Books

THE FEYNMAN LECTURES ON PHYSICS

by Richard P. Feynman, Robert B. Leighton and Matthew Sands

Addison-Wesley *$8.75*

Reviewed by Robert R. Blandford '59, graduate student in geophysics

There is little doubt in my mind that this collection of lectures given to Caltech freshmen by Prof. Feynman in 1961-1962 fully deserves to be reviewed in the standard book review journals, such as *The New York Times Book Review,* because it has great artistic and philosophic worth, besides being a textbook which probably should be owned by every scientist and engineer.

The fact that it almost certainly will not be reviewed in a journal of general interest is partly because of the split, such as it is, between scientists and humanists; and partly because the dispiritingly low level of life and comprehensibility in the typical text has prejudiced most editors to such a degree that they do not watch the non-popular publications in the hope that one may have general interest.

However, this book is for freshmen, and crackles with life. Those graduates of Caltech who have heard Prof. Feynman speak to small and large groups will remember his humor, his dramatic flair, and his interests in philosophy. All this is preserved wonderfully in this book, and for this we all owe thanks to the co-authors, Professors Leighton and Sands. The taped lectures have been transformed into a large, well-edited volume with wide margins which contain many clear, illustrative line drawings. Everyone connected with this volume is to be congratulated.

But, of course, Prof. Feynman assumes the major responsibility, and deserves the major credit. In the introduction he discusses how much credit he deserves, and, quite properly, evaluates this solely in terms of how much he succeeded in teaching his students.

Evidently, from test results and the volume of letters to the *California Tech,* some students were baffled by the multiplicity of subjects introduced, and by the speed and depth with which they were pursued. Prof. Feynman finds this discouraging, and around Caltech various ways of remedying and understanding the problem are being discussed. But I prefer to discuss the lectures from the point of view of a man who has had at least a liberal education in physics – mathematics through calculus, and an introductory physics course – who wants to understand the natural world about him, and who is prepared to give as much effort to Feynman's lectures as he gives to Joyce's *Ulysses.* The parallel between the two works is suggestive because both may be read for a greater understanding of the world, yet both abound in wit and humor and demand considerable concentration.

Prof. Feynman was evidently aware that some readers might take the wide range of topics and the casual tone to imply a shallow treatment characteristic of a survey course, because in the introduction he feels constrained to say that the lectures are meant to provide a thorough grounding in physics – which they do.

The philosophy contained in the book is mostly indirect and only rarely erupts into direct statement. When direct statements are made they make no pretense at rigor and either introduce or follow a long series of concrete scientific insights which serve as illustrations. To an unusual degree this book will imbue the careful reader with the author's specific brand of scientific spirit and philosophy.

The book opens with three chapters which prepare the philosophical ground and give a survey of all science. Prof. Feynman's casual yet powerful approach is immediately apparent. "If, in some cataclysm, all of scientific knowledge were to be destroyed, and only one sentence passed on to the next generation of creatures, what statement would contain the most information in the fewest words? I believe it is the *atomic hypothesis* (or the atomic fact, or whatever you wish to call it) that *all things are made of atoms – little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another.* In that one sentence, you will see there is an *enormous* amount of information about the world if just a little imagination and thinking are applied." Prof. Feynman then makes the necessary applications and discusses phenomena ranging from gases to human beings.

He then surveys the branches of physics – mechanics, electromagnetism, nuclear physics, and so on – and moves on to consider the relations of other sciences to physics. This chapter is opened with a warning to some perhaps naive freshmen: "We must, incidentally, make it clear from the beginning that if a thing is not a science, it is not necessarily bad. For example, love is not a science. So, if something is said not to be a science, it does not mean that there is something wrong with it; it just means that it is not a science."

In discussing the relation of astronomy to physics, he says: "One of the most impressive discoveries was the origin of the energy of the stars, that makes them continue to burn. One of the men who discovered this was out with his girl friend the night after he realized that *nuclear reactions* must be going on in the the stars in order to make them shine. She said, 'Look at how pretty the stars shine!' He said, 'Yes, and right now I am the only man in the world who knows *why* they shine!' She merely laughed at him. She was not impressed with being out with the only man who, at that moment, knew why stars shine. Well, it is sad to be alone, but that is the way it is in this world."

