Spin–Orbit Coupling Effects in Two-Dimensional Electron and Hole Systems

by

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Dear Readers of the Book

I apologize for the misprints that escaped my notice before releasing the manuscript to the printer. Below you find a list of errata which I am aware of today. (I did not include in the list obvious typographic errors which do not cause confusion.) I am grateful to J. Alicea, A. E. Botha, S. Chesi, H.-A. Engel, B. Foreman, D. Jayathilaka, D. de Jong, S. Murphy, A. Palyi, and M. Wimmer for pointing out misprints.

I would appreciate if you could inform me of any further errors you might encounter. Please send them to my e-mail address given below. The newest update of errata is available at

http://www.niu.edu/rwinkler/research/stmp.pdf

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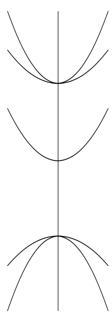
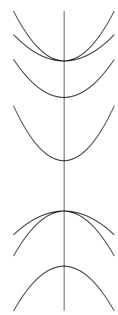
p. 22 According to Koster et al. [4] the compatibility relations between the irreducible representations of O_h and T_d read:

O_h		T_d
Γ_1^+	$\rightarrow$	Γ_1
Γ_2^-	$\rightarrow$	Γ_1
Γ_4^-	$\rightarrow$	Γ_5
Γ_5^+	$\rightarrow$	Γ_5
Γ_6^-	$\rightarrow$	Γ_7
Γ_7^+	$\rightarrow$	Γ_6

Accordingly, Table 3.1 should read:

Table 3.1. Symmetry classification of the bands in the extended Kane model

Single group			Double group		
	O_h/T_d	Full rotation group $\mathcal{R}$		O_h/T_d	
	$\Gamma_4^-/\Gamma_5 \leftarrow$	$l=1 \quad (\mathcal{D}_1^-)$ p antibonding	$j=3/2 \quad (\mathcal{D}_{3/2}^-)$	$\rightarrow \Gamma_8^-/\Gamma_8$	
			$j=1/2 \quad (\mathcal{D}_{1/2}^-)$	$\rightarrow \Gamma_6^-/\Gamma_7$	
	$\Gamma_2^-/\Gamma_1 \leftarrow$	$l=0 \quad (\mathcal{D}_0^-)$ s antibonding	$j=1/2 \quad (\mathcal{D}_{1/2}^-)$	$\rightarrow \Gamma_7^-/\Gamma_6$	
	$\Gamma_5^+/\Gamma_5 \leftarrow$	$l=1 \quad (\mathcal{D}_1^+)$ p bonding	$j=3/2 \quad (\mathcal{D}_{3/2}^+)$	$\rightarrow \Gamma_8^+/\Gamma_8$	
			$j=1/2 \quad (\mathcal{D}_{1/2}^+)$	$\rightarrow \Gamma_7^+/\Gamma_7$	

p. 41 The third line below Eq. (4.10): ... the number of states per unit energy range $\pm \mathrm{d}E$ and ...

p. 41 Eq. (4.11) should read:

$$D(E) = \pm \frac{1}{\mathcal{L}^2} \frac{\mathrm{d}}{\mathrm{d}E} \mathcal{N}(E) = \sum_{\alpha,\sigma} \int \frac{\mathrm{d}^2 k_\parallel}{(2\pi)^2} \, \delta\big[E - E_{\alpha\sigma}(\boldsymbol{k}_\parallel)\big] \, . \qquad (4.11)$$

p. 41 Eq. (4.13) should read:

$$\frac{m^*_{\alpha\sigma}(E)}{m_0} = 4\pi\,\frac{\hbar^2}{2m_0}\,D_{\alpha\sigma}(E) = \frac{1}{\pi}\,\frac{\hbar^2}{2m_0}\int \mathrm{d}^2k_\| \,\delta\big[E - E_{\alpha\sigma}(\boldsymbol{k}_\|)\big]\ . \tag{4.13}$$

p. 43 First paragraph Sec. 4.4: Citation numbers corrected

... Most publications on the calculation of Landau levels in 2D hole systems have restricted themselves to the axial approximation (see Sect. 3.6) to Luttinger's 4×4 $\boldsymbol{k}\cdot\boldsymbol{p}$ model [7,8]. In [38], the split-off valence band Γ_7^v ... Few publications [23,37,41,42] have analyzed Landau levels beyond the axial approximation. ...

