

# Clarifications and corrections

## Chapter 1

- In the sentence after Eq. (1.2) the term “over the *ensemble* of particles” means “over an *ensemble* of identical copies of the system, all prepared with similar initial conditions”.
- In footnote 5 the relation  $|\mathbf{M}| \propto \chi|\mathbf{B}|$  should be  $|\mathbf{M}| = \chi|\mathbf{H}|$ , with  $\mathbf{H}$  the magnetic field.
- In Eq. (1.35) part of the symbol of absolute value is missing from the last equality. The correct equation should be

$$P(\hat{I} \rightarrow I_0|t) = |c_{I_0}(t)|^2 = |\langle \Psi_{I_0} | \Psi(t) \rangle|^2.$$

- I have derived Eq. (1.49) assuming the state vectors to be orthogonal. However, this condition is not necessary to define the statistical operator (1.48). This is the reason why there could be equivalent representations of the statistical operator with different macro-states (see Footnote 31 and Exercise 1.3).
- In Sec. 1.4.5 (Open quantum systems) the identity operators in Eq. (1.64) are interchanged. That equation should read

$$\hat{H} = \hat{H}_e \otimes \hat{1}_{ph} + \hat{1}_e \otimes \hat{H}_{ph} + \hat{H}_{e-ph}$$

- In Sec. 1.4.5 (Open quantum systems), when I refer to Eq. (1.74), and state “for an arbitrary  $\mathcal{L}$  Eq. (1.73) does not necessarily admit a stationary solution”, I am referring to  $\mathcal{L}$  operators that do depend on time. If this is the case, the corresponding equations of motion for the statistical operator are called *quantum master equations* (see Appendix C). If  $\mathcal{L}$  does not depend on time (and the Hilbert space is finite) then there is (at least) one stationary solution.

## Chapter 2

- In the last paragraph of page 41, the sentence “This implies that on average (over all particles)” should be understood as “This implies that on average (over an ensemble of identical copies of the system)”.

- The discussion in Sec. 2.3.2 (The use of Density-Functional Theory in the Kubo approach) may be a bit cryptic for those not so much familiar with density-functional theory. The interested reader can consult either the references in that section or, for a more extensive account and the relation to the Landauer approach, the paper G. Vignale and M. Di Ventra, “Incompleteness of the Landauer formula for electronic transport”, Phys. Rev. B 79, 014201 (2009), where these concepts are explained in some detail with specific reference to the transport problem.
- Eq. (2.97) is not correctly written in terms of the density. The correct Hartree energy is

$$W \simeq \frac{e^2}{2} \int d\mathbf{r}' \int d\mathbf{r} \frac{n(\mathbf{r})n(\mathbf{r}')}{|\mathbf{r} - \mathbf{r}'|}$$

- Note that in order to make the distribution function  $f$  dimensionless one needs to divide  $d\mathbf{r}_i d\mathbf{p}_i$  in Eqs. (2.119)-(2.123) by  $h^3$ , where  $h$  is the Planck’s constant. For instance Eq. (2.119) should read

$$d\Omega = \frac{1}{N!} \prod_{i=1}^N \frac{d\mathbf{r}_i d\mathbf{p}_i}{h^3}.$$

For the same reason, the infinitesimal element  $d\mathbf{p}_i$  should be replaced by  $d\mathbf{p}_i/h^3$  in all equations of Sec. 2.7

- In footnote 55 by “elastic collisions” I mean collisions that conserve single-particle energy.
- Note that the first equality in Eq. (2.142) does not require the statistical operator  $\hat{\rho}$  to be diagonal in a given representation. However, the second equality does require  $\hat{\rho}$  to be diagonal in the states  $\{|\Psi_i\rangle\}$ .
- On page 87 after Eq. (2.146) it is stated that from this equation one can derive the second law of thermodynamics. This statement is incorrect. What one can show is that the canonical entropy can be related to the heat exchanged by the system with the environment in a quasi-static transformation (Exercise 2.14).
- Note that unlike what is stated before Eq. (2.143) the states  $\{|\Psi_i\rangle\}$  do not need to form a complete set in the Hilbert space, but I have assumed them to diagonalize the statistical operator.
- In Eq. (2.147) there is no comma between  $H$  and  $[\rho, \ln \rho]$  in the second equality. That equation should read

$$\frac{dS[\hat{\rho}]}{dt} = \frac{i k_B}{\hbar} \text{Tr}\{[\hat{H}, \hat{\rho}] \ln \hat{\rho}\} = \frac{i k_B}{\hbar} \text{Tr}\{\hat{H}[\hat{\rho}, \ln \hat{\rho}]\} = 0.$$

