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RICHARD FEYNMAN'S CURIOUS LIFE

Reminiscences of Richard Feynman and His View of String Theory:

"Hey, Schwarz! How many dimensions are you in today?" Feynman would sometimes shout to me down the hallway in Caltech's theoretical physics group. He was alluding to one of the speculative ideas that arose in my research: the possible existence of extra dimensions of space (as many as six or seven) beyond the obvious three dimensions of space. I knew him well enough to understand that he was being playful, not derisive or mocking. In fact, I was pleased that he knew my name and what I was working on. The existence of extra dimensions is one of the predictions of superstring theory, the subject that has been the focus of my research since the early 1970s. For reasons that I won't explain here, it seems very likely that the extra dimensions of space are much too small to be directly observed using any foreseeable technology. Even so, the details of their shape and size are largely responsible for determining the properties of particles and forces that experimentalists can observe. For this reason, the exploration of possible geometries of the extra dimensions has been a very active and important research area for over 30 years.

I joined Caltech's theoretical physics group in 1972, twenty years after Feynman. The group had five professors at that time (I started in a non-professorial position). It included two world-renowned Nobel-Prize-winning superstars: Richard Feynman and Murray Gell-Mann. My research interests were more closely aligned with Gell-Mann's than Feynman's, but I interacted quite a bit with both of them for more than five years. I was very fortunate to have had such a unique experience. It is hard to believe that by now I have been at Caltech longer than either of them was. In fact, I have occupied "Feynman's office" in Lauritsen Laboratory (built in 1968) for about thirty years, ten years more than Feynman did. I guess it now qualifies as my office even though visitors stop by from time to time to view "Feynman's office".

Feynman and Gell-Mann frequently discussed their ideas with one another, but they co-authored a publication only once — in 1958. Their paper is very well-known by particle physicists, but it is not the most famous work by either of them. In this paper they proposed a theory, which came to be called the "V-A theory", for the weak nuclear force. This force is responsible for the decay of the neutron, for example. As happens surprisingly often, the same theory was proposed independently by others at about the same time. To make a long story short, the V-A theory made testable predictions for certain experiments. In fact, the crucial experiment had already been carried out, but the published results disagreed with the V-A theory's predictions. Feynman and Gell-Mann were very confident that their theory was right, so they boldly asserted that the experiment's results must be wrong. Later experiments confirmed that the predictions of the V-A theory were indeed correct and the original experiment was wrong. Nowadays, the V-A theory is incorporated in the "standard model" of elementary particles.

Often in the 1970s and 80s, several of us would go to lunch with Feynman at the Caltech cafeteria, Chandler Dining Hall (also known at the time as "the greasy"). On many such occasions he would relate one of his personal stories, most of which were later published in the bestselling book "Surely You're Joking, Mr. Feynman" and its sequel. We heard many of these stories long before they were published, as well as some that were not published. Dick enjoyed being the centre of attention, but nobody at these luncheons was bothered by that, because his stories were so interesting and entertaining.

Two of Feynman's stories that I remember particularly clearly concerned his experiences on a trip to Oak Ridge National Laboratory that took place during the period when he was working on the Manhattan Project at Los Alamos. He must have been about 26 years old then. At the time, Oak Ridge was separating the fissile isotope of uranium, U^{235}, from the other uranium isotopes. (U^{235} is only 0.7% of naturally occurring uranium.) One of the steps involved passing uranium hexafluoride gas through semipermeable membranes in specially constructed gaseous diffusion plants. One purpose of Feynman's trip was to inspect the plants. The plants were constructed with redundancy so that if any one component were to fail they could continue to operate. The blueprints contained symbols whose meaning was intelligible only to specialised engineers — not theoretical physicists, not even Feynman. So Feynman pointed randomly at one of the many hundred symbols in the blueprints, not knowing what it was, and asked "What if this valve were to fail?" As luck would have it, he had correctly identified a weak point in the plan! The second anecdote from the same trip, which I don't think has been published, concerned the storage of the enriched U^{235}. Its purpose was a closely held secret, which was not known even by the people who were carrying out the enrichment. Feynman asked to be shown where the enriched uranium was kept, and he discovered that all of it was kept in containers that were right next to one another in a single location. Without giving away any secrets, Feynman requested that one container should be put in one location, a second in another location, and so forth!

