When physics meets biology: a less known Feynman

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Abstract: A less know aspect of Feynman’s scientific work is here discussed, centred about his interest in molecular biology, which arose around 1959 and lasted for several years. In particular, we focus on Feynman’s work on genetics with Robert S. Edgar in the laboratory of Max Delbrück, which was later quoted by Francis Crick and others in relevant papers, as well as on Feynman’s lectures given at the Hughes Aircraft Company on biology, organic chemistry and microbiology, whose notes taken by the attendee John Neer are available on the web. In this way, an intriguing perspective comes out about one of the most interesting scientists of the XX century.

Keywords: Molecular biology, Back-mutations, Hughes lectures.

1. Introduction

Richard P. Feynman has been – no doubt – one of the most intriguing characters of XX century physics (Mehra 1994). This applies not only to his work as a theoretical physicist – ranging from the path integral formulation of Quantum Mechanics to Quantum Electrodynamics (granting him the Nobel prize in Physics in 1965), and from helium superfluidity to the parton model in Particle Physics –, but also to his own life, as shown, for instance, in his own popular books (Feynman 1985, 1988).

Feynman’s genuine interest in the study of nature often led him to particularly distant areas of research, whose borders were easily crossed by his own curiosity. For example, after the completion of his 1955 work on polaron physics (Feynman 1955), he decided to make excursions into different fields ranging from engineering to biology.

Robert Hellwarth, a research fellow of Feynman at Caltech, moved to “Hughes Aircraft Company” (1955-1965) and arranged for Feynman to give there lectures for scientists, engineers and technicians on subjects of mutual interest. Feynman continued lecturing regularly at Hughes for many years on a variety of topics, ranging from astrophysics and cosmology to classical and quantum electrodynamics, relativity, scattering theory, as well as mathematical methods in physics and even molecular biology.

Feynman’s interest in biology raised around 1959, when he decided to spend his entire sabbatical year (1959-1960) at Caltech in the laboratory of Max Delbrück. Indeed, Caltech was one of the top international research and training centers in molecular biology (Kay 1993). With Robert S. Edgar he worked on a project about the characterization of back-mutations, while with Matt Meselson he worked on ribosomes. His peculiar guiding view was that “there is nothing that living things do that cannot be understood from the point of view that they are made of atoms according to the laws of physics” (Feynman *et al.* 2005). Given the relevant results he obtained, Feynman was invited to give a seminar on his work at Harvard, where he met James Watson, Francis Crick and others. Interesting enough, a key paper by Crick *et al.* (1961) quoted Feynman’s work with Edgar on genetics, which was then published in 1962 (Edgar *et al.* 1962).

In the present contribution, we deal with Feynman’s incursions in the field of biology, by focusing on his work on genetics with Edgar as well as on his lectures at “Hughes Company” about biology, organic chemistry and microbiology. These topics will be addressed in section 2 and 3, while in section 4 some concluding remarks will be presented.

2. Plus and minus classes: Feynman at work on genetics

In 1950s-1960s Caltech became one of the leading research centers in molecular biology, and would be visited sooner or later by all the main scientists in the field. Feynman too, who often visited Max Delbrück, often attended seminars given by these visitors (Mehra 1994), and being a frequent visitor of the biology department, he was able to meet for example Renato Dulbecco and Seymour Benzer.

In 1959 Feynman realized that he might like to do some work in biology and decided to spend his sabbatical year working in Delbrück’s laboratory. Then, Delbrück sent him to Robert S. Edgar, a postdoc who was carrying on bacteriophage research, which Delbrück was losing interest into. As a task, he was given to work on back-mutations, i.e. mutations appearing to restore a mutant gene to its normal state. It is important to notice that back-mutations do not always bring back to exactly the starting point. His work follows previous studies by Benzer, who first recognized the uniqueness of *rII* mutants, namely, their inability to form plaques on Escherichia Coli *K12*. According to him, this property could be useful to analyze the nature of genes, because it allows a small fraction of wild-type recombinants from crosses to be easily enumerated. In this way, it is possible to study the detailed genetic fine structure of the *rII* region (Benzer 1955, 1961). Benzer was able to genetically map a huge number of mutations in the *rII* gene, and that allowed him to understand two main features about genes: the sequence of a gene is linear and the smallest units of recombination is between two adjacent DNA base pairs.

