Errata and Suggested Updates for

Combustion Thermodynamics and Dynamics
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1. p. 17: Eq. (1.65) requires that 2.9×10^7 be replaced by 2.9×10^{17}.

2. p. 22: Just before Eq. (1.103), replace $\overline{\rho}_O = 0.0004442414$ by $\overline{\rho}_O = 0.000442294$.

3. p. 22: In Eqs. (1.104, 1.105), replace 0.0004442414 by 0.000442294.

4. p. 24: In Eq. (1.112), a_{13} should include units of 1/s. So we should find

$$a_{13} = 1.85 \times 10^{11} \left(\frac{\text{mol}}{\text{cm}^3}\right)^{-1} \frac{1}{\text{s}}(\text{K})^{-0.5}, \ldots \quad (1.112)$$

5. p. 35: In Eqs. (1.205), (1.206), the units for a_2 should include $1/\text{K}^{1.01}$.

$$a_2 = \left(9.7 \times 10^{-15} \left(\frac{\text{molecule}}{\text{cm}^3}\right)^{-1} \frac{1}{\text{K}^{1.01}\ \text{s}}\right)\left(6.02 \times 10^{23}\ \frac{\text{molecule}}{\text{mol}}\right), \quad (1.205)$$

$$= 5.8394 \times 10^9 \left(\frac{\text{mol}}{\text{cm}^3}\right)^{-1} \frac{1}{\text{K}^{1.01}\ \text{s}}, \quad (1.206)$$

6. p. 60: Problem 1.3 should have "....to identify the local time scales..."

7. p. 60: Problem 1.4 should have "...energy conservation of Eq. (1.336)..."

8. p. 83: Problem 2.2 should mention the two gases are inert, so the wording should be "A volume with two chambers contains inert calorically perfect ideal gases."

9. p. 98: An addition can be considered to distinguish the so-called "adiabatic gamma", γ_a, from the γ of Eq. (3.147) which is the ratio of specific heats. It could read as follows.

   "Here we consider the so-called *adiabatic gamma*, γ_a. It is closely related to the ratio of specific heats γ, but appeals to energy conservation. In this discussion, we build on the analysis of Davis.[1]

[1] W. C. Davis, 1985, "Equation of state for detonation products," *Eighth International Detonation Symposium*, ed. J. Short, Naval Surface Weapons Center, White Oak, Silver Spring, MD, pp. 785-795.

Let us begin with the Gibbs equation $T\ ds = de + P\ dv$, and take it in the isentropic limit for which $ds = 0$:

$$de + P\ dv = 0.$$

For a general caloric equation of state, we can expect

$$e = e(P, v).$$

Thus

$$de = \left.\frac{\partial e}{\partial P}\right|_v dP + \left.\frac{\partial e}{\partial v}\right|_P dv.$$

Eliminate de to get

$$\begin{aligned} \left.\frac{\partial e}{\partial P}\right|_v dP + \left.\frac{\partial e}{\partial v}\right|_P dv + P\ dv &= 0, \\ dP + \frac{\left.\frac{\partial e}{\partial v}\right|_P + P}{\left.\frac{\partial e}{\partial P}\right|_v}\ dv &= 0, \\ dP + \underbrace{\frac{v\left(\left.\frac{\partial e}{\partial v}\right|_P + P\right)}{P\ \left.\frac{\partial e}{\partial P}\right|_v}}_{\equiv\gamma} \frac{P}{v}\ dv &= 0. \end{aligned}$$

We now define the adiabatic gamma, γ, as

$$\gamma_a(P, v) \equiv \frac{v\left(\left.\frac{\partial e}{\partial v}\right|_P + P\right)}{P\ \left.\frac{\partial e}{\partial P}\right|_v}.$$

For a general material, γ_a is a thermodynamic variable that is a function of two independent variables, e.g. $\gamma_a = \gamma_a(P, v)$. It is easy to show for a calorically perfect ideal gas that $\gamma_a = c_P/c_v$ and is a constant. So for a calorically perfect ideal gas $\gamma_a = \gamma$, the ratio of specific heats.