- In Exercise 2.8, Eq. (E2.7), there should be no  $t'$ . That equation should read

$$\chi_{AB}(\omega) = \int dt e^{i\omega t} \chi_{AB}(t).$$

- In Exercise 2.14, in Eq. (E2.19) the symbol  $dW$  should be  $\delta W$ , namely that equation should be

$$\delta W = \sum_{\beta} F_{\beta} d\chi_{\beta}.$$

Same for the symbol  $dQ$  which should be  $\delta Q$ , so that Eq. (E2.21) should read

$$dS[\hat{\rho}_C^{eq}] = \frac{\delta Q}{\theta} \equiv \frac{\text{Tr}\{d\hat{\rho}\hat{H}\}}{\theta}, \quad \forall d\beta, d\chi_{\beta}.$$

This is not a minor point, because neither  $\delta W$  nor  $\delta Q$  are exact differentials. Only the entropy variation  $dS[\hat{\rho}_C^{eq}] = \delta Q/\theta$  is an exact differential, with  $\theta$  the *integrating factor*.

- In the same Exercise 2.14 it is also stated that “Eq. (E2.21) is the second law of thermodynamics”. This is clearly not generally correct. The equality (E2.21) is only one aspect of the second law for quasi-static transformations. The second law states that for *arbitrary* transformations of an isolated system from one equilibrium state to another the entropy cannot decrease.

### Chapter 3

- Before Eq. (3.96), the word *future* should be *past*.
- In order to obtain Eq. (3.218) one multiplies by  $u_f(\mathbf{r}_{\perp R}) u_i^*(\mathbf{r}_{\perp L}) e^{-i(k_i x_L - k_f x_R)}$  without the transmission amplitude.
- Eq. (3.219) should be

$$G^+(\mathbf{r}_{\perp R}, \mathbf{r}_{\perp L}, E) \equiv G^+(\mathbf{r}_{\perp R}, x_R; \mathbf{r}_{\perp L}, x_L; E) e^{-i(k_i x_L - k_f x_R)}$$

- On page 176 the symbols  $\lambda_i$  should be  $t_i$ .
- In the sentence after Eq. (3.310)  $\mu_3$  of probe 3 is a function of  $\mu_1, \mu_2, \mathcal{T}_{31}$  and  $\mathcal{T}_{32}$  not  $\mu_3$  as it is currently written.
- In footnote 65 the definition of magnetoresistance percentage should be

$$R = \frac{R_{\uparrow\downarrow} - R_{\uparrow\uparrow}}{R_{\uparrow\downarrow}}.$$

- In Eq. (3.319) there are some  $c$  (speed of light) factors missing. That equation should read

$$V_{B,s}(\mathbf{r}, \mathbf{r}') = \frac{ie\hbar}{2mc} [\mathbf{A}(\mathbf{r}) + \mathbf{A}(\mathbf{r}')] \cdot \nabla \delta(\mathbf{r} - \mathbf{r}') + \frac{e^2}{2mc^2} A^2(\mathbf{r}) \delta(\mathbf{r} - \mathbf{r}') + \mu_B g_0 s B(\mathbf{r}) \delta(\mathbf{r} - \mathbf{r}')$$

- On page 197, in the section “Local resistivity spin dipoles”, when I discuss “spin-dependent transport” I mean here in the presence of spin-orbit interaction. The symbols  $s = 1/2$  and  $s = -1/2$  in Fig. 3.22 are then meant only as labels and not as good quantum numbers. Also the shape and orientation of the spin dipoles are not meant to represent an exact scattering case. They may vary according to the junction charge-scattering potential and type of spin-scattering potential (see Mal’shukov and Chu, 2006).
- In Exercise 3.22 the functional  $A[\chi]$  is proportional to the scattering amplitude (when  $|\chi\rangle = c|\Psi\rangle$ ) at all energies and potential strengths not just in the limits reported.

