# Drinking deep from the cup of science

**Truth and Beauty: Aesthetics and Motivations in Science.** S. Chandrasekhar. The University of Chicago Press. 1987. 170 pp. Price $27.55.

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Perhaps it is desirable to begin this account of a book of essays by the most distinguished astrophysicist of our time with some justification for its appearance in a journal devoted to the science of genetics. It so happens that another recent book, *What Mad Pursuit* by Francis Crick, offers in part the views of a distinguished life scientist on closely related themes, and so it seemed that there might be more than passing interest in juxtaposing these two views originating in what may be called the two complementary areas of the natural sciences. It is therefore with this in mind and in response to such a request that this appreciation is offered.

For similar reasons it is also appropriate, keeping in view the likely nature of the readership of this journal, to give at first a very brief biographical sketch of the author, and to convey to those not so well acquainted with the physical sciences the nature and magnitude of his work, and the special position he occupies in the world of physics.

Subrahmanyan Chandrasekhar was born on the easily remembered date of 19th October 1910 in the town of Lahore (then in India, now in Pakistan). During his undergraduate years at the Presidency College in Madras, there was a most fortunate meeting with the German physicist Arnold Sommerfeld, through whom he learnt of the latest advances in quantum mechanics and in particular of the uses of the new Fermi–Dirac statistics for electrons. Possibly Chandrasekhar's most remarkable work has been the analysis of the late stages in the evolution of massive stars, in which the form of the new quantum statistics in its relativistic version plays a crucial role. The period 1930 to 1937 spent at Cambridge, first as a student leading to the PhD in 1933 and then as a Fellow of Trinity College, saw him carry out these epoch-making researches into astrophysics, and the derivation of the famous mass limit named after him, the Chandrasekhar limit of 1.4 solar masses. This is a major dividing line: less massive stars end their lives as so-called white dwarfs; while heavier stars evolve, as has since been realized and accepted, into either neutron stars or black holes. The occasion of his presentation of these findings at the 11th January 1935 meeting of the Royal Astronomical Society resulted in an unexpected and personally shattering controversy with Arthur Stanley Eddington, the most distinguished astrophysicist of that time, which deeply coloured his attitudes to research and manner of working as well. In 1937, Chandrasekhar moved to the University of Chicago, where he became a professor in 1944, and Morton D. Hull Distinguished Service Professor in 1952. Over a long career of sustained work of the highest order, he has directed his penetrating attention to one major branch of physics after another, endeavouring to bring order to and attaining 'a certain perspective' in each one, and leaving it in much better condition than when he entered it. Among the fields he has touched and decisively influenced are stellar structure and dynamics, radiative transfer, hydrodynamics and hydromagnetics and, most recently, the mathematical theory of black holes. Apart from many other honours, in 1983 he shared with William Fowler the Nobel Prize for Physics.

The range, depth and volume of Chandrasekhar's work are all truly staggering; and in these respects one can only compare him with Lord Rayleigh in the 19th century. His attitude to his work (and here one possibly sees an effect of the incident with Eddington), is best expressed in his comment upon award of the Nobel Prize: 'I work for my own personal satisfaction on things generally outside of the scientific mainstream. Usually my work becomes appreciated only after some length of time.' Along with a certain reserve and shyness, and a precision and elegance in expression, there is also a subtle humour that comes through. It may not be out of place to recall two instances of the latter here. Of one occasion when he was asked what might be said of him biographically, he reports, 'I told the young lady that I had been a Professor at the University of Chicago for the past 37 years, what more is there to say?' On another occasion after an elegant and somewhat intricate mathematical lecture given by him at MIT, on being asked by Victor Weisskopf why he had undertaken that piece of work, he is reported to have replied, 'I thought this was a free country.'

Let me now turn to the book at hand. It consists of seven essays broadly grouped into two sets—the first four dealing with aspects of aesthetics and motivations in the pursuit of the physical sciences, the last three being basically biographical in nature, except that the very last one comes back to an analysis of the aesthetic base of the general theory of relativity. All the essays are the complete texts of formal addresses given on various occasions. While the opening essay dates from 1946, all the others are from a later period, the decade from 1975 to 1986. Thus, apart from all other things, this collection affords a unique opportunity to see the maturing of a gifted and sensitive mind over some four decades, from the age of 36 to that of 76. In his preface Chandrasekhar does remark that he would now express somewhat differently the ideas he expounded in his 1946 lecture on 'The Scientist', (one in a series titled 'The Works of the Mind' and including such other speakers as Frank Lloyd Wright, Arnold Schoenberg, Marc Chagall and John von Neumann). Some of the key issues Chandrasekhar raises forcefully and often in these lectures are the changed attitudes to science in passing from the era of Kepler, Galileo and Newton to the last century and down to our own times; the contrasts between instances of stunning discoveries and flashes of insight into the secrets of nature as against the results of sustained and persistent lifelong efforts; the evident differences in the patterns of creativity in the arts as against the sciences; and the sensitivity to beauty in science, and the extent to which such sensitivity to the aesthetic aspects of a theory actually aids one in posing and solving substantive and deep problems. Except possibly for the last, all these issues surely have relevance outside the particular domain of the physical sciences alone. Chandrasekhar's purpose is evidently not to provide definitive answers to these various questions; but one does find here and there hints of his own feelings and, as is only to be expected, his own personality and style of work come through again and again.