With this definition of γ_a, the first law of thermodynamics becomes

$$dP + \gamma_a \frac{P}{v}\ dv = 0.$$

We could also say

$$\begin{aligned} \frac{dP}{P} &= -\gamma_a(P, v)\frac{dv}{v}, \\ \ln \frac{P}{P_o} &= -\int \gamma_a(P, v)\frac{dv}{v}. \end{aligned}$$

This is as far as we can go for a general equation of state with $\gamma_a = \gamma_a(P, v)$. However, in the case that γ_a is a constant, which is the case for a CPIG, we get $\ln(P/P_o) = -\gamma_a \ln(v/v_o) = \ln(v_o/v)^{\gamma_a}$. This gives $Pv^{\gamma_a} = P_o v_o^{\gamma_a}$, our polytropic relation for a calorically perfect ideal gas.

We can also say

$$\gamma_a(P,v) = -\frac{v}{P}\left.\frac{\partial P}{\partial v}\right|_s = -\left.\frac{\partial \ln P}{\partial \ln v}\right|_s$$

Also, because $v = 1/\rho$, $dv = -1/\rho^2\ d\rho$, we have

$$dP - \gamma_a \frac{P}{\rho}\ d\rho = 0,$$

giving

$$\left.\frac{\partial P}{\partial \rho}\right|_s = \gamma_a \frac{P}{\rho} = c^2.$$

For non-ideal gases, recall the ratio of specific heats γ must be

$$\gamma = \frac{c_P}{c_v} = \left.\frac{\partial v}{\partial P}\right|_T \left.\frac{\partial P}{\partial v}\right|_s .$$

In order for $\gamma_a = \gamma$, we must have $-v/P = \partial v/\partial P|_T$. This is the case for ideal gases, but not for general non-ideal gases.

10. p. 116: Two terms in Eq. (3.317) should have units of kJ/kmol K. So we should find

$$\begin{aligned}
&-2\left(5.9727\times 10^5\ \frac{\text{kJ}}{\text{kmol}} - (6000\ \text{K})\left(216.926\ \frac{\text{kJ}}{\text{kmol K}}\right)\right) \\
&+\left(2.05848\times 10^5\ \frac{\text{kJ}}{\text{kmol}} - (6000\ \text{K})\left(292.984\ \frac{\text{kJ}}{\text{kmol K}}\right)\right) = \left(8.314\ \frac{\text{kJ}}{\text{kmol K}}\right) \\
&\qquad\times (6000\ \text{K}) \ln\left(\frac{y_{\text{N}}^2}{y_{\text{N}_2}}\frac{P}{P_o}\right).
\end{aligned} \tag{3.317}$$

11. p. 129: just after Eq. (4.28), one should find $\chi_3 = CO_2$.

12. p. 163: in the first line at the top of the page, the subscript "N" should be italicized giving

    "Thus, for the mixture of ideal gases, $e(T, \overline{\rho}_1, \ldots, \overline{\rho}_N) = e_o$."

13. p. 178: Eq. (5.31) should have $\overline{c}_P$ and read

$$\frac{d\rho}{dt} = M\sum_{j=1}^{J} r_j \sum_{i=1}^{N} \nu_{ij}\left(\frac{\overline{h}_i}{\overline{c}_P T} - 1\right), \tag{5.31}$$

14. p. 181: Eq. (5.61) should have "..... $+ \overline{R}T$....". It should read

$$\overline{g}_i = \overline{\mu}_i = \overline{h}_i^o - T\left(\overline{s}_i^o - \overline{R}\ln\left(\frac{P_i}{P_o}\right)\right) = (\overline{h}_i^o - T\overline{s}_i^o) + \overline{R}T\ln\left(\frac{P_i}{P_o}\right). \quad (5.61)$$

15. p. 182: Eq. (5.62) should have "..... $+ \overline{R}T$...." yielding the correct

$$\overline{\mu}_i = \overline{\mu}_i^o + \overline{R}T\ln\left(\frac{P_i}{P_o}\right). \quad (5.62)$$

16. p. 190: In Eq. (5.158), on the left side of the equation, the last entry should be n_N. That is the N should be in italics as N. Thus we should find