p. 46 Eq. (4.31) should read (sign reversed)

$$\psi_{\alpha N\sigma}(\boldsymbol{r}) = \sum_n \big|L_n = N - m_n - \tfrac{3}{2}\big\rangle\,\xi^{\alpha N\sigma}_{m_n}(z)\,u_{n\boldsymbol{0}}(\boldsymbol{r}) \tag{4.31}$$

p. 46 Eq. (4.32b) should read (sign reversed)

$$\Psi_{\alpha\mathcal{N}\sigma}(\boldsymbol{r}) = \sum_{\alpha',\,N,\,\sigma'} c^{\alpha' N\sigma'}_{\alpha\mathcal{N}\sigma}\sum_n \big|N - m_n - \tfrac{3}{2}\big\rangle\ \xi^{\alpha' N\sigma'}_{m_n}(z)\,u_{n\boldsymbol{0}}(\boldsymbol{r})\ . \tag{4.32b}$$

p. 54 End of second paragraph: If expressed in a basis of eigenstates of J_z all four eigenstates of J_x and J_y are a mixture of both HH and LH states.

p. 63 Eq. (5.10) should read (opposite sign for Darwin term)

$$\begin{aligned}\Bigg[\frac{p^2}{2m_0} + V + \frac{e\hbar}{2m_0}\boldsymbol{\sigma}\cdot\boldsymbol{B} - \frac{e\hbar\,\boldsymbol{\sigma}\cdot\boldsymbol{p}\times\boldsymbol{\mathcal{E}}}{4m_0^2c^2} + \frac{e\hbar^2}{8m_0^2c^2}\nabla\cdot\boldsymbol{\mathcal{E}}\\ - \frac{p^4}{8m_0^3c^2} - \frac{e\hbar p^2}{4m_0^3c^2}\boldsymbol{\sigma}\cdot\boldsymbol{B} - \frac{(e\hbar B)^2}{8m_0^3c^2}\Bigg]\tilde{\psi} = \tilde{E}\tilde{\psi},\end{aligned} \tag{5.10}$$

p. 66 Eq. (5.13) should read

$$\tilde{\psi}_c = \left[1 + \frac{P^2}{6}\left(\frac{2k^2 - (e/\hbar)\,\boldsymbol{\sigma}\cdot\boldsymbol{B}}{E_0^2} + \frac{k^2 + (e/\hbar)\,\boldsymbol{\sigma}\cdot\boldsymbol{B}}{(E_0+\Delta_0)^2}\right)\right]\psi_c \tag{5.13}$$

p. 71 Footnote 2 should read: Strictly speaking, even for the diamond structure only T_d but not O_h is a subgroup of the space group. The reason is that the diamond structure has a *nonsymmorphic* space group with point group O_h, i.e. the symmetry operations in O_h must be combined with a nonprimitive translation of the translation subgroup of the diamond structure in order to map the diamond structure onto itself. Nevertheless, ...