Among some younger physicists there is a tendency to dismiss as unworthy of consideration any branch of physics which can be treated classically. However, with his customary insight into what the problems of our understanding of the world are, Prof. Feynman devotes a paragraph to the importance of an analysis of turbulent flow.

Energy, velocity, acceleration

After this the successive chapters take up the detailed discussion of physics. The concepts of energy, velocity, and acceleration are introduced. Then Newton's law of gravitation enables a numerical calculation to be carried out in detail to give the shape of the path of a planet around the sun. By this numerical integration the mathematical problems are minimized and the points of physical interest are brought out clearly. This is an example of Prof. Feynman's consistent emphasis on physical insight, and his slight patience with mathematics for its own sake. After displaying the equations for N gravitationally interacting bodies, he writes: "So, as we said, we began this chapter not knowing how to calculate even the motion of a mass on a spring. Now, armed with the tremendous power of Newton's laws, we can not only calculate such simple motions, but also, given only a machine to handle the arithmetic, even the tremendous complex motions of the planets, to as high a degree of precision as we wish!"

Then a careful discussion of the definitions of mass and momentum prepares the way for relativistic momentum. Relativity already makes its first appearance!

In the discussion of vectors, the modern concepts of symmetry are suggested immediately. A discussion of symmetry under translation leads to an amusing statement, perhaps bordering on the obvious, of the need for common sense in physics. "Suppose we build a complicated machine . . . (and another) exactly the same only displaced laterally by some distance . . . Will one machine behave exactly the same as the other? . . . Of course the answer may well be *no*, because if we choose the wrong place for our machine it might be inside a wall and interferences from the wall would make the machine not work. All of our ideas in physics require a certain amount of common sense in their application; they are not purely mathematical or abstract ideas."

The concept of force

When the concept of force is given a detailed discussion, Prof. Feynman first mentions the definition of force as mass times acceleration. Then he says: "There must be something wrong with that, because it just is not saying anything new. If we have discovered a fundamental law, which asserts that the force is equal to the mass times the acceleration, and then *define* the force to be the mass times the acceleration, we have found out nothing . . . The real content of Newton's laws is this: that the force is supposed to have some *independent properties* . . . not completely specified by Newton or by anybody else, and therefore the physical law $F = ma$ is an incomplete law." The discussion goes on, but the characteristic revealed here for the first time is Prof. Feynman's willingness to attack head on, right from the start, all the paradoxes and "crazy" questions which students are wont to puzzle over.

He points out the fundamental distinction between empirical and fundamental laws, using as an example of the former the coefficient of friction. (Many of us have learned to solve problems using the coefficient of friction.) A more sophisticated example is the "law" that the drag on an airplane is proportional to the square of the velocity. Why does this law have a lower status than $F = ma$? "The reason is that . . . as we understand nature this law is the result of an enormous complexity of events and is not, fundamentally, a simple thing. If we continue to study it more and more . . . we find out that it is 'falser' and 'falser.' "

The concept of conservative forces and work is next introduced in a conventional manner, and then two full chapters are devoted to the special theory of relativity including four-vector momentum. In this discussion Feynman's tendency to play with philosophy and to face squarely any interesting paradoxes is shown at its best. "When this idea (relativity) descended upon the world, it caused a great stir among philosophers, particularly the 'cocktail-party philosophers,' who say, 'Oh, it is very simple: Einstein's theory says all is relative' . . . In addition they say 'It has been demonstrated in physics that phenomena depend on your frame of reference.' We hear that a great deal, but it is difficult to find out what it means . . . That what one sees depends on his frame of reference is certainly known to anybody who walks around, because he sees an approaching pedestrian first from the front and then from the back; there is nothing deeper in most of the philosophy which is said to have come from the theory of relativity than the remark that 'A person looks different from the front than from the back.'

