# This Week's Citation Classic

**Korringa J.** Nuclear magnetic relaxation and resonance line shift in metals.
*Physica* **16**:601-10, 1950.
[Institute of Theoretical Physics, University of Leiden, Leiden, The Netherlands]

**An absolute thermometer for very low temperatures and a means of studying the effects of interactions between conduction electrons are contained in a theoretical equation that relates the nuclear magnetic relaxation time in metals to the 'Knight shift,' which is the difference in resonance frequency of a nucleus in the metallic state and the molecular state. [The *SCI*® indicates that this paper has been cited over 325 times since 1961.]**

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"They were happy days at mid-century in Leiden. The war was over, the Kamerlingh Onnes Laboratory was under the inspiring leadership of C.J. Gorter, and the Lorentz Institute, headed by H.A. Kramers, was again attracting 'who's who in physics.' One day, Gorter expressed to me his belief that the nuclear magnetic relaxation time in metals is somehow related to the 'Knight shift.' I just happened to be in between problems, the previous one having bogged down in complexity. I was hooked instantly. Both my predoctoral teacher Kramers and my postdoctoral teacher R. Kronig did pioneering work in the theory of magnetism and I was well acquainted with the literature.

"Within a week I found a very simple solution, which is valid when the most energetic conduction electrons carry no angular momentum and can be treated as quasi-independent (Bloch model). The first restriction could be removed, at the expense of the universality of the relation, and concerning the second constraint, I could speculate what the effects of electron-electron correlations might be.

"This small effort led to great rewards in terms of citations. The paper has an aesthetic side, in that the relation is 'universal,' i.e., contains no material constants. This is unusual in solid-state physics. There is also a practical side: deviations shed light on the effects of correlations, which in those days were often debated but not well understood. One side of the relation, representing the fact that the product of absolute temperature, T, and relaxation time, $T_1$, is a material constant, has achieved popularity as a thermometer at very low temperatures. Heitler and Teller[1] had obtained this in 1936, but in those early days the equations of solid-state theory were not taken seriously enough to warrant a precise evaluation. A third factor may be the timing. That year the International Low Temperature Conference was held in Leiden. All the experts were there, and parallel sessions were not yet needed. I gave a 20-minute paper, which was through in ten minutes, and was surprised that it aroused so much discussion.

"I have wondered about the relation between citing and studying. My evidence is sobering. In the equation for higher angular momentum, two coefficients were wrong. Thirteen years after publication, a colleague discovered this. Fifteen years after that, one of my students saw that this new version was also wrong. She gave the correct expression, but has not published it.

"I believe in the use of the *Science Citation Index*® to measure the impact of a paper, however. In this connection, a study by Dieks and Chang[2] of Utrecht, the Netherlands, is of interest.

"Although the paper is 30 years old, the subject is still alive. With modern computers, higher angular momentum corrections can be obtained within the framework of electron band theory. This has not yet been done. On the negative side, the validity of $T_1T = \text{Const}$ succumbs to traces of magnetic impurities. This was discovered in low temperature thermometry and has been explained in detail on the basis of the 'Kondo effect' in the PhD thesis of W. Roshen."[3]

1. **Heitler W & Teller E.** Time effects in the magnetic cooling method. Part I. *Proc. Roy. Soc. London Ser. A* 155:629-39, 1936.
2. **Dieks D & Chang K H.** Differences in impact of scientific publications: some indexes derived from a citation analysis. *Soc. Stud. Sci.* 6:247-67, 1976.
3. **Roshen W.** *Nuclear spin relaxation in dilute magnetic alloys—Kondo systems and spin glasses.* PhD thesis. Columbus, OH: Ohio State University, 1981. 190 p.