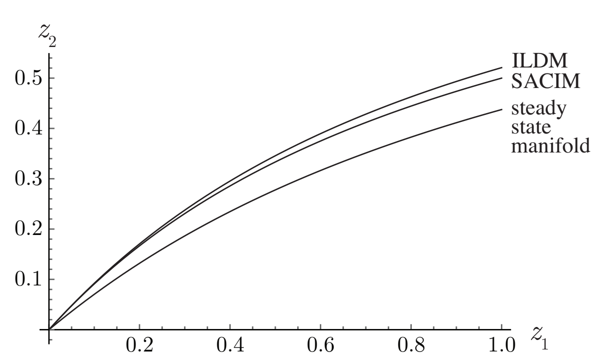
$$\begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{pmatrix} = \begin{pmatrix} n_{1o} \\ n_{2o} \\ \vdots \\ n_{No} \end{pmatrix} + \begin{pmatrix} \mathcal{D}_{11} \\ \mathcal{D}_{21} \\ \vdots \\ \mathcal{D}_{N\ 1} \end{pmatrix}\xi_1 + \begin{pmatrix} \mathcal{D}_{12} \\ \mathcal{D}_{22} \\ \vdots \\ \mathcal{D}_{N\ 2} \end{pmatrix}\xi_2 + \cdots + \begin{pmatrix} \mathcal{D}_{1\ N-L} \\ \mathcal{D}_{2\ N-L} \\ \vdots \\ \mathcal{D}_{N\ N-L} \end{pmatrix}\xi_{N-L}. \quad (5.158)$$

17. p. 190: In Eq. (5.160), on the left side of the equation, the last entry should be n_N. That is, the N should be in italics as N, yielding

$$\begin{pmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{pmatrix} = \begin{pmatrix} n_{1o} \\ n_{2o} \\ \vdots \\ n_{No} \end{pmatrix} + \begin{pmatrix} \mathcal{D}_{11} & \mathcal{D}_{12} & \dots & \mathcal{D}_{1\ N-L} \\ \mathcal{D}_{21} & \mathcal{D}_{22} & \dots & \mathcal{D}_{2\ N-L} \\ \vdots & \vdots & \vdots & \vdots \\ \mathcal{D}_{N1} & \mathcal{D}_{N2} & \dots & \mathcal{D}_{N\ N-L} \end{pmatrix}\begin{pmatrix} \xi_1 \\ \xi_2 \\ \vdots \\ \xi_{N-L} \end{pmatrix}. \quad (5.160)$$

18. p. 195: The last sentence on the page should read, "And once it reaches...."

19. p. 255: In Fig. 6.6, the labels "SACIM" and "ILDM" should be reversed, yielding



20. p. 260: Eq. (6.65) should be

$$z_1 + z_2 + 2z_3 = 4/120 = 0.03333333 \text{ mol/g}, \qquad (6.65)$$

for N conservation.

21. p. 260: Eq. (6.66) should be

$$z_1 + z_4 + 2z_5 = 4/120 = 0.03333333 \text{ mol/g}, \qquad (6.66)$$

for O conservation.

22. p. 277: Problem 6.2. Replace "Find the critical value of beta for which the CIM is neither attracting or repelling" with "Study the behavior as β is varied. Identify values of β that induce attraction and those that induce repulsion. Describe the behavior of the transition from attraction to repulsion."

23. p. 304: Eqs. (8.51), (8.52) need a $-\boldsymbol{\sigma}$. We should find

$$\begin{aligned} \mathbf{Z}(t) &= e^{-\boldsymbol{\sigma} t} \cdot \mathbf{Z}_o, \qquad (8.50) \\ \mathbf{S}^{-1} \cdot (\mathbf{Y}(t) - \mathbf{Y}_{eq}) &= e^{-\boldsymbol{\sigma} t} \cdot \mathbf{S}^{-1} \cdot (\mathbf{Y}_o - \mathbf{Y}_{eq}), \qquad (8.51) \\ \mathbf{Y}(t) &= \mathbf{Y}_{eq} + \mathbf{S} \cdot e^{-\boldsymbol{\sigma} t} \cdot \mathbf{S}^{-1} \cdot (\mathbf{Y}_o - \mathbf{Y}_{eq}). \qquad (8.52) \end{aligned}$$

