The Science and Legacy of Richard Phillips Feynman

Physicist, teacher, showman, and more . . .

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Have a look at `http://arXiv.org/abs/1810.07409`

The Legacy

Popular Literature:

- Official Website: http://www.richardfeynman.com/
- Birth Centenary Celebration Event, https://feynman100.caltech.edu/
- Nobel Prize Banquet Speech, https://www.nobelprize.org/prizes/physics/1965/feynman/speech/
- Los Alamos from Below, http://calteches.library.caltech.edu/34/3/FeynmanLosAlamos.htm (Lectue on Science and Society, UCSB, 1975).
- "Surely You're Joking, Mr. Feynman!" Adventures of a Curious Character, as told to Ralph Leighton (W.W. Norton & Company, 1985).
- "What Do You Care What Other People Think?" Further Adventures of a Curious Character, as told to Ralph Leighton (W.W. Norton & Company, 1988).
- R.P. Feynman, The Meaning of It All: Thoughts of a Citizen-Scientist (Addison-Wesley, 1998).
- Letters of R.P. Feynman, Don't you have time to think? Ed. M. Feynman (Penguin Books, 2005).

Expositions:

- On Nanotechnology: There's Plenty of Room at the Bottom, Talk at the 1959 Annual Meeting of the APS.
- The Feynman Lectures on Physics, http://www.feynmanlectures.caltech.edu/ (freely available online, 1963-1965).
- R.P. Feynman and A.R. Hibbs, Path Integrals and Quantum Mechanics (McGraw-Hill, 1965).
- The Character of Physical Law, The 1964 Messenger Lectures (MIT Press, 1965).
- QED: The Strange Theory of Light and Matter, The 1983 Alix Mautner Memorial Lectures (Princeton University Press, 1985).
- Appendix to the Challenger Disaster Report, https://science.ksc.nasa.gov/shuttle/missions/51-l/docs/rogers-commission/Appendix-F.txt https://www.youtube.com/watch?v=uljATTG58TY
- Feynman Lectures on Computation, Eds. A.J.G. Hey and R.W. Allen (Perseus Books, 1996).

Biographies:

- J. Gleick, Genius: The Life and Science of Richard Feynman (Pantheon Books, 1992).
- J. Mehra, The Beat of a Different Drum: The Life and Science of Richard Feynman (Oxford University Press, 1994).
- J. Gribbin and M. Gribbin, Richard Feynman: A Life in Science (Dutton, 1997).

Scientific Works:

Selected Papers of Richard Feynman (with commentary), Ed. L.M. Brown (World Scientific, 2000).

Some Quotes

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On QED: So what happened to the old theory that I fell in love as a youth? Well, I would say that it has become an old lady that has very little attractiveness left in her, and the young today will not have their hearts pound any more when they look at her. But, we can say the best we can for any old woman, that she has been a very good mother and she has given birth to some very good children.

Cars at Caltech

Murray Gell-Mann's car licence plate

Geoffrey Fox (my thesis advisor) had a car with licence plate "QUARK3".

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This van didn't need a license plate.

Scientific Breadth

- Path integrals in quantum and statistical mechanics

Lagrangian description of quantum theory, convenient for relativistic problems. Analogous to Huygens's wave propagation, with $\exp(iS/\hbar)$ as the amplitude for each possible path from the initial to the final point. Non-perturbative variational setting with quantum fluctuations.
Went from thesis, to review article, to a textbook, with not many publications inbetween.

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- Quantum electrodynamics: Antiparticles, diagrams, renormalisation

Space-time approach to quantum fields visualised in terms of particle trajectories (propagators and vertices). Antiparticles as negative energy solutions travelling backward in time. Manifestly relativistic and gauge invariant regularisation, with efficient calculational technique.
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- **Superfluid Helium: Ground state and excitations**

Microscopic description of a Bose liquid, in terms of a variational wavefunction. Proliferation of quantised vortices causes phase transition. Roton as an atom passing through a tiny vortex ring.
Quantum turbulence produced by interacting vortices is still an open question.

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- **Weak interactions: V-A theory**

A collaboration with Gell-Mann dictated by the department chairman. Brought out two component nature of neutrinos, with specific roles of vector and axial vector currents.
A theory invented by Sudarshan and Marshak, published by Feynman and Gell-Mann, and completed by Cabbibo.

