mu\nu} = 8\pi G(T_{\mu\nu} - \frac{1}{2}g_{\mu\nu}T)$.
- Page 278, 3rd line below equation 23.51: R_{tt} should be R_{rr} .
- Page 278, equation 23.52: right side should be $-8\pi G f \sigma$, not $-8\pi G C \sigma$.
- Page 287, last line: change “ \approx ” to “ $=$ ”
- Page 288, equation 24.6: replace $r^{-1/2}$ by $\vec{v}_G = H_0 \vec{r}_G$.
- Page 289, 12th line from the end: change “average galactic separation” to “average inverse galactic separation”.
- Page 295, line below equation 25.3: change $2g_{tt}dt d\vec{r}$ to $2g_{rr}dt d\vec{r}$.
- Page 296, third line below equation 25.14: Change $\sin(\vec{r}/R)$ to $i \sin(\vec{r}/R)$.
- Page 297, caption of figure 25.1, 5th line: change “ $q(\vec{r}) = R$ ” to “ $\chi \equiv \vec{r}/R$ ”.
- Page 300, last entry in fourth line for R22: should be $\frac{1}{4AD}C_0D_0$ not $\frac{1}{4AC}D_0C_0$.
- Page 316, problem P26.9, part d: change “scale factor R ” to “curvature scale R ”.
- Page 316, problem P26.10, just before part a: change “Hubble constant” to “Hubble parameter”.
- Page 320, equation 27.16: replace L with L_s , to distinguish the luminosity measured in the source frame with L in the previous paragraph, which is the inferred luminosity in the *observer’s* frame.
- Page 321, figure 27.3(b): Label the vertical axis “ $a(t)$ (unitless)”.
- Page 328, line below equation 28.1: change $4\pi G \rho_{0(m,r,v)}/3H_0^2$ to $8\pi G \rho_{0(m,r,v)}/3H_0^2$.
- Page 331, third paragraph in the **Photon Decoupling** section, third line: change “directly proportional” to “inversely proportional”. Also note that Ta is a constant (see equation 26.10), and T at the present is 2.73 K.
- Page 337, fifth line above exercise 28.5.1: Change ρ_{m0}/m_p to ρ_{b0}/m_p , and add to next line after the close parenthesis “, ρ_{b0} is the normal-matter portion of the current total matter density ρ_{m0} ”.
- Page 341, 9th line before the end: change 10^{-5} to 10^5 .
- Page 343, third paragraph, fifth line: Change “ $\rho \approx$ ” to “ $\rho_r \approx$ ”.
- Page 343, third paragraph, fourth line from the bottom: For clarity change “ $t_e \sim [10 \cdot \frac{8}{3} \pi G \rho]^{-1/2}$ ” to “ $t_e \sim [\frac{8}{3} \pi G \rho_r]^{-1/2} \sim [10 \cdot \frac{8}{3} \pi G \rho_r]^{-1/2}$ ”. Also put a period after “box 29.5”.
- Page 360, 3rd line from the end: “ $af + bf_0$, where a and b are constants” should be “ $f + bf_0$, where b is a constant”.
- Page 365, 3rd line above equation 31.13: “ $(-g_{tt})^{1/2}$ ” should be “ $(-g_{tt})^{-1/2}$ ”.
- Page 366, Figure 31.1: in each diagram except the one on the upper left, there is one dot outside the ellipse that should be moved to the nearest point on the ellipse.
- Page 367, next-to-last paragraph: This paragraph is seriously out of date! LIGO first detected gravitational waves (from a pair of coalescing black holes) on September 14, 2015 (announced in February of 2016) and has subsequently observed waves from a number of similar events. Leaders of the LIGO experiment won the 2017 Nobel Prize for physics for this triumph.

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- Page 367, 2nd and 3rd lines of last paragraph: delete “now renamed the New Gravitational-wave Observatory (NGO),” and replace “which might be launched in the late 2020s” with “which is planned for launch in the 2030s”. (The ESA is now formally committed to funding the original LISA proposal, not the somewhat reduced NGO proposal.) Also replace all subsequent instances of “NGO” in this paragraph with “LISA”.
- Page 371, equation 31.13r: add “= 0” to the end, to make it like equation 31.13.
- Page 371, third line of exercise; change “Lorentz” to “Lorenz”.
- Page 378, equation 32.7a: “ $h_+(t, z) =$ ” should be “ $h_+(t, z) \equiv$ ”.
- Page 378, equation 32.8a: “ $A = -1$ ” should be “ $A = 1$ ”.
- Page 378, equation 32.8b: change all “1” subscripts to “0” and all “4” subscripts to “3”.
- Page 385, line below equation 33.5: Change “moment of inertia” to “reduced quadrupole moment”. This tensor is sometimes called the “moment of inertia” tensor, but it is different from the tensor of that name in mechanics, and students find this confusing.
