Teacher notes

Physicist stories, some funny, some definitely not.

Feynman meets Dirac.

Dirac was Feynman's hero. They met for the first time at Princeton in 1946. As far as personalities were concerned, they could not be more different. Feynman was gregarious, ebullient and an extrovert. Dirac was shy, totally eccentric and spoke few words. (A unit of speech called the dirac had been invented: one dirac was one spoken word per hour. His only hobby was to climb trees.) The following conversation ensued (from the book *Genius* by J. Gleick, 1992):

F: I am Feynman.
D: I am Dirac.
(Silence)
F: It must be wonderful to be the discoverer of that equation.
D: That was a long time ago.
(Pause)
D: What are you working on?
F: Mesons.
D: Are you trying to discover an equation for them?

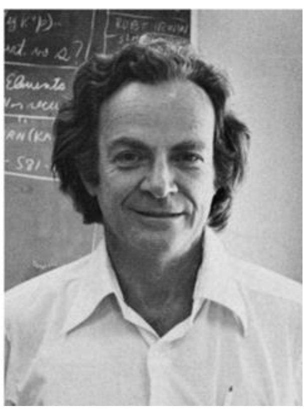
F: It is very hard.
D: One must try.

Their second meeting was at the Pocono conference in 1948 which was attended by the elite of the physics community. There, Feynman introduced his new theory of quantum electrodynamics including Feynman diagrams. The day before, his main competitor Julian Schwinger, had lectured on his own version of quantum electrodynamics. Feynman's lecture did not go well. Teller objected to it. Bohr stood up and made remarks that implied that Feynman did not understand even elementary physics!

At some point Dirac raised his hand and asked, "Is it unitary?" Feynman did not understand the question and went on, saying later that he could hear Dirac muttering "Is it unitary?" on many occasions. A few moments later Dirac asked the same question "Is it unitary?". Feynman replied, "Is what unitary?" Dirac said, "Is the matrix that takes you from past to future unitary?" Feynman gave in: "Since I have antiparticles moving backward in time I don't know if it is unitary".

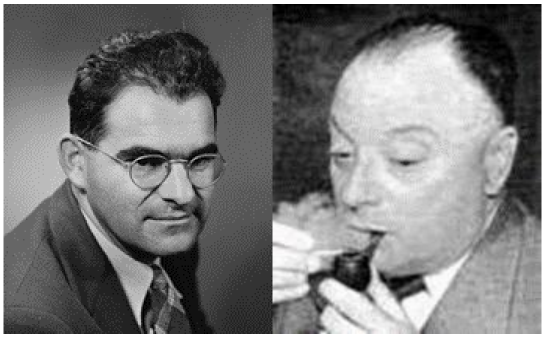
Feynman decided to go ahead and publish his work in a series of papers. His theory was eventually accepted and the Feynman diagram approach dominated quantum field theory for decades.

