The Man Who Discovered Einstein:
Max Planck and the Birth of the Quantum

By Peter DeArmond

Introduction

"Those who are not shocked when they first come across quantum theory cannot possibly have understood it." - Niels Bohr

"I think I can safely say that nobody understands quantum mechanics." - Richard Feynman

For decades, physicists have acknowledged the challenge of trying to explain the paradoxical nature of quantum theory. But they also have pointed out that even with all the peculiar aspects, it remains the most thoroughly tested and successful theory about the nature of matter and energy. Science historians correctly describe it as a scientific revolution.

It did not begin that way.

It started as an attempt to solve a relatively minor but stubborn problem in physics regarding the spectral distribution of blackbody radiation. The German physicist known as the father of quantum theory, Max Planck, presented his solution in December, 1900, but he did not view his idea as any kind of scientific revolution.

"When Planck established his formula, he was still convinced that he had maybe tweaked some of the classical methods and introduced some problematic and novel concepts, but he was convinced that he had found a classical solution to a classical problem," said Dr. Jürgen Renn, director of the Max Planck Institute for the History of Science in Berlin. "People are largely in agreement now that the establishment of Planck's radiation spectrum by itself didn't constitute the quantum revolution. It was at best the beginning of it, even better it was the end of classical physics in a way. Because it was the cornerstone, the last stone in the building of classical physics that made the entire building crumble."

One of the key events that led to the "classical crumble" occurred in 1905, when 26-year-old Albert Einstein submitted several papers to the prestigious journal, *Annalen Der Physik*, where Planck was one of the editors. Einstein's paper on the photoelectric effect (for which he later won the Nobel Prize in Physics) introduced the idea that light was not just an electro-magnetic wave, but also a particle, based on the value of Planck's constant, h, the quantum of action. Over the next 15 years Planck's constant was cited numerous times by other theoretical physicists seeking a better understanding of the nature of matter and energy. Danish physicist Niels Bohr, for example, used it to propose the first modern model of the atom in 1913.

It was Planck who convinced Einstein to come to Berlin to join the Prussian Academy of Sciences in 1914, shortly before the outbreak of World War I. Einstein was not assigned to any teaching position and basically was given free reign to work on his general theory of relativity, which was published in 1916. Although Planck was two decades older than Einstein, the two became good friends and often played music together at Planck's house. However, they each had distinctly different personality types, which at times led to different views on both politics and science.

For example, Planck had ensured that Einstein's papers of 1905 would be published without full committee review — an unusual act — and he made specific contributions in support of Einstein's work on special relativity. But he thought Einstein's quantum interpretation of the photoelectric effect was wrong. Said Dr. Renn: "When Planck greeted Einstein's entry into the Prussian Academy, he made the remark that basically he agreed to this entry in spite of Einstein's work on the quantum theory. He excused Einstein's over-speculative work, as he then saw it." It took years, but Planck eventually changed his mind.

It is noteworthy that when reflecting on his career as a physicist, Planck half-joking said that his greatest discovery was Einstein. In one sense he did "discover" Einstein but of course, Planck is better known as the father of quantum theory, and he won the Nobel Prize for Physics in 1918.

While historians of science have written about the theories, events and ramifications of quantum theory, some of the historical accounts have proven to be inaccurate and very few, if any, address the impact of different personality types on the development of theories and ideas in this field. How did Planck's personality type influence his approach to analysis, problem solving and scientific philosophy? How did that affect his approach to resolving problems related to the spectral distribution of blackbody radiation? In what ways were the personality types of Einstein and Planck similar, and in what ways did they differ significantly? How did this lead to the end of their long friendship?

These questions merit exploration if one wishes to gain a better understanding of the human factors that affected the birth of quantum theory and its successful development in the early 20th century.

"Considering the enormous consequences which the quantum theory has had, it is astonishing that so little attention has been devoted to detailed study of the reasoning which brought Planck to the first radical step of introducing quanta," said Dr. Martin J. Klein. "There are, of course, many descriptions of the origin of the quantum theory in the literature but almost all of them are historically inaccurate, uncritical and quite misleading as to both Planck's own work and the context in which it was done."

