Li-Ion was good enough for many Breakthroughs

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1. Introduction

Based on the title you can probably guess that this post is about Li-Ion Batteries. However, rather than looking to the future of these amazing energy storage devices, we are going into the past to see how these played a key role in two technological revolutions. And furthermore, we will look at the people that developed them, especially one individual whose name is in the above title and also below.

2. John Goodenough

Nobel Laureate John B. Goodenough, one of the inventors of the lithium-ion battery, died on 25 June at age 100.[1]

Goodenough, a professor of electrical and computer engineering at the University of Texas at Austin, authored more than 800 technical papers during his career. He and his colleagues were recently granted a U.S. patent, shortly before his 100th birthday.

A mathematician and physicist by education, Goodenough had a 70-year career in physics and chemistry. He probably is best known for developing the lithium cobalt oxide cathode in 1980—which became the foundation for Sony's first commercial lithium-ion battery in 1991.

For that, he won a 2019 Nobel Prize in Chemistry, sharing the award with M. Stanley Whittingham, who created the lithium-ion concept, and Akira Yoshino, who developed the anode chemistry that was used in Sony's first lithium-ion battery.

Goodenough was awarded the 2012 IEEE Medal for Environmental and Safety Technologies for discoveries that "paved the way for development of the rechargeable lithium-ion battery technology."

Starting in the 1990s, his lithium cobalt oxide cathode was used in many electronic products including camcorders, laptop computers, and mobile phones. It later became the chemistry of choice for early electric cars including the 2008 Tesla Roadster.

3. Early Life

Although IEEE Spectrum had a reasonable description of John Goodenough's early life, I found that reference 2 below (The Nobel Prize site) had autobiographical text for this, and I always find it better to let people speak for themselves. This was fairly long with quite a few incidental facts, so I redacted quite a bit of this text. If you would like to read the full text, go through the link in reference 2 on the next page.

[1] Charles J. Murray, IEEE Spectrum, "Remembering Lithium-Ion Battery Pioneer John Goodenough," July 13, 2023, https://spectrum.ieee.org/john-goodenough-tribute

My parents lived in Oxford, England, for three years and my father enjoyed the culture of the Weimar Republic; he spent much of his long summer vacations in Germany as well as in Rome. My grandfather was able to support my father before the market crash of 1928. After my parents returned to the U.S. from Oxford, my father became a professor of the history of religion at Yale University…[2]

I entered Yale University as an undergraduate student in 1940. As I left home, I determined never again to take money from my parents; I had no idea how I would support myself at Yale, but my focus was to do well in my College Board Exams. Fortunately, I was given a summer job tutoring a grandson of the Rector; it would give me room and board for the summer and enough money to pay for a room in a dormitory at Yale the following year…

A common temptation of youth is the desire to be famous or glamorous or powerful. I realized that not everyone can be "king of the mountain" even for a short time. Can being king, therefore, be what gives meaning to life? I began to understand that any meaning to a life is not to be king of a castle, but the significance and permanence of what we serve. Is service to ourselves, our tribe (ethnic group or family), or to our country the highest service? In a time of war against evil, service to the cause of a more just world and therefore to our war effort was meaningful; but the destructive means of war is always an appalling waste on all sides. I struggled to find a meaningful calling beyond the war. Perhaps it would be in science; so, for my sophomore year, I decided to enroll in the philosophy of science and in physics…

When I went to enlist in 1942, my mathematics professor, Egbert Miles, called me into his office and said, "John, don't sign up for the marines like all your friends. The military needs boys with backgrounds like yours to sign up for meteorology in the U.S. Army Air Corps." I had no stomach to play the hero in war, so I acted on this friendly advice…

Adjustment to military life was not a problem for me. After a brief orientation in Boca Raton, Florida, I went by troop train to Grand Rapids, Michigan, for training to be a practicing meteorologist. The Army training, mostly by civilians, was efficient and quite professional.

Upon commission in the autumn of 1943, I was immediately posted at an air base in Houlton, Maine a few miles south of a more active air base in Presque Isle. Fighter planes were being dispatched from Presque Isle to England. After two weeks, I found myself in charge of the weather station in Houlton. In those days we drew our own maps and made our own forecasts; there was no satellite and no computer-aided forecast from Washington.

Maine proved to be a good training experience for my next posting the following summer in Stephenville on the west coast of Newfoundland. Stephenville was the jumping-off base for the cargo B54s flying to either the Azores, the base of the northern route, or directly to England…

[2] The Nobel Prize, John B. Goodenough, https://www.nobelprize.org/prizes/chemistry/2019/goodenough/facts/

With the surrender of Japan, our thoughts turned to the question of how to return to civilian life. A letter from headquarters invited me to stay in the Army as a meteorologist; I was then a Captain. However, I thought our responsibilities in peacetime would be less than those we had assumed in war, so the invitation was declined.

… I received a TELEX in the spring of 1946 to return from the Azores to Washington, D.C., within 48 hours. I packed up my duffle bag with great excitement; my turn to go home had come, and I was to embark on a new adventure!