Feynman diagrams and Schwinger



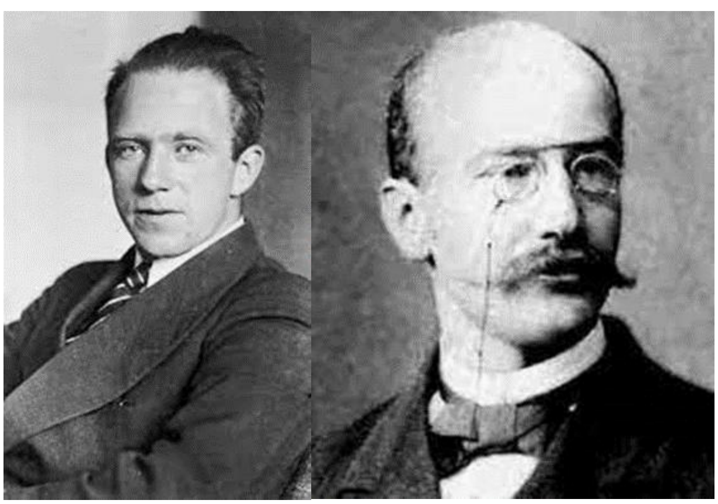

Quantum electrodynamics was developed independently by Feynman, Schwinger and Tomonaga. They shared a Nobel prize for this work. Schwinger's approach was very dense and obscure, and few could understand it. Oppenheimer used to say that when most people lecture, it is to tell you how something is done but when Schwinger lectures it is to tell you that only he can do it! Things changed when Feynman introduced his diagrammatic way for calculating scattering amplitudes. Schwinger said that Feynman gave "calculating power to the masses". Gell-Mann (of quarks fame) once spent a sabbatical at Harvard when Schwinger was on sabbatical elsewhere and he rented the Schwinger house. One room was locked. Gell-Mann used to joke that that was the room where Schwinger kept his calculations with Feynman diagrams!

Weisskopf and Pauli



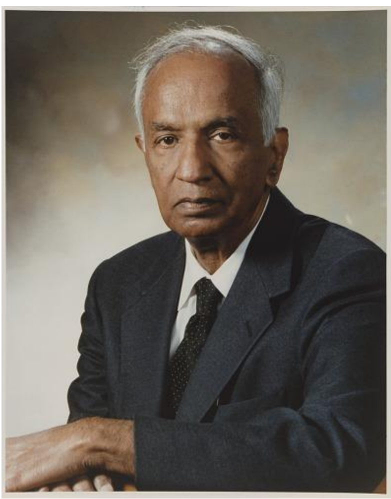
Victor Weisskopf was for many years professor of Physics at MIT. As a new Ph.D. he was hired to be the assistant to the great Wolfgang Pauli. Weisskopf recalls their first meeting. He knocked at the door and waited for a bit to no avail. He knocked again and a voice said to come in. Pauli was calculating. He said, "You have to wait until I finish calculating". Weisskopf introduced himself and Pauli said "Ah, ja, my new assistant". Pauli then said, "I must tell you that I wanted Bethe, but he now works on solid state physics. I don't like solid state Physics even though I created it". Pauli then gave Weisskopf a problem and said, "Go away and we will talk in 10 days". In 10 days, Pauli asks to see the progress Weisskopf made. Pauli looked over the calculations and said: "I should have taken Bethe".

Heisenberg and Lindemann



Heisenberg's father was a professor at the University of Munich and arranged for his young son to go and see various professors so that the young Heisenberg would decide what to study at University. The first appointment was with the great mathematician Lindemann. In 1882 Lindemann (along with Weierstrass) had shown that the number π was transcendental, i.e. it could not be the root of a polynomial equation with rational coefficients. This provided the solution to an ancient Greek problem in geometry, the squaring of a circle. Could one construct a square whose area was the same as that of a given circle using ruler and compass only? The Lindemann theorem made the answer a definite no. Heisenberg entered a large dark room, an old Lindemann sitting behind a large desk surrounded by a massive array of books, unmoved by Heisenberg's presence. A dog lay by Lindemann's side. The ensuing conversation did not go well. Next time Heisenberg went to see Arnold Sommerfeld in the Physics department. Sommerfeld was standing by the blackboard in a bright room discussing with lively students. Heisenberg chose Physics.

Chandrasekhar and Eddington




In 1930 a young Indian physicist started the boat trip to England where he was awarded a scholarship to study at Cambridge University. During the long voyage Subrahmanyan Chandrasekhar applied Einstein's theory of relativity to the material of a white dwarf star and showed that the star could remain in equilibrium only if its mass did not exceed a certain limit (about 1.4 solar masses), a limit now known as the Chandrasekhar limit. Chandrasekhar had frequent meetings with Arthur Eddington the leading astronomer of his time and the "best measuring man in England". Eddington wrote a book on Einstein's theory of general relativity and is credited for introducing the theory to the English-speaking world. He is best known for leading the expedition to observe the solar eclipse of May 29, 1919. Measurements showed that light bent around the Sun by the amount predicted by Einstein's theory. This was the first experimental confirmation of Einstein's theory.

