Editor's LETTER

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Nobel Carbon, a Worthy Element

The ability of carbon to form long and stable carbon−carbon bonds underpins the existence of all known living systems. This property allows for the formation of a countless number of diverse compounds. While Nature determined ways to synthesize complex carbon-based compounds well before life existed, reproducing the same fundamental reaction in a test tube remained elusive until relatively recently. Now, the carbon−carbon bond-forming reaction is an essential step in the synthesis of valuable commodities, including drugs, plastics, and electronics, thanks in part to the pioneering work in palladium-based catalysis of the winners of the 2010 Nobel Prize for Chemistry.

In early October, the Prize was awarded to Richard F. Heck, formerly of the University of Delaware; Ei-ichi Negishi, affiliated with Purdue University; and Akira Suzuki of Hokkaido University for their seminal contributions to "palladium-catalyzed cross couplings in organic synthesis". The 10 million Swedish kronor (approximately $1.5 million) award will be split among the three recipients.

Previous to the groundbreaking work of this year's winners, the synthesis of stable carbon−carbon bonds had been a particularly challenging task. In the early 1900s, the French chemist Victor Grignard devised a method for generating carbon−carbon bonds using magnesium to couple ketones and alkyl halides. For the development of this method, he won the 1912 Nobel Prize in Chemistry. This technique had its flaws, however, not the least of which was the unwanted byproducts generated in the process.

Heck developed a novel chemical reaction that used palladium to bring carbon atoms of arylmercury compounds and olefins in proximity of each other and facilitate bonding under relatively mild conditions. This work was published in 1968 with Heck as the sole author in seven back-to-back articles in the *Journal of the American Chemical Society* (*1*, *2*). A drawback to this protocol was that it worked most efficiently with toxic mercury-substituted aromatic rings. In 1971, Tsutomu Mizoroki from the Tokyo Institute of Technology published important work in which he described the nontoxic coupling of halide-substituted aromatic rings with alkenes using palladium as a catalyst (*3*). As a result, over the past 40 years the nomenclature of this reaction has been a debated point ("Heck reaction" or "Mizoroki−Heck reaction"?) among chemists (*4*). Unfortunately, in 1980, Mizoroki succumbed to pancreatic cancer before he could be honored with a Nobel Prize.

Negishi, a Japanese chemist affiliated with Purdue University, was instrumental in further developing this palladium-based coupling method by efficiently producing unsymmetrical biaryls. In 1977, he developed the "Negishi coupling reaction", which introduced organozinc compounds to a nickel- or palladium-catalyzed coupling reaction. Two years later, Dr. Akira Suzuki, from Sapporo, Japan described the palladium-catalyzed cross coupling between organoboronic acid and halides, known as the "Suzuki coupling reaction".

Through the pivotal work of these three distinguished Nobel laureates, chemists the world over can now more easily synthesize functional molecules around a stable carbon backbone, producing commercially viable products; it is estimated that 25% of all chemical reactions in the pharmaceutical industry utilize these methods. According to Nobel Prize Committee member Claes Gustafsson, palladium-catalyzed coupling reactions are being used to develop new antibiotics against resistant bacteria and are integral in the produc-

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tion of widespread, commercially available pharmaceuticals such as the anti-inflammatory drug naproxen, the active compound in Aleve (*5*).

We congratulate Heck, Negishi, and Suzuki for their pioneering work and for laying the foundation of an ultimate goal of chemistry: the ability to synthesize any organic compound of our choosing.

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