In Washington, I was told that I was one of 21 returning officers who had been chosen to do graduate study in either Physics or Mathematics at the University of Chicago or at Northwestern University; we would remain in-grade, but under the command of the Quartermaster Corps. My decision was made. I had decided to study physics at the University of Chicago…

At the end of four years, we took a 32-hour written examination on four successive days. Students were only told that the examination would cover all aspects of physics and pertinent topics in mathematics and chemistry… On the fourth and final day there was only one question. The student was allowed to use the library to answer this one. For example, one such final problem was to write a proposal for funding an experiment that required design of a bathysphere for a deep-ocean study, a defense of the scientific significance of the study, and a design of the instruments to be used to accomplish the desired measurements. The first time I took this examination, I did well enough to be granted an MS degree, but I would have to take it a second time to be allowed to go on for a Ph.D. On my second try six months later, I was so discouraged after the third day that I almost didn't sit the fourth… I decided I had nothing to lose if I went for the fourth day. I have never really understood why they allowed me to go on for the Ph.D. degree. Only 10% of those with whom I entered the Department in 1946 had made it through this hurdle…

…I knew that I didn't want to go into nuclear physics, so I opted to do my research in solid-state physics. Professor Clarence Zener was the obvious choice. Zener was involved in the physics of metals, so I asked him to take me on as a student in his group. I was to come back the following Thursday to learn of his decision. That Thursday I entered his office with some trepidation. To my relief, he said "Yes, you can be my student." Then he added, "Now you have two things you must do. The first is to find your research problem and the second is to solve it. Good day!"

Author's comments: A Zener diode (named after the professor in the prior paragraph) is a special type of diode designed to reliably allow current to flow "backwards" (inverted polarity) when a certain set reverse voltage, known as the Zener voltage, is reached.[3]

They are used to generate low-power stabilized supply rails from a higher voltage and to provide reference voltages for circuits, especially stabilized power supplies. They are also used to protect circuits from overvoltage, especially electrostatic discharge.

I believe the above autobiographical text will let you understand John Goodenough as a person, and the last few paragraphs, how he started the journey that he would be known for.

I'm now moving back to the IEEE Spectrum article (reference 1).

[3] Wikipedia article on Zener diode, https://en.wikipedia.org/wiki/Zener_diode

4. Professional Accomplishments

After Goodenough earned a Ph.D. in 1952 in solid-state physics, he joined MIT's Lincoln Laboratory, in Lexington, Mass., as a researcher. He was part of a team there that developed the world's first random-access magnetic memory. His ability to cross disciplines started at MIT. [1]

"At Lincoln Lab, in order to solve problems, we had to bring physics and chemistry together with engineering," he said during an interview in 2016.

In 1976 he moved to England to work at Oxford, where he was appointed head of its inorganic chemistry laboratory, despite little formal chemistry coursework. It was there that Goodenough made his mark while working on a rechargeable lithium battery with Koichi Mizushima, a postdoctoral researcher.

Exxon researcher Whittingham had developed a lithium titanium disulfide battery in the 1970s; Goodenough decided to replace the titanium disulfide with lithium cobalt oxide. It gave the battery a significant voltage boost: from 2.4 to 4 volts. The higher voltage made his new battery chemistry almost impossible to ignore.

Author's comment: The above cathode chemistry used the "LCO" abbreviation for this type of lithium-ion battery.

Goodenough patented his battery in 1980, signing away his financial claim to it in order to fund the patent.

Sony produced its first commercial lithium-ion battery in 1991 using Goodenough's and Mizushima's cobalt oxide cathode. The company originally employed the battery in its Handycam, and the lithium-ion technology soon made its way into billions of mobile phones and laptop computers.

While still at Oxford in 1981, Goodenough worked with Michael M. Thackeray on a lithium manganese oxide battery. The LMO battery was less expensive and safer to use than lithium cobalt oxide, and it became a mainstay in tools and medical devices. In 2010 Nissan used it in its Leaf electric car.

Goodenough moved back to the United States in 1986 and joined the University of Texas at Austin as a professor of mechanical engineering. He worked on another lithium-ion chemistry there in 1995: lithium iron phosphate (LFP).

At first, he had little confidence in the chemistry, thinking it was too low in energy. But French battery scientist Michel Armand called Goodenough and offered to collaborate on it. The duo created a lithium-ion battery with lower voltage but also lower cost and greater safety.

Twenty-five years later, the battery is gaining momentum in the auto industry as a means of reducing the cost of electric cars. Today it is being employed by Chinese EV manufacturers including BYD, as well as by Ford, General Motors, and Tesla.

5. Awards and Memberships

During his 70-year career, Goodenough received numerous awards. In addition to the Nobel Prize, he received the 2011 U.S. National Medal of Science from President Barack Obama.

Goodenough's other honors included the Royal Society's 2019 Copley Medal, a 2014 Charles Stark Draper Prize from the National Academy of Engineering, the 2001 Japan Prize, the 2018 Benjamin Franklin Medal, and a 2009 Enrico Fermi Award.

He was a member of the National Academy of Engineering, the National Academy of Sciences, the French Academy of Sciences, and the National Academy of Sciences in India.