I suggest that this context should include not only an account of the known theoretical challenges, but also the human factors, such as philosophical positions based on personality, that can be seen in the published work, and world views, of both Planck and Einstein.

———-

Part 1: Leading up to 1900

On December 14, 1900, a group of scientists gathered for their regular meeting at the German Physical Society in Berlin to hear a quiet, conservative, 42-year-old professor give a brief presentation about a new idea that just might resolve a minor problem in the world of physics. The presentation generated nothing more than a polite but unenthusiastic response, and was pretty much ignored for a few years. But over the next three decades, with the contributions and ideas of other scientists, this little idea blossomed into the most consistently reliable and far-reaching scientific revolution the world has ever seen: quantum theory.

Today it's known as quantum mechanics, the mathematical body of work that not only describes the bizarre nature of the atom, but also raises some deeper philosophical questions. Does observation create reality? Can we really define the concept of cause and effect? Is there a relationship between quantum theory and human consciousness?

These are fascinating questions, but before delving into the paradoxical mysteries of quantum mechanics, it is important to review the influencing factors — especially the personalities — that led to its formation.

As a long-time journalist who has a passion for the history of science, I continually read many books and journaled articles on the subject. I have also interviewed physicists and historians of science from around the world. One thing I've learned is that over the years, different versions of the early quantum history have been told — so that what Planck really accomplished has not always been expressed accurately.

I also learned is that in many respects, Planck's life story is more fascinating than Einstein's, full of ironic twists and disappointments, several tragic personal events, the honor of the Nobel Prize in Physics and a stressful confrontation with a notorious dictator. Later in his life, Planck himself candidly called his quantum idea "an act of desperation." It had taken him a long time to resolve this little problem in physics that had defied all other attempts to solve it -- and in his desire to provide a theoretical explanation, Planck had to embrace an idea that he had stood against for most of his professional life. What made him change his mind?

Another fascinating aspect of Planck's life was the connection with Einstein — a compelling study in different personality types. Planck not only helped to ensure that Einstein's ideas about special relativity would become widely accepted, he later convinced Einstein to come to the University of Berlin, where Einstein was given free rein to work on his general theory of relativity.

Planck was much older than Einstein but they became good friends, and for years they played music together at Planck's house. But everything changed when the Nazis took over in Germany in 1933. By then Planck was 75 years old, and Einstein left Germany because of Hitler's persecution of the Jews. Stories have been told about Planck having a very stressful meeting with Adolf Hitler shortly after Hitler came to power. What was the outcome, and how did that affect Planck?

During his long life Planck became one of the top leaders of Germany's academic institutions. He had a reputation of honesty and integrity, but he was a person who tried to hold on to his *Welt Anschauung* — his world view — at a time when the whole world of classical thinking was crumbling around him, both socially and scientifically. Tragically, he tried but failed to save the German higher education institutions from the Nazis. And he lost more than that in his long life: Planck was a devoted family man who cherished his time with his wife and four children. The tragic fate of each one of them, especially his youngest son, was like a stab in the heart for Planck. As one writer put it, his life story had the elements of heroic tragedy.
So how was it that this modest, conservative, middle-aged German scientist, who never wanted to start a revolution in physics, become the person who did just that?

Planck was born in 1858 in Kiel, in what is now northern Germany, where his father was a law professor. His family tree included well-educated academics, theologians and intellectuals, and his full given name reflected a tradition of honoring family and friends: He was Max Karl Ernst Ludwig Planck, the fourth child born to Johann Julius Wilhelm Planck. He grew up in an environment that promoted the Enlightenment ideals of rationalism and tolerance, along with the belief that logic and reason were the keys to understanding the world. From his father Planck also gained a deep respect and loyalty to the institutions of authority. When he was born, Germany was not yet a unified country, but there was a thriving sense of German nationalism that was already underway — and Planck identified with that for the first half of his long life.

