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1.9 Interactions (Insert in p. 54 after Sect. 1.8) 54 a

A number of subjects are not touched upon in the present monograph. In particular, the role temperature plays in the structure and decay of nuclei, and that of bare (e.g. the argonne NN-potential) and/or effective forces (e.g. Gogny, Skyrme, etc). In what follows we briefly ellaborate on this last point, referring to Bortignon et al (1998) and refs. therein concerning the first one.

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(54)b (1)

The Coulomb interaction resulting from the exchange of photons between charged particles defines the domain area of quantum electrodynamics (QED). Being the electron and the photon fields in interaction, what we call an electron is only partially to be associated with the electron field alone. It is also partially to be associated with the photon field which dresses the electron field. And conversely what is called the photon field can materialize itself in space in terms of an electron and a positron*).

The Coulomb interaction is the best known of all physical interactions, and QED constitutes the paradigm of theories which can be considered correct. In natural units in which the magnetic moment of the electron emerging from Dirac equation has the value of 1, the results of QED corrections agree — once divergent contributions have been renormalized by properly adjusting the value of the bare electron mass and charge (**) ← p. (54)c —, within experimental errors, that is down to the eleventh decimal figure, with observation (1.00115965221 ± 0.00000000003 (exp.); 1.00115965246 ± 0.00000000020 (QED); Quantum Electrodynamics, ed. Kinoshita WSPC (1990)).

The energy difference between the $2S_{1/2}$ and the $2P_{1/2}$ states of the hydrogen atom which according to Dirac's theory should be degenerate,

* J. Schwinger, Quantum Mechanics, Springer, Heidelberg ( ).

footnote to p. ~~1~~ 54 b

54 c ~~1~~ a

**) Changing indirectly the Coulombinteraction. Not that observed in the laboratory and acting between physical (dressed) electrons, but the "bare" Coulomb interaction acting between the "naked" electron fields, and used in the calculation of the variety of process through which the " photon field dresses the electrons.

emerges naturally, according to QED, from the dressing of hydrogen's electron by the photon associated with the zero point fluctuation of the electromagnetic vacuum. The measured value of the Lamb shift*) is 1057.845 (9) MHz (Lunden et al (1981), Lunden et al (1986), Pipkin (1990))**), an experimental value whose accuracy is limited by the ≈ 100 MHz natural line width of the $2P_{1/2}$ state. The best QED value, limited by uncertainties in the radius of the proton, is 1057.865 MHz (Sapirstein et al, (1990), Grotch et al (1994))***).

The above two numbers (electron magnetic moment and Lamb shift), are results of ab initio calculations within the framework of an effective field theory (QED). Ab initio to the extent that quantum mechanics in general (Heisenberg (1925), M. Born and P. Jordan (1925), M. Born, W. Heisenberg and P. Jordan (1925), P.A.M. Dirac (1925), E. Schrödinger (1926), M. Born (1926), Heisenberg (1927), Pauli (1925)) and the Dirac equation

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**) S.R. Lundeen and F.M. Pipkin, PRL 46, 232 (1981); S.R. Lundeen and F.M. Pipkin, Metrology 22, 9 (1986); F.M. Pipkin, Quantum Electrodynamics, ed. T. Kinoshita, World Scientific, Singapore (1990) p. 697.

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*) W.E. Lamb, Jr. Fine structure of the hydrogen atom, Nobel lecture

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***) J.R. Saperstein and D.R. Yennie in Quantum Electrodynamics ed. T. Kinoshita World Scientific, Singapore (1990)
H. Grotch, Foundations of Physics 24, 249 (1994)

(Dirac (1928 a, b)) in particular can be considered, on grounds of their ~~un~~ universal validity, to be such, including QED with its bare mass and charge parameters used to cure infinities (renormalization)*.

Having adopted nuclear field theory (NFT) in our description of both nuclear structure and reactions, to follow the approach taken by QED (in particular, ~~that~~ diagramatic of Feynman's) in the description of the interaction of light with matter, through the correspondence (electron, positron) → (nucleons), photons → (collective vibrations), the role of specific nuclear forces becomes somewhat blurred. Also because of the very large contribution the exchange of collective vibrations between nucleons. As large as that of the bare force, or larger.**) Starting from the mean field (see Eq (1,2.6)) at the basis of the non-observable bare single-particle energies, one employs a generic shape (Woods-Saxon), adjusting the depth, radius and diffusivity of the central potential, and the depth of the spin-orbit one, so that the dressed single-particle states reproduce the experimental findings***). Parallel to the bare mass parameter entering renormalized QED.

**) In particular concerning the contribution to the pairing gap of ^{120}Sn ($\Delta \approx 1.45$ MeV) arising from the bare $^1S_0$ (pairing) interaction, v_{14} (Argonne NN-potential (reference)) and that associated with the exchange of collective vibrational modes between nucleons moving in time reversal states close to the Fermi energy (Idini et al PRC 92, 031304(R) (2015)).

in connection with an r-dependent effective k-mass (exchange potential),

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*) R.P. Feynman, PR 76, 769 (1949); J. Schwinger, J. Schwinger, 73, 416 (1948); S. Tomonaga Progress of Theoretical Physics, Vol I, 27 (1946); See also F.J. Dyson, PR 75, 486 (1949), Quantum Electrodynamics Ed. J. Schwinger, Dover, New York (1958) S.S. Schweber, QED, Princeton University Press, Princeton (1994).

