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CAUSALITY IN INDEFINITE-METRIC THEORIES

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SUMMARY. -- It has recently been claimed by Rechenberg and Sudarshan that theories with shadow states are consistent with macroscopic causality, even though they lack the normal physical-region analytic structure. This claim is based on a number of incorrect statements, which are here pointed out. These errors invalidate the claim.

I. INTRODUCTION

In an attempt to cope with the unitarity difficulties of indefinite metric theories E. C. G. Sudarshan and co-workers (1) have introduced the idea of shadow states. The central idea, in brief, is that certain particles are identified as shadow particles, and every state containing a shadow particle is identified as a shadow state. These shadow states are assumed to be propagated by one-half the sum of the advanced and retarded propagators, instead of by the usual retarded propagator. This modified propagator has no imaginary part, and hence the intermediate shadow states do not contribute in the usual way to the left-hand side of the unitarity equation $2 \text{ Im } T = TT^{+}$. Consequently, the restriction of the S matrix to the "physical" subspace, which is the subspace of nonshadow states, is unitary.

The question immediately arises whether this truncated form of unitarity has any physical significance. The proponents of shadow theory claim that only the physical states are observable, and hence the truncated form is indeed significant. However, this claim is not adequately supported. In fact, it seems clear that the claim is incorrect. For since the shadow states are propagated by one-half the sum of the advanced and retarded propagators there will be observable effects on ordinary (i.e., nonshadow) particles due to the retarded propagation of shadow states. These effects can be used to detect the propagating shadow states, which will therefore not be unobservable (2).

Another question concerns the effects of the advanced part of the shadow-state propagators. The direct effect of these advanced propagators is to give long-range interactions corresponding to the propagation of shadow states backward in time. These interactions lead to problems with macroscopic causality.

In a recent paper (3) Rechenberg and Sudarshan have advanced the claim that quantum field theory with shadow states is consistent with macroscopic causality, even though the theory does not have the normal physical-region analytic structure. That claim contradicts a theorem proved several years ago by Iagolnitzer and myself (4). The purpose of the present note is to point out that the paper of Rechenberg and Sudarshan contains a number of incorrect statements about the content of reference (4), and that they have, in fact, not circumvented the conclusions of the theorem proved there.

II. ERRORS IN THE ARGUMENTS OF RECHENBERG AND SUDARSHAN

1. Rechenberg and Sudarshan state that local relativistic causality is built into the macrocausality requirement of ref. (4), and that a sharp separation between space-like and time-like regions plays a decisive role in the derivation of analyticity. These statements are not correct. The macrocausality condition of ref. (4) permits any sort of short-range nonlocal interaction, and no sharp separation between space-like and time-like regions enters into the derivation of analyticity. In other words, particles can have any finite radius, and can interact via any sort of interaction that is exponentially damped under space-time dilation, and moreover every space-time region can be smeared over any bounded set of space-time displacements, without disrupting the proof of analyticity.

The contrary claim of Rechenberg and Sudarshan seems to be based on a basic misunderstanding of the macrocausality property of ref. (4). The essential idea there is that all space-time requirements are formulated in a scaled coordinate system, where the scaled coordinate x' is related to the physical space-time coordinate x by $x = x'\tau$. Macrocausality is expressed as a fall-off property of certain scattering transition probabilities as τ goes to infinity. But as τ goes to infinity any finite-radius interaction in x space shrinks to a point interaction in x' space, and macrocausality is specifically formulated so that any such finite-radius interaction, or any finite-range interaction, can be introduced without affecting the macrocausality property. That property asserts only that any interaction that does not have finite range must be carried by physical particles. The finite-range interactions are unrestricted.

2. Rechenberg and Sudarshan (RS) object to the space-time dilation of the physical system that is used in the proof of analyticity. They claim that it goes far beyond what is known in particle physics. But all that is involved here is a theoretical consideration of a sequence of scattering processes that are related to each other by a transformation that moves the initial and final particles increasingly far apart in x space, but leaves their center-of-mass motions fixed in x' space. The possiblity of considering such a sequence is built into quantum theory. Nothing new is involved. It would be new to say that one could not consider these various different processes.

