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Feynman diagram approach to atomic collisions*

BABAJI CHARAN MISHRA and TRILOCHAN PRADHAN
Institute of Physics, A/105 Saheed Nagar, Bhubaneswar 751 007, India

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Abstract. A quantum field theoretic formulation of atomic collision phenomena involving non-relativistic free and bound systems is developed and a calculational procedure in terms of Feynman diagrams is prescribed. Matrix elements of several atomic collision processes have been calculated. In most cases standard quantum mechanical results are reproduced. But in some cases new terms appear in the scattering matrix whose contribution though negligibly small in the low energy region, become important at higher energies.

Keywords. Non-relativistic field theory; Feynman rules; charge form-factor of an atom; Kramers-Heisenberg formula; Van der Waals interaction.

1. Introduction

In the Feynman diagram approach to atomic collision problems developed earlier (Pradhan and Khare 1976), the Bethe-Salpeter method was used to obtain the vertex function involving the atom and its constituents while standard expressions were used for propagators. This method was adequate for some collisions involving hydrogen-like atoms. For some other collisions involving hydrogen-like atoms and collisions involving three-body bound states, this method is not applicable. It is the purpose of the present paper to develop a Hamiltonian approach within the framework of quantum field theory for the interaction among the non-relativistic bound systems involving two particles and their constituents and their interactions with photons. From this, Feynman diagrams and the rules for writing down the corresponding S-matrix elements would follow quite naturally.

The problem that one would encounter in perturbation theory for scattering of particles that can form bound states is that such states would not come out of the theory unless these are used as inputs. For instance in nonrelativistic electron-proton collision, it would be necessary to put hydrogen atom, in addition to electron and proton, into the Hamiltonian before doing perturbative calculations for scattering processes. A familiar example from particle physics may be useful. In the problem of collision between a pion and a nucleon, a resonance occurs around pion laboratory energy of 200 MeV. A successful perturbation theory of pion-nucleon collision phenomena must, therefore, use this resonant state as an input in the Hamiltonian.

Having made our point that the bound entity must be used as input, the task of implementing the same has to be undertaken. For this let us first consider the

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