It is also of notice, that the dimension, structure, non-locality and $\omega$-dependence of the function (6.6.1) is expected to be rather different from that of the structure wavefunction of the Cooper pair, a question closely connected with linear response (see discussion following Eq (6.4.16)). While this concept ⓐ-ⓐ pp ①-④



scattering experiments. Consequently, the non–local, correlated formfactors,

$$F(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_{Ap}) = F_{succ} + F_{sim} + F_{NO}, \tag{6.6.1}$$

sum of the successive and simultaneous transfer processes and of the non–orthogonality correction, calculated with different stes of two–nucleon spectroscopic amplitudes can be compared at profit to each other. This is in keeping with the fact that they can be related, in an homogeneous fashion, with the absolute cross sections or, better, with the square root of these quantities.

### 6.6.4 Closing the circle[37]

In the first reference of this monograph[38] entitled "Quantum mechanics of collision phenomena", Born considers the elastic scattering of a beam consisting of $N$ electrons which cross unit area per unit time, scattered by a static potential. The stationary wavefunction describing the scattering process behaves asymptotically as,

$$e^{ikz} + f(\theta, \phi)\frac{e^{kr}}{r}, \qquad \left(k = \frac{mv}{\hbar}\right). \tag{6.6.2}$$

The number of particles scattered into the solid angle $d\Omega = \sin\theta d\theta$ is given by $N|f(\theta, \phi)|^2 d\Omega$. To connect with Born notation one has to replace $f(\theta, \phi)$ by $\Phi_{mn}$, where $n$ denotes the initial–state plane wave in the $z$–direction and $m$ the asymptotic final–state in which the waves move in the direction fixed by the angles $(\theta, \phi)$. Then Born writes that $\Phi_{mn}$ determines the probability for the scattering of the electron from the $z$– to the $(\theta\phi)$–direction, adding a footnote in proof, as already mentioned, stating that a more precise consideration shows that the probability is proportional to the square of $\Phi_{mn}$. In a second paper with the same title of the first[39] he states explicitly that the probability is to be connected with the modulus squared[40]. Within this context, the matrix element between the entrance and exit channel distorted waves of $F(\mathbf{r}_1, \mathbf{r}_2, \mathbf{r}_{Ap})$ is proportional to $f(\theta, \phi)$ and thus $\Phi_{mn}$. The function $F$ is not directly measurable, but the closer one can come of a theoretical construct connecting the Cooper pair (s+r) to experiment. For superfluid nuclei lying along the stability valley, this construct does not change much with the theory one uses to calculate the spectroscopic two–nucleon transfer amplitudes, provided they display

[37] In this section we follow closely Pais (1986)

[38] Born (1926a).

[39] Born (1926b)

[40] The motion of particles follows probability laws but the probability itself propagates according to the law of causality. And concerning the distinction between classical and quantal probabilities he states: "The classical theory introduces the microscopic coordinates which determine the individual processes only to eliminate them because of ignorance by averaging over their values; whereas the new theory get the same results without introducing them at all... We free the forces of their classical duty of determining directly the motion of particles and allow them instead to determine the probability of states".

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~~reaction~~ to p. 439

(a) ~~While the concept of linear response~~ has been ~~quite~~ and continuous to be useful in the ~~[illegible]~~ study of many-body systems, ~~it~~ ~~may lead to not correct conclusion~~ ~~it is quite a subtle one~~ it is a subtle one.

In direct two-nucleon transfer reactions induced by both light and heavy ~~reaction~~ ion grazing collisions, the ~~interaction~~ contact between the two interacting nuclei is weak. Nonetheless, even a very low density overlap between target and projectile may induce important ~~chang~~ modifications in ~~[illegible]~~ cooper pairs. Most importantly, allow~~[illegible]~~ nucleon partners to profit from the enlarged volume as compared to that available in the target nucleus to expand, recede from each other and, in the process, lower the relative kinetic energy of confinement. As a consequence, one-nucleon can be transferred at a time, successive ~~tunneling~~ being the dominant transfer mechanism.

København 11/09/17 (2)

This is the reason why Cooper pair transfer displays absolute cross sections of the same order of magnitud of one-nucleon transfer processes.

