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ABSTRACT

The relationship to the S-matrix theory of the photon and its associated long range forces is discussed. It is suggested that the S-matrix theory as it is presently conceived is only consistent for the strong interactions; the inclusion of photons and leptons leads to basic inconsistencies.

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Over the past two or three years there has been a revival of interest in the S matrix as a vehicle for the formulation of fundamental microscopic laws. Stapp,[1] Gunson,[2] and Olive[3] have attacked the problem of finding suitable axioms to formalize the notion of "maximal analyticity," which all workers in this area now recognize as an essential adjunct to Heisenberg's original postulates of Lorentz invariance and unitarity.[4] Stapp has made it overwhelmingly plausible that TCP invariance and the usual connection between spin and statistics will be automatic properties of an analytic S matrix.[1] Zwanziger and Stapp have shown how unstable particles can be treated on the same footing as the stable ones.[5] In none of the above papers is any distinction made between strong, electromagnetic, and weak interactions; nor does such a distinction arise in the observations of Polkinghorne that the Landau branch points probably constitute the minimal set of singularities consistent with the analytic continuation of unitarity in the presence of poles.[6] There are reasons, nevertheless, for questioning the scope of the currently discussed S-matrix theory. The purpose of this note is to argue that the theory now under construction is destined only to encompass strong interactions and that this limitation should be considered a natural feature, not a fatal defect.

A historical background for our argument may be found in the circumstance emphasized recently by Dirac[7] that up to now nature has revealed her secrets in a well-defined sequence of installments, and that human intellect has rarely if ever been able to grasp more than one installment at a time. Why nature should be so kind to physicists no one knows, but she has been so in the past and at the moment she seems to be repeating the pattern by inviting us to understand strong interactions as a more or less isolated collection of phenomena. All the evidence pouring in suggests that nuclear particles owe their existence to the strong forces acting between them, with electromagnetism, weak interactions, and gravitation acting only as small perturbations.

A basic tenet of the S-matrix approach is that the only physical observables are scattering amplitudes as functions of ingoing and outgoing particle momenta. This assumption is easy to defend for strong interactions, which all are of short range, but it has not so far been made convincing for macroscopic experiments, where electromagnetism is essential. A second tenet is the unitarity condition, which assumes that every scattering process has a beginning and an end; again we are in trouble with classical electric and magnetic fields. Further, the S matrix has not even been defined so as to include the infinite number of soft photons accompanying any scattering process. The status of unitarity in this connection is obscure. These well-known difficulties, although often dismissed as superficial by S-matrix enthusiasts, provide a legitimate source of suspicion about the scope of the conventional S matrix. A less discussed but more significant circumstance is the necessity for coarse-grained macroscopic space-time measurements in order to define velocity (and thus momentum), even though no space-time continuum need be introduced. These macroscopic measurements are always experimentally accomplished via long-range electromagnetic interactions of precisely the character that has defied an S-matrix description. It seems doubtful that the needed definition of a coarse-grained space time ever could be achieved via the short-range strong interactions. It is true that the time ordering of a sequence of events is embodied in the singularity structure of the S matrix, but the work of Goldberger, Watson, and Froissart[8] suggests that the concept of a classical trajectory is tied to the possibility of many successive small-angle collisions and thus to long-range forces.

The above circumstances lead us to the following picture: Electromagnetism is essential to S-matrix theory in that it provides the definition of coarse-grained space time through which momenta are measured, but at the same time electromagnetism is not itself described by the conventional S matrix. It lies outside, in spite of the fact that single photons behave in many ways like nuclear particles. Current S-matrix theory in this view is incomplete, but it shares its incompleteness with all previous theories and perhaps all future ones. If it is capable of explaining the origin and properties of nuclear particles to an accuracy of order $e^2/\hbar c$ we should be well satisfied.

To the extent that their primary interactions are electromagnetic the electron and the muon should not be expected to emerge from the conventional S matrix, nor should the neutrino which always occurs in association with these particles. The question then arises: How should the photon and the leptons be approached if we reject quantum field theory?[9] Temporarily one may continue to use makeshift perturbation recipes, tacking the photon and the leptons on the S matrix from the outside, with their masses and coupling constants as arbitrary parameters; but where is an ultimate explanation to be sought? It is here that the inconsistent nature of current S-matrix theory may provide a clue.

The theory is inconsistent in that it requires a coarse-grained space time without providing internally for the mechanism of definition. One may hope that a future installment of nature's serialized story may generalize the S matrix, perhaps retaining analyticity but substituting some new property for unitarity, as suggested by Gunson,[2] to permit a consistent relation between axioms and measurements. At this point, if we are on the right track, electromagnetism would be forced upon us together with who knows what else, if the electron mass is of electromagnetic origin as long suspected. We see no reason why this future development should reinstate quantum field theory because the difficulty to be overcome is of a macroscopic nature. On the other hand, one may imagine a role for the classical electromagnetic field concept in achieving the connection with physical measurements.* Any true observable is a candidate for inclusion in the theoretical structure.

Coming back to earth, we ask what are the immediate implications of the above point of view with respect to <u>current</u> S-matrix theory--which has not yet been precisely formulated but which is developing rapidly. First of all, if our arguments are correct the much debated question of associating the photon or the leptons with Regge poles is meaningless. The constants associated with these particles will remain undetermined so long as the combination of analyticity with conventional unitarity remains the keystone of the theory.

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* Lest the reader wonder how a classical field can be envisaged without its quantum counterpart, we recall Stapp's remark[1] that the S-matrix approach discards nearly all the apparatus of quantum theory--operators, state vectors, commutation rules--retaining only the superposition principle. The Planck constant $\hbar$ does not even enter until one considers the experimental interpretation in terms of cross sections.

On the other hand, the prospect that the foregoing two principles will allow the construction of an S matrix without arbitrary parameters is enhanced. The strong-interaction regime is experimentally characterized by the absence of small (or large) dimensionless parameters, so the "bootstrap" mechanism[10] here has *a priori* some chance of success. If electromagnetic and (or) weak interactions were required to emerge, one could not maintain much hope for bootstrapping within an analytic S matrix.

To sum up, strong interactions may be understandable entirely in terms of what euphemistically may be called "dynamics," the particles owing their existence to the same "forces" that cause them to interact with each other.[11] An optimist can hope that the physics of this situation is contained in the conventional S matrix. Electromagnetism, on the other hand, is a far more subtle phenomenon, in spite of the fact that it was discovered sooner, being related to the logical structure of the theory which at present is inconsistent. The unitarity condition must be modified to remove this inconsistency before we can properly consider strong and electromagnetic interactions together. Whether a still further evolution will be needed to accommodate the leptons is hard to guess, but they cannot be a part of the currently discussed S matrix.

I am grateful to Professor Heisenberg for discussion of a number of these questions. Also to be acknowledged with gratitude is the hospitality extended to me during the past year by Churchill College.

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