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DISPROOF OF SENITZKY'S "FUNDAMENTAL THEOREM IN QUANTUM OPTICS"*

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A "fundamental theorem in quantum optics" has recently been enunciated by Senitzky[1]: "All [field] sources on which the effect of the detector [of some field property] is negligible may be treated as classical sources in the interaction under consideration."[2] On the basis of this theorem, a number of discussions which have recently proved of both conceptual and practical interest in quantum electronics are dismissed.[3] In this note we point out that Senitzky's "fundamental" theorem is incorrect.

Before discussing the error in Senitzky's proof, we indicate several conceptual difficulties connected with this theorem.

Senitzky's theorem implies that the classical versus quantum behavior of an electromagnetic field depends upon the causal relationship between the source of the field and possible field measurements. This result contradicts the fact that a field can be excited to an arbitrary (quantum statistical) state by a source which can then be decoupled from the field before any measurements are performed. Since the measurements would then not be able to affect the decoupled source dynamically, Senitzky's theorem implies that mere decoupling of the source from the field forces the field to become classical.

As emphasized by Senitzky, the theorem applies to practically every experiment in optics and spectroscopy since the source and detector are usually well separated. In particular, it applies to experiments in which single-photon beams are emitted by a source and then absorbed by a material system. Although it is possible to calculate the matrix elements for the absorption process correctly with semiclassical theory,[4] a complete understanding of the process requires the quantum theory of radiation. Senitzky's theorem would imply, for example, that Einstein's quantum explanation of the photoelectric effect was unnecessary.

The proof of Senitzky's theorem and its application to quantum optics is based on the incorrect assumption that, once two systems no longer interact, a measurement involving one system cannot influence the statistical properties of the other system. This assumption ignores the correlations which can be established between two systems through their past interaction. Quantum mechanics contains numerous examples of correlations resulting from interactions which are terminated before measurements are performed.[5] For instance, if an electromagnetic field is excited by a source which is eventually decoupled, the energy gain of the field is correlated with the energy loss of the source even though the field and source do not interact dynamically when the field energy is measured.

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[1]I. R. Senitzky, Phys. Rev. Letters 15, 233 (1965).

[2]Senitzky uses quotation marks around the word detector because the interaction under consideration involves all systems coupled to the radiation field other than the source.

[3]The Hanbury Brown–Twiss experiment, the quantum mechanical nature of laser radiation, and the validity of semiclassical coherence theory (references 6-9 of Senitzky's paper).

[4]L. I. Schiff, Quantum Mechanics (McGraw-Hill Book Company, Inc., New York, 1955), 2nd ed., Chap. X.

[5]Senitzky's claim that certain commutators vanish contradicts this view, and can easily be shown to be incorrect by explicit calculation.

PERTURBATION INDUCED IN ELASTIC SCATTERING BY CROSSING OF MOLECULAR STATES*

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Differential ion-atom scattering is becoming a sensitive tool for the study of interactions in diatomic systems. For ease of both experimental and theoretical study, the system $He^+ + He$ excels. Its differential elastic scattering spectra combine sufficient structure to be interesting with sufficient simplicity to be intelligible. The most pronounced feature is a regular oscillation representing interference between scattering in even (g) and odd (u) electronic states of the ion He_2^+. As a result of a good deal of experimental[1,2] and theoretical[3,4] study, this interference is rather well understood. At larger angles it is supplemented, in the case of identical nuclei, by a secondary interference pattern arising from the nuclear symmetry,[2,4,5] while at small angles and energies ($E\theta \lesssim 250$ eV deg) one observes the expected rainbow structure arising from the attractive portion of the odd (u) potential.[2,4]

From a rather early stage in our study of the simple oscillations, we had noted that their regularity was marred by reproducible perturbations at certain points, and one of us suggested that some of these irregularities might be due to the crossing (or "pseudocrossing") of two molecular electronic curves of the same symmetry.[6] We now believe we have identified one of these features with a particular crossing, and we wish to point out how such a perturbation can be used to estimate both the location of such a crossing and the magnitude of the interaction energy.

The feature in question is clearly shown in Fig. 1 in the region near $\theta_{lab} = 17°$ on the curve representing the scattering spectrum of $He^+ + He$ at $E_{lab} = 100$ eV: The peak at 17° is notably taller than the envelop of its neighbors, and the next peak on the left, at 14°, is distorted in shape and lowered; the valleys at 13.5° and 19° are raised above the smooth curve through their neighbors, while the one between them, at 16°, is approximately normal. Figure 1 also shows examples of similar patterns of rises

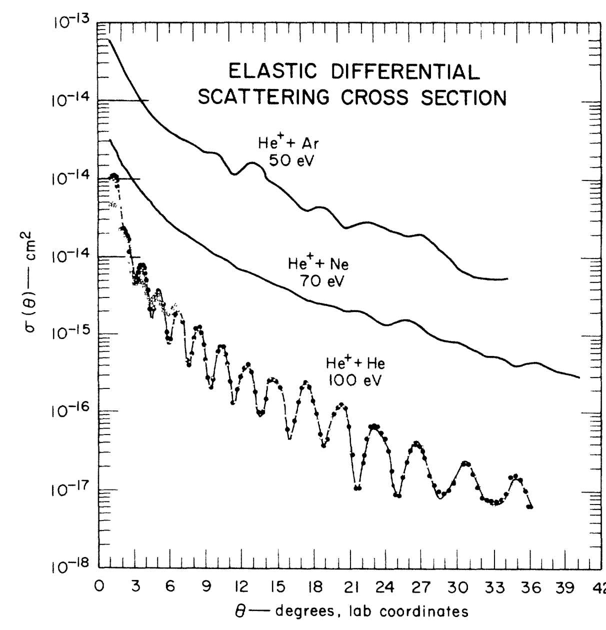

FIG. 1. Perturbation effects in differential elastic-scattering patterns. For the $He^+ + He$ system the actual experimental points are shown and the data are taken from reference 2. The $He^+ + Ar$ and $He^+ + Ne$ data are from unpublished work of Aberth and Lorents.