



The Character of Physical Law. Richard Feynman; with a new foreword by Frank Wilczek. The MIT Press, Massachusetts Institute of Technology, Cambridge, Massachusetts 02142, USA. 2017. vi + 173 pages. Price: US\$ 17.95.

The Messenger Lectures at Cornell University were instituted in 1924 by Hiram J. Messenger ‘to provide a course or courses of lectures on the evolution of civilization for the special purpose of raising the moral standard of our political, business and social life’. In November 1964, Feynman gave seven lectures, extempore with the help of brief notes, on ‘The Character of Physical Law’. The transcripts were prepared and published by BBC in 1965. They have ever since been a classic of the physics literature. The 1992 Penguin edition had an Introduction by Paul Davies, and the present 2017 MIT Press edition has a Foreword by Frank Wilczek. Even half a century later it remains an inspiration and profoundly educative to read these lectures for their content, style and quality of language.

It is amply evident that these lectures were not read out from an already written text; there is such a sense of spontaneity and wealth of ideas and insights practically in every sentence and on every page.

Richard Phillips Feynman (1918–1988) was a superbly gifted teacher and communicator of physics, both to students and working scientists, and to the general public. Those closest to him in his mid-20th century path-breaking work on quantum electrodynamics said of him:

Freeman Dyson – ‘... the most original mind of his generation ...’.

Julian Schwinger – ‘... an honest man. The outstanding intuitionist of our age...’.

Comparable in level and style to ‘The Character of Physical Law’ are his 1983 lectures on ‘QED: the strange theory of light and matter’ published in 1985.

The title of this book captures perfectly the structure of its contents. At that time our understanding of the gravitational force based on the work of Newton and later Albert Einstein was very good. So were the classical Maxwell theory of electromagnetism and its quantum version; so also quantum mechanics itself. In contrast, the understanding of the weak interactions, while satisfactory in lowest order, was yet to reach maturity; and as for the strong nuclear forces, the theoretical understanding was in the exploratory stage. The explosive experimental discoveries of hordes of strongly interacting but short-lived particles was in full flow, along with new types of leptons. The violation of parity in weak interactions had been established, and just a few months before the lectures even CP had been seen to be violated. In quantum mechanics, John Bell’s pioneering analysis of the roles of locality and realism as envisioned by Einstein, and based on the slightly earlier work of David Bohm in the direction of hidden variables in quantum mechanics, had just been completed. All this is to recall for today’s reader the overall situation in physics at the time Feynman lectured. The Foreword by Wilczek succinctly summarizes the progress since then.

As an illustrative example of a law in physics, Feynman uses the case of universal gravitation. The notion of law itself is described as the study of rhythms and patterns in natural phenomena, understandable only through careful observation, analysis and the use of mathematics. He recalls the ideas of the Ancients, then the contributions of Copernicus, Brahe, Kepler, Galileo, and finally Newton’s magnificent synthesis. The way Neptune was predicted and found, the immense distances over which Newton’s law of gravitation seems to work, Galileo’s experiment at Pisa, the Cavendish experiment, those much later of Eötvös and Dicke, the organization and scale of the universe, Einstein’s principle of equivalence, and much else, are all described in a mere 20-odd pages. This itself is a tour de force, to be able to

convey so much about one physical law so succinctly. However, there is no mention of black holes, so much in the news today; their time was yet to come.

All along there are striking sentences that stay in one’s memory – ‘The law of inertia has no known origin’; and ‘Nature uses only the longest threads to weave her patterns, so each small piece of her fabric reveals the organization of the entire tapestry’.

The laws of electricity and magnetism, or those of the weak and strong interactions as then understood, are not dealt with in comparable detail. However, there is a separate chapter devoted to the puzzling quantum mechanical behaviour of electrons and photons.

The succeeding chapters deal with the general characteristics of physical laws, super laws if you will, reflecting the overall general qualities of Nature. These include the relation between mathematics and physics; the basic conservation laws or constants of motion (COM); and the profound link between their existence and continuous symmetries of the laws themselves (Noether’s theorem).

On the mathematics–physics relationship, Feynman suggests that it is reasonable to expect that mathematics will be useful in analysing complicated and large systems made up of many constituents and involving statistical features. But the surprising fact is that it is needed also to state the basic physical laws in simple situations – such as, for example, Newton’s inverse square law of gravitation. In the use of mathematics he sees a trend towards increasing abstraction. He characterizes mathematics in elegant ways – its power comes from being a language combined with logic, a tool for reasoning and making connections. Overall for physics he favours the Babylonian approach or tradition in mathematics to the more axioms-based Greek tradition. Where physics differs fundamentally from mathematics is in the need to compare constantly against the behaviour of Nature.

For newer generations of readers, two classics on this topic may be mentioned: Paul A. M. Dirac’s *The Relation between Mathematics and Physics* (1939), and E. P. Wigner’s *The Unreasonable Effectiveness of Mathematics in the Natural Sciences* (1959). To the latter there have been rejoinders.