Chandrasekhar sees a difference in attitude to science exhibited by men like Kepler, Galileo and Newton, and those who followed much later. Thus with these giants, there was always present a wholeness of vision, an attempt to place their work in the context of all of science. Even Lagrange and Laplace who followed in the 18th century, and who in large part worked out the complex *consequences* of the fundamental physical discoveries of Galileo and Newton, followed this path and gave a view of the whole accompanied by a proper appreciation of the portion contributed by them. But in later times, already with Maxwell and later definitely with Einstein, Chandrasekhar finds a change, an emphasis on one's own discoveries and the impetus they have given to the progress of science 'in the small'. To some extent perhaps this is understandable as the early pioneers had performed the task of identifying the outlines and setting the programme for natural science in the succeeding centuries; added to this, the totality of science at some stage inevitably passed beyond the grasp of a single individual. But with Chandrasekhar one wonders whether a continuation of the older pattern may have prevented the divide between the arts and the sciences! The attentive reader also cannot escape the feeling that the importance of this issue for Chandrasekhar stems from his own attitude and style of work, captured in his statement: '... the method I have adopted in my own work has always been first to learn what is already known about a subject; then to see if it conforms to those standards of rigor, logical ordering, and completion which one has a right to ask; and if it does not, to set about doing it. The motivation has always been systematization based on scholarship.'

The contrast between discoveries based upon long and arduous work over many years, and those that result from almost inexplicable flashes of insight and understanding, is one to which Chandrasekhar is particularly drawn. While only the former qualifies to be called a *method* of working, each has had its share of successes and failures. Chandrasekhar recounts with much feeling the cases of Kepler and Michelson as examples of great success stories from sustained endeavour. The former appears at the cross-roads between dogma and modern science, devoting 22 years of work to the single goal of unravelling the geometry of planetary motions; the latter devoted 50 years of his life to the task of measuring the speed of light with ever-increasing precision. In these cases one sees a constancy and a doggedness that paid rich dividends. But there have been failures too: Eddington who devoted 16 years to his 'Fundamental Theory' but failed to win the approval of his contemporaries; and Heisenberg's unified theory of elementary particles dating from the 50s. In both cases there was a certain lack of touch with reality. Turning to the other 'sudden' pattern of discovery, naturally only the successes are remembered. Chandrasekhar recalls the cases of Einstein who in 1907 came upon his Principle of Equivalence, later characterized by him as 'the happiest thought of my life'; Dirac's realization on a Sunday evening walk in 1925 of the deep connection between Poisson brackets in classical physics and commutators in quantum theory; his later discovery of the relativistic electron wave equation; and Heisenberg's final intuitive burst of creativity in May–June 1925 that resulted in the matrix version of quantum mechanics. In more than one place in these essays Chandrasekhar expresses the view that successes of this kind can have the effect of producing later a kind of cocksureness and arrogance in one's perceived ability to comprehend nature. He quotes with approval J. J. Thomson's assessment of Lord Rayleigh: 'There are some great men of science whose charm consists in having said the first word on a subject, in having introduced some new idea which has proved fruitful; there are others whose charm consists perhaps in having said the last word on the subject, and who have reduced the subject to logical consistency and clearness. I think by temperament Lord Rayleigh belonged to the second group.' And this seems to go well with Chandrasekhar's own declaration: 'One's place in science, as posterity will duly assign, depends very largely on one's continuous exertion, at the edge of one's ability; . . . I think one could say that a certain modesty towards understanding nature is a precondition to the continued pursuit of science.'

Heisenberg's passage in his book *Physics and Beyond*, describing his feelings at the end of his struggles culminating in the discovery of matrix mechanics, holds a special fascination for Chandrasekhar, as he quotes it no less than three times in these essays! Only one sentence from Heisenberg needs to be recalled here: 'I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy at the thought that I now had to probe this wealth of mathematical structure nature had so generously spread out before me.' Indeed this is one of the most moving accounts of the effect of inspired discovery on the discoverer, to which Chandrasekhar is repeatedly drawn. And even a lay reader cannot help comparing such words with Plato's passage from *The Phaedrus*: 'The soul is awestricken and shudders at the sight of the beautiful, for it feels that something is evoked in it that was not imparted to it from without by the senses, but has always been already laid down there in the deeply unconscious region.'