Eddington encouraged Chandrasekhar's work on collapsed stars and early work on what later would be called black holes and asked him to present it at the 1935 meeting of the Royal Astronomical Society. Unknown to Chandrasekhar was that his talk was to be followed by one by Eddington. To Chandrasekhar's great surprise Eddington attacked his work calling it mathematical wizardry with no physical content. Even worse, he would later call it "stellar buffoonery". After 7 years at Cambridge Chandrasekhar moved on to the University of Chicago where he remained for the rest of his academic career. In 1983 he received the Physics Nobel prize for his work on collapsed stars. He was one of the most prolific and influential astrophysicists of the 20th century. Every ten years he would publish the definitive book on a topic he had been studying. During his Cambridge years Chandrasekhar remained on friendly terms with Eddington (and Milne another astrophysicist who, like Eddington, thought he knew everything about stars and had opposed his ideas). He thought of them "on one hand as misguided fools and on the other as human beings of rare quality, worthy of honour and respect" (Dyson, F. The death of a star. *Nature* **438**, 1086 (2005)).

In later life Eddington became obsessed with the unscientific field of numerology. He had a conjecture that the fine structure constant α should have the exact value of $\alpha = \frac{1}{136}$. (The 136 came from $10^2 + 6^2$ with the 10 and the 6 coming from the number of independent components of symmetric curvature and metric tensors in general relativity!) The fine structure constant is given by $\alpha = \frac{e^2}{2\varepsilon_0 hc} = \frac{1}{137.036\cdots}$.

There is no known reason why the reciprocal of α should be an integer or the integer 136 or 137 for that matter. Eddington thought so much of this number that he postulated that the number of protons in the Universe should be exactly 136×2^{256} which is about 1.57×10^{79}. The argument leading to this conjecture is purely speculative. When it was pointed out to him that the integer closer to the reciprocal of α was 137 and not 136, he ad hoc added 1 to 136 leading to people making fun of his name as Arthur Adding-one.

Speaking of Eddington, and for a more positive view of the man, watching the 2008 TV movie *Einstein and Eddington* by Philip Martin is very worthwhile.

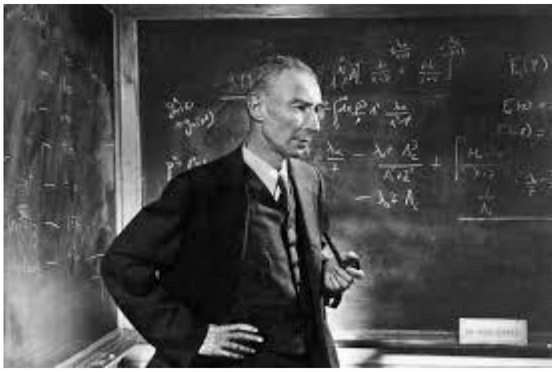
Ulam asks von Neumann a question.

Stanislaw Ulam was a famous mathematician and famous for his design (with Edward Teller) of the first American hydrogen bomb. John von Neumann was a genius of the first rank and famous for too many things to mention here! Ulam once gave Neumann the following problem: two cyclists are a distance 100 km apart. At the same time, they start cycling towards each other with speeds 8 km/hr and 12 km/hr. At the same time a fly leaves one cyclist's nose and heads towards the other at speed 25 km/hr.

When the fly meets the other cyclist, it turns around and the process repeats. What distance did the fly cover when the cyclists meet asked Ulam. Neumann immediately gave the correct answer. Ulam then said that Neumann knew the trick. What trick said Neumann, I just summed the series!

What is the trick and what is the series?