On the fact that quite often basic physical laws can be expressed in several

equivalent mathematical forms, Feynman makes an important point – while their predictions are the same and they are therefore physically equivalent, they are psychologically not equivalent as they may suggest different ways in going beyond the known to the unknown. This deep insight is expressed more than once in these lectures, and indeed was repeated in his Nobel Prize lecture given about a year later.

The existence of fundamental (great) conservation laws and their link (in many cases) to continuous symmetries of the underlying physical laws are among the most important overarching principles (super laws) common to many theories. They are explored in two chapters. These conservation laws are great because they are always valid. Some are relatively simple and involve just counting – electric charge, baryon number, strangeness (only approximately, and at that time a ‘recent’ discovery). In some cases, the conserved quantity is the source of a field. Turning to ‘deeper’ examples, Feynman discusses the cases of energy and angular momentum in detail, bringing out many of their subtle features. (However, the angular momentum due to spin is not mentioned.) The physics of neutrinos at one end, and of (then recently discovered) quasars at the other, are both discussed in this context. The circumstance that on account of special relativity all conservation laws have to be local is beautifully explained.

In next exploring the connections to symmetries, Feynman stresses the difference between geometric symmetries of particular configurations of physical systems in space, and of the forms of equations under transformations of variables. (As Feynman mentions, the latter concept was clearly articulated for the first time by H. Poincaré.) We may say the former symmetries are kinematic, the latter dynamical. Symmetries of physical laws are much deeper and more abstract. As examples of transformations, rotations in a plane and one-dimensional pure Lorentz transformations are compared and contrasted. Transformations which are *not* symmetries – such as scale changes, uniform rotation – are also considered. The deep continuous symmetry – COM link is then shown using the action principle and its invariances. Interestingly, according to Feynman, this link exists only in the framework of quantum mechanics, because for him the

classical principle of stationary action comes from his own path integral formulation of quantum mechanics. Some features of discrete symmetry like space inversion or parity, and CP too, and the violation of the corresponding conservation laws, are also discussed. The relevance of space inversion in the biological context is brought in. As a sign of the times, he says in passing that antihydrogen has not yet been seen or created.

The chapter on the distinction between past and future begins with its roots in the psychology of human experience – the contrasts between memory and hope, regret and free will. Irreversibility in time is a fact of human experience. In physical terms, the problem is to understand why time-symmetric microscopic laws lead to macroscopic irreversibility. After much entertaining and insightful text, Feynman says the clue is: the passage from order to disorder, in the direction of increasing probability, is Nature’s way. The entire discussion is very ‘physical’. Especially important is the insight that when our scientific knowledge is arranged in a hierarchical manner from elementary to complex levels, at each level there arise concepts that possess autonomy and utility at that level. Complete reductionism is not the most useful or practical attitude. One passage stands out: ‘... an understanding of the physical laws does not necessarily give you an understanding of things of significance in the world in any direct way. The details of real experience are often very far from the fundamental laws’. Despite his stated disregard for formal philosophy, Feynman ends up conveying much philosophical truth in the language of physics.

The presentation of quantum mechanics, and the occurrence of irreducible probabilities in its workings, is based on the well-known two-slit interference experiment. Feynman’s use of this as containing ‘all of the mystery of quantum mechanics’ is well known. Near the beginning, along with the history of the subject, he remarks that we have no right or reason to expect Nature to function always in the same way as we see it at our own scale. There are warnings against approaching Nature with philosophical prejudices and prior expectations. It is again a sign of those times that the entire discussion dwells on wave-particle duality, in Alain Aspect’s characterization the first quantum revolu-

tion which ended around 1930. The second revolution inspired by Bell’s work and based on entanglement, which began in the 1960s, was just around the corner. Feynman ends the chapter with a rebuke to philosophers.

The final chapter on ‘Seeking new laws’ is in a slightly different tone than the earlier ones. There is more on how the human mind works, makes guesses and predictions, checks against experiment, and so forth. Many points are emphasized – all theories are provisional, always open to revision; they can never be proved to be right; at any given time a theory is either ‘not yet falsified’ or ‘falsified’. If the former, the theory is useful for the present; but domains of validity get refined. Earlier ideas have often to be given up. The existence of psychological differences between different formulations of a successful theory in going forward is repeated. There is an extended discussion on how to go about making guesses for new laws – a combination of intelligence, reasoned guess work and imagination, ‘but imagination in a terrible straight-jacket’.

Feynman felt we live in a lucky era in which scientific discoveries are still possible, but this may end. What finally ‘explains’ why we are able to make successful guesses about the behavior of Nature? This he said is an unscientific question, and gave an unscientific answer – ‘it is because Nature has a simplicity and therefore a great beauty’. This echoes what Keats, Dirac and Chandrasekhar, each in his own way, felt and said. Truly this book is a marvel of insights and exposition.

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