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On form factors of boundary changing operators

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Abstract

We develop a form factor bootstrap program to determine the matrix elements of local, boundary condition changing operators. We propose axioms for these form factors and determine their solutions in the free boson and Lee–Yang models. The sudden change in the boundary condition, caused by an operator insertion, can be interpreted as a local quench and the form factors provide the overlap of any state before the quench with any outgoing state after the quench.

1. Introduction

Integrable $1+1$ dimensional systems are very special quantum field theories as they can be solved exactly [1,2]. The models and the obtained solutions are interesting in many respects. First, they appear on various areas of theoretical physics ranging from statistical physics to string theory. Second, the exact solutions can be compared to and test alternative approximate solutions.

The procedure of solving integrable theories consists of two steps. In the first step the scattering (S) and reflection (R) matrices, connecting asymptotic initial and final states, are determined. These contain the on-shell information of a given bulk or boundary quantum field theory. In the second step restrictive functional equations are formulated for the form factors involving the

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already determined S and R matrices. The solutions of these equations provide off-shell information which then can be used to calculate the correlation functions via the spectral representation.

Recently there has been increasing interest in quench type problems. They appear when, at a given time, a parameter of the physical system is changed. They are relevant in statistical physics and solid state problems. On the string theory side they appear when the strings split, fuse or change their boundary conditions [3,4]. So far the integrable approaches assumed a squeezed coherent (boundary) state form of the system after the quench, see [5–7] and references therein. Contrary, we would like to analyze a different quench, which is related to form factors. As an example let us suppose that we introduce a quench in a system at a moment by inserting a local operator $\mathcal{O}$, which we can even integrate in space $\int \mathcal{O}(x,0)dx$. In the quench framework we are interested in how a given state (say the vacuum) will evolve after the quench. This is probed by the matrix elements

$$\langle\theta_1,\dots,\theta_n|\int \mathcal{O}(x,0)dx|0\rangle = F^{\mathcal{O}}(\bar{\theta}_n,\dots,\bar{\theta}_1)\delta_P \quad , \qquad \bar{\theta}=\theta+i\pi\,, \tag{1.1}$$

which is basically the form factor of the operator $\mathcal{O}$, and δ_P projects onto zero momentum states. Clearly, form factors do not exponentiate, except for free theories. This quench is, however, localized in time, and cannot be regarded as a change of a parameter of the model.

In the following we will be interested in another integrable quench, which changes the parameters of the theory but still corresponds to form factors. We analyze an integrable boundary system in which at a moment we change the integrable boundary condition from α to β by inserting a boundary condition changing operator. These kinds of boundary quenches have been used to calculate the Loschmidt echo in the Resonant Level Model [8]. As the vacuum evolves to the form factors of the boundary condition changing operator we formulate axioms to determine these quantities.

In [9,10] the authors proposed form factor axioms both for boundary operators and for boundary changing operators. First they adopted the boundary form factor axioms from lattice models [11] and adjusted them for the relativistic kinematics. Then, on the example of the free massive fermion model they generalized them for operators which change the boundary condition and they further analyzed the solutions of these equations. Finally, they extended the axioms for non-trivial bulk scatterings and investigated the sinh-Gordon model, where they calculated the form factors of boundary changing operators up to 4 particles. They also extended the analysis for massless scatterings and applied the results for the double well problem of dissipative quantum mechanics.

In [12] the authors analyzed the form factors of local boundary operators from a different perspective. They derived a closed set of boundary form factor axioms from the boundary reduction formula [13]. These axioms, besides of the previous ones of [9], additionally contained the boundary kinematical singularity axiom, making the whole system complete in the sense, that the space of solutions is in one to one correspondence with the space of all local boundary operators of the UV boundary conformal field theory [14]. This boundary form factor program was carried out in many integrable models and was generalized to nondiagonal scattering theories [15–18].

The aim of the present paper is to extend this form factor program for boundary changing operators, i.e. our axioms, additionally to the axioms of [9], contain the boundary changing analogue of the boundary kinematical singularity axiom. We also show that our axioms are complete in the above sense, as we find as many solutions as many boundary changing local operators exist in the UV limiting boundary conformal field theory.