Oppenheimer and Blackett




We mentioned in the teacher note on Oppenheimer that he spent time as a graduate student at Cambridge University. His tutor was P.M.S. Blackett, an experimentalist who was exasperated by Oppenheimer's complete lack of talent in experimental physics. Oppenheimer hated his stay there and found experimental work dry and boring and he hated Blackett; so much so that he once left an apple laced with poison on Blackett's desk. (No one ate the apple!) It took some effort not to have Oppenheimer expelled. We also talked of Oppenheimer's 1930 paper which some consider to be the precursor to the discovery of the positron. C. Anderson is credited with that glory. But Blackett and Occialini also had photographs of particle tracks that suggested a positively charged electron. But they were too cautious to announce their result and so missed out on the big discovery. Oppenheimer must have been pleased about that!

Erwin Schrödinger

E. Schrödinger (1887 – 1961) is famous for the Schrödinger equation, the equation obeyed by the wavefunction of a quantum mechanical system. He is also famous for the thought experiment involving a cat! Born of a Lutheran mother and a Catholic father he was himself an atheist. He was interested in many diverse parts of Physics but also in philosophy, especially Indian philosophy and Psychology. In the influential book *What is Life*? Schrödinger applied Physics to Biology and postulated that complex molecules contain the genetic code (a book that both Crick and Watson mention as a major inspiration for their later work on the structure of DNA). He also thought about the concept of consciousness, objective reality, and free will. Schrödinger shared the 1933 Physics Nobel prize with Paul Dirac.

Schrödinger opposed Nazism and left Austria and Germany. But he could not keep positions at the University of Oxford and Princeton due to his unusual domestic situation: he lived with his wife and a second woman in a *ménage à trois* arrangement. What is worse is that this intelligent and creative polymath was also a pedophile. He sexually abused countless young girls and recorded his actions in a diary he called *Ephemeridae*. In it, he justifies his "predilection for teenage girls on the grounds that their innocence was the ideal match for his natural genius".

His equation, $i\hbar\frac{\partial\Psi}{\partial t}=H\Psi$, is inscribed on his gravestone in a cemetery in Alpbach in Austria.

Einstein and peer review

In 1936, Einstein and his collaborator Nathan Rosen (both of wormholes fame) wrote a paper entitled "Do Gravitational Waves exist?". In a letter to Max Born, Einstein made it clear that the answer was no.

> *Together with a young collaborator, I arrived at the interesting result that gravitational waves do not exist, though they had been assumed a certainty to the first approximation. This shows that the non-linear general relativistic field equations can tell us more or, rather, limit us more than we have believed up to now.*

The paper was submitted to the American Journal *The Physical Review*. About two months later Einstein received the reviewer's comments on the paper; the anonymous reviewer was very critical of the paper and had pointed out errors. The editor's note to Einstein was that he would be glad to receive Einstein's reaction to the comments. Four days later Einstein wrote to the editor:

> *Dear Sir,*
> *We (Mr. Rosen and I) had sent you our manuscript for publication and had not authorized you to show it to specialists before it is printed.*
> *I see no reason to address the—in any case erroneous—comments of your anonymous expert.*
> *On the basis of this incident, I prefer to publish the paper elsewhere*.
> *Respectfully,*
> *P.S. Mr. Rosen, who has left for the Soviet Union, has authorized me to represent him in this matter.*

Einstein sent the paper to another journal (*The Journal of the Franklin Institute* in Philadelphia) that duly accepted it for publication. In the meantime, the anonymous reviewer, who happened to be H. P. Robertson, became friends with Einstein's new assistant, L. Infeld, and explained to him in detail the error of Einstein's ways. Robertson was trying to correct Einstein mildly without confronting him. When Infeld conveyed all this to his boss, Einstein said that he had discovered the mistake himself the night before (!). The paper to the Philadelphia journal was then corrected!

It appears that this was the first time Einstein had received a critical review of any of his papers. He could have benefited by reading the reviewer's comments carefully and not dismissing them out of hand. When he himself acted as reviewer for German journals his frequent review comment was "wertlos" or worthless.

For more fascinating details about this amazing story, you can refer to the article by Daniel Kennefick in *Physics Today* **58** (9), 43–48 (2005).

