Development of Many-Body Perturbation Theory: How to combine with Quantum ElectroDynamics

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The basic difficulty of combining many-body perturbation theory (MBPT) with quantum electrodynamics (QED) is that the structures of the two procedures are seemingly incompatible - MBPT is based upon standard quantum mechanics with a single time, while QED is based upon relativistic covariance with individual time for each particle. In order to combine the two, one way is to sacrifice the full covariance and apply the equal-time approximation. Fortunately, it turns out that this has very small effect on problems in atomic/molecular physics and quantum chemistry.

In the first part of the lecture the standard procedures of MBPT and QED will be reviewed. Here, emphasis will be put on the so-called folded term of the Bloch equation of MBPT, which represents the remainder after the singularities, due to intermediate model-space states, are eliminated (also referred to as "model-space contribution" or "reference-state contribution"). It turns out that this plays an important role in the generalization of the procedure, needed to include QED and other energy-dependent perturbations.

In the standard procedures the effects of MBPT (primarily electron correlation) and of QED (retardation, self-energy etc) are treated independently. The second part of the lecture will deal with the possibility of treating the two effects coherently. Such a procedure has recently been developed, based upon the covariant-evolution operator (CEO) method for QED, which has a structure quite akin to that of MBPT [1, 2]. The CEO also has singularities due to intermediate model-space states, and the regular part is referred to as as the *Green's operator*, due to its analogy with the standard Green's function. This operator can be regarded as a time-dependent generalization of the wave operator of standard MBPT, and it satisfies a Bloch-type equation, quite similar to that of the MBPT counterpart. The only difference lies in the form of the folded term, which in the Green's-operator case also contains the energy derivative of the perturbation. This leads to a general *time-dependent perturbation theory* and makes it is possible to include time- or energy-dependent perturbations, such as those of QED, into the MBPT expansion in a rigorous fashion.

The combined MBPT-QED procedure is now being tested, and some numerical results for heliumlike ions will be presented.

References

[1] I. Lindgren, S. Salomonson, and B. Åsén, Physics Reports 389, 161 (2004).

[2] I. Lindgren, *Relativistic Many-Body Theory: A New Field-Theoretical Approach* (Springer-Verlag, New York, 2011).