Feynman’s work consisted in mapping a reasonably large number of *rII* markers in a second phage strain, the *T4D* one (Edgar *et al.* 1962). By analyzing back-mutants that were evidently not completely normal, he realized that such back-mutants had both the *r43* mutation and a second mutation that somewhat enhanced its effects. Such mutations – which we may call “suppressors” – had by themselves quite a strong effect, similar to that of *r43*. However, when combined with *r43*, they brought back the phage close to the starting, normal state. Feynman also showed that different suppressors, when combined between them, do not produce mutual suppression, but rather they appear to suppress only the *r43* mutation: the former were shown to be located near the latter.

By studying back-mutations of suppressors, Feynman found that they were due to new suppressors similar to the *r43* mutation, which were referred to as plus and minus mutations. Combination of a plus and a minus mutation brings the phage almost back to its normal state. Such a picture was confirmed by Crick *et al.* (1961) in the famous paper where the genetic code was unveiled, showing that each amino acid in the protein synthesis corresponds to three nucleotides. Feynman went close to such a finding, but did not realize the importance of what he had uncovered. In Benzer's words:

> He had discovered something without realizing it. [...] It was related to the later discovery by Crick and Brenner, using the *rII* mutants. This had to do with the nature of the genetic code. [...] It was something under his nose, and its significance was just not apparent at that time (Benzer 2002, p. 52).

What Feynman was missing – while known to Crick *et al.* – was that the plus and minus mutations corresponded to additions and deletions of nucleotides, respectively. Also, he did not understand that the number three was peculiar, and to be identified with the coding ratio; this was famously discovered by Crick and coworkers in the mentioned paper (Crick *et al.* 1961).

3. A course on biology, organic chemistry and microbiology at Hughes

In the fall of 1955, Robert Hellwarth, who joined Caltech Physics department as a research fellow, together with Frank Vernon, an engineering research student working at "Aerospace Corporation", drew Feynman's interests on more applied research topics. In 1956 Hellwarth moved to "Hughes Aircraft Company" and arranged for Feynman to give there lectures for scientists, engineers and technicians on subjects of mutual interest. Feynman continued lecturing regularly at Hughes for many years on a variety of topics, including in particular molecular biology.

The lectures went on regularly until the end of the 1970s, reserved to the employees of the Company, but unfortunately there was no audio or video recording systems, so that we can rely only on notes taken by the attendees. In particular, notes for the Statistical mechanics lectures of 1961 were taken by R. Kikuchi and H.A. Feiveson; these notes were later published in the now famous book Statistical Mechanics: a set of lectures (Feynman 1972). Other sets of notes were taken by J.T. Neer, who later made them freely available on the web (Feynman 1970a). The other lectures apparently went unrecorded. The notes taken by Neer include lectures given by Feynman from October 1966 to June 1971 about the following topics:

1. October 1966 - June 1967:
   Astronomy, Astrophysics, Cosmology;
2. October 1967 - June 1968:
   Electrostatics, Electrodynamics, Matter-Waves Interacting, Relativity;
3. July 1968 - June 1969:
   Matter-Wave interacting continued, Introduction to Quantum Mechanics, Scattering theory, Perturbation theory, Methods & problems in QED;
4. October1969 - May 1970:
   Biology, Organic chemistry and Microbiology;
5. October 1970 - June 1971:
   Mathematical methods in Engineering & Physics.