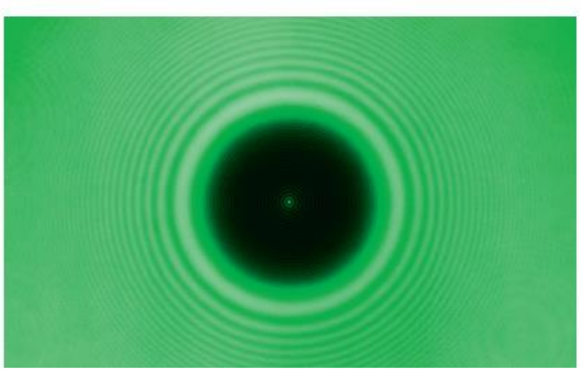
Max Planck and André-Marie Ampère – two lives in tragedy

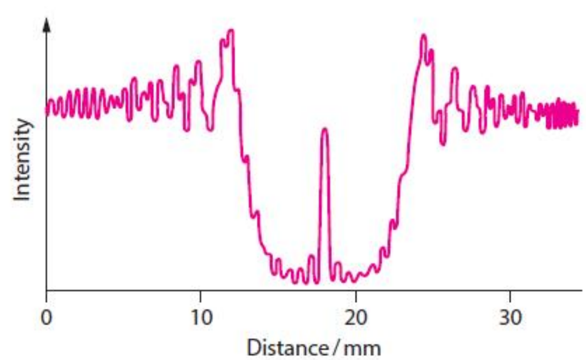

Max Planck is one of the founding fathers of quantum theory. This began with his work on black body radiation and its solution through his radical idea of energy appearing in packets, quanta, each of energy *hf*. He was a friend and supporter of Einstein and helped him with the calculations of the bending of light by the Sun. But his personal life was full of tragedies as Bill Bryson describes in *A brief History of Almost Everything*. He had two sons and twin daughters. His wife, Marie, died young. The oldest son, Karl, was killed in WWI at the battle of Verdun. His daughter Grete died while giving birth. The other daughter, Emma, moved in to help with raising the baby, fell in love with her sister's husband and married him. Two years later she also died while giving birth. Both babies survived and were named Grete and Emma. In 1944, when Planck reached the age of 85, allied bombing destroyed his house and a lifetime of belongings. The final cruel blow came when his other son, Erwin, was caught in a conspiracy to assassinate Hitler and was sentenced to death in a parody of a trial. A letter sent to Hitler by Max Planck, pleading for his son's life, was ignored. Erwin was executed in 1945 some three months before Germany capitulated. Max Planck died in 1947.

André-Marie Ampère's life was not any happier. His wife died young, and his father was publicly guillotined during the French Revolution. He remarried but the marriage was unhappy. He died from pneumonia at 61. His gravestone reads *Tandem felix* (Happy at last). James Clerk Maxwell called him "the Newton of Electricity".

Fresnel and Poisson

In 1817, the Academy of Sciences in Paris announced that diffraction was going to be the main topic for a competition of essays for the famous biannual *Grand Prix* in Physics. There were only two entries. It was expected that the essays would be based on the particle nature of light, the Newtonian view that prevailed in France at that time. Augustin-Jean Fresnel entered with an essay based on the wave nature of light. The judging committee consisted of France's greats: P. Laplace, S. Poisson, J. P. Biot, J. L. Gay-Lussac and D. Arago. The committee deliberated for months; during that time Poisson, using Fresnel's theory, discovered theoretically that if a small disc was illuminated, a bright spot would appear behind the disc. This he considered an absurd conclusion. Immediately, Arago, another member of the committee, performed the exact experiment that Poisson had treated theoretically. Arago observed a bright spot behind the disc as seen in this modern version of the experiment!





The *Grand Prix* went to Fresnel, and this marked the beginning of a change in France, in favor of the wave theory of light; but not immediately. The convincing work came from studies on polarization in which Fresnel also had decisive contributions.