Science and scientific attitude

S. Chandrasekhar

On Apollonius, Kepler and Einstein, Newton and Shakespeare, and Madonna and Mrs Pelham.

One of the matters to which I have devoted some thought in recent years concerns one's motivations in the pursuit of science; and some of my thoughts on the subject are included in the collection of my lectures, *Truth and Beauty: Aesthetics and Motivations in Science* (University of Chicago Press, 1987). In this essay, I wish to consider some related questions: (1) the aspect of nature that is in some sense the most incomprehensible; (2) the goals that one strives for in the pursuit of knowledge; and finally (3) the sources of one's satisfaction in such pursuits.

While these questions may seem disparate, it will appear in the discussion that follows that they are in fact related, even if only tangentially.

1

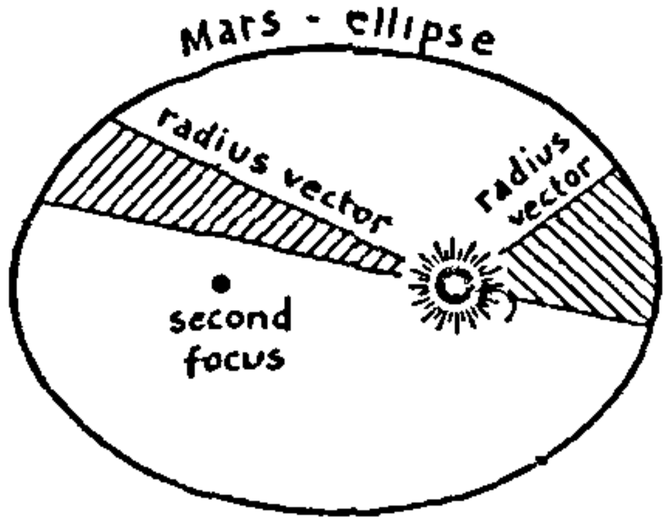
In the context of the first of the topics I have enunciated, I shall consider the following statement of Einstein:

> The most incomprehensible fact about Nature is that it is comprehensible.

This expresses a profound truth and it is echoed in the writings of other great men of science. Thus, Eugene Wigner has written of the two miracles: 'the miracle of the existence of laws of Nature and the miracle of the capacity of the human mind to divine them'; and he has also written about 'the unreasonable effectiveness of mathematics in the understanding of Nature'. And Schrödinger considers that this latter capacity of the human mind to divine nature's laws may well be beyond human understanding.

Let me elaborate on these statements with two illustrative examples.

Geometrical curves, their beauty and their forms, held fascination for the Greeks; they are enshrined in their sculptures and their architecture. The straight line and the circle dominate Euclid; and the perfection of the circle was sacrosanct: it underlies Aristotle's conception of celestial bodies and it provides the basis for Greek astronomy from Eudoxus to Ptolemy. But the Greeks did not confine their studies to straight lines and circles only. They sought curves that would encompass the geometrical properties of straight lines and circles in a more beautiful and harmonious synthesis; and they discovered this harmony in the curves obtained as sections in a cone: the ellipse and the hyperbola. Their curiosity with respect to these curves was not motivated by any physical fact they discerned. And yet, in the second half of the third century BC, Apollonius of Perga wrote eight monumental volumes devoted to these curves. Apollonius is eloquent about their geometrical properties; he describes them as miraculous. But it did not occur to him, or to the other Greek mathematicians, that the curves, which they studied so earnestly for their intrinsic beauty, had any relevance to the real physical world.



Kepler on his law of areas (the radius vector describes equal areas in equal intervals of time): 'Since I was aware that there exists an infinite number of points on the orbit and accordingly an infinite number of distances [from the Sun] the idea occurred to me that the sum of these distances is contained in the *area* of the orbit. For I remembered that in the *same manner* Archimedes *too divided* the area of a circle into an infinite number of triangles'.

Kepler on his law concerning the elliptical nature of the orbits of the planets: 'Why should I mince my words? The truth of *Nature, which I had rejected and chased* away, returned by stealth through the backdoor, disguising itself to be accepted . . I *thought* and *searched, until I went nearly* mad, for a reason, why the planet preferred an elliptical orbit'

Yet some eighteen centuries later, when Kepler was analysing the orbits of the planets on the copernican system, he discovered that the very curves that the Greek mathematicians had studied for their intrinsic mathematical beauty were exactly those needed to represent the orbits of the planets. Commenting on this discovery of Kepler, Einstein has written:

> *Our admiration for Kepler is transcended* only by our admiration and reverence for the mysterious harmony of Nature in which we find ourselves. Already in antiquity, man had devised curves exhibiting the simplest forms of regularity. Among these, next to the straight line and the circle, the most important were the ellipse and the hyperbola. We see that the last two are embodied—at least very nearly so—in the orbits of heavenly bodies.

Einstein continues:

> It seems that the human mind has first to construct forms, independently, before we *can find them in things*. Kepler's marvellous achievement is a particularly fine example of the fact that knowledge cannot spring from experience alone but only from a comparison of the inventions of the intellect with the facts of observation.

