The Character of Physical Law

R.Feynman

August 2, 2019

Vintage Feynman. This is actually a transcription of a series of lectures given by the author at Cornell back in 1964. He was by that time already a celebrity, famous for his lecture style and his Feynman lectures given at Cal Tech although he had not yet been awarded the Nobel Prize, the canonical measure of scientific success and wider public recognition. The lectures were filmed by the BBC and were essentially extemporized by Feynman as he went along. Back then long before the advent of You Tube, it was necessary to make a transcription of the lectures in order to reach a wider audience and also to serve as memory aid to those who might have seen the series aired but would like to be retroactively reminded of their wording[1].

Feynman is a physicist, and as such he is at pains to distance himself from the mathematicians and the philosophers, especially from the philosophers whom he founds a dismal bunch indeed. Mathematics is of course unavoidable to a physicist, which may or may not be unfortunate, but philosophy is of course not. This is somewhat ironic as much of the contents of the lectures are indeed philosophical, in particular at the end. If you talk on physics you have to be technical and mathematical, and most of your audience will be lost; on the other hand if you talk in a philosophical vein, meaning in a general and vague way, almost everyone will understand and marvel at the profundity of what is being expounded on.

Feynman's philosophy of science is very much along the lines of Popper, although he does not speak about falsifiability using those very words but the gist of it is the same. Was Feynman aware of Popper at that time? Hard to know, but most likely he would not need to be told about the way to do science by some philosopher repeating to him the obvious inanities, as he might have thought of them as. Science feeds on observation, or more precisely confronting theories with the world. To come up with theories is very, very hard, and ultimately it is all about guesses, be they informed and inspired. It does not matter how a theory is thought up, as both Popper and Feynman emphasize. the objectivity of a theory has nothing to do with its origin, only how well it stands up to reality[2]. Also science is about guesses as no one can prove anything in science, contrary to public misconception. The idea of scientific proof, bandied around a lot, is if anything an oxymoron. Theories are good only so long they survive tests, and theories are always tested ruthlessly, and especially at their weakest points, in extreme situations they are not expected to hold at all. Newtonian physics withstood tests for a very long time, and really in everyday world they are fully adequate. Einsteins refinements, although one should

[1] Nowadays those lectures are of course available on You Tube, the technical quality is of course poor, but the sound is acceptable.

[2] This is in contrast to the real world of men, say in politics. The origin of a political party plays a role, not only how it stands up to the present.

not think of them as refinements, because Einstein's approach is fundamentally different than Newton's. Theories are simple and beautiful. You do not replace a perfect theory, such as Newton's, by various patching-ups, that would be ugly and go against the strain, but making a totally different approach. Theories must be able to be proved wrong if they are to have any worth. Vague theories cannot be proven wrong and thus they lead to no interesting questions, because the questions they may generate have no interesting answers that can lead us on. To know that something is not so is very important in science, without it, with keeping anything potentially open, you will be swamped. To make up a new theory is not easy, in fact it is as hard as it gets. There are no formulas of how to proceed. You can look at history and see how new theories have seen the light of day, but that is retroactive wisdom and that is easy to come by. Every really new theory involves some kind of revolution, thinking of things in entirely new ways. It is easy to make holes in a theory, of doubting this and that. But that does not take much imagination, what takes imagination is to find things to plug the holes with, to come up with alternative ways. You do not doubt things until you are forced to. Coming up with some new alternative thinking, you really do not understand that it is an alternative until you realize that it will conflict with cherished views, and then, and only then, you may start thinking of abandoning some of those cherished views. Rejections are necessities forced on you, not something you start out with.

Feynman used to amuse himself with cracking safes. Say you are involved in cracking a safe and have come up with all kinds of things, like the middle number cannot be even say, or a hoist of other restrictions, and then comes the janitor along. Have you tried 10-20-30 he asks out of the blue. Most likely that might have been one of the first obvious things you tried (if you even bothered), but that is of course not the way to crack a safe, choosing combinations at random, or trying them all. But as a physicist you often get well-meaning advice like that by people who have no idea of what you are really grappling with.

Feynman does envision the end of science, at least the science of finding out the fundamentals. Those are finite, he seems to indicate, at least if there is beauty, simplicity and economy in it. Once that has been achieved, there will of course be plenty of things to do, because most of the phenomenon of real life cannot be explained by first principles; but basically it will be dull, and the philosophers will take over, because now there will be nothing to stop them, no real mysteries left of the world to make them shut up. We are indeed living in exciting times he tells his audience.