#### Chapter 4

- In Section 4.5 (Coulomb blockade) at the end of the discussion of the “Orthodox picture of Coulomb blockade”, the final sentence should read *the total tunneling resistance must be much larger than the quantum resistance (per spin),  $R \gg h/e^2$* , not “smaller” as it is now reported.

#### Chapter 5

- On page 259 before the last paragraph I write “Both have a power spectrum that is independent of frequency (white noise)”. That statement should be “Thermal noise has a power spectrum that is independent of frequency (white noise)”.
- Eq. (5.12) has a typo in the definition of the current autocorrelation function. That equation should read

$$S(t') = \lim_{T_p \rightarrow \infty} \frac{1}{T_p} \int_{-T_p/2}^{T_p/2} \Delta I(t) \Delta I(t+t') dt = \langle \Delta I(0) \Delta I(t') \rangle,$$

- After Eq. (5.14) the sentence “Before replacing 5.10 into” should be “Before replacing 5.13 into”.
- In Eq. (5.49) the sum is over  $m$  and should thus read as

$$G(k) = \sum_{m=0}^{\infty} \frac{(ik)^m S_m}{m! e^m},$$

- Same for Eq. (5.50)

$$\ln G(k) = \sum_{m=1}^{\infty} \frac{(ik)^m}{m!} \langle \langle n_m(t) \rangle \rangle,$$

## Chapter 6

- In Eq. (6.3)  $m$  should be  $M_i$ .
- The index  $i$  of the operators in Eq. (6.14) should be  $j$ . That equation should read

$$\begin{cases} \hat{b}_j |N_j\rangle = \sqrt{N_j} |N_j - 1\rangle \\ \hat{b}_j^\dagger |N_j\rangle = \sqrt{N_j + 1} |N_j + 1\rangle \\ \hat{b}_j |0_j\rangle = 0, \end{cases}$$

- Footnote 13 should read “This energy may contain, in principle, an extremely large number of terms.”
- In Eqs. (6.52), (6.53) and (6.56), the argument inside the operators  $D_j$  should be  $\hbar\omega$ , not  $E$ .
- In Eq. (6.75) the steady state condition has the wrong sign. It should read

$$P_v = I_{th}^{out} - I_{th}^{in} \implies \theta_{eff} = (\theta_0^4 + \theta_v^4)^{1/4}, \quad \text{finite background } \theta$$

- Unlike what is stated in the text, in order to evaluate Eq. (6.97) there is no need to expand the transmission coefficient to first order. Nonetheless, we need to assume that we are away from electronic resonances otherwise we may need to retain orders higher than the first in the Sommerfeld expansion.
- In footnote 40 of Section 6.4 (Thermopower), the function  $L(E)$  is

$$L(E) = \frac{\partial [\mathcal{T}(E)(E - \bar{\mu})]}{\partial E},$$

which arises from the integration by parts

$$\int_{-\infty}^{+\infty} dE \frac{\partial [\mathcal{T}(E)(E - \bar{\mu})]}{\partial E} f(E) = \int_{-\infty}^{+\infty} dE \mathcal{T}(E)(E - \bar{\mu}) \left( -\frac{\partial f(E)}{\partial E} \right)$$

## Chapter 7

In Sec. 7.5 after the *initial-state maximum entropy principle* when referring to *Prigogine's principle* the terminology “close to equilibrium” really means “close to local (in space) thermodynamic equilibrium”. This implies that if  $n$  forces  $X_j$  ( $j = 1, \dots, n$ ) act on the system producing the  $n$  fluxes  $J_j$ , there exists a linear relation of the type

$$J_i = \sum_k L_{ik} X_k$$

where the linear-response coefficients  $L_{ik}$  satisfy the Onsager's relations

$$L_{ik} = L_{ki},$$

a direct consequence of the *micro-reversibility* of the Hamilton equations of motion (2.127). In the same local thermodynamic equilibrium assumption, the local entropy production rate  $\sigma$  can be written as

$$\sigma = \sum_k X_k J_k = \sum_{ki} L_{ik} X_i X_k,$$

from which Prigogine's principle can be proved.

