"The Story of Spin"

From Spectroscopy to Relativistic Quantum Mechanics

N Mukunda

The Story of Spin
Sin Itiro Tomonaga
Translated by Takeshi Oka
The University of Chicago Press, 1997

After Hideki Yukawa won the Physics Nobel Prize in 1949, his class-fellow Sin-Itiro Tomonaga was the next Japanese theoretical physicist to be so honoured. He shared the 1965 Prize with Richard Feynman and Julian Schwinger for their renormalisation theory of quantum electrodynamics. Apart from being a master theoretical physicist, Tomonaga was also a highly gifted writer (and culturally very refined and sensitive in a deeply Japanese way); his two books on quantum mechanics are masterpieces deserving much greater attention than they seem to have received.

In *The Story of Spin,* Tomonaga describes many key developments in microscopic physics in the crucial period from the early 1920's to about 1940 generally revolving around the concept of spin. It is based on a series of twelve lectures delivered over several months in the early 1970's, and put together in the form of a book in Japanese in 1974. Tomonaga begins with the struggles to understand spectroscopic data and the detailed ways in which spectral lines split in magnetic fields, and how the idea of a new degree of freedom for the electron – its spin – slowly evolved. Many now forgotten historical details are carefully recalled. Around this time quantum mechanics too was about to appear on the scene, and the stories get intertwined. We read about the state vector concept in quantum mechanics, Dirac's 'majestic transformation theory', the Pauli description of spin and his nonrelativistic equation, and then – like a bolt from the blue – the emergence of the Dirac equation.

Tomonaga spent two years in Leipzig in the late thirties working with Heisenberg. It is understandable (and in any case it must be so!) that Heisenberg's work in many areas is very carefully discussed, giving a lot of attention to his motivations and method of thinking. We learn about his work on ferromagnetism, the exchange interaction, the basic ideas of the nuclear force, isotopic spin and so on. The Dirac idea of second quantisation, and the Pauli theorem of 1940 on the relation between spin and statistics, get especially thorough treatment. The concept of spinors, and the way they behave under rotations, is also beautifully explained.

Tomonaga traces the deep connections and motivations linking important events and discoveries which we today tend to view as isolated advances – Bohr's idea of nonconservation of energy in beta decay and inapplicability of quantum mechanics within the nucleus; Pauli's neutrino idea and Fermi's use of it; Heisenberg's theory of the exchange force between protons and neutrons and the later Yukawa theory of the meson, and so on. Only a master in the subject can achieve such a perspective and write about it so well. There is also a good deal of mathematical treatment of the Lorentz group, in connection especially with the work of L H Thomas.

Probably the best chapters are the third, on the Pauli and Dirac equations for the electron; the eighth, sketching Pauli's derivation of the spin-statistics connection; the ninth, on the amazing discoveries in 1932 and how they influenced the future of physics; and the tenth, largely concerned with Heisenberg's inauguration of nuclear physics within the basic quantum mechanical formalism. Tomonaga's explanations are very leisurely and lucid; and when mathematical he stops at just the right place! Some of the material is quite demanding, calling for a high degree of maturity from the reader. His assessments of the characters of the giants of the field and their attitudes towards one another are charming, a sample being: "Dirac's acrobatics, Pauli's frontal assault, and Heisenberg's analogising: each is uniquely characteristic of its practitioner so that we are never bored following their work". Anecdotes and vignettes abound.

This is a very sophisticated, highly personal account of major developments in physics, and those who brought them about, largely to do with the spin of elementary particles but covering a lot of ground in related areas. It bears much and careful re-reading to fully extract all the meanings and linkages, that only a gifted raconteur like Tomonaga can show us.

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Naturalists in a Nutshell: 90 Minute Biographies of Eminent Scientists

S Mahadevan

Mendel, Curie, Darwin, Faraday, Galileo, Newton, Halley and Einstein
By John and Mary Gribbin
Universities Press, Each Rs. 45

Though scientific principles are universal and transcend personal prejudices and subjective points of view, our understanding of them was made possible because of contributions of great scientific minds. Part of the charm of appreciating monumental scientific discoveries is in knowing about the lives and times of the men and women who made them possible and the circumstances that led them to rise above the rest. Well-written biographies of great scientists are always a source of inspiration and enlightenment, particularly for those who are beginning their pursuit of scientific discoveries. The biography series penned by John and Mary

Gribbin serves as an appetizer for those interested in knowing more about some of the great scientific personalities of all times. The series consists of nutshell biographies of Curie, Darwin, Einstein, Faraday, Galileo, Halley, Mendel, and Newton. Though short and concise, these sketches provide sufficient historical information to appreciate the scientific achievements of these legendary figures.

