

seems minimal. Requiring consent for republication just adds one more paper formality to the many with which a scientist's work is already burdened.

I propose, therefore, that the time is ripe for scientific societies and publishers of scientific literature to reach a formal agreement by which illustrations in scientific articles and texts can be freely copied by members or authors of all parties to the agreement, subject only to explicit acknowledgment of the sources. Any possible adverse consequence of implementing this proposal would be outweighed by the advantages. But, if doubts remain, the agreement could start out as a five-year experiment, and future authors could retain the option of limiting use of specified material.

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Gap Filled in History of Ladder Compounds

In reading Barbara Goss Levi's excellent piece about the theoretical work on the fascinating new ladder compounds (PHYSICS TODAY, October 1996, page 17), I was surprised that the connection of the undoped compounds to the Haldane gap of integer spin chains was not mentioned. In my view, the connection is quite direct and enlightening.

Consider, for example, the result that a two-leg Heisenberg ladder is gapped for arbitrarily weak coupling between the legs of the ladder. To my knowledge, this result was first obtained in 1992 by Andy Millis and myself using Abelian and non-Abelian bosonization.¹ We determined that the ladder has a gap growing linearly with the strength of the interleg coupling, but after obtaining the results, we discovered that the exact operators responsible for the gap had been analyzed in 1982 by Marcel den Nijs in the context of the spin-1 chain² and in 1986 by Heinz Schulz³ for general S spin chains.⁴

Their studies demonstrated that, in Abelian bosonization, the spin-1 chain could be expected to have a gap for all excitations, rather than arbitrarily low-lying, spin-wave-like excitations. Schulz further showed that this behavior occurs in bosonization for all integer spin chains, but not half-integer spin chains. His work thus confirmed Haldane's conjecture of the now well accepted Haldane gap⁴ for integer, and only integer, spin chains. The Haldane gap behavior

found by Schulz should be considered together with the fact that, as I mentioned, the operators that Andy and I found to gap the two-leg spin ladder are identical to those argued to gap the spin-1 chain. Since the same correspondence occurs for all spin S chains and $2S$ leg ladders, with the only differences between the ladders and the spin chains being the signs with which the relevant operators appear, it follows immediately that even-leg, but not odd-leg, spin ladders should be fully gapped.

In fact, it is interesting to note that historically the Haldane gap appears to have been discovered by the reverse argument: Haldane himself applied Abelian bosonization to the study of the spin- $\frac{1}{2}$ chain in reference 5 and mentioned in a subsequent work⁶ that future research efforts would study higher S spin chains by means of the bosonization of coupled, spin- $\frac{1}{2}$ chains. Although those works never materialized, the Haldane conjecture of a gap for integer, but not half-integer, spin chains, followed immediately thereafter. It appears that, historically, it was an unpublished study of spin ladders and their peculiar odd-even alternation that led to the Haldane gap proposal, and that a particularly uncomplicated way to understand the undoped ladder compounds is to turn that approach on its head.

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