This Week's Citation Classic

Gibala R. Internal friction in hydrogen-charged iron.
Trans. Met. Soc. AIME **239**:1574-85, 1967.
[Dept. Metallurgy, Case Institute of Technology, Cleveland, OH]

Internal friction measurements on hydrogen-charged iron are reported. Two relaxation peaks, identified as a hydrogen Snoek peak and a hydrogen cold-work peak, are observed. The results show evidence of partitioning of hydrogen between solid solution and dislocations. The hydrogen-dislocation binding energy is estimated to be 27 kJ per mole H. [The *SCI*® indicates that this paper has been cited over 115 times since 1967.]

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"This paper is a good illustration of a person being at the right places among the right people at the right time. In 1964 I was leaving the University of Illinois where, as a graduate student with Charles Wert, I had learned the analytical capabilities of internal friction techniques for investigation of defect interactions in solids. Among several bits of career advice Wert gave me were: 'Find a good research project that can be completed quickly' and 'Never pass up the opportunity to do good experiments on iron.'

"I arrived at Case Western Reserve University, where the problem of hydrogen embrittlement of steels had been investigated extensively by William Baldwin[1] and Alexander Troiano.[2] I learned quickly the essence of this problem from Troiano, who pointed out the importance of determining the magnitude of the interaction between hydrogen in solid solution and dislocations in iron. Some back-of-the-hand calculations revealed that internal friction could supply the answer, but that a high sensitivity apparatus was required.

"Fortunately, Donald Gibbons had recently come to Case from Bell Labs and had set up a beautiful acoustics laboratory that had everything I needed! It took two months to build minor ancillary equipment and to learn from Troiano's students the art of charging hydrogen into iron. The experimental work required another six months, and part of a summer was spent analyzing the data. Some iterations on the analysis and conversations with many people finally led to the conclusion that the hydrogen-dislocation binding energy in iron was 'large'—at least 25-30 kJ/mole H. This result established the viability of models of hydrogen embrittlement based on important roles of parts-per-million levels of hydrogen in solution and of related hydrogen-dislocation interactions, an idea that had been championed by Troiano. Until that time, it had been difficult for many investigators to believe that a proton-like defect could interact significantly with dislocations.

"Reaction to the paper was rapid and favorable. The paper received the Alfred Noble Prize of ASCE in 1969, and I am still asked to give papers on hydrogen in metals, even though my work in the area has not been large. The paper has probably been well cited because it answered a current fundamental research question for a technologically important materials problem on the eve of a big burst of new activity in the area that continues presently.

"Several improvements have been made on the findings of the original paper. More detailed experimental work has been done by Birnbaum at the University of Illinois, Moser in Grenoble, Kronmuller in Stuttgart, and Smialowski in Warsaw. Hirth at Ohio State University and Seeger in Stuttgart have produced improved theoretical models. The current status is summarized in the excellent review by Hirth.[3] The qualitative conclusions of the paper remain intact, but some evidence[4] suggests the binding energy might be higher than originally estimated, possibly by as much as a factor of two!"

1. **Toh T & Baldwin W M, Jr.** Ductility of steel with varying concentrations of hydrogen.
(Robertson W D, ed.) *Stress corrosion cracking and embrittlement.*
New York: Wiley, 1956. p. 176-86.
2. **Troiano A R.** The role of hydrogen and other interstitials in the mechanical behavior of metals.
Trans. Amer. Soc. Metals **52**:54-80, 1960.
3. **Hirth J P.** Effects of hydrogen o.+the properties of iron and steel.
Met. Trans. A—Phys. Met. Mater. Sc. **11**:861-90, 1980.
4. **Kumnick A J & Johnson H H.** Deep trapping states for hydrogen in deformed iron.
Acta Metallurgica **28**:33-9, 1980.