Let me repeat the crucial part of this remarkable statement: 'The human mind has first to construct forms, independently, before we can find them in things'.

I should like to illustrate this same aspect in Einstein's own development of *his general theory of relativity*, a theory that has been described as 'the supreme example of speculative thought'.

More than one hundred and thirty years ago in a celebrated lecture,

---

This essay is the substance of an address delivered at Roorkee University, India, on 28 November 1989.

Bernhard Riemann, analysing the foundations of geometry, came to the view that space is not a lot of points close together but a lot of distances interlocked, and further, that these metrical properties of space are causally linked with its matter-content. He states:

> Therefore, either the reality on which our space is based must form a discrete manifold or else the reason for the metrical relationships must be sought for, externally, in the binding forces acting upon it.

With this conception of the possible role of geometry in describing the physical world, Riemann developed a system of geometry more general then Euclid's, a system which has come to be known as riemannian geometry.

Some sixty years later, Einstein was absorbed in trying to understand a miracle that underlies the newtonian theory of gravity and an inconsistency in it which he perceived. The miracle is *that all bodies are equally accelerated in* gravitational field, as manifested by *Galileo's well-known demonstration* from the leaning tower at Pisa. It requires the inertial mass and weight to be identical—an enigmatic fact well established but not really understood before Einstein. And the inconsistency that Einstein perceived is that Newton postulated that the action of gravity at a distance is instantaneous—contrary to Einstein's own prohibition that no signal can be propagated with a velocity *exceeding that of light. In resolving* these paradoxes, Einstein found that *Riemann's geometry provided him with* a framework ideally suited for developing his general theory of relativity; not unlike Kepler who found in the geometrical works of Apollonius the framework for his understanding of planetary motions.

And Einstein's theory, developed on what appeared to many of his contemporaries as a very frugal basis on which to found a physical theory, has revealed *a richness of content that continues to* baffle the imagination.

2

Accepting our 'inability' to understand the 'reasonables' of Nature, what are we to understand by the common phrase 'The pursuit of knowledge' as it applies to science?

'Pursuit' *has the common meaning of* a chase in hunting; and, characteristic of our times, we are also familiar with the word in the combination 'pursuit-plane'. Is this the association which the word 'pursuit' evokes intended? And if it is, are we to conclude that knowledge, like the fox in a chase, or the enemy plane in a hot pursuit, is something whose existence we know of in advance and our pursuit is to aim for it. Of course, some aspects of what we include under knowledge are in this category. Thus, to unearth the fossil remains of creatures of long past, or the relics of bygone civilizations, to scale the highest peaks, or to fathom the deepest oceans, are all endeavours of high human aspiration.

But one may still ask: is knowledge, then, something which we seek to attain in the same spirit as the mountaineer who aspires to ascend the Everest *'because it is there'? If that is the case,* what are we to understand when we are told that research is a quest after the unknown to chart territories whose existence we may not even be aware of when we started? Kepler did not know, when he began his long and arduous analysis of the centuries of accumulated observations on planetary motions, that buried in that mass of details were the simple laws he discovered. Neither did *Newton know, before he saw the apple* fall, that Kepler's laws could be under*stood so simply in terms of his laws of* motion and of gravitation.

Perhaps I shall be accused of quibbling. For one may, in truth, say that in the pursuit of scientific knowledge—if I may be pardoned for that combination of words—while one does not aim for something which is material and concrete, one does aim for the enlargement of that order and that harmony which are the key signatures *of nature. Indeed, for a scientist, the* order, the harmony, the uniformity and *the universality of the laws of nature are* as real as the peak of the Everest is for the mountaineer. And so it is in the other branches of abstract knowledge.

But is that *all* there is to our quest for knowledge? Do we wish, for example, to quantify new knowledge by the extent to which others can share in it and still others can make use of it for human delight or for human welfare? And if that is our wish, what value do we attach to the refinement of one's own perception and to the enlargement of *one's own vision*? Is there no real content to Wordsworth's famous lines on Newton:

> The marble index of a mind for ever
> Voyaging through strange seas of Thought alone.

Indeed, there is ample evidence that the very greatest artists, in their ennobled maturity, withdraw into themselves. Here, for example, is T. S. Eliot commenting on the late plays of Shakespeare.

> *It seems to me to correspond to some law of* nature that the work of a man like Shakespeare, whose development in the course of his career was so amazing, that it should reach, as in Hamlet, the point at which it can touch the imagination and feeling of the maximum number of people to the greatest possible depth and that, thereafter, *like a comet which has approached the* earth and continued away on its course, he should gradually recede from view until he tends to disappear into his private mystery.

What T. S. Eliot has said of Shakespeare applies equally to Beethoven. In his late compositions and especially in his late quartets, Beethoven was indeed 'Voyaging through strange seas of Thought alone'—voyaging, in fact, to enlarge his own personal vision.

