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The Brat Pack of Quantum Mechanics

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Who can ever tire of learning about the great discoveries in physics during the first forty years of the twentieth century, and about the men and women who were responsible? The benchmark texts are the surveys and biographies written by the late physicist and historian Abraham Pais, though all the essentials are gathered in a more condensed—and, to my taste, somewhat more digestible—form in the relevant chapters in William H. Cropper's *Great Physicists* (2001). Now here is Gino Segrè with an original and worthwhile contribution to the field.

Faust in Copenhagen: A Struggle for the Soul of Physics
By Gino Segrè
Viking ~ 2007 ~ 310 pp.
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Faust in Copenhagen is an exceptionally thorough account of the emergence of modern quantum mechanics over the years from 1925 to 1933, aimed at a general reader—which is to say, there are no equations. This is a difficult story to tell in any straightforward way. So many different and concurrent threads have to be woven together that a simply chronological narrative can't be given. Some more subtle organizing principle is called for. Segrè has used the Copenhagen conference of April 1932 as his focus, returning repeatedly to it, and to its participants, as a way of keeping us oriented.

These Copenhagen gatherings were held annually from 1929 to the onset of the Second World War, so the 1932 conference was the fourth. One participant at the 1937 Copenhagen meeting was Emilio Segrè, the author's uncle, and Gino Segrè has himself had a long career as a theoretical physicist. He understands the science as well as anyone, and has a close knowledge of all the great players, in some cases from first-hand acquaintance. He is just the right person to write a book like this, and has done a fine job, occasionally weaving in some small details of his own family, but in a way that is not self-indulgent or obtrusive.

"Writing this book has been a labor of love," the author tells us, "allowing me to spend time in the company of many of the intellectual heroes of my youth." The love shows. Through a skillfully designed narrative and many personal insights, Segrè brings to his reader the warmth of his admiration and reverence for some towering figures of our civilization.

Segrè has placed at the heart of his story seven key physicists. One of them, Wolfgang Pauli, did not actually attend the 1932 meeting. Three others of Pauli's generation (ages 25 to 31) were present in Copenhagen: Paul Dirac, Werner Heisenberg, and Max Delbrück. To balance these four young revolutionaries, Segrè includes three older (ages 46 to 53) participants among his magnificent seven: Niels Bohr, Paul Ehrenfest, and Lise Meitner. There were of course others present at the gathering—close to forty altogether, Segrè tells us—and we hear about some of them in passing.

The reason Segrè has taken the 1932 conference as his focus is that this was a pivotal year in the development of modern quantum mechanics. The theoretical foundations of the subject had been laid down in the first three decades of the century, from Max Planck's great 1900 paper implying the quantization of energy through Pauli's postulating of the neutrino (Gino Segrè's research specialty) at the end of 1930. Now the experimentalists were beginning to take over from the theorists. Mere weeks before the 1932 conference, James Chadwick had become the first person to observe neutrons in experiment. In the summer of that year, bracketing the conference, Carl Anderson at Caltech observed the positron, which had been postulated by Dirac in 1928. Experimental results then came thick and fast, culminating in July 1945 with a dramatic event in the desert outside Alamogordo.

The year 1932 was the pivot. It was preceded by the long theoretical slog that had culminated with a sensational burst of creativity from 1925 to 1930: Heisenberg's matrix mechanics, Schrödinger's wave mechanics, Pauli's exclusion principle, Heisenberg's uncertainty principle, and Dirac's relativistic equation. It was followed by the great experiments: Anderson's positron, the "splitting of the atom" (actually of the atomic nucleus) by Hahn and Strassmann, Fermi's chain reaction, the Bomb. The *Faust in Copenhagen* year, the year 1932, was the eye of the storm.

It was also the last year of the Weimar Republic. Adolf Hitler was sworn in as chancellor of Germany in January 1933, with grave consequences for many of the Copenhagen conferees. Four of Segrè's seven key physicists were Jewish or of Jewish descent. Three of the four fled the Nazis. Pauli went to the United States, then to Switzerland. Meitner went to Sweden, then England. Bohr (Jewish on his mother's side) took the same route as Meitner somewhat later, going on to the United States, but returning to Denmark after the war.

Of the Gentiles, Dirac relocated from Cambridge to Florida in 1970, Delbrück switched to molecular biology and lived out the rest of his life in California, while Heisenberg stayed in Germany through the war and afterwards, to his death in 1976.

What precisely Heisenberg was up to in the war years remains unclear. Says Segrè:

> Some argue that he did all he could to build a German atom bomb while others maintain he deliberately sabotaged the program, with many left believing Heisenberg never resolved his own ambivalence. Nor did his subsequent presentations ever settle the question decisively.