p. 82 Eq. (6.23) should read (prefactor corrected)

$$\mathfrak{r}_{41}^{6c6c} = -\frac{\mathrm{i}eP^2}{3}\left[\sum_\beta \frac{\langle c_\alpha|z|l_\beta\rangle\langle l_\beta|\mathfrak{k}_z|c_\alpha\rangle - \langle c_\alpha|\mathfrak{k}_z|l_\beta\rangle\langle l_\beta|z|c_\alpha\rangle}{\varDelta_{\alpha\alpha}^{cl}\,\varDelta_{\alpha\beta}^{cl}} - \sum_\beta \frac{\langle c_\alpha|z|s_\beta\rangle\langle s_\beta|\mathfrak{k}_z|c_\alpha\rangle - \langle c_\alpha|\mathfrak{k}_z|s_\beta\rangle\langle s_\beta|z|c_\alpha\rangle}{\varDelta_{\alpha\alpha}^{cs}\,\varDelta_{\alpha\beta}^{cs}}\right], \tag{6.23}$$

p. 94 Eq. (6.43c) should read (overall sign reversed)

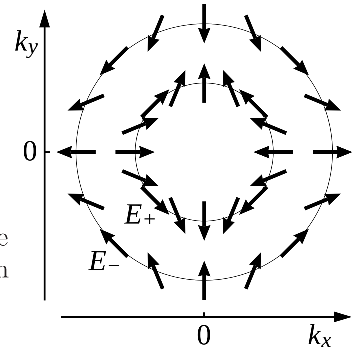
$$D_\alpha^h = -\frac{3\mathrm{i}}{4}\sum_{\beta\neq\alpha}\left[\frac{\langle h_\alpha|z|h_\beta\rangle\langle l_\beta|\mathfrak{k}_z|h_\alpha\rangle - \langle h_\alpha|\mathfrak{k}_z|l_\beta\rangle\langle h_\beta|z|h_\alpha\rangle}{\varDelta_{\alpha\beta}^{hh}\,\varDelta_{\alpha\beta}^{hl}} - \frac{\langle h_\alpha|z|h_\beta\rangle\langle h_\beta|\mathfrak{k}_z|l_\alpha\rangle - \langle l_\alpha|\mathfrak{k}_z|h_\beta\rangle\langle h_\beta|z|h_\alpha\rangle}{\varDelta_{\alpha\beta}^{hh}\,\varDelta_{\alpha\alpha}^{hl}} + \frac{\langle l_\alpha|z|l_\beta\rangle\langle l_\beta|\mathfrak{k}_z|h_\alpha\rangle - \langle h_\alpha|\mathfrak{k}_z|l_\beta\rangle\langle l_\beta|z|h_\alpha\rangle}{\varDelta_{\alpha\alpha}^{hl}\,\varDelta_{\alpha\beta}^{hl}}\right], \tag{6.43c}$$

Eq. (6.44) should read (signs reversed)

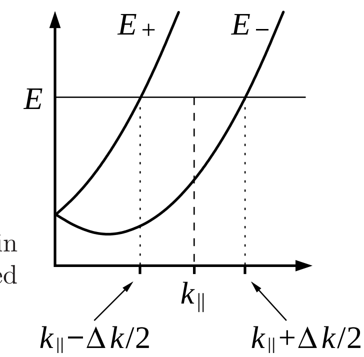
$$D_1^h = -\frac{3a}{4}\left[\frac{1}{\varDelta_{12}^{hh}\,\varDelta_{11}^{hl}} + \frac{1}{\varDelta_{11}^{hl}\,\varDelta_{12}^{hl}} - \frac{1}{\varDelta_{12}^{hh}\,\varDelta_{12}^{hl}}\right], \tag{6.44}$$

Eq. (6.45) should read

$$D_1^h = \begin{cases} -\dfrac{m_0^2}{\hbar^4}\,\dfrac{256w^4}{9\pi^6\,(\gamma_1 - 2\gamma_2)\,(3\gamma_1 + 10\gamma_2)} & \text{rectangular QW} \\[2ex] -\dfrac{m_0^2}{\hbar^4}\,\dfrac{6w^4}{(\gamma_1 - 2\gamma_2)\,(\gamma_1 + 4\gamma_2)} & \text{parabolic QW}\ , \end{cases} \tag{6.45}$$



p. 116 A minus sign is missing in the body of Fig. 6.17 (only in the printed version of the book).