***) see e.g. Barranco et al PRL ^{11}B and Barranco et al PRC ^{10}Li.

In connection with the coupling between nucleons and surface vibrations, namely the strength Λ_α, one adjusts K so as to reproduce the properties of the collective mode, (see inset Fig. 1.2.3), a procedure which parallels the tunning of the bare charge, and thus the strength of the coupling between electrons and photons (and of the bare Coulomb interaction) in renormalized QED

The Mayer and Jensen sequence of levels around N=8 ~~[illegible]~~ magic numbers $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$ (Fig. 1.1.3), while experimentally $^{11}_{4}Be_7$ displays the sequence*) $1/2^+$, $1/2^-$ (bound), $5/2^+$ (resonance). A consequence of the dressing of the bare $1p_{1/2}$, $1d_{5/2}$ and $s_{1/2}$ states by the quadrupole vibration**) of ^{10}Be ($\beta_2 \approx 0.9$). This extremely large value of the dynamically deformation parameter implies a Lamb-shift like mechanism which the bare $1p_{1/2}$ and $2s_{1/2}$ orbitals by more than 3 MeV, the resulting dressed levels coinciding with the experimental ones ($\varepsilon_{\tilde{1/2}^+} = -0.5$ MeV, $\varepsilon_{\tilde{1/2}^-} = -0.18$ MeV, i.e. $\Delta\varepsilon_{\tilde{1/2}^+ - \tilde{1/2}^-} = 0.32$, ~~see~~ Fig. 7.2.1). It is of notice ~~that~~ at the same time, the bare $d_{5/2}$ resonance is moved down, from its bare energy, by ≈ 6 MeV. The resulting centroid of the dressed $5/2^+$ resonance is ≈ 1.45 MeV ($\Gamma = 0.17$ MeV), to be compared with the experimental values of 1.28 MeV and $\Gamma = 0.1$ MeV.

The predicted E1-decay between the parity inverted levels is $B(E1; \tilde{1/2}^- \to \tilde{1/2}^+) = 0.11\, e^2 fm^2$, a value to be compared to the experimental value**) $B(E1) = 0.102 \pm 0.002\, e^2 fm^2$ (ref. [8] PRL ^{11}Be)

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*) ref [8] ^{11}Be PRL

**) Barranco et al PRL 119, 082501 (2017)

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54 g

The two (three) numbers ($\varepsilon^{\sim}_{1/2^+}$, $\varepsilon^{\sim}_{1/2^-}$ ($\Delta\varepsilon$), and $B(E1)$) can, arguably, be used to asses the accuracy of renormalized NFT results on something which one can call equal footing, with the two numbers (electron magnetic moment and Lamb shift) discussed above in connection with the assesment of the level of accuracy of QED results.

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(54) ~~(6)~~

It would be computationally useful and conceptually satisfying to have a bare NN-potential, eventually derived from QCD, reproducing the NN-phase shifts and which, employed in nuclear structure calculations, lead to bare static (Eq.(1,2.6)) and time-dependent (dynamic, Eq.(1,2,7)) mean fields whose solutions (bare single-particle states and bare vibrational modes), interweaved according to the rules of a (effective) field theory, e.g. NFT (Sect. 2,7,2), accounted for the value of the observable resulting from a "complete" set of probes (see e.g. Figs. 2.10.1 and 7.3.1). Concerning single-particle motion: energies, absolute one-particle transfer differential cross sections and thus insight into both single-particle content and renormalized single-particle wavefunctions (form factors), γ-decay and associated effective charges, etc. Concerning collective vibrations: energies, γ-decay, absolute differential cross sections for inelastic and Coulomb excitations (surface modes) and for two-nucleon transfer processes (pairing vibrations).

Until such desideratum becomes reality, the aim at shedding light onto the physics (at the basis) of new experimental results and that of providing guidance in the scope to achieve a deeper and unified picture of nuclear structure and reactions can be carried out in terms of empirical renormalization.

W. Heisenberg Z. Phys. 33, 1925 (1925)
M. Born and P. Jordan Z. Phys. 34, 858 (1925)
M. Born, W. Heisenberg and P. Jordan Z. Phys. 35, 557 (1925)
P. A. M. Dirac, Proc. Roy. Soc. A109, 642 (1925)
W. Pauli, Z. Phys. 31, 765 (1925)
E. Schrödinger Ann. der Phys. 79, 361 (1926)
M. Born Z. Phys 37, 863 (1926)
P. A. M. Dirac Proc. Roy. soc. A117, 610 (1928 a)
P. A. M. Dirac Proc. Roy. Soc A118, 351 (1928 b)