Summary

Nucleons moving in time reversal states lying close to the Fermi energy and interacting through the exchange of mesons ($^1S_0$ NN-interaction) and of collective vibrations (induced pairing interaction), lead to $L=0$, $S=0$ nuclear Cooper pairs. Making use of the two-particle wavefunction describing them, it is found that the partner nucleons come closer to each other, as compared to the uncorralated pair situation.

Cooper pairs were introduced in physics to describe low temperature superconductivity in metals, and constitute the building blocks of BCS. The BCS ground state wavefunction describes the condensation of these weakly bound (through the exchange of virtual photons and lattice phonons), widely extended (dimensions much larger than typical distances between uncorralated electrons), strongly overlapping quasi bosons (pair of electrons moving in time reversal states $(\nu, \bar{\nu})$ with momentum and spin $(\vec{k}\uparrow, -\vec{k}\downarrow)$).

In presence of an external field, for example that associated with the tunneling interaction of a Josephson junction – involving energies smaller than the transition temperature and thus acting on the Cooper pairs center of mass – all pairs move in an identical (coherent)

fashion, leading to a supercurrent across the junction of carriers with charge $q=2e$. Its (maximum) intensity being equal to the (normal) single-electron current associated with a junction bias equal to the Cooper pair binding energy divided by the electron charge.

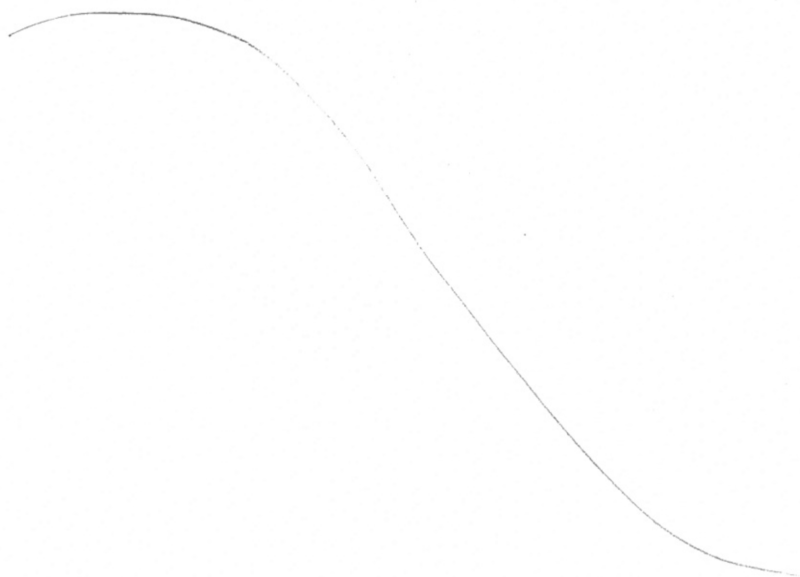
When the momentum imparted to the center of mass of the condensed Cooper pairs acquires a value of the order of the inverse of the mean square radius of the Cooper pairs (correlation length), the back-and-forth ($l=0$) radial motion of electron partners (intrinsic $(\nu,\tilde{\nu})$ motion) cannot follow suit, getting out of step and resulting in the breaking (unbinding) of the pairs (critical current). As a consequence, supercurrent ceases and only normal current, ($q=e$) flows.

The traditional view of nuclear Cooper pairs described above, seems to be partially at odds with that found at the basis of low temperature superconductivity. In particular concerning what can be considered the only (specific) coupling field able to detect Cooper pair (gauge) phase correlation, namely tunneling across a Josephson junction. In each of the two weakly coupled superconductors, pairs of electrons recede from each other as compared to the normal situation. In this way, they lower their relative kinetic energy of confinement, profiting best of the weak, attractive, retarded interaction. Being the electron pair phase correlated, with a correlation length much larger than the barrier thickness, although they tunnel one at a time, they do so as a single particle (of mass $2m_e$ and charge $2e$), and the probability of going through the junction is comparable to that of a single electron. It is like interference in optics, with phase coherent phase mixing.

In the transient, time dependent, Josephson-like junction established between two superfluid nuclei in a heavy ion collision about and below the Coulomb barrier, one finds that for bombarding energies leading to distances of closest approach smaller or of the order of the correlation length, quantity much larger than nuclear dimensions, the probability P_2 of pair transfer – process dominated by successive transfer where nuclear Cooper pair partners are about a correlation length apart from each other – is about equal to that of one-nucleon transfer (P_1). For larger distances, for which the intrinsic back and forth relative motion of the partner nucleons characterizing the intrinsic structure of the nuclear Cooper pair gets uncorrelated, and the system undergoes a phase transition from the superfluid (S) to the normal (N) state, this ($P_2 \approx P_1$) is not anymore so. Already for distances of closest approach about 1 fm – 1.5 fm larger than the nuclear correlation length, the probability of one-nucleon transfer is an order of magnitude larger than that associated with two-nucleon tunneling.

The nuclear S-N phase transition as a function of the distance of closest approach, where the Cooper pair is probed (stressed) beyond the correlation length, parallels that associated with the one undergoing by a low temperature superconductor where Cooper pairs are forced to move with a center of mass moment of the order of the inverse of the correlation length.

The gained homogeneity between the pictures of Cooper pairs in nuclei and in superconductors, is a consequence of fulfilling a basic requirement of quantum mechanics. Namely, that to specify the experimental setup in discussing a physical phenomena. In the present case, that of of the structure of nuclear Cooper pairs emerging from probing it through pair tunneling in heavy ion collisions between superfluid nuclei, and comparing theory with experiment in terms of absolute cross sections.



The overwhelming role played by successive transfer is a consequence of the fact that, given the possibility, the partners nucleons receed from each other, to distances of the order of the correlation length. During the formation of the Josephson-like junction in a heavy ion collision, the partners nucleons of either the target or projectile nucleus, are not any more confined by the corresponding single-particle potential acting as a strong "external" field, but trasiently share the extended common field of both target and projectile. In the process, they lower their kinetic energy of confinement, remaning correlated across the neck (junction) region.

The need for a unified treatment of structure and reactions, as it happens in nature, is evident. Need which also accounts for the subtitle of the present monograph.