p. 118 Two minus signs are missing in the body of Fig. 6.18 (only in the printed version of the book).

p. 140 Eq. (7.14a) should read:

$$\mathcal{K} = \frac{\hbar^2}{2m_0} \frac{\kappa\delta}{\mathrm{i}} \sum_\alpha \frac{\langle h_1|[\mathfrak{k}_z, z]|l_\alpha\rangle \, \langle l_\alpha|\mathfrak{k}_z^2|h_1\rangle}{E_1^h - E_\alpha^l}\,, \tag{7.14a}$$

p. 140 Eq. (7.15) should read (factors 2 missing):

$$g^{\mathrm{HH}}_{[nn\overline{(2m)}]} = 6\left(2 - 3\sin^2\theta\right)\sin\theta\,\sqrt{4 - 3\sin^2\theta} \times \sqrt{\left(\mathcal{K} - \mathcal{G}_2\right)^2 \sin^2\theta + \left(\mathcal{K} - \mathcal{G}_3\right)^2 \cos^2\theta}\,, \tag{7.15a}$$

$$g^{\mathrm{HH}}_{[\bar{1}10]} = -6\left(2 - 3\sin^2\theta\right)\sin^2\theta\,|\mathcal{K} - \mathcal{G}_3|\,. \tag{7.15b}$$

p. 142 First paragraph:

The values $u_1 = u_2 = 1/2$ correspond to a parabolic QW. For the rectangular QW we have $u_1 = 1$ and $u_2 = 0$, ...

p. 146 Eq. (7.19a) should read (several signs reversed):

$$\mathcal{H}^{\mathrm{HH}}_{[001]} = -\tfrac{3}{2} q\mu_{\mathrm{B}} \left(B_x\sigma_x - B_y\sigma_y\right) + \mathcal{Z}^{\mathrm{HH}}_{[001]}\, \mu_{\mathrm{B}}^3 \left\{\gamma_2 \left[(B_x^3 - B_x B_y^2)\sigma_x - (B_y^3 - B_y B_x^2)\sigma_y\right] - 2\gamma_3 \left[B_x B_y^2 \sigma_x - B_y B_x^2 \sigma_y\right]\right\} , \tag{7.19a}$$

p. 146 Eq. (7.19b) should read:

$$\mathcal{Z}^{\mathrm{HH}}_{[001]} = \frac{6\mathrm{i} m_0}{\hbar^2}\Bigg(\kappa \sum_\alpha \frac{\langle h_1|z^2|l_\alpha\rangle\langle l_\alpha|[\mathfrak{k}_z, z]|h_1\rangle + \langle h_1|[\mathfrak{k}_z, z]|l_\alpha\rangle\langle l_\alpha|z^2|h_1\rangle}{E_1^h - E_\alpha^l} + 2\gamma_3 \sum_\alpha \frac{\langle h_1|z^2|l_\alpha\rangle\langle l_\alpha|\{\mathfrak{k}_z, z\}|h_1\rangle - \langle h_1|\{\mathfrak{k}_z, z\}|l_\alpha\rangle\langle l_\alpha|z^2|h_1\rangle}{E_1^h - E_\alpha^l}\Bigg). \tag{7.19b}$$

p. 147 Eq. (7.20) should read (several signs reversed):

$$\mathcal{Z}^{\mathrm{HH}}_{[001]} = \left(\frac{w^2 m_0}{\pi^2\hbar^2}\right)^2 \left[\frac{\kappa}{2\gamma_2}\left(\pi^2 - 6\right) - \frac{27\gamma_3}{16\gamma_1 + 40\gamma_2}\right]. \tag{7.20}$$

p. 147 Eq. (7.22) should read (μ_{B}'s added)