24. p. 305: In Eq. (8.54) the entry in the lower left corner of the matrix $\mathbf{A}$ should be -990000. This affects Eq. (8.56) as well. This correction renders $\mathbf{A}$ to be consistent with Eq. (8.59). Thus we should have Eq. (8.54) as

$$\mathbf{A} = \begin{pmatrix} 1000000 \text{ s}^{-1} & -99000000 \text{ s}^{-1} \\ -990000 \text{ s}^{-1} & 99010000 \text{ s}^{-1} \end{pmatrix}, \quad \mathbf{Y}_o = \begin{pmatrix} 10^{-2} \\ 10^{-1} \end{pmatrix}, \quad \mathbf{Y}_{eq} = \begin{pmatrix} 10^{-5} \\ 10^{-6} \end{pmatrix}. \qquad (8.54)$$

We should have Eq. (8.56) as

$$\frac{dY_2}{dt} = (990000 \text{ s}^{-1})(Y_1 - 10^{-5}) - (99010000 \text{ s}^{-1})(Y_2 - 10^{-6}), \quad Y_2(0) = 10^{-1}. \qquad (8.56)$$

25. p. 307: In Eq. (8.74) the entry in the lower left corner of the matrix A should be -990000. This affects Eq. (8.76) as well. Thus we should have Eq. (8.74) as

$$\mathbf{A} = \begin{pmatrix} 1000000 \text{ s}^{-1} & -99000000 \text{ s}^{-1} \\ -990000 \text{ s}^{-1} & 99010000 \text{ s}^{-1} \end{pmatrix}, \quad \mathbf{Y}_o = \begin{pmatrix} 10^{-2} \\ 10^{-1} \end{pmatrix}, \quad \mathbf{Y}_{eq} = \begin{pmatrix} 10^{-5} \\ 10^{-6} \end{pmatrix}. \qquad (8.74)$$

Eq. (8.76) should be

$$\begin{aligned} \left(10^2 \ \frac{\text{cm}}{\text{s}}\right) \frac{dY_2}{dx} = \left(10^1 \ \frac{\text{cm}^2}{\text{s}}\right) \frac{d^2 Y_2}{dx^2} &+ (990000 \text{ s}^{-1})(Y_1 - 10^{-5}) \\ &-(99010000 \text{ s}^{-1})(Y_2 - 10^{-6}), \qquad (8.76) \end{aligned}$$

26. p. 308: In Eqs. (8.83, 8.84), terms just to the right of ℓ_1 and ℓ_2 should be enclosed by the absolute value symbol so as to render the result positive. Thus we should find

The relevant length scales are

$$\ell_1 = \left|\frac{1}{\left(5 - 5\sqrt{400001}\right)\ \mathrm{cm}^{-1}}\right| = 3.2 \times 10^{-4}\ \mathrm{cm}, \quad (8.83)$$

$$\ell_2 = \left|\frac{1}{\left(5 - 5\sqrt{41}\right)\ \mathrm{cm}^{-1}}\right| = 3.7 \times 10^{-2}\ \mathrm{cm}. \quad (8.84)$$

27. p. 308: Just after Eq. (8.84), there is extra spacing in the sentence and some improper kerning. It should read

"Especially for ℓ_1, these are both well estimated by the simple formulæ of Eq. (8.71):"

28. p. 310: In Eq. (8.99) the entry in the lower left corner of the matrix A should be −990000. Thus we should find

$$\mathbf{A} = \begin{pmatrix} 1000000\ \mathrm{s}^{-1} & -99000000\ \mathrm{s}^{-1} \\ -990000\ \mathrm{s}^{-1} & 99010000\ \mathrm{s}^{-1} \end{pmatrix}. \quad (8.99)$$

29. p. 312: Problem 8.3 should refer to Section 8.2.2.