- Quantum gravity: Gravitons and ghosts

Demonstrated that a massless spin-2 field in flat space, when consistently coupled to the energy-momentum tensor of matter, leads to Einstein's general relativity. Invented "ghosts" to restore unitarity in one-loop covariant gauge calculations of non-abelian gauge theories. Noted that quantum gravity may not be renormalisable.

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- Strong interactions: Parton model, hadronisation, confinement

Explained Bjorken scaling to experimentalists in his own language. Exemplified point-like constituents inside hadrons, including both quarks and gluons. Parton model reviewed in "Photon-hadron Interactions", and finally justified by asymptotic freedom of QCD. Described Quark and gluon fragmentation in to jets after hard scattering. Attempt to explain confinement in Yang-Mills theory via dynamical generation of flux tubes remained incomplete.

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- Computation: Parallel computers, quantum computers

Led the "IBM group" of Manhattan project, speeding up calculations by organising parallel threads. Pushed for miniaturisation and nanotechnology, announcing personal prizes. Designed communication router and algorithm for evaluating logarithms bit-by-bit for Thinking Machines. Explored potentialities and limitations of computers as per the laws of physics. Emphasized that quantum hardware, with natural capability of superposition and non-classical correlations, would simulate physical systems far more efficiently than importance sampling methods.

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Feynman published less than 100 papers in refereed journals, although he maintained detailed notes of his work.
Impressively, he ensured publication of his many lectures and courses (as textbooks), which has had a tremendous pedagogical impact.

Tidbits

Laughter

Montreal

Striptease

FKYMS

Guage theory

Mathematical tricks (integrals, logs)

Physics X

Story-telling and theatrics

Flux Tube Model

The following story of my interaction with Feynman illustrates his persistent hunt for innovative solutions to physics problems, as well as his irrepressible curiosity and generosity.

I took the course "Topics in Theoretical Physics" taught by Feynman in Spring 1983, focused on his ideas about QCD. In the later part of this course, he decided to talk about what would happen to QCD at finite temperature. He was using a flux tube picture to describe confinement in QCD [1], and argued that the fluctuations of the flux tube with increasing temperature would increase the entropy and produce a transition to the deconfined phase. This was in analogy to his work on behavior of vortices in liquid He, which I was not aware of.

I was working on lattice gauge theories at that time, and pointed out to him that the situations for SU(2) and SU(3) gauge theories were quite different. The deconfinement transition is of second order for SU(2), but of first order for SU(3). The difference is due to the the center symmetries Z(2) and Z(3) of the gauge groups, which control the finite temperature dynamics of the Wilson line, and Monte Carlo calculations have confirmed it. Feynman wanted a physical picture, and not a lattice QCD description in terms of the abstract Wilson line. I argued that a description using the flux tube connecting a quark and an antiquark cannot be the full story. The baryons would have to play a role, even though they were too heavy compared to the transition temperature.

Our arguments did not converge for a few lectures, because we could not adapt them to each-other's language. After one such inconclusive discussion in the lecture, I left for lunch. When I had gone just outside the Lauritsen laboratory building, a student informed me that Feynman wanted to tell me something. So I returned to the building, entering at the bottom of the stairwell. Feynman was waiting at the top. He shouted, frantically waving his arms, "Percolation, percolation!", and went back to his office. I was too stunned to say anything.

I met him later in the day, and he asked me to make a model of this picture. I did that, explaining how the dynamics of the same Z(3) center symmetry governs the baryons as well as the Wilson line. Feynman was happy with this result, and his secretary (Helen Tuck) gave me the privilege of calling him at his home to discuss physics. I prepared a draft of the paper, and asked Feynman about including him as an author. He declined, but also said that he would proof-read the paper. He carefully went through the draft, made some changes in what I had written, and then the paper was published [2].

1. R.P. Feynman, *The Qualitative Behavior of Yang-Mills Theory in 2+1 Dimensions*, Nucl. Phys. B188 (1981) 479-512.
2. A. Patel, *A Flux Tube Model of the Finite Temperature Deconfining Transition in QCD*, Nucl. Phys. B243 (1984) 411-422.