$$\mathcal{H}^{\mathrm{HH}}_{[001]} = z_{51}^{7h7h}\mu_{\mathrm{B}} \left(B_x k_x^2 \sigma_x - B_y k_y^2 \sigma_y\right) + z_{52}^{7h7h}\mu_{\mathrm{B}} \left(B_x k_y^2 \sigma_x - B_y k_x^2 \sigma_y\right) + z_{53}^{7h7h}\mu_{\mathrm{B}} \left\{k_x, k_y\right\} \left(B_y\sigma_x - B_x\sigma_y\right) , \tag{7.22}$$

p. 147 Eq. (7.23) should read

$$z_{51}^{7h7h} = -\tfrac{3}{2}\kappa\gamma_2\mathcal{Z}_1 + 6\gamma_3^2\mathcal{Z}_2 , \tag{7.23a}$$

$$z_{52}^{7h7h} = \tfrac{3}{2}\kappa\gamma_2\mathcal{Z}_1 - 6\gamma_2\gamma_3\mathcal{Z}_2 , \tag{7.23b}$$

$$z_{53}^{7h7h} = 3\kappa\gamma_3\mathcal{Z}_1 - 6\gamma_3\left(\gamma_2 + \gamma_3\right)\mathcal{Z}_2 , \tag{7.23c}$$

p. 147 Eq. (7.24) should read

$$\mathcal{Z}_1 = \mathrm{i}\,\frac{\hbar^2}{m_0}\,\frac{\langle h_1|[k_z, z]|l_1\rangle\,\langle l_1|h_1\rangle + \langle h_1|l_1\rangle\,\langle l_1|[k_z, z]|h_1\rangle}{E_1^h - E_1^l} , \tag{7.24a}$$

$$\mathcal{Z}_2 = \mathrm{i}\,\frac{\hbar^2}{m_0}\sum_\alpha \frac{\langle h_1|k_z|l_\alpha\rangle\langle l_\alpha|z|h_1\rangle - \langle h_1|z|l_\alpha\rangle\langle l_\alpha|k_z|h_1\rangle}{E_1^h - E_\alpha^l} . \tag{7.24b}$$

p. 147 Eq. (7.25) should read

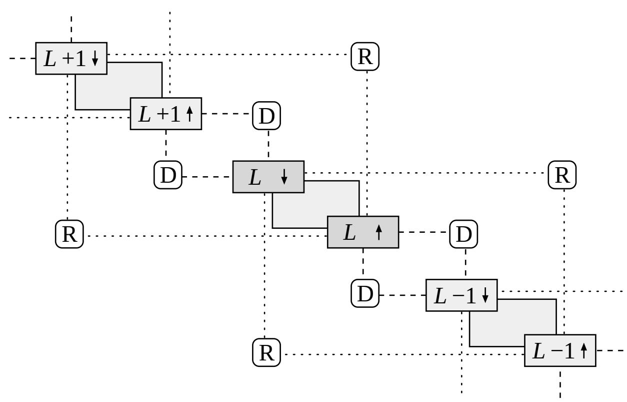
$$\mathcal{Z}_1 = \frac{w^2}{\pi^2 \gamma_2} \, , \tag{7.25a}$$

$$\mathcal{Z}_2 = \frac{512 w^2}{27\pi^4 \left(3\gamma_1 + 10\gamma_2\right)} \, . \tag{7.25b}$$

p. 152 Eq. (8.3) should read:

$$\langle s \,|\, \hat{\boldsymbol{e}} \cdot \boldsymbol{v} \,|\, t \rangle = \frac{\lambda_\mathrm{c} E_{ts}}{\hbar} \left\langle s \,\middle|\, e_+ a + e_- a^\dagger + e_z \lambda_\mathrm{c} k_z \,\middle|\, t \right\rangle \, , \tag{8.3}$$

p. 167 Two minus signs are missing in the body of Fig. 8.12 (only in the printed version of the book).