The biographies of Curie and Faraday are moving as they depict the success stories of two great scientists with humble beginnings who attained great heights because of relentless pursuit of their goals, fighting against circum-stances that may have pulled down a normal human being. Though better and more exhaustive biographies of Newton and Mendel have been written, the present ones do have some interesting and novel insights. The only drawback is that some of the negative aspects of Newton's personality, particularly the controversy with Robert Hooke, have been overlooked. Hooke has been portrayed rather unfairly as the villain in this version. The author's description of Mendel as a gentle and affectionate teacher with genuine consideration for his students' welfare should inspire many modern teachers. In the account on Darwin's life, the exchange between Darwin and Wallace brings into focus the equal contribution of Wallace to the concept of natural selection. This is not appreciated by many, including some biologists. The biography of Halley is probably the most interesting and entertaining. The authors have done justice to the great astronomer by bringing him out of the shadow of his illustrious contemporary, Newton. The description of Halley as one with the attributes of Stephen Hawking, Horatio Hornblower, Thomas Edison and James Bond is amusing. In terms of historical context, the sketch of Galileo, the first scientist in the modern sense, is the best.

Among the series, the most disappointing one is the biography of Einstein. Here, the authors have allowed the details about his personal life to overshadow his scientific achievements. The fact that it is not easy to describe the concepts of relativity without going into mathematical details may have hampered their efforts to some extent. My most serious criticism of the series is that the authors do not provide any information as to the sources of their information. Nor do they refer interested readers to more exhaustive biographies of the scientists whenever they exist. But they do provide a readable account of life stories of some of the most revered names in the scientific world and are worth a quick look. After all, each book takes only 90 minutes!

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For more on these books see '*From Galileo to Einstein*' by G S Ranganath in the following two pages.

From Galileo to Einstein[1]

G S Ranganath

The desire to know the principles governing the physical universe is as old as man has been on this planet. The four little books under review are brief biographical sketches of four eminent scientists who have profoundly transformed our understanding of the physical world. In this review of these books I will draw attention to some unfamiliar facts of their lives and times.

An impression is created in popular literature that Galileo was the first to invent a telescope. The authors bring out the interesting fact that Leonard Digges had built both reflecting and refracting telescopes way back in 1550 more than a century before Galileo. Probably, Galileo was the first to make the best use of it. His discoveries concerning the phases of Venus established on a firm footing the heliocentric theory. As a result, he had to suffer years of persecution because this theory was in direct conflict with that held by the church. The authors makes a telling point when they write " The Pope, John Paul II, formally pardoned Galileo on 31st October 1992 ... "

The book has a graphic description of Galileo's family life. His father had promised, just before his death, a substantial dowry to Galileo's sister. Galileo had to give dowry to his second sister also. However, his financial status was so miserable that even to eke out a normal living he at times had to give private tuition. Thus he could not meet these social obligations in his entire life and to add insult to injury his brothers-in-laws sued him in a court for not settling their dowries. This left such a scar on him that he forced his two daughters, whom he loved very dearly, to be nuns for life.

No standard book on physics stresses the fact that Galileo was the first to introduce the concept of inertia. This point has been made out clearly by the Gribbins. He invented this principle to account for the eternal circular motions of planets round the sun. He believed that a circular motion is the natural motion due to inertia. It was Renee Descartes who realised that this concept of inertia applied only to motions in a straight line. But it was left to Newton to solve the problem of motion on a curve.

This brings us to Newton's biography. There is a general belief that Newton was born in 1642, the year Galileo died. But in reality Newton was born on 4th January 1643. This discrepancy is due to the fact that the British being mostly Protestants were naturally suspicious of the Pope and did not adopt the Gregorian calendar until 1752. This biography also tells us how Newton arrived at his law of gravitational attraction. The arguments found in the book look extremely plausible. Newton was aware of Kepler's discoveries about planetary motion. He had to reconcile them with his discovery of the centrifugal force. A planet moving in an orbit

[1] see pages 90, 91.

would experience a centrifugal force that would drive the planet away from the sun. To keep it in its stable orbit around the sun there must be an equal and opposite force of attraction tugging it towards the sun. Using Kepler's law about orbital periods he discovered that this force of attraction should fall inversely as the square of the distance from the sun. Thus Newton's universal law of gravitational attraction was born.

Edmund Halley is not as well known as Galileo or Newton. Thus his biography is very welcome. Though he is known for his work on comets, it is not generally recognised that Halley made a very significant discovery concerning stars. This came about after his friend Newton took over as the President of the Royal Society. The Royal Greenwich Observatory had been set up so that Flamsteed could prepare more accurate astronomical tables to improve navigation. But Flamsteed was extremely reluctant to part with his data since he had spent a lot of his own money in improving the telescope. When he became adamant the Queen stepped in and appointed Newton to get this data. Newton in turn assigned this job to Halley. Halley added a lot of his own data to the ones supplied by Flamsteed. While on this job he carefully compared the stellar co-ordinates he had on hand with similar data of Hipparchus of second century BC. He found to his amazement that the recently measured co-ordinates of most of the stars agreed with the ancient data. Halley boldly suggested that these stars had moved in the intervening centuries. Thus he shattered the myth that stars are fixed objects in the sky.