String theory was originally developed in the late 1960s and early 1970s as theory of the strong nuclear force. This is the force that hold protons and neutrons together inside of the nuclei of atoms. It is also the force that holds quarks and gluons together inside protons and neutrons. String theory, as a theory of the strong nuclear force, had several unrealistic features and was therefore abandoned after a few years by almost all of its practitioners. It was superseded in 1973 by a theory called quantum chromodynamics (QCD). Within months of its introduction almost all of the experts were convinced that QCD is the correct theory of the strong nuclear force. However, Feynman was not convinced. He understood that QCD was elegant and simple and had achieved various successes. But he needed more proof that this was the correct theory. He needed to understand it in his own way, not just by accepting what others were saying. This led him to several years of detailed investigations at the end of which he became convinced that QCD is indeed the correct theory. In the process, he developed several concepts and techniques that play a central role in modern studies of QCD. As an aside, I should also mention that it is possible that there is a different version of string theory that is equivalent (or "dual") to QCD, but such a string theory has not yet been formulated. If a string theory that is dual to QCD were to be discovered, it would be very useful.

Even though string theory had failed as a theory of the strong nuclear force, Jo¨el Scherk and I felt that it was so beautiful that it must be good for something. In 1974, we realised that string theory showed considerable promise as a quantum theory containing gravity. (This was also proposed independently by Yoneya.) We had not set out to understand quantum gravity, but there it was in the equations – begging to be taken seriously. String theory showed promise as a quantum mechanical framework for unifying gravity with the other fundamental forces. More conventional approaches were known not to work. One price for this change of the role of string theory was that the strings needed to be 20 orders of magnitude smaller than had been required to describe the strong nuclear force. This is an astonishing leap, but the mathematics was largely unchanged. Once we understood this, I knew what I would be studying for the rest of my career. This proposal was largely ignored, with a few exceptions, for about a decade. Murray Gell-Mann was very supportive throughout this period, though he did not participate in the research.

After some breakthroughs in our understanding of superstring theory in 1984 – 1985, the subject suddenly became very popular. When it could no longer be ignored, it also acquired some prominent critics, including Richard Feynman and Stephen Hawking. Feynman's scepticism concerning superstring theory was based mostly on the concern that it could not be tested experimentally. This was a valid concern, which my collaborators and I shared. However, Feynman did want to learn more, so I spent several hours explaining the essential ideas to him. Even though there is still no smoking-gun experimental support for string theory, it has proved its value in many other ways that I will not attempt to describe here.

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A book entitled "Superstrings; A Theory of Everything?" was published by Cambridge University Press in 1988 based on a set of BBC Radio interviews with prominent theoretical physicists a couple of years earlier. In the chapter based on Feynman's interview he is quoted as follows: "I have noticed when I was younger, that lots of old men in the field couldn't understand new ideas very well, and resisted them with one method or another, and that they were very foolish in saying these ideas were wrong — such as Einstein not being able to accept quantum mechanics. I'm an old man now, and these are new ideas, and they look crazy to me, and they look like they're on the wrong track. Now I know that other old men have been very foolish in saying things like this, and therefore I would be very foolish to say this is nonsense. I am going to be very foolish, because I do feel strongly that this is nonsense! I can't help it, even though I know the danger in such a point of view." Even though I disagree strongly with Feynman's conclusion, I like this statement very much. I am older now than Feynman was when he died, and I find his remarks quite easy to relate to. They are much more charming and understandable than those in the interview of another prominent physicist in the same volume who compared string theory to medieval theology.

Obviously, Feynman was an exceptionally talented and creative theoretical physicist. This alone does not make him unique, since there were a couple dozen such people in the twentieth century. Among these, he was one of the few who was also a dedicated and engaging teacher. His remarkable pedagogical skills are in full display in the three-volume "Feynman Lectures in Physics" as well as in various of his lectures that can be found on the internet. He also had remarkably broad interests and talents including art, music, and much more. Feynman did not put up with charlatans, but he was a gentleman with everyone else. He was considerate and respectful with everyone – especially those who shared his passion for physics – regardless of gender, seniority, or background, in contrast to some other Caltech faculty of that era. As a result, *everybody loved him*.

Sincerely yours,

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Theoretical Physics, Emeritus