"There is another school of philosophers who say, 'It is obvious that one cannot measure his velocity without looking outside. It is self-evident that it is *meaningless* to talk about the velocity of a thing without looking outside; the physicists are rather stupid for having thought otherwise, but it has just dawned on them that this is the case. If only we philosophers had realized what the problems were that the physicists had, we could have decided immediately by brainwork that it is impossible to tell how fast one is moving without looking outside, and we could have made an enormous contribution to physics.' These philosophers are always with us, struggling in the periphery to try to tell us something, but they never really understand the subtleties and depths of the problem."

A direct attack

The next topics discussed include rotations, coriolis forces, and angular momentum. There is a humorous example of Feynman's direct attack on paradoxes in his discussion of the precession of a gyroscope. "It is very strange that when one suddenly lets go of a gyroscope it does not *fall* under the action of gravity but moves sideways instead! Why is it that the *downward* force of the gravity which we *know* and *feel*, makes it go *sidewise?* What really happens is . . . if we suddenly let go, there will instantaneously be a torque from gravity. Anyone in his right mind would think that the top would fall, and that is what it starts to do, as can be seen if the top is not spinning too fast. . . . When the motion settles down, the axis of the gyro is a little bit lower than it was at the start. Why? (These are the more complicated details, but we bring them in because we do not want the reader to get the idea that the gyroscope is an absolute miracle. It *is* a wonderful thing, but it is not a miracle.)"

The discussion moves on to complex numbers and the harmonic oscillator. Illustrations of resonance are given from many fields, among them atmospheric tides and the Moessbauer effect.

Geometrical optics

In the discussion of geometrical optics, Prof. Feynman emphasizes how the best lenses are now designed with straightforward numerical computation. As usual, he places primary emphasis on physical understanding and, preparing the way for quantum mechanics, develops optics from Fermat's principle of least time. About this, he says:

"The following is another difficulty with the principle of least time, and one which people who do not like this kind of a theory could never stomach. With Snell's theory we can 'understand' light. Light goes along, it sees a surface, it bends because it does something at the surface. The idea of causality, that it goes from one point to another, and another, and so on, is easy to understand. But the principle of least time is a completely different philosophical principle about the way nature works. Instead of saying it is a causal thing, that when we do one thing, something else happens, and so on, it says this: we set up the situation and *light* decides which is the shortest time, or the extreme one, and chooses that path. But *what* does it do, *how* does it find out? Does it *smell* the nearby paths, and check them against each other? The answer is, yes, it does, in a way." And he goes on to explain.

One of the triumphs of this introductory course in physics, to my thinking, is its treatment of electromagnetism. The topics are discussed on a level of clarity and consistency usually not found until a graduate course. First, by means of an elegant, relativistically correct, formula for the field emitted by an accelerating charge, the far field of a slowly oscillating dipole is deduced. Then the interference patterns of several dipoles are discussed and applications are made to radio transmission, diffraction gratings, radio astronomy antennas, colored films, crystals, and diffraction by opaque screens. All these applications are characterized by physical arguments of gratifying clarity.

The most advanced topic in the book is relativistic effects in radiation. The discussion is exceptionally clear and direct for such a difficult subject and considers, among other topics, synchrotron radiation and the ω, k four-vector.

Color vision

It will come as no surprise to anyone associated with Prof. Feynman's interests in common natural phenomena to find two full chapters devoted exclusively to color vision. The typical physics student elsewhere would go through an undergraduate *and* graduate school without hearing a single lecture on the subject, yet here it is given roughly the same amount of space as is devoted to such a fundamental topic as angular momentum. The vector theory of color vision is discussed, the chromaticity diagram is introduced, and the most recent experiments bearing on the mechanism of color vision and the physiology of vision are discussed in some detail. The only interjection of "standard" physics comes in the discussion of the resolving power of the eye of the bee.

Is this divergence from topics of more fundamental interest justifiable? On the one hand it certainly deprives some students of needed elaboration on more fundamental topics; but on the other hand, for the more creative student and for the general reader, it serves well as a window to the complex world outside the simplified house of physics, and illustrates a general method of approach to more complex phenomena.