This attempt by the greatest minds to enlarge their personal vision is, I believe, manifest also in the remoteness and in the laminated and glacial style of Newton's *Principia*. The lasting value of the *Principia* lies as much in Newton's vision of the Universe, as in the surpassing quality of his discoveries which it summarizes and organizes.

3

And finally I wish to consider the sources of one's satisfaction in scholarly *endeavours*.

Perhaps I should first eliminate, *ex cathedra,* that the rewards of scholarship consist of celebrity and of public honours. The supreme Magisters of Castalia, in Hermann Hesse's *Glass Bead Game*, had learned to renounce them. I suppose that one does renounce them in the end—at least, one feels that one ought to transcend them. But the matter is not as simple as that. None of us are so immune to human sensibilities that we are not all, to some extent, sensitive to the approval of our colleagues whom we respect. And I am sure that all of us hope, each in his own way,

that posterity will assign to us our due and humble places so long as we persevere at the limits of our capabilities.

But posterity can be harsh. Here, for example, is John Ruskin's criticism of the English painter Sir Joshua Reynolds:

> Why did not Sir Joshua—or could not—or would not Sir Joshua—paint *Madonnas*?... Yet! While we acknowledge the discretion and simple heartedness of these men ... we have to remember... that amiable discretion is not the highest virtue, nor to please the frivolous, the best success.... There is probably some strange weakness in the painter, and some fatal error in the age, when in thinking over the examples of their greatest work, for some type of culminating loveliness, or veracity, we remember no expression either of religion or heroism, and instead of reverently naming a *Madonna di San Sisto*, can only whisper modestly, 'Mrs Pelham feeding chickens.'

If one recognizes that one can never come to painting a Madonna, what, then, are the satisfactions and the rewards? I suppose that one must count them in those brief moments of sudden insight which occur to one on rare occasions. One may never come to painting a Madonna. But, perhaps, in capturing on canvas, the rugged lines in the face of Mrs Pelham, etched by the toils of her life, the painter may have experienced a sudden insight into the sadness of the human condition which he may cherish all his life. And so it is in all other walks of creative effort.

While one may grant that the rare moments of illumination one experiences during the course of one's life are the precious rewards, one is still troubled; for, one may ask: is he condemned to live only in the memory of his past moments of illumination? The answer, it seems to me, is that, if one is not to be so condemned, one must seek in one's enlarged and refined perception a source for quiet contemplation. In other words, 'Voyage through strange seas of Thought alone'. But even this may not always be possible, as Hermann Hesse poignantly describes in his portraiture of Joseph Knecht in the *Glass Bead Game*.

The *Glass Bead Game* is the wondrous tale of one who, in his youth, aspired to the ideals of Castalia and who, in time, rose to become the supreme Magister Ludi. But in the end, in deep doubts, he renounces his office, exiles himself from Castalia, only to be drowned accidentally in a Swiss lake.

Let me try to answer directly the question why one, fully aware of one's inherent and often insurmountable limitations, nevertheless devotes oneself to scholarship and to a life of constant endeavour, many failures and fewer successes? The answer is, as T. S. Eliot has given in his 'Confidential Clerk':

> It is strange isn't it,
> That a man should have a consuming passion
> To do something for which he lacks the capacity?

S. Chandrasekhar is in the Laboratory for Astrophysics and Space Research, The University of Chicago, 933 East 56th Street, Chicago, Illinois 60637, USA.

MEETINGS/SYMPOSIA/SEMINARS

Eighth Congress of the Asia and Pacific Division of the International Association for Hydraulic Research

Place: Pune, India
Date: 20–23 October 1992
Themes include: river hydraulics, environmental aspects, coastal and maritime hydraulics, water resources, measurements in hydraulic research and hydraulic structures
Contact: Dr P. P. Vaidyaraman
Chairman, Local Organizing Committee
VIII-APD-IAHR Congress
Central Water and Power Research Station
Pune 411 024
Telephone: (91) 0212 445550–51; Telex: (91) 0145–7390
Telefax: (91) 0212–445268

33rd Annual Conference of Association of Microbiologists of India

Place: Goa
Date: 5–7 November 1992
Contact: Prof. S. Mavinkurve
Organizing Secretary, 33rd Annual Conference of AMI
Department of Microbiology
Goa University
Goa 403 202

Environmental Regeneration in Headwaters

Place: Prague, Czechoslovakia
Date: 2–6 November 1992
Contact: Dr Josef Krecek
Institute of Applied Ecology
Agricultural University of Prague
281 63 Kostlec n.C.l.,
Czechoslovakia
Fax: (42) 203 97458

World Neem Conference, 1993

Place: Bangalore, India
Date: 24–28 February 1993
Contact: Dr T. S. Subramaniam
Conference Secretariat
'World Neem Conference'
Agricultural Research Centre
ITC Ltd., *International Business Division*
7th Floor, Anrutha Topaz, Somajguda
Hyderabad 500 482
Telephone: (91) 842 210161, 210162, 211824