30. p. 389: The last equation of Eq. (12.130) should have instead $\rho_1 u_1 \lambda_1$. Thus, we should find

$$U \begin{pmatrix} \rho_2 - \rho_1 \\ \rho_2 u_2 - \rho_1 u_1 \\ \rho_2\left(e_2 + \frac{1}{2}u_2^2\right) - \rho_1\left(e_1 + \frac{1}{2}u_1^2\right) \\ \rho_2\lambda_2 - \rho_1\lambda_1 \end{pmatrix} = \begin{pmatrix} \rho_2 u_2 - \rho_1 u_1 \\ \rho_2 u_2^2 + P_2 - \rho_1 u_1^2 - P_1 \\ \rho_2 u_2\left(e_2 + \frac{1}{2}u_2^2 + \frac{P_2}{\rho_2}\right) - \rho_1 u_1\left(e_1 + \frac{1}{2}u_1^2 + \frac{P_1}{\rho_1}\right) \\ \rho_2 u_2 \lambda_2 - \rho_1 u_1 \lambda_1 \end{pmatrix}. \quad (12.130)$$

31. p. 400: There is a sign error Eq. (12.223) in the term involving q. This propagates to Eqs. (12.236, 12.237). Thus, for Eq. (12.223), we should find

$$\left(\frac{v}{v_o}\right) = \frac{\left(1 + \frac{D^2}{P_o v_o}\right)\left(1 + \hat{\mu}^2\right)}{2\frac{D^2}{P_o v_o}} \pm \frac{\sqrt{\left(1 + \frac{D^2}{P_o v_o}\right)^2 \left(1 + \hat{\mu}^2\right)^2 - 4\frac{D^2}{P_o v_o}\left(1 + \left(1 + \frac{D^2}{P_o v_o}\right)\hat{\mu}^2 + 2\hat{\mu}^2 \frac{\lambda q}{P_o v_o}\right)}}{2\frac{D^2}{P_o v_o}}. \quad (12.223)$$

For Eq. (12.236), we should find

$$\left(\frac{v}{v_o}\right) = \frac{\left(1+\frac{D^2}{P_o v_o}\right)\left(1+\hat{\mu}^2\right)}{2\frac{D^2}{P_o v_o}}$$

$$\pm\frac{\sqrt{\left(1+\frac{D^2}{P_o v_o}\right)^2\left(1+\hat{\mu}^2\right)^2 - 4\frac{D^2}{P_o v_o}\left(1+\left(1+\frac{D^2}{P_o v_o}\right)\hat{\mu}^2 + 2\hat{\mu}^2\frac{q}{P_o v_o}\right)}}{2\frac{D^2}{P_o v_o}}. \qquad (12.236)$$

For Eq. (12.237), we should find

$$\left(1+\frac{D_{CJ}^2}{P_o v_o}\right)^2\left(1+\hat{\mu}^2\right)^2 - 4\frac{D_{CJ}^2}{P_o v_o}\left(1+\left(1+\frac{D_{CJ}^2}{P_o v_o}\right)\hat{\mu}^2 + 2\hat{\mu}^2\frac{q}{P_o v_o}\right) = 0. \qquad (12.237)$$

32. p. 402: In Eq. (12.238) one of the terms inside the parenthesis that is inside the radical needs changed: $2\hat{\mu}^2$ should be $2\hat{\mu}^2\frac{q}{P_0 v_0}$. We should find

$$\frac{D_{CJ}^2}{P_o v_o} = \frac{1+4\hat{\mu}^2\frac{q}{P_o v_o} - \hat{\mu}^4 \pm 2\sqrt{\frac{2q}{P_o v_o}\hat{\mu}^2(1+2\hat{\mu}^2\frac{q}{P_0 v_0} - \hat{\mu}^4)}}{(\hat{\mu}^2-1)^2}. \qquad (12.238)$$

33. p. 407: Fig. 12.6. The lower right $T(\hat{x})$ should be $T(-\hat{x})$.

34. p. 435: It should be emphasized that our calculations are for $P = 1$ atm and not Lehr's $P = 0.421$ atm.

35. p. 448: Problem 12.6 as stated will yield non-physical results. To render its results physical and retain coherence among earlier problems, take $D = 2700$ m/s for Problems 12.4, 12.5, and 12.6.

36. p. 453: In the author index, one simply reads "Chen, 173" and should be "Chen, J.-Y., 173".

37. p. 453: Add "Date, A. W., 173" to the author index