The biography of Albert Einstein has nothing new to recommend it. The little book dwells upon all the known facts. I wish the authors had been a little careful. They make two misleading statements. It has been stated that the Bose–Einstein statistics(BES) applies to particles whose number is not conserved and that when the particle number is conserved it is the Fermi–Dirac statistics (FDS)that will have to be used. The right statement would have been that BES applies to particles with integral spin while FDS applies to particles with half-integral spin. They end Einstein's biography with the statement:

" Number two to Newton in physics rankings is surely a position he would be proud to hold – though he may have to share that number two slot with Richard Feynman"

I think that many will not agree with this elevation of Feynman to the level of Einstein.

I would strongly recommend these books to every pre-college student. They will hopefully motivate and inspire our young students who of late have been opting out of basic sciences. The Universities Press has done a service to the student community publishing these books at such low prices.

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Linear Algebra

D R Choudhari

Linear Algebra
Henry Helson
Trim Series, Texts and Readings in Mathematics, 4
Hindustan Book Agency, 2nd Edn.
Current Book Store Price: Rs.170

The book under review is comparatively slim, and yet by treading a carefully chosen path the author covers as much ground as many other standard books on linear algebra.

The book starts with solutions of systems of equations and by way of *Gaussian elimination* and *row reduction* quickly arrives at the *Fredholm alternative* (Theorem 3, page 13).

Vector spaces have been introduced in the second chapter along with the related concepts of *subspace, linear dependence, basis* and *dimension* of a vector space. The *cardinality invariance of bases* has been established using the results on systems of equations. Rightly, *inner products* have been introduced early and full use has been made of the standard inner product on $\mathbf{R}^n$ and on $\mathbf{C}^n$.

The author is of the view that the applications of linear algebra are not as obvious as those of calculus, for instance, and hence the subject should be learnt for its own sake first, before coming to meaningful applications. Therefore, the text has not been overloaded with applications which may otherwise have impeded the flow. The method of *least squares* in statistics is presented as the first application of the ideas involving *dot product*, *Gram–*

By treading a carefully chosen path the author covers as much ground as many other standard books on linear algebra.

Schmidt orthonormalisation and *linear equations*.

The chapter on *linear transformations* is short but contains all the essentials including *change of basis, self-adjoint, normal, unitary* and *positive operators,* etc.

The chapter on *determinants* is concise, sharp and in a very economic manner covers all the properties of determinants. The uniqueness of the determinant as a skew-symmetric *n*-linear functional has been established. This chapter should take the dread out of establishing the properties of determinants in detail in the class room. It concludes with a discussion of *volumes* in *n*-dimensions.

In the initial sections of the chapter on *reduction of matrices,* after discussing *eigenvalues* and *eigenvectors,* the author, with surprising ease, enters the heart of the subject matter of self-adjoint operators to establish the *spectral theorem*. The results of the first three sections are then used in the lucid section on *quadratic forms.* Next come the *upper triangular* and *Jordan canonical* forms of a matrix. This chapter contains a method of obtaining the largest or the least eigenvalue for a self-adjoint operator using the familiar methods of calculus. The *polar decomposition* of a linear operator on $\mathbf{C}^n$ as a product of a unitary and a positive semi-definite operator (similar to that of a complex z in the form $z = |z|e^{i\theta}$) is then established and the chapter concludes with an application to *factor analysis*, again in

This book is well suited to beginning undergraduate students of mathematics and slightly more advanced science/engineering students.

statistics!

The final chapter on *matrix factoring* ensures that a person studying linear algebra is familiar with the numerical techniques in the area such as the *LU*-factoring of a matrix into a product of a lower (L) and an upper triangular (U) matrix or the *Choleski decomposition* of a positive semi-definite matrix as LL^t where L is a lower triangular matrix with non-negative diagonal elements.

Of course, a book of such a size as the present one cannot contain everything that we feel the students should know. Two of the important topics that need more explicit attention are minimal polynomials of linear operators and simultaneous diagonalisation of commuting operators, although these are touched upon in an indirect way in the exercises. We hope that these topics will be included in a future edition. Also, those using the book for self-study would find it more helpful if the chapter on matrix factoring is enlarged with a few more examples and exercises.

This book is well suited to beginning undergraduate students of mathematics and slightly more advanced science/engineering students.

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Reproducing 'Still photograph of a localized vibration. Exposure time was 1 sec' in colour for more clarity. See for details *Resonance* Vol.3, No.10, pp.58, 1998.

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