General Questions

Question 1. *Identical Particles*

When I have an even number of fermions, then the whole system acts bosonic, thus the wavefunction must be symmetric. However, we learnt that under exchange of fermions the wavefunction must be asymmetric - what exactly is now antisymmetric, and what is bosonic?

Answer: Well, we always have to be clear about symmetry or antisymmetry under exchange of which particles we are talking about. In a way, it's as simple as this:
Wavefunctions are antisymmetric with respect to exchange of identical fermions, symmetric with respect to exchange of identical bosons.
This means:
If we have a system of 4 particles in total - all of which identical fermions - and we devide it into two subsystems A and B containing two fermions each, this implies the following:

$$P_{12}\psi_A = -\psi_A \tag{L.1}$$
$$P_{34}\psi_B = -\psi_B \tag{L.2}$$
$$P_{AB}\Psi = \Psi, \tag{L.3}$$

where P_{12} and P_{34} denote exchange of particle 1 with particle 2 or exchange of particles 3 and 4 respectively, P_{AB} denotes exchange of systems A and B, Ψ is the total wavefunction and ψ_A and ψ_B the wavefunctions of subsystems A and B respectively ($\Psi = \psi_A \otimes \psi_B$).
Furthermore,

$$P_{12}\Psi = -\Psi \tag{L.4}$$
$$P_{13}\Psi = -\Psi \tag{L.5}$$
$$... \tag{L.6}$$

Thus we have: under exchange of fermions (all individual particles here are fermions) the wavefunction is antisymmetric, under exchange of bosons (systems A and B are bosons each because they consist of even number (2) of fermions) the wavefunction is symmetric.

Make sure you understand Chpt. 3.1.21!

Chapter 1

Question 2. *Optical Theorem*

Help... I do not understand the optical theorem!

Answer: For now, look at Schwabl 18.4 (look at our books suggestion)! If you still have a question about the optical theorem or scattering in general, send it and I can include it in the FAQ.

Chapter 2

Question 3. *I don't understand the Wigner-Eckart theorem...*

The Wigner-Eckart theorem is a statement about tensor operators, which are objects (a tuple, or group, of operators typically) that have some kind of structure similar to, or compatible with, angular momentum. It tells you that if you have eg. an interaction term T in your hamiltonian for which you would like to calculate matrix elements in the angular momentum basis, and if T happens to have this tensor operator structure, then the matrix elements of T are essentially Clebsch-Gordan coefficients,

$$\langle n, j, m | T_q^{(k)} | n', j', m' \rangle \quad \propto \quad \big\langle j', k; m', q \big| j, m \big\rangle \ .$$

Viewing the ket on the right of T_q^k as "spin before interaction", and the bra on the left as collapse/test overlap with "spin after interaction", then one can view the Clebsch-Gordan coefficients appearing as consequence of "adding" the "incoming spin" with the "spin of the interaction term" to yield the "spin after interaction".

The Wigner-Eckart theorem is actually a statement about the representations these tensor operators live in, and can be formulated in the language of representation theory.

The Wigner-Eckart theorem was treated in QM2 exercise sheet #4. We refer also to the following references for further study:

- Cohen-Tannoudji (more practical and less representation theory) (see litterature on our QM2 web page)
- Lecture notes of Prof. G. M. Graf (formulated mathematically in terms of representation theory)
- most standard textbooks on (Advanced) Quantum Mechanics have a section about the Wigner-Eckart theorem.