- Page 385, equation 33.7: The second term on the right should be negative and multiplied by G .
- Page 386, the first and second lines below equation 33.10c: Change “moment of inertia” to “quadrupole moment” (once in each line).
- Page 386, second line above equation 33.11: change “subtracting the trace from each nonzero element” to “subtracting symmetric fractions of the trace from each remaining nonzero diagonal element”.
- Page 387, equation 33.15: delete the extra factor of 2 in the second term on the right.
- Page 387, equation 33.16: Note that the \vec{n} vectors depend on θ and ϕ , so whatever θ -dependence remains after the integration over ϕ must be carried into the integral over θ . (Some find the notation confusing.)
- Page 391, exercise 33.4.1: “by raising” should be “by raising or lowering”.
- Page 391, third line below equation 33.37: Change A_{TT}^{jk} to A_T^{jk} (we aren’t traceless yet).
- Page 396, problem P33.9, first line of part a: change “moment of inertia” to “quadrupole moment”.
- Page 396, problem P33.9, first line after equation 33.50: change “moment of inertia” to “quadrupole moment”.
- Page 398, 2nd line above equation 34.1: “xy plane” not “xz plane”.
- Page 398, next to last line: Change $4GM\eta D^2 \omega^2 / R_0$ to $-4GM\eta D^2 \omega^2 / R_0$.
- Page 399, second line: Change “clockwise” to “counterclockwise”.
- Page 399, line before equation 34.8: reference should be to equation 33.12, not 33.4.
- Page 400, equation 34.16a: $A_+ = 7.7 \times 10^{-21}$, not 8.7×10^{-21} .
- Page 400, 2nd line after heading “The Evidence for Gravitational Waves”: change “PSR 1913+16” to “PSR B1913+16”.
- Page 401, caption of figure 34.1, 1st line: change “PSR B1913-16” to “PSR B1913+16”.
- Page 405, exercise 34.5.1, 2nd line: Change GM to $GM\omega$.
- Page 409, second line after equation 35.9: delete “except that the sign of the $\partial \vec{A}_C / \partial t$ term is reversed.”
- Page 413, equation 35.24a: change $\vec{\nabla} \times \vec{\nabla} \times \vec{F}$ to $\vec{\nabla} \times (\vec{\nabla} \times \vec{F})$.
- Page 416, equation 35.29, 2nd line, left side: change $+\Gamma_{\mu\nu}^\alpha u^\mu s^\alpha$ to $+\Gamma_{\mu\nu}^\alpha u^\mu s^\nu$.
- Page 418, last line of first paragraph: Change “rotating star or black hole” to “rotating black hole”.
- Page 418, equation 36.5: change R^5 to $2R^5$ in the denominator of the last term.
- Page 420, section on **Importance of the Kerr Solution**: The Kerr solution applies *only* to black holes, and *not* to the spacetime outside arbitrary axially-symmetric objects. Items 1 and 2 therefore need to be rewritten.
- Page 423, equation 36.18: Change “4” to “6” in all of the initial factors (in each of the four lines), and change the $R^2 r^2$ term (the final term) inside each of the square brackets to $\frac{1}{3} R^2 r^2$.
- Page 424, equation 36.8r, 2nd line: add “ dt ” following the close parenthesis (making it agree with eqn. 36.8).
- Page 425, exercise 36.5, 7th line from the bottom: reference should be to problem P22.1, not P22.2.
- Page 425, exercise 36.5, 6th line from the bottom: $r \equiv (1 + 2GM/R)^{1/2} R$, not $r \equiv (1 - 2GM/R)^{1/2} R$.
- Page 429, line above equation 37.9: $2dr/d\tau$ should be just $dr/d\tau$.
- Page 430, second line below equation 37.14: “ $|\Omega|$ is smaller” should be “ $|\Omega|$ is smaller”.
- Page 441, 5th line below the “Cosmic Censorship” heading: change “ $r^2 + a^2 \cos^2 \theta = 0$ ” to simply “ $r = 0$ ”.
- Page 447, problem P38.5, equation 38.28: change $\phi(r) = 2\sqrt{GM} a \dots$ to $\phi(r) = \sqrt{2GM} a \dots$.
- Page 448, problem P38.10, last line of part b: change “ $u \cdot w$ ” to “ $\mathbf{u} \cdot \mathbf{w}$ ”.
- Page 444, box 38.4, first line: add “at a given instant of time” after “The outer Kerr event horizon”.
- Page 448, P38.9, part e, first line: Change “falling object moving” to “falling object with $\ell = 0$ moving”.
- Page 460, equation 39.31: change $4\pi k_B G$ in the numerator of the first factor to $4\pi k_B$.

(This list does not include some minor typographical errors that are not likely to lead to confusion.)