The problem of the differences in the patterns of creativity of an artist—in literature as much as in music—and a scientist is taken up by Chandrasekhar in his 1975 Ryerson Lecture entitled 'Shakespeare, Newton and Beethoven or Patterns of Creativity'. In the light of what has been said above, one can truly claim that this is an example on a broader canvas of a similar variation in patterns of creativity seen within science itself! Chandrasekhar provides incisive thumbnail sketches of the lives of Shakespeare, Beethoven and Newton; and in the process shows his own wonderful sensitivity to these master spirits and their creations. He sees in both Shakespeare and Beethoven the importance of continuity of growth and evolving maturity, a wholeness in their output, and a conscious sense of completion and drawing to a close at the end. Of Shakespeare's tragedies belonging to the period 1604–08 he says: 'It staggers one's imagination to realize that these great plays, so utterly different from one another, could have been written, in succession, with such unfaltering inspiration.' And of the *Winter's Tale* he quotes a well-known critic to say: '*Winter's Tale* is beyond criticism and even beyond praise.' The sense of a continuous and upward movement until the very end is wonderfully captured in his quotation from T. S. Eliot: 'The standard set by Shakespeare is that of continuous development from first to last, a development in which the choice both of theme and of dramatic and verse technique in each play seems to be determined increasingly by Shakespeare's state of feeling by the particular stage of his emotional maturity at the time. . . . We may say confidently that the full meaning of any one of his plays is not in itself alone, but in that play in the order in which it was written, in its relation to all of Shakespeare's other plays, earlier and later; we must know all of Shakespeare's work in order to know any of it.' The same is true of Beethoven as well; for after recalling the early period, the onset of deafness, and Beethoven's resolve to 'take Fate by the throat', Chandrasekhar presents an extract from the Heiligenstadt testament containing the sentence 'For indeed it seemed impossible to leave this world before I had produced all the works that I felt urged to compose'; and at the end Sullivan's summing up: 'One of the most significant facts, for the understanding of Beethoven, is that his work shows an organic development up until the very end. . . . The greatest music Beethoven ever wrote is to be found in the last string quartets, and the music of every decade before the final period was greater than its predecessor.' But with Newton we see a difference: an explosion of genius, an unsurpassed achievement over a brief two-year period in his early twenties, then an unparalleled effort of the most intense concentration and activity in his early forties while composing the *Principia*; but thereafter no comparable major work of similar magnitude. Chandrasekhar sees the same trend, a slowing down and retirement after a creative outburst, in the cases of Maxwell and Einstein as well, and wonders why this must be so. Significantly and understandably he finds no *scientist* to compare with Newton, only Shakespeare and Beethoven. His concern and analysis of this 'problem' of course brings the reader back to his own career, and an indication of where his sympathies lie. Indeed he has said of his latest book *The Mathematical Theory of Black Holes* completed in 1983 and comprising the results of his work in the preceding decade, that it has been the hardest project he has worked on and the one that gave him the greatest satisfaction. But may it not be that this difference between the arts and the sciences is a reflection of the different ways in which man relates to nature in these two realms? One is reminded here of the mathematician Harish-Chandra's statement: 'I have often pondered over the roles of knowledge or experience on the one hand and imagination or intuition on the other, in the process of discovery. I believe that there is a certain fundamental conflict between the two, and knowledge, by advocating caution, tends to inhibit the flight of imagination. Therefore, a certain naiveté unburdened by conventional wisdom, can sometimes be a positive asset.' May be there is a complementarity between knowledge and discovery, crucial advances in science and insight into nature generally requiring the unfettered daring and imagination of youth; while on the other hand creativity in the arts depends essentially upon human experience and individual emotional development and maturity, so that one's finest works are the products at the end of the creative life. Possibly the gifted scientific mind exposes a direct resonance with nature, not as much dependent on human events and feelings.

