

## ERRATA for A GENERAL RELATIVITY WORKBOOK (2nd Printing)

- Page 14, delete the final sentence and replace with “In special relativity, we define an **inertial reference frame** (IRF) to be a frame in which a free object moves at a constant velocity (that is, Newton’s second law is obeyed) to some specified accuracy everywhere in the frame. (In general relativity, the best we can do is find frames that are inertial over a sufficiently small region of space and time.)
- Page 72, title for box 6.3: Change “6.3THE” to “6.3 The”.
- Page 79, equations 7.4b and 7.4c: Technically, the  $x$ ,  $y$ , and  $z$  subscripts should be superscripts.
- Page 94, equation 8.24: Technically, the  $\partial$  symbols in the leftmost term should be  $d$  (ordinary derivative) symbols.
- Page 109, figure 9.2: The  $\Delta\tau$  labeling the interval on the left vertical worldline should be  $\Delta\tau_E$ .
- Page 117, figure 10.1, left diagram: The horizontal line should be labeled  $\vec{E}$ .
- Page 118, second line below equation 10.11: The  $r^2$  should simply be  $r$ .
- Page 123, second line above exercise 10.4.3 AND in exercise 10.4.3 itself: change  $\ell$  to  $|\ell|$ .
- Page 130, figure 11.2: The  $\vec{E}$  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 220, problem P18.2, fifth line: Change “plate of with” to “plate with”.
- 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 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 263, P22.1, third line: for consistency, replace “ $\theta = \tan^{-1}$ ” with “ $\theta \equiv \tan^{-1}$ ”.
- Page 263, P22.1, part a, fourth line: change “ $h_u$ ” to “ $h_{rr}$ ”.
- Page 263, P22.6, part b, first and third lines: replace  $\Phi_G$  with  $\vec{\nabla}\Phi_G$ .
- Page 263, P22.6, part b, third line from the end of the part: replace “get a finite” with “get finite”.
- Page 264, P22.7, part b, first and third lines: replace  $\Phi_G$  with  $\vec{\nabla}\Phi_G$ .
- 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 281, second paragraph, end of second line: replace “elliptic” with “elliptical”.
- Page 296, third line below equation 25.14: Change  $\sin(\bar{r}/R)$  to  $i\sin(\bar{r}/R)$ .
- 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 325, Problem P27.6, part d, 2nd line: Change “Big Bang in our” to “Big Bang in this”.
- Page 326, P27.10, fifth line: Change “energy does even” to “energy even”.
- Page 331, third paragraph in the **Photon Decoupling** section, second sentence (starting with “First of all,”): Delete this sentence and replace with “Note that the observed blackbody temperature  $T$  of the photons is now 2.7 K (not 3000 K),  $T$  is inversely dependent on the most probable photon wavelength, and  $Ta$  is constant.”
- Page 337, fifth line above exercise 28.5.1: Change  $\rho_{m0}/m_p$  to  $\rho_{b0}/m_p$ , and add to next line after the close parenthesis “,  $\rho_{b0}$  is the normal-matter portion of the current total matter density  $\rho_{m0}$ .”
- Page 338, P28.4, sixth line from the bottom: Change “between the these” to “between these”.
- 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 “ $t_e \sim [\frac{8}{3} \pi G \rho_v]^{-1/2} \sim [10 \cdot \frac{8}{3} \pi G \rho_r]^{-1/2}$ ”. Also put a period after “box 29.5”).
- Page 344, last line of paragraph about eternal inflation: Change “plausible of” to “plausible model of”.
- Page 353, end of third line after equation 30.12: replace “a” with “an”.
- Page 365, first line after equation 31.10: change “Lorentz” to “Lorenz”.
- 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 starting with the 8th line: replace the semicolon after the “vacuum” with a period. Delete up to the last sentence and replace with “LIGO is able to detect waves with amplitudes below  $10^{-22}$  over a frequency range from 60 Hz to 800 Hz, and has already detected a number of black hole and neutron-star merger events. Leaders of the LIGO experiment won the 2017 Nobel Prize in physics for this triumph.”

(continued)

- Page 367, last paragraph: delete the first sentence and replace with “I personally have been working to prepare the wave for LISA (Laser Interferometer Space Antenna), which is currently projected to launch in 2034 as an ESA (European Space Agency) mission.” Then delete the following sentence about NASA and ESA: the situation is now more complicated than that. In the next sentence, change “NGO” to “LISA”. In the next sentence, change “5 million km” to “2.5 million km”. In the sentence beginning “In spite of larger interferometer arms,” delete from the next NGO through the NGO in the next sentence and replace with “LISA will have a somewhat lower sensitivity than LIGO, but will be most sensitive to waves with frequencies between  $10^{-2}$  Hz to  $10^{-4}$  Hz. While LIGO has to wait for high-frequency events that happen rarely, LISA” and continue from there
- Page 367, last line: Change the URL to “www.elisascience.org”.
- 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 385, line below equation 33.5: Change “moment of inertia” to “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 be 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 33.16: Move the  $\sin\theta$  to just before the  $d\phi$  (two times). (Some people found the notation confusing. Note that the  $n$ -vector depends on both  $\theta$  and  $\phi$ .)
- Page 387, equation 33.17: Move the  $d\theta$  to just after the first integral sign (three places).
- Page 387, equations 33.18, 33.19, 33.20 left side of the equals sign in each case: move the  $d\theta$  to just after the first integral sign.
- Page 390, title of Box 33.3: insert a capital A just before the orphaned  $^{\mu\nu}$  superscripts
- Page 391, third line below equation 33.37: Change  $A_{TT}^{jk}$  to  $A_T^{jk}$ .
- Page 394, equations 33.19r, 33.20r, 33.46a, 33.46b, 33.46c, 33.47, on the left side of the first equals sign in each case: move the  $d\theta$  to just after the first integral sign.
- 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, 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 405, exercise 34.5.1, 2nd line: Change  $GM$  to  $GM\omega$ .
- Page 406, equation 34.23: Separate the  $j$  superscript more from the  $\neq$ : it is too hard to read.
- Page 418, last line of first paragraph: Change “rotating star or black hole” to “rotating black hole”.
- Page 420, section on Importance of the Kerr Solution, starting with item 1: change “and compact source (including black holes).” to “uncharged black hole.” Delete item 2. Renumber the remaining items 2 through 5. (The Kerr solution only applies to black holes, not to the empty space outside general axisymmetric objects, contrary to what the original implied.)
- Page 421, first line of item 5 (item 4 after the change above): Change “strongly believed” to “strongly believe”.
- Page 423, equation 36.18: Change “4” to “6” in all of the initial factors (in each of the four lines), and multiply change the  $R^2 r^2$  term (the final term) in each of the square brackets to  $\frac{1}{3} R^2 r^2$ .
- Page 443, exercise 38.3.1: Delete “Note: Requires numerical integration.”
- Page 448, P38.9, part e, first line: Change “falling object moving” to “falling object with  $\ell = 0$  moving”.