"It was 13 years after his birth that the German unification occurred in 1871. As Germany grew in commerce, in wealth, in political importance, so did Planck's career prosper," said Dr. John Heilbron, award-winning author of a biography on Planck. "To him, it was really difficult for him to separate his own idea of himself from the idea of Germany and the German empire."

In 1867, when Planck was nine years old, his family moved to Munich, where his father had received an appointment as professor at the university. Planck was enrolled at a well-known school called the Maximilian Gymnasium, a special kind of European school that prepared students for enrollment at a university by the time they were in their late teens. Planck was particularly good in languages and mathematics, and especially music.

In school Planck was remembered more for his personality than his academics, and by at least one account, he often won the annual school prize for good conduct. By the time Planck graduated from the Gymnasium at age 16, he had to choose between music and mathematics as his major focus of university study. He seriously considered music, for good reason: He could play the organ, the cello and the piano, and he had a very good tenor singing voice.

According to Heilbron, Planck was not just good at music, "but favored with perfect pitch perhaps and an ability at the piano that probably he could have been made into the basis of a concertizing career."

But toward the end of his years at the Gymnasium he had been drawn to physics and math by his teacher, Hermann Müller. In particular Müller introduced Planck to the recently-established ideas about the conservation of energy — the first and second laws of thermodynamics — and Planck became fascinated with the subject. When he enrolled at the University of Munich in 1874, math and physics became his new passion, although he continued to play the piano and organ for relaxation throughout his life.

In his Scientific Autobiography, Planck said he was neither a fast nor a multi-tasking type of learner — he felt he had to take his time to completely study and grasp an idea. But once he had mastered it, he understood it with the kind of clear insight that few could match.

"Physics, in its mathematized form, had a great appeal to him," said Heilbron. "and that was because of his great interest in encompassing wide aspects of reality in very general theories. And physics seemed to have some such theories, particularly thermodynamics, which he fell in love with in the university even though it was not a popular subject — which required mathematics for its development, and which seemed to rest upon universal principles."

Planck told a friend that one of his professors at the university, Phillip von Jolly, advised him against pursuing a career in physics because the discovery of the principles of thermodynamics had completed the structure of theoretical physics. Von Jolly reportedly said, "In this field, almost everything is already discovered, and all that remains is to fill a few unimportant holes." Planck replied that he didn't want to discover new things, only to reinforce the known foundational principles of the field. He emphasized this view throughout his life.

Thermodynamics became an important subject during the 19th century — indeed, it continues to be to this day — and it actually has everything to do with how quantum theory got started. To understand thermodynamics a little better, one need only look at the invention of the steam engine.

The earliest versions of the steam engine were highly inefficient until the Scottish engineer James Watt came up with the idea of using a separate condenser — connected to the cylinder by a valve — to cool the used steam while keeping the cylinder hot. With this change, the engine became far more efficient and used about 75 percent less fuel.

The engineers and inventors of Watt's time experimented with more ways to improve the steam engine, but there had been no real scientific investigation — and no theory — to explain what made the steam engines more or less efficient. Finally, in 1824, a young French military engineer, Sadi Carnot, published his study, Reflections on the Motive Power of Fire. Carnot introduced the first modern concept of how heat energy can produce real work. Over the next few decades, Carnot's book inspired several other European scientists to develop theories and experiments to explain the nature of heat and other forms of energy.

Some amount of heat energy is always lost when it's used to produce work, and between 1850 and 1865, a German physicist named Rudolf Clausius described how this applied to steam engines. He also invented the term Entropy to describe the second law of thermodynamics, that is, how energy diffuses, to become less concentrated in one physical location or one energetic state — sort of like how something hot always cools down. Clausius described it as Verwandlungsinhalt, meaning "content transformation."

Between 1859 and 1860, right after Planck was born, the German physicist Gustav Kirchhoff was studying how heated objects produce light. And from this we will find a more direct connection to how quantum theory got started.