The quest for and sensitivity to beauty in science are naturally deep concerns of Chandrasekhar. He addresses them in the R. R. Wilson Lecture of 1979, and here he partly returns to the themes of the Ryerson Lecture. He presents to us G. N. Watson's description of the transports of joy he felt on encountering some of Ramanujan's mathematical formulae; Boltzmann's reactions to Maxwell's work on the dynamical theory of gases; Einstein's emotions on the completion of his general theory of relativity; Weyl's giving precedence to beauty over agreement with experiment in his work in physics; and once again the passage from Heisenberg on the discovery of matrix mechanics. Chandrasekhar expresses himself thus: 'It is, indeed, an incredible fact that what the human mind, at its deepest and most profound, perceives as beautiful finds its realization in external nature.' From these many instances it emerges that scientists always use the language of the arts in describing the beauties of science—there is no other way to communicate these matters! But Chandrasekhar also sounds a note of caution—astounding success in science can later lead to an excess of confidence in oneself, to errors of judgement, and the loss of a critical and balanced attitude. Here it is amusing to remark that in his 1946 essay Chandrasekhar had said, speaking of appropriateness and coherence in scientific theory: 'I admit that these are things which cannot be defined any more than beauty in art can be defined; but people who are acquainted with the subject have no difficulty in recognizing or appreciating it.' But by 1975, in speaking of evaluating scientific theories as works of art, he is rather critical of an almost identical statement of Dirac from 1939; for he says: "It will not do, I think, to dismiss such an inquiry with an assertion such as Dirac's (made in a different context): 'Mathematical beauty cannot be defined any more than beauty in art can be defined, but which people who study mathematics usually have no difficulty in appreciating.'"

The case of the general theory of relativity has special appeal to Chandrasekhar, and on more than one occasion he tells us why 'It is probably the most beautiful of all existing theories'. He sees it in the fact that the theory brings together space and time on the one hand, and matter and motion on the other; that like Moore's characterization of the greatest sculptures as revealing new aspects of beauty at every distance from which they may be viewed, this theory too is beautiful at all levels, all scales of examination. And as he expounds in great detail in the concluding essay, the appreciation of its aesthetic base has been of direct relevance in formulating and solving highly nontrivial physical problems within the theory.

The three biographical essays are devoted respectively to Edward Arthur Milne, Arthur Stanley Eddington, and Karl Schwarzschild. Each of them is written with a master's eye and pen. This is not the place to recall any of the technical matters dealt with in these pieces. Suffice it to say that on going through them, one gets a fine picture of the founding of the various branches of the modern science of astrophysics, and of the seminal contributions made by each of these three figures. Chandrasekhar is of course eminently qualified to speak of them, having known both Milne and Eddington personally over long periods of time; and in the case of Schwarzschild not merely because Chandrasekhar himself is one of the ablest practitioners of the general theory of relativity. The portraits of Milne and Eddington are vividly drawn with sympathy and sensitivity, and yet with a critical and discerning attitude to their work and personalities. With Milne, Chandrasekhar finds his style and approach to physical problems to have been of more lasting value than his actual accomplishments. In the Eddington essay one reads of the 1935 incident that had such a decisive influence on Chandrasekhar's own career; and of the successive controversies in which Eddington was involved with Milne and Jeans. Chandrasekhar expresses very high regard for Eddington's early mastery of the general theory of relativity, and for his book on it, but finds that he achieved less than he was capable of. The final lecture shows in brief how much Karl Schwarzschild accomplished in so many fields in so short a time; and brings home the tragedy of his early death due to a disease contracted on the war front in 1915.

To sum up: there is a continuity of thought and expression in the essays in this volume, a concern for beauty and motivation in scientific endeavour, a caring for music and literature in a complete personality. Each piece stands as a model of composition and craftsmanship, evidence of command over expression and elegance. In reading them one cannot but keep remembering Chandrasekhar's own scale and depth of achievement. In an interview he had once said: 'One of the unfortunate facts about the pursuit of science the way I have done it is that it has distorted my personality. I had to sacrifice other interests in life—literature, music, travelling. I have devoted all my time, every living hour practically, to my work.' But one feels that this cannot really be the case, as one finds here a sensitivity to art, to music and literature, to Shakespeare and Shelley, Keats and Eliot and Beethoven, no less than to Newton and Einstein.

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## Topics in physics

**Electricity and Magnetism.** A. S. Mahajan and A. A. Rangwala. Tata-McGraw Hill Publishing Co., New Delhi. 1988, 508 pp.

This book is a useful addition to the list of good undergraduate textbooks in electricity and magnetism. As the authors say in the Introduction, the book is aimed, apart from engineering students, to second-year undergraduates in science. This perhaps is the reason why the book omits some important topics like radiation from accelerated charges, waveguides, reflection and refraction of light and so on. In my opinion, a more comprehensive coverage, possibly in two volumes would have been more useful.

The twelve chapters in the book follow the standard development. The first chapter is devoted to vector analysis following which one has the usual sequence of electrostatics, current electricity, electromagnetism leading up to Maxwell's equations (with discussion of its solutions only in simple cases).

The authors must be congratulated for the meticulous care they have taken in being correct in both the physics presented and the mathematics invol-