This Week's Citation Classic

Zener C. Non-adiabatic crossing of energy levels.
Proc. Roy. Soc. London Ser. A **137**:696-702, 1932.
[Cambridge, England]

This paper described a general class of systems in which alterations induced by a change in parameters are critically dependent upon the time rate of this change. Below a certain critical rate the system changes radically; above this rate it remains essentially unchanged. [The *SCI*® indicates that this paper has been cited in over 495 publications since 1961.]

C. Zener
Department of Physics
Carnegie-Mellon University
Pittsburgh, PA 15213

June 22, 1983

"I shall never forget one spring day in 1931, even though it was more than 50 years ago. I vividly remember my desk, and how it was located in the Athenaeum at the California Institute of Technology. I was miserably rereading my last paper, just published. It was incomprehensible. My graduate years at Harvard University, 1926-1929, had been during the blossoming of quantum mechanics. To all of us graduate students, classical mechanics was passé. This paper[1] before me, 'The interchange of translational, rotational, and vibrational energy in molecular collisions,' gave no physical insight into what were the pertinent physical factors in the problem under study. It merely gave the results of quantum mechanical calculations. No one would read this kind of article. The pertinent physical concepts were, however, part of the cultural background of everyone living in our modern civilization. When one starts a child swinging in a swing, the duration of the push must be short compared to the period of the swing. Out of this miserable day some 52 years ago came the recognition that the key to the rate at which many processes take place lies in the ratio of two times, the time during which the pertinent force acts over the period of the pertinent oscillation. A ratio small compared to unity implies high rates; a high ratio implies loss rates.

"A short article was immediately written acknowledging my mistakes, as well as those of my contemporaries. To quote: 'This failure was due in part to the reluctance of modern theoretical physicists to work with classical methods even when their use is justifiable.' During the following year I assiduously scanned the six outstanding physics journals to spot phenomena interpretable by this rate concept. During this year, six articles[2-6] were communicated for publication. All six were in areas where the rate processes were governed by the ratio of time of force application to period of oscillation. Fortunately, during this year a National Research Fellowship enabled me to have the stimulus of residing for short periods at four universities, Princeton, Cambridge, Oxford, and Bristol. My *Citation Classic* paper was the last of these six articles.

"In all cases the key to the solution lay in the recognition of the classical ratio of two time constants. The precise way in which the rate of reaction depends upon the constant usually requires the use of quantum mechanics. In the classic paper, I observed that my calculated rate constant differed by a factor of 2π in the exponent from a calculation of Landau, as reported by Rosenkewitsch.[7] Rosenkewitsch wrote me that my Plank's h differed from Landau's Dirac's h by just this factor of 2π. Landau's calculation appeared in the following volume[8] of the *Physikalische Zeitschrift der USSR*.

"The popularity of my *Citation Classic* was due primarily to the generality of the problem solved. I believe a contributing factor was the conditions under which it was written. After three years of postdoctorate fellowships, I was desperate to obtain a faculty position. I therefore took particular pains to write in a lucid style."

1. **Zener C.** The interchange of translational, rotational, and vibrational energy in molecular collisions. *Phys. Rev.* **37**:556-9, 1931.
2. ----------. Elastic reflection of atoms from crystals. *Phys. Rev.* **40**:178-84, 1932.
3. ----------. The exchange of energy between monatomic gases and solid surfaces. *Phys. Rev.* **40**:335-9, 1932.
4. **Zener C & Rosen N.** Double Stern-Gerlach experiment and related collision phenomena. *Phys. Rev.* **40**:502-7, 1932.
5. **Zener C.** Some observations on the theory of interchange of vibrational and translational energy. *Proc. Camb. Philol. Soc.* **29**:136-41, 1933.
6. ----------. Dissociation of excited diatomic molecules by external perturbations. *Proc. Roy. Soc. London Ser. A* **140**:660-8, 1933.
7. **Rosenkewitsch L.** Über die Aktivierungsenergie. *Phys. Z. USSR* **1**:425-7, 1932.
8. **Landau L.** Zur Theorie der Energieubertragung. *Phys. Z. USSR* **2**:46-51, 1932.