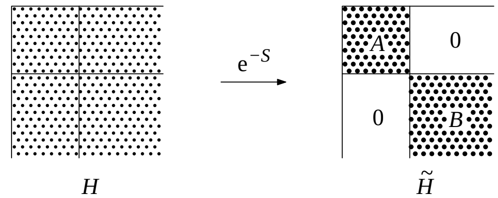


p. 187 Eq. (9.14b) and Eq. (9.14c) should read:

$$\begin{aligned} \mathcal{H}^b_- = \tfrac{\mathrm{i}}{8} \big[& c\left(3c^2 - 1\right) \left(k_-^3 + \{k_+, k_-, k_+\} - 4k_+ k_z^2\right) \\ & + 6cs^2 \left(\{k_-, k_+, k_-\} - 4k_- k_z^2\right) \big] \, , \end{aligned} \tag{9.14b}$$

$$\begin{aligned} \mathcal{H}^b_z = \tfrac{\mathrm{i}}{16} \big[& 3s\left(c^2 + 1\right) \left(k_-^3 - k_+^3\right) \\ & + s\left(3c^2 - 1\right) \left(\{k_-, k_+, k_-\} - \{k_+, k_-, k_+\}\right) \\ & + 4s(3c^2 - 1)(k_+ - k_-) k_z^2 \big] \, , \end{aligned} \tag{9.14c}$$

p. 202 A minus sign is missing in the body of Fig. B.1 (only in the printed version of the book).



p. 203 Equation (B.13) should read

$$H^0\,|\psi_n\rangle = E_n\,|\psi_n\rangle\ , \tag{B.13a}$$
$$H_{nn'} \equiv \langle\psi_n|H^1 + H^2|\psi_{n'}\rangle\ . \tag{B.13b}$$

where $n, n' \in \{m, l\}$.

p. 209 In Table C.2, T_{yz} should read

$$T_{yz} = \frac{\mathrm{i}}{2\sqrt{6}}\begin{pmatrix} -1 & 0 & -\sqrt{3} & 0 \\ 0 & \sqrt{3} & 0 & 1 \end{pmatrix}$$

p. 210 Table C.3(c) should read (see above the corrected Table 3.1.):

$\Gamma_8^{c\,-}\,(\Gamma_8^c)$	$\Gamma_6^{c\,-}\,(\Gamma_7^c)$	$\Gamma_7^{c\,-}\,(\Gamma_6^c)$	$\Gamma_8^{v\,+}\,(\Gamma_8^v)$	$\Gamma_7^{v\,+}\,(\Gamma_7^v)$	
+	+	+	−	−	$\Gamma_8^{c\,-}\,(\Gamma_8^c)$
	+	+	−	−	$\Gamma_6^{c\,-}\,(\Gamma_7^c)$
		+	−	−	$\Gamma_7^{c\,-}\,(\Gamma_6^c)$
			+	+	$\Gamma_8^{v\,+}\,(\Gamma_8^v)$
				+	$\Gamma_7^{v\,+}\,(\Gamma_7^v)$

p. 210 Table C.10 should read (prefactors $\sqrt{2}$ added)

$$\begin{aligned}\mathcal{H}^k_{8v\,8v} = &-(\hbar^2/2m_0)\big[\,\gamma_1'k^2 + \tilde{\gamma}_1'(k_\|^2 - 2k_z^2)(J_z^2 - 5/4) \\ &-2\sqrt{2}\,\tilde{\gamma}_2'\big(\{k_z,k_+\}\{J_z,J_-\} + \{k_z,k_-\}\{J_z,J_+\}\big) - \tilde{\gamma}_3'\big(k_+^2J_-^2 + k_-^2J_+^2\big)\big] \\ \mathcal{H}^k_{8v\,7v} = &-(\hbar^2/2m_0)\big[\,3\tilde{\gamma}_1'(k_\|^2 - 2k_z^2)U_{zz} \\ &-6\sqrt{2}\,\tilde{\gamma}_2'\big(\{k_z,k_+\}U_{z-} + \{k_z,k_-\}U_{z+}\big) - 3\tilde{\gamma}_3'\big(k_+^2U_- + k_-^2U_+\big)\big]\end{aligned}$$