Paul Ehrenfest, the fourth of the Jewish physicists in Segrè's seven, shot himself and his son (who had Down syndrome) in an Amsterdam park in 1933, five days after attending that year's Copenhagen conference. The darkening shadows over Europe, and the decision by his beloved friend Einstein in March that year not to return to Germany, were factors in his unhappiness, but there were personal issues too. Great physicists are no more immune to sicknesses of mind and body than the rest of us.

Niels Bohr was the convener of the Copenhagen conferences and, in a way, the central figure in Segrè's book. Bohr had made his name as a physicist with five papers published between 1913 and 1915 defining what is now known as the Bohr model of the atom. He had studied under Ernest Rutherford at the University of Manchester, at a time when the outline structure of the atom—nucleus, electrons—was just beginning to be understood. His five papers had resolved some conundrums raised by Rutherford's "solar system" model for the atom, by applying Planck's quantum principles to the electrons in their orbits around the nucleus.

Having achieved fame, Bohr was in want of a professorship. Rutherford was glad to oblige. The two men had bonded: Bohr's fifth son, born in 1924, was named Ernest in Rutherford's honor. However, as Segrè tells us:

> Denmark, now concerned that it might lose Bohr, responded by creating its first professorship in theoretical physics and appointing him to fill the position. Rutherford tried to counter the offer and keep him in Manchester.... But the pull of home was too strong for the Bohrs, and home was always Denmark. Niels and Margrethe [Nørlund, whom Bohr had married in 1912] returned to Copenhagen in 1916.

Bohr spent the next few years in lecturing and energetic fundraising. By 1921 he had his own institute in Copenhagen; it would be a home, think tank, meeting place, and haven for many of the world's greatest physicists for the next decade and a half. The Copenhagen phase of modern physics was underway, with an assist from Bohr's Nobel Prize in Physics, awarded to him in 1922 when he was thirty-seven years old.

The terrific theoretical turmoil of

the 1920s, and most especially of 1925-27, gets five of this book's fourteen chapters. The task facing the author here is to bring out the *conceptual* revolution that took place in those years, the unprecedented need for a new way of thinking about the subatomic world. These were the years when it dawned on researchers that the intuitions we acquire through our interactions with reality at everyday scales of measurement are simply not appropriate to events in the realm of electrons and protons.

Segrè takes great care in explaining the era's major discoveries and navigating through its major debates—such as the clash between Bohr and Einstein at the October 1927 Solvay conference in Brussels. The Solvay conferences had a longer pedigree than the Copenhagen ones, having begun in 1911. They were also triennial; the 1927 conference was the fifth. Einstein was forty-eight years old at this point, world-famous of course, and—let it not be forgotten—one of the originators of the quantum theory of energy. Segrè quotes him as saying to a friend: "I have thought a hundred times as much about the quantum problems as I have about the General Relativity Theory."

Einstein seems at first to have agreed with the formulation of quantum mechanics as it emerged from the great theoretical advances of 1925-27—the "Copenhagen interpretation," so called because it was distilled chiefly by Bohr and Heisenberg at Bohr's institute. Then, in December 1926, Einstein made a now-famous expression of dissent in a letter to Max Born:

> Quantum mechanics is very impressive. But an inner voice tells me that it is not yet the real thing. The theory produces a good deal but hardly brings us closer to the secret of the Old One. I am at all events convinced that *He* does not play dice.

By the time of the Solvay conference ten months later, Einstein had definitely set his face against the Copenhagen interpretation. "It went against the grain of what he deeply believed to be the truth," Segrè writes.

Throughout the six days of the conference, Bohr and Einstein engaged each other in private conversations, usually with Paul Ehrenfest as a third party. Though Einstein could not be reconciled to the Copenhagen interpretation, he and Bohr were close friends before, during, and after the conference, and repeatedly expressed their admiration for each other. Their differences of opinion were entirely intellectual. It is true that Einstein never attended any of the Copenhagen conferences, but by the time they began in 1929, he had settled into a peripatetic, celebrity-intellectual lifestyle that did not easily accommodate such affairs.

It was also in this period that the deep metaphysical problems posed by quantum mechanics first came into

view. To some degree, the differences of opinion that emerged in these years are still with us today. Segrè: "Perhaps [Einstein] was even right, although there is no evidence for this. The argument still goes on.... Now, almost eighty years after Solvay, the repeatedly verified Bohr interpretation still stands, as solid as ever, but still questioned, as it should be."

I think this perhaps gives a little too much weight to Einstein's "hidden variables," for which there has not been much of a market since the 1970s. Certainly, though, aspects of quantum mechanics—the ontological status of Schrödinger's state vector, and of the wave function's collapse when it encounters an observer—remain matters of argument today. Most working physicists accept the math as an adequate description of all their measurements without fussing over the underlying realities, if there are any—Bohr's point of view, more or less. Others accept the wave function but balk at the collapse, preferring a "many worlds" interpretation in which, instead of all but one of the superpositions of the wave function vanishing, they persist in realms inaccessible to each other, each realm presumably populated by its own observers. Perhaps there are, too, as Segrè says, some residual Einsteinians still fretting in odd corners.