As to mathematics he contrasts the Babylonian way with the Greek way. In the Babylonian way you know a lot of facts and theorems, they may not fit logically together, but you cannot have everything. In the Greek way everything is based on axioms, there are no contradictions, everything fits logically together by means of those very axioms and impeccable logic. Physicists are Babylonians, mathematicians are Greek. However, I would not be so categorical, mathematics is not done through deductions starting with first principles, mathematicians too have at their disposal many facts and theorems, which they combine and recombine to their hearts content, and of course also in mathematics you can do the same thing in many very different ways. In fact mathematics thrives on it. Feynman puts great store in the fact that the conservation of momentum can be derived for a collection of particles, but have a much wider application and domain of veracity. The way a physical law can transcend itself and be applicable and relevant in very different contexts is something he thinks is very distinctive about physics, and not something that would arise in mathematics. Maybe so if you think of mathematics as a purely deductive game based on axioms, but this is not the way mathematics really live.

True physics is different from mathematics. It involves a physical reality whose manifestations impinge on us whether we want it or not, and need not be made manifest through deductions or computations. We have a theory of how atoms behave encoded by the Schrdinger equation, but this can only be solved for the simplest cases of atoms, but in the real world it is done 'instantaneously' in the most complicated cases. We can view experimental facts, such as a level of 7.82 or so in the energy levels of a C^{12} nucleus, which is essential to the formation of it through the collision of three helium nuclei, but it is one thing to divine the importance of it and to observe it, quite another thing to compute it from basic principles.

The first lecture is on gravity and the succinct formula which encapsulates it all. Feynman address a non-mathematical audience and hence takes great care not to involve himself in technical mathematical jargon. Ostensibly non-mathematicians are supposed to benefit from this beating around the bush, while the mathematically literate may get impatient. In reality though, I suspect that the non-mathematicians will nevertheless only get more confused and pick up new misconceptions, while the mathematicians are the ones that truly profit from it, because they both know the underlying mathematics and they are being encouraged to look at it from a new angle. Of course this takes great skill, otherwise explanations will become as opaque to the experts as to the laymen, which is something that not rarely characterizes popularized mathematical science.

Now the Newtonian formulation of gravitational attraction has other, profoundly different, yet mathematically equivalent formulations. One using potentials and gradients, which makes the non-local picture local (the potential is harmonic so we have the mean value property), another one looks at all possible paths for a particle acting under gravitational forces and picks the one which minimizes the so called action. All three, in spite of being equivalent, are psychologically very different and engender very diverse philosophical reactions. The psychological differences are very important, because doing physics, as opposed to the physical reality which is the ostensible subject of study, is about man and his mental abilities. Those different ways of looking at things, give rise to very different ways of generalizing and thinking about new theories. The same thing happens of course in mathematics, where some objects can have very different incarnations and playing them against each other provides much, if not even most, of the pleasure of mathematical activity. It is remarkable, as Feynman points out, that had their not been a power of two, but some other power, in Newtons formula, this phenomenon of very different but equivalent formulations would not have arisen. Are we really talking about a physical or mathematical mystery? Anyway it is an illustration of the fact that you get much more out of an equation than you put into it.

In his gravitation lecture he gives Newtons classical proof, set in Euclidean garb, that Kepler's second law holds for all central forces[3], contrasting it with the modern method of

[3] It is not really Euclidean although based on vintage Euclidean reasoning, except of course of the

vector analysis which is mindless [4]. I guess only a mathematician would appreciate this.

Newtonian gravity is modern mathematics, Feynman insists in the beginning of his performance. Modern, if not recent, and as indicative of modern physics as anything more recent. He is a stickler for the concrete having little patience for the vague and general, as noted before, and the gravitational formula gives many an occasion for digressions and exemplifications. But he also discusses some relativity theory as well as the paradoxes of Quantum theory which no one knows how to explain satisfactorily. The two-slit experiment, in which an electron is shown both to act as a particle and as a wave depending on the manner of observation is indeed the central experiment to which all those paradoxes can be reduced.

Other physical laws or types of physical laws discussed are those of symmetries and conservation, which are intimately related to each other. A nice demonstration that the conservation of potential energy implies the Archimedian law of the level is given. He cannot of course resists discussing the apparent irreversibility of physical processes which are themselves locally reversible, including the useful distinction between energy as such, which is indestructible, and available energy which is slowly but inexorably dissipating, leading to a world of maximal entropy (the word is hardly used) in which nothing can happen really[5].

One may compare the actual delivery with the text of the book. The latter seems pretty faithful to the former, but you lose some by reading rather than listening. In the recording you are present when Feynman formulates his mind, with hesitations and second thoughts, and with which you could identify as a lecturer, but which in a published written version are smoothed over.

August 3, 2019 **Ulf Persson:** *Prof.em, Chalmers U.of Tech., Göteborg Sweden* ulfp@chalmers.se

notion of infinitesimals. What you have here is an approximation, which gets better and better as you subdivide, but at an quicker rate. So if you divide something into n-parts the local errors appears on the order of $1/n^2$ so you get something that goes to zero (as $1/n$) as you add it all up

[4] It is simply, in Newtonian notation, of differentiating $r \times r^{\cdot}$ getting zero as $r^{\cdot\cdot}$ is parallel to r

[5] Some people may be tempted to claim that in a society in which everybody is equal and there are no differences and inequalities, there will be a deadening stasis.