3. RS say that classical concepts should be applied only in the large; i.e., they should not be used to derive knowledge about the microscopic situation. That is precisely our position: macrocausality imposes conditions on the large-scale space-time behavior, and from these macroscopic conditions we derive analyticity properties in the physical region itself. Microscopic behavior, on the other hand, is related to analyticity properties away from the physical region, about which we say nothing.

4. RS say "In small space-time regions, on the other hand, interactions are conceivable that have no corresponding counterparts in macroscopic domains to which they could be (analytically) connected. To exclude these forces from the very beginning seems to us equivalent to the assumption that essentially no analyticities are contained in the scattering amplitude anyway. Therefore we are not very surprised that none come out from the Iagolnitzer-Stapp proof."

As already emphasized, macrocausality places no conditions at all on the short-range forces: they are not excluded from the very beginning, and they are not excluded at the end, since the only analyticity properties obtained are physical-region analyticity properties, whereas short-range forces are association with singularities far away from the physical region (2). Thus we do not try to "derive knowledge of the microscopic situation from the corresponding asymptotic and, therefore, macroscopic situation." Rather we derive the momentum-space equivalent of a macroscopic space-time causality condition.

5. The suggestion of RS that we "use···a part of strict local causality, namely that (part corresponding to) large causal dilations ···" is false. We use no part of strict local causality, either at large distances or small. All light cones and other space-time regions can be smeared by any finite amount, without disturbing macrocausality.

6. RS say that one cannot, as was done in ref. (4), use wave packets of the Omnes form

$$\phi_\tau(p) = X(p) \exp[-(p - P)^2 \gamma\tau]$$

in a theory with a genuine nonlocality. They argue that the singularities associated with shadow states introduce long-range contributions into the wave functions, which therefore cannot be gaussian. However, the function $X(p)$ is a function of compact support. This support can be very tiny, and need not include any singularity of the reaction that determines the wave function. Note that the wave functions of the initial and final particles are determined by the production and detection reactions, and the locations of the singlarities associated with these reactions are not the same as those associated with the reaction under study. Thus there appears to be

no logical basis for the claim by RS that Omnes-type wave functions cannot be used to describe the initial and final particles of scattering experiments.

III. CONCLUSION

The discussion by Rechenberg and Sudarshan of the results of reference (4) is based on a misunderstanding of that work, and they have not circumvented the equivalence proved there between macroscopic causality and the normal analytic structure.

IV. ADDITIONAL COMMENT

The discussion of causality given by Sudarshan and Rechenberg differs markedly from the one given by T. D. Lee (5), in connection with his indefinite metric theory. Lee admits that there will be acausal effects, but assumes that the particles associated with the abnormal analyticity properties will be unstable. In that case the acausal effects will be confined to short distances, and Lee argues that the numerical coefficients will probably be small enough to make the acausal effects unobservable in practice, even though they are present in principle. Sudarshan and Rechenberg, on the other hand, never assert that the shadow particles are unstable, and apparently do not base their discussion of causality on this assumption. However, if there are stable shadow particles then there will, as a consequence of the shadow theory rules for calculating the S matrix in the physical sector, be acausal effects on normal particles (due to the acausal propagation of shadow states backward in time) that are not short ranged, but which rather extend over macroscopic distances. These effects could be used to transmit signals backward in time (2), and hence they must, in accordance with ordinary usage, be identified as acausalities. RS never explain how these acausal effects are to be reconciled with their claim that shadow theory is compatible with macroscopic causality. The effects are certainly incompatible with the macroscopic causality condition formulated in reference (4), and no alternative recognizable definition of macroscopic causality is set forth by RS.

FOOTNOTES AND REFERENCES

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