The tempo of the breakthroughs in this fruitful period for physics was, for some of the researchers, literally exhausting. Segrè captures the pace of the physicists' discoveries and shows how the intensity of their interactions during the interwar years—their conversations, conferences, and rapid-fire correspondence—was only heightened by the smallness of the world of theoretical physics at the time. To illustrate the point, Segrè describes how, over the period of a few days in December 1925, Bohr came to accept the idea that electrons spin:

> On the way from Copenhagen to Leiden, Bohr's train stopped in Hamburg. He found Pauli and [Otto] Stern waiting for him, wanting to know what he thought of electron spin. He replied that the idea was interesting but apparently wrong. A day later, Ehrenfest and Einstein greeted him at the Leiden train station. They explained to him how, in the meantime, they [had resolved a technical problem relating to electron spin]. Bohr immediately switched to being an ardent advocate of electron spin.
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> A few days later...Bohr returned to Copenhagen with a stopover in Göttingen. Heisenberg was at the station, asking him what he thought about electron spin. He replied that it was a great advance, a triumph for quantum theory. Proceeding on, Bohr met Pauli at the Berlin train station, Pauli having made the trip from

> Hamburg expressly to see if Bohr had changed his mind during his Leiden visit.

Segrè writes that it "came as somewhat of a revelation to find what a key figure Bohr was" in these critical years. The Dane was an intellectual impresario—responsible, as Segrè puts it, for making Copenhagen "the mecca of theoretical physics." He used his influence to arrange fellowships for promising young thinkers (sometimes just hours after meeting them) and to help Jewish scientists escape Nazi persecution. He bent his powerful mind to working out complex problems without quitting; he would, Heisenberg said, "follow the thing out to the very end, just to the point where he was at the wall." Bohr was almost uniformly kind and courtly when arguing and teaching, prefacing his disagreements with mannerly disclaimers: "I don't mean to criticize, but…" And at his institution he "led, prodded, stimulated, challenged, and united the younger theoretical physicists," creating for them "an atmosphere where the very best in them would be drawn out."

It was a milieu of informal collegiality, and of comfortable, silly humor. The Copenhagen conferences that Bohr hosted ended with some light relief: comical skits, working up the personalities and discoveries of their discipline into a parody of some well-known stage or movie drama. Since the 1932 conference fell on the centenary, very nearly to the day, of the death of Goethe, that year's younger participants picked on his *Faust* as the basis for their comic production. Segrè quotes several passages from Goethe's *Faust* and from the Copenhagen parody, but one selection particularly highlights a prominent theme: that many of these physicists were young, very young, and worried that age would gutter the flames of their genius. These lines uttered by the student Baccalaureus in Goethe's *Faust*…

> Age is, in sooth, a fever cold,
> With frost of whims and peevish need:
> When more than thirty years are told,
> As good as dead one is indeed.

…are adapted by the physicists in their skit:

> Certainly! Old age is a cold fever
> That every physicist suffers with!
> When one is past thirty,
> He is as good as dead!

Wolfgang Pauli had formulated the exclusion principle by the time he was 25. Werner Heisenberg was only 23 when he discovered matrix mechanics and just 25 when he developed the uncertainty principle. Paul Dirac's reconciliation of quantum mechanics and special relativity came when he was 26. All three eventually received the Nobel Prize for work they had done before the age of 30. Their revolutionary discoveries in the 1920s inspired the term *Knabenphysik*—boys' physics—and

Segrè describes "the curse of the *Knabenphysik*, the notion that one should have done something of significance before turning thirty." The causes of decline are mysterious:

> Maybe you stop believing you can change the world, or maybe you realize more quickly that a crazy idea is just that and do not pursue it as vigorously. Maybe you can't assimilate new material as rapidly as you did when you were younger. Perhaps, having set a new course for physics once, you experience a psychological and intellectual resistance to shifting direction again.

For older physicists—like Einstein, whom the younger generation revered but ignored—it wasn't easy to keep up. And even for the revolutionaries, the transition from being prodigies to professors was difficult; neither Pauli, Heisenberg, nor Dirac achieved anything nearly as important after turning thirty as they had before.

Gino Segrè has written an admirable book, engaging us with the personalities of the great creative geniuses of this critical period in physics, and, so far as it can be done in a book written for non-specialists, with their work. These were men and women who struggled mightily, but always with forbearance and mutual respect, to understand what can barely be understood, and to uncover the deepest mysteries of the natural world. Gino Segrè has done them justice.

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