Thesis Examiner

Dedication in my thesis

अज्ञानतिमिरान्धस्य ज्ञानांजनशलाकया ।
चक्षुरुन्मिलितं येन तस्मै श्रीगुरवे नमः ॥

Salutations to that noble teacher, who with the collyrium-stick of knowledge has opened eyes of one, blinded by darkness of ignorance.

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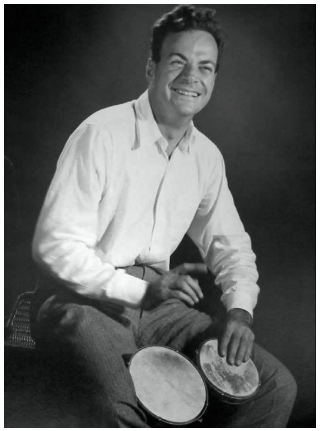
On my graduation day (Caltech, 1984)

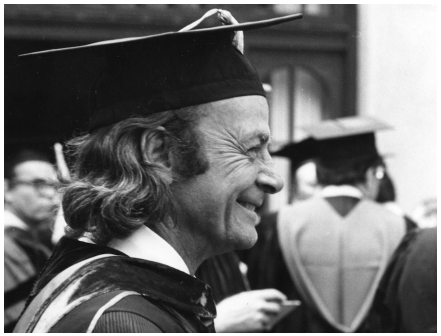


Bongo player

Costume party

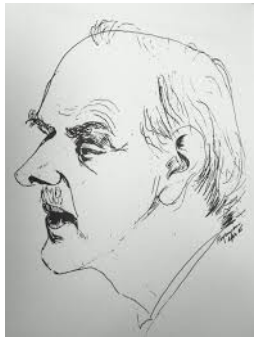
South Pacific musical

Caltech commencement

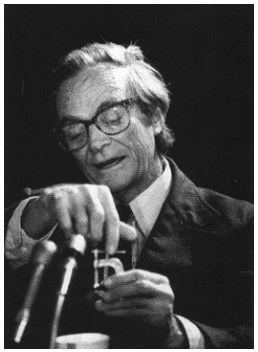


Professor
(Caltech convocation)

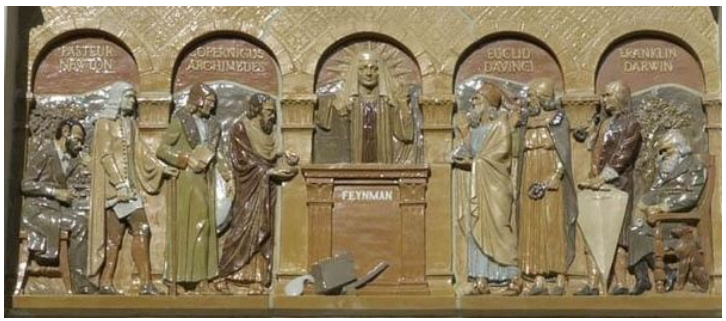
Ladakhi Monk
(Portrait by Sylvia Posner)



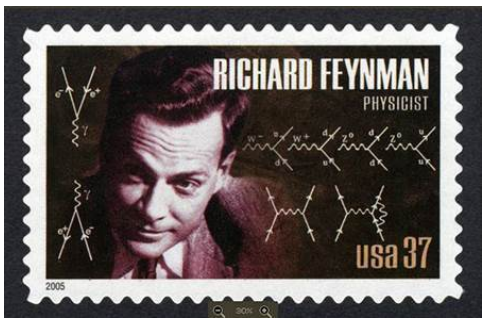
Artist
(Dirac sketch)



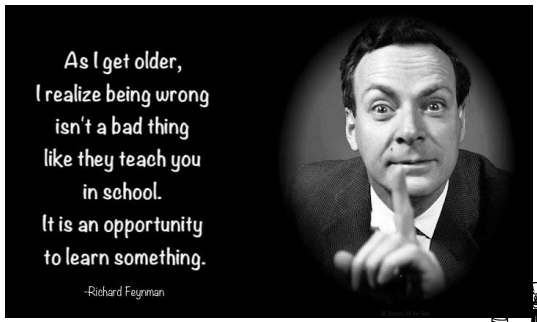
Investigator
(Challenger case)



Bas relief (Nobel celebration)



Commemorative stamp



Advice to students