Note, however, that Prigogine's principle has a meaning only when two or more forces act on the system. In the case of a two-terminal current device in the linear regime, the only force acting on the system is the bias. The only corresponding flux is the current, so that Prigogine's principle does not apply.

## Chapter 8

- After Eq. (8.30) it is written that the bulk viscosity of liquids is generally much smaller than their shear viscosity. This is true for the electron liquid but not for all ordinary liquids.
- In Eq. (8.65) the steady state condition has the wrong sign. It should read

$$P_e = I_{th}^{out} - I_{th}^{in} \implies \theta_{eff} = (\theta_0^2 + \theta_e^2)^{1/2}, \quad \text{finite background } \theta$$

- In the discussion in Sec. 8.6.1 (Electron heat conduction), I have implicitly neglected a term  $(\mu_L + \mu_R) \mathcal{T}(E) [f_L(E, \theta_R) - f_R(E, \theta_L)]/2$  in the integral of Eq. (8.66). This term, which is directly related to the variation of number of particles, is negligible in the limit of zero bias and for  $\mathcal{T}(E)$  independent of energy, which is what I assume in that section.

- In Eq. (8.72) the entropy and velocity field in the first term on the left-hand side depend on time. That equation reads

$$\sigma_{ij}(\mathbf{r}, t) \partial_j v_i(\mathbf{r}, t) + \nabla \cdot [k(\mathbf{r}, t) \nabla \theta_e(\mathbf{r}, t)] = n_{cP} \left( \frac{\partial \theta_e}{\partial t} + \mathbf{v}(\mathbf{r}, t) \cdot \nabla \theta_e(\mathbf{r}, t) \right).$$

### Appendix A

- There is a typo in Eq. (A.30):  $N_i$  should be  $N_j$ . That equation should read

$$\hat{b}_j |N_1, \dots, N_j, \dots\rangle = \sqrt{N_j} |N_1, \dots, N_j - 1, \dots\rangle.$$

### Appendix C

- In Eqs. (C.18) and (C.19), I have chosen  $t_0 = 0$ .
- Note that it is thanks to the choice of the particular projector (C.10) that Eq. (C.18) can be closed. Indeed, this equation generally has the extra term

$$e^{t(1-P)\mathcal{L}_{tot}} \hat{\rho}_2(t_0)$$

namely Eq. (C.18) should be

$$\hat{\rho}_2(t) = e^{t(1-P)\mathcal{L}_{tot}} \hat{\rho}_2(t_0) + \alpha \int_{t_0}^t d\tau e^{\tau(1-P)\mathcal{L}_{tot}} \mathcal{L}_{int} \hat{\rho}_1(t - \tau).$$

However, from (C.11) we get  $\hat{\rho}_2(t_0) = 0$  (which is equivalent to  $P\hat{\rho}_{tot}(t_0) = \hat{\rho}_{tot}(t_0)$ ).

- Note that Eq. (C.22) has a meaning when acting on  $\hat{\rho}_S$ .
- In Eq. (C.28) the coefficient  $2\hbar$  should be  $\hbar^2$ .
- Referring to Sec. C.3, note that for a time-independent Lindblad operator (namely a time-independent system Hamiltonian and bath operators) and for a finite Hilbert space there is (at least) one stationary solution to Eq. (C.30).

### Appendix K

- In Eq. (K.4) there should not be the symbol  $P$  of Cauchy principal value. That equation should read

$$\mu(\omega \rightarrow \infty) \equiv \mu_\infty = \frac{2}{\pi} \int_0^\infty d\omega' \eta(\omega') \simeq \frac{\eta(\omega \rightarrow 0)}{\tau}$$