In particular, Kirchhoff wanted to measure the light spectrum from a special kind of heated object. The object had to be perfectly black — meaning that it couldn't reflect any light that shined on it, and in fact would have to absorb any light that fell on it. The reason for this was Kirchhoff wanted to have a reliable measurement of light that came strictly from the heated object, with no interference from any reflected light. He called this object a "blackbody" and, when it was heated up until it glowed, he called the light from this object "blackbody radiation." (Anyone who seriously studies the early history of quantum theory will be quickly overwhelmed by references about experiments with blackbody radiation.)

The ideal blackbody produces a unique spectrum of light when it's heated up, and from that, Kirchhoff wanted to prove a point: that the light from this object is strictly dependent on the temperature, not on the size, shape or material of the object itself. Kirchhoff proved his point, but he also posed a problem, because the light that the human eye can see is actually very small on the scale of light waves. What kind of equation will give an accurate prediction of the whole light spectrum at any given temperature? The answer didn't come until 40 years later, in 1900. And even then, it was a crazy answer that was not immediately embraced.

During his studies at the University of Munich, Planck continued to play the piano for recreation, knowing that he was talented enough to pursue a career in music. He chose physics instead, for a noteworthy reason, having to do with his personality type. Said Heilbron, "It may well be that what decided him in favor of physics was this romantic notion that through physics one could comprehend material nature better than any other way because physics had some universal principles, particularly those of thermodynamics."

Reinforcing the classical foundation principles of science was his only goal. He made it clear to everyone that he never had any intention of kicking off a revolution in science. That was a big part of his careful, conservative personality. He was a good, sound scientist, not a careless speculator of ideas that couldn't be proved.

In 1878, Planck spent a year of study at the University of Berlin. There he heard, among others, the lectures of Gustav Kirchhoff and Hermann von Helmholtz. Both men were famous for their contributions to science, but Planck said their style of lecture wasn't very appealing to him at that time. Instead, he began his own private study of the mechanical theory of heat, which was the work of Rudolf Clausius, the man who had coined the term entropy. This was Planck's attempt to master thermodynamics as independently as possible and he described it as, "Nur nach eigener Überzeugung" ("Only after I have convinced myself"). These investigations prepared him for his dissertation on the second law of thermodynamics, for which he received his doctoral degree at the University of Munich in the summer of 1879. He was 21 years old. In that same year, Albert Einstein was born.

After writing a second thesis on heat and entropy, Planck was deemed qualified to be an unpaid lecturer at the University of Munich. For a few years he lived with his parents, hoping to find a paying position. But theoretical physics was a fairly new field in those days, so teaching positions were scarce. In 1885, possibly through his father's connections, Planck finally landed a paid position as an assistant professor at the University of Kiel. With a salary, he was able to marry his fiancée from Munich, Marie Merck, the daughter of a banker. They had four children: two daughters and two sons.

Within a few years, Planck was hired as an assistant professor at the University of Berlin where he remained for the rest of his life. Planck settled in and continued his research work on thermodynamics and related fields, with a special focus on entropy. Over the years, he became known for his expertise on the subject of entropy, and especially for his strong view that entropy is an absolute irreversible process.

But several years before Planck entered the picture, a physicist from Vienna, Ludwig Boltzmann, had taken a different approach to explaining the second law of thermodynamics with his work on the kinetic theory of gases.

Boltzmann said that movement of small particles — atoms and molecules — defined the properties of gases and all matter. This was controversial because there was no proof that atoms and molecules existed. If they existed, they couldn't be seen or measured. Furthermore, since the laws of mechanics are reversible or symmetric in time, Boltzmann also said that these atoms exhibited random behavior, meaning that their positions could only be described by statistical probability.

All of this did not go over well with most physicists of that time, including Planck. The idea that statistical probability governed the behavior of gas particles meant that, in theory, mathematically, the process could work in reverse, and Planck's life-long work emphasized defining entropy as absolute irreversible process.