After the chapter on color vision come a number of chapters treating rather disconnected topics. There are two chapters giving a careful discussion of the experimental basis for the wave-particle duality in quantum mechanics, a chapter on the kinetic theory of gases in which the equipartition of energy is proved, and an introduction to statistical mechanics.

In five more chapters are found a startling diversity of topics seldom discussed in an introductory course, such as Johnson noise, Rayleigh's law for the thermal equilibrium of radiation, Planck's distribution, evaporation, thermionic emission, thermal ionization, chemical kinetics, induced emission, ionic conductivity, thermal conductivity of gases, the relation between mobility and molecular diffusion, reversible engines, and the Clausius-Clapeyron equation.

The third chapter of three on thermodynamics may be the most outstanding in the volume. It is titled "Ratchet and Pawl," and discusses the paradox that all our fundamental physical laws are reversible, yet the experience of life is that time's arrow exists. The discussion moves easily from the scale of a tiny ratchet and pawl machine lifting a flea, through the concept of entropy as disorder, to the observations of astronomers which indicate that the entire known universe is ordered. The chapter closes with the paragraph: "Another delight of our subject of physics is that even simple and idealized things, like the ratchet and pawl, work only because they are part of the universe. The ratchet and pawl works only in one direction because it has some ultimate contact with the rest of the universe. If the ratchet and pawl were in a box and isolated for some sufficient time, the wheel would be no more likely to go one way than the other. But because we pull up the shades and let the light out, because we cool off the earth and get heat from the sun, the ratchets and pawls that we make can turn one way. This one-wayness is interrelated with the fact that the ratchet is part of the universe. It is part of the universe not only in the sense that it obeys the physical laws of the universe, but its one-way behavior is tied to the one-way behavior of the entire universe. It cannot be completely understood until the mystery of the beginnings of the history of the universe are reduced still further from speculation to scientific understanding."

From sound to anti-matter

A chapter is devoted to the linearized sound equation in air, and the subjects of beats and modes of oscillation are introduced and discussed with the aid of Fourier analysis. A chapter is devoted to a qualitative discussion of waves in the earth and in water, and the volume closes with a chapter discussing symmetry in physical laws, of which the chief result is an understanding of the known facts about conservation of parity. Prof. Feynman points out that if instructions were given to an anti-matter world to make a replica of ourselves, then right and left would be confused: "So if our Martian is made of anti-matter and we give him instructions to make this 'right' handed model like us, it will, of course, come out the other way around. What would happen when, after much conversation back and forth, we have each taught the other to make spaceships and we meet halfway in empty space? We have instructed each other on our traditions, and so forth, and the two of us come rushing out to shake hands. Well, if he puts out his left hand, watch out!"

This book seems to me to demand criticism on other than its purely scientific and pedagogical merit (although the scientific merit is beyond dispute, and those students who have understood the material may have a start which will make them great scientists of the future). I have quoted and detailed the contents extensively because it seems to me that we have before us a work of art, capable of standing by itself and of contributing substantially to a complex world view.

One of the characteristics of many great novels is that between the great spiritual flights the reader is deluged by great volumes of "the real" which the author has gathered in his notebooks. The effect is to expand the reader's world, and to set off the peaks of spiritual achievement.

Throughout Prof. Feynman's lectures much of the same pattern may be seen. The complex data of the physical world is presented in wide-ranging yet penetrating detail. The leaven to the loaf is his constant good humor, found more in the tone than in jokes. And then, occasionally, while one is held on this high plateau of excitement and interest, a philosophical summation is given which, if not rigorous, is alive and convincing.

As does the novelist, Prof. Feynman portrays the observed world and points beyond it. I am reminded of the close to *The Origin of the Species*: "There is a grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, while this planet has gone circling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and wonderful have been, and are being evolved." Darwin was devoted to clarity, honesty, and graciousness. In our times one such man speaks with a Brooklyn accent. The times have changed but the men are still with us.