It can be stated that this picture is again ~~a result~~ an example of the fruitfulness of linear response to shed light on subtle questions regarding many-body systems. In the case under discussion, it allows the partners of the nuclear Cooper pair to correlate over dimensions larger than nuclear dimensions and in so doing make their intrinsic structure observable, almost free of the strong presures of the external mean field*). The above discussion is illustrated in Fig. 6.5.5.

With it one comes back to the original question (sect. 1.1). Which are the proper variables to be used in an attemp of describing the nuclear system? Elementary modes of excitation is a valid choice.

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*) Within this context, think of the need of both right and left superconductors with respect to the dioxide layer to be able to measure gauge phase difference in the Josephson effect. Within this context see also Magierki et al (2017)

P. Magierski et al PRL 119, 042501 (2017)

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But because these modes are in interaction, (3) the above choice is not sufficient (unique). An operative definition requires ~~that~~ also ~~the~~ the specific probe, reaction or decay process is specified. In fact, if one were to study Cooper pairs through electron scattering (two-nucleon correlations), one would obtain a picture of the system as that marked by the small ellipses in Fig. 6.5.5. Thus, rather different from the one which emerges from the (p,t) process (large ellipse, correlation length ξ).

(a)–(a)

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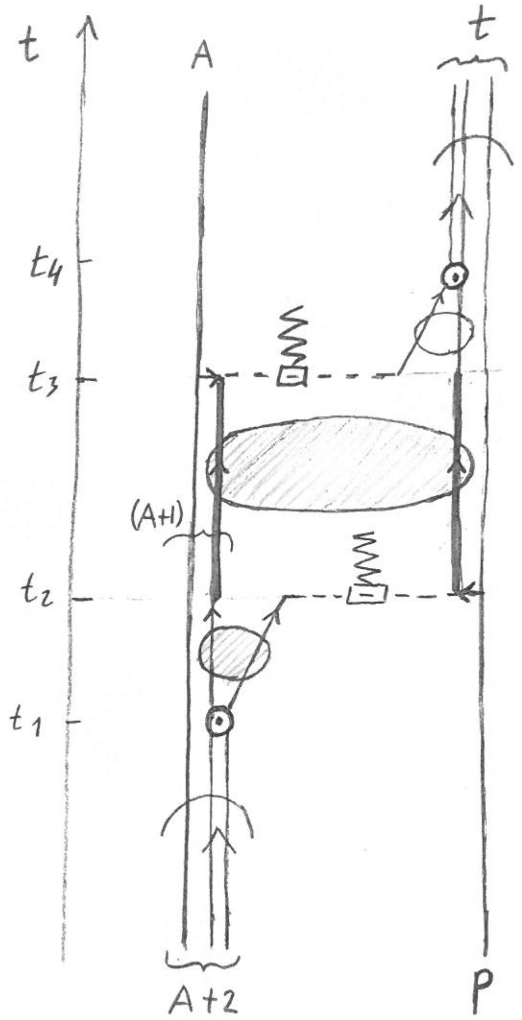
$R_d =$

$R_t =$




in the interval $\Delta t = t_3 - t_1$,

In other words, this is the observable Cooper pair in terms of its specific probe, and the reason why the neutrons are described in terms of bold face arrowed lines.

Fig. 6.5.5

Diagram describing structure and reaction aspects of the main process through which a Cooper pair (di-neutron) tunnels from target to projectile in the reaction $(A+2)+p \rightarrow A+t$. In order that the two-step process $(A+2)+p \rightarrow (A+1)+d \rightarrow A+t$ takes places, target and projectile have to be in contact at least in the time interval running between $t_2$ and $t_3$. During this time, the two systems create, with local regions of ever so low nucleonic presence, a common density over which the non-local pairing field can be established, and the Cooper pair correlated. Even with region in which the pairing interaction may be zero. Small ellipses indicate situations in which the two neutron correlation is distorted by the external mean field. The large ellipse indicated the region in which the two partners of the Cooper pair correlate over distances of the order of the correlation length $\xi$. Is this information that the outgoing particle brings to the detector.