These sets of notes were only slightly edited, therefore are a good example on Feynman in action. This is especially intriguing for the first and the fourth sets, which witness Feynman dealing with fields outside his main research, using lectures as a means to enter a subject he was interested in. Now we will focus on the fourth set of lectures (Feynman 1970a), i.e. that concerning molecular biology. As discussed above, Feynman was not new to biology in 1969, having worked previously in a biology lab for one year, but, being an outsider, he found the material challenging and time consuming. As a result, this set of lectures is considerably shorter than the other sets and, moreover, the lectures ended earlier than prevented, Feynman being more and more involved in that period in the development of his parton theory (Feynman 1969).

The lectures highlight quite a standard course on organic chemistry, biomolecules, genetics, and microbiology. However, some considerations are present here and there that betray his being a physicist. In the introduction, Feynman noted that, unlike physics and chemistry, biology lacks a basic foundation of fundamental laws, developed by theory and proven by experiments. Lacking such a guiding principle, he organized the material according to scale, ranging from the molecular level to more and more complex systems, up to ecology, i.e. the study of many complex biological systems interacting in a closed environment. Feynman was thus naturally led to the molecular biology approach, according to which "the chemical constituents react according to known chemical and physical laws in a manner which can account for life" (Feynman 1970b). He was as well convinced that "he could derive all of the properties of living things from the Quantum Mechanics of the carbon atom" (Bridges 2004).

After the introduction, Feynman began a brief survey of the essentials of organic chemistry: hydrocarbons, functional groups, alcohols, carbonyl compounds, esters, chiral molecules. After that he switched to biochemistry, i.e. biomolecules and metabolic pathways, then he discussed sugars and cellular energy production (photosynthesis, Krebs cycle). After that he continued with other biomolecules, i.e. fats, amino acids and proteins, discussing in detail the structure of the latter, going from the alpha-helix to globular proteins, highlighting the role of hemoglobin and myoglobin.

The course then turned to molecular biology, namely the structure of nucleotides and of the nucleic acids, discussing DNA reproduction, the genetic code, protein synthesis and mutations. In the last part of the course the focus shifted, as announced, to more complex systems such as the retina, antibodies, cell differentiations, nerve cell growth and social amoebas. As said above, however, the course was interrupted by Feynman earlier than prevented, so that no further discussion on microbiology is present, nor on the planned ecology section.

4. Conclusions

In the late 1950s, Feynman was deeply involved in a number of physics research topics, where he actually gave important contributions. In addition to studies on quantum gravity (Feynman 1963) and, especially, to his well-known results about the *V-A* (vector-axial) character of weak interactions, the two-component spinor formulation of the Dirac equation (Gell-Mann *et al.* 1958) and the density matrix approach to polaron theory in solid state physics (Feynman *et al.* 1962) (just to quote some examples), his own character led him to devote himself also to calculations on the tracking of artificial satellite Explorer II at the "Jet Propulsion Laboratory" (Mehra 1994) or even to pedagogical (with his most famous *Lectures on Physics* (Feynman *et al.* 2005), for example) and popularization (about nanotechnology (Feynman 1960), just to quote one) issues. In any of these topics Feynman excelled but, in our opinion, only his peculiar curiosity brought him to be interested also in possible algebraic manipulations performed by computers or other similar, apparently strange things for a well pictured theoretical physicist.

However, it is probably Feynman's unexpected involvement in biological issues that better highlights what truly lies behind his curiosity. Indeed, it is somewhat apparent from what discussed above that it was not properly the satisfaction for testing one's own abilities in getting some important result in even different fields of research (even for social utility and not for egoistic purposes) that drove Feynman's curiosity, but rather the challenge to understand Nature in all its different facets.

This manifested, in Feynman's biological works, priory in the "mapping experiments with *r* mutants" of a bacteriophage performed in Delbrück's laboratory, which led to results that were well acknowledged by the fathers of genetics. But, then, the "challenge" has to be perpetuated by others, and, in this respect, is not at all strange Feynman's involvement in teaching biology at "Hughes Aircraft Company".

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