Said Heilbron: "Planck never wanted to talk about statistics, because in his absolutist conception of nature, the laws of thermodynamics always held true."

Planck did not directly attack Boltzmann's ideas about entropy, but his assistant, Ernst Zermelo, did publish several objections in scientific journals. Boltzmann knew that Zermelo probably was working with Planck's blessing and possible guidance, so he held a professional grudge against Planck, and Planck knew it. But Planck was the least of Boltzmann's concerns, because other more prominent scientists, such as Ernst Mach and Ludwig Ostwald, were vehement in their attacks on Boltzmann's atomic ideas.

Meanwhile, a colleague of Planck's, Wilhelm Wien, attempted to solve the problem of predicting the spectrum of blackbody radiation. By the mid-1890s, Wien had come up with a formula, based on observations, that seemed to provide a reliable prediction of the spectrum of blackbody radiation. Planck, who had first met Wien when both were teenagers, was pleased with this news. He saw his task as providing a theoretical basis for Wien's formula, using the principles of electromagnetism, which had been established by James Clerk Maxwell, and thermodynamics. Planck's goal was to provide a reliable foundation based on accepted theory. For a few years, he worked on different ideas that he thought would accomplish this. But each attempt ended in failure.

This process continued through the late 1890s, and each time Planck attempted to derive Wien's formula through the laws of entropy, he was met with more frustration. During this time the scientists who were conducting experiments on blackbody radiation were developing more sophisticated tools to measure the extremes of the blackbody spectrum at different temperatures. Planck had gained a reputation as a person of modesty and integrity, and he had earned the respect and friendship of fellow scientists at the University of Berlin and the Physicalisch Technische Reischanstaldt, the Imperial Institute of Physics and Technology, which was sort of like the national bureau of standards.

The scientists who conducted experiments there, such as Otto Lummer, Ernst Pringsheim, Heinrich Rubens and Ferdinand Kurlbaum, who knew Planck well and kept him informed of their progress.

As Heilbronn described it: "He was in touch with these experimenters; they met regularly at seminars and at the university... and it was a very interesting time in the late (18)90s because the measurements kept changing. And that's hard for a theorist if the target keeps changing... and the initial efforts of Planck seemed to pay off. By the late 1890s, he seemed to have a formula; he seemed to be able to prove this formula, but then ... more of these measurements were made."

One of the known formulas worked well for high frequencies, but failed in predicting the low frequencies. Another formula worked well in low frequencies, but not in high ones. In mid October of 1900 some of the scientists who had been conducting these tests and measurements were scheduled to give a report on their progress to the German Physical Society. A few days before this event, Planck invited Heinrich Rubens and his wife to dinner at his house. Rubens told Planck about the newest measurements that had been done, and that Wien's formula had failed in the low spectrum. This frustrated Planck, and after Rubens left Planck went right to work on a new formula for the radiation energy that would be consistent with the new results.

"So he proceeded in a way that you would not expect a theorist who worked from fundamental principles to do," said Heilbron. "He knew, from these experiments, how the formula should look at low wavelengths ... So he found an ingenious way or bringing these two formulas together."

Planck came up with what I would call a mathematical contrivance by combining two formulas into one formula that would accurately predict all the frequencies from the low end to the high end. He wrote it down on a postcard, which Rubens received the following day. A few days later Rubens reported back to Planck that the new formula worked — seemed to fit all his lab measurements. To this day that formula is known as Planck's Radiation Law, and it still works.

So the math gave accurate results, but what did it mean?

"So as an empirical formula, as one descriptive of experimental results, Planck's formula as announced in the autumn of 1900 fit very well. But Planck couldn't leave things there, right? Because that was not his goal. His goal was to produce a theory which fell under the principles of thermodynamics, and electrodynamics, and the most general ideas he could find, and it was in trying to derive the formula that he had worked out, and in which he believed now because it agreed with all the available measurements, and in trying to find principles to anchor that, he invented the quantum."

Part 2: What Planck did — and did not — suggest in his quantum theory.