

On Science Education and Scientific Research

To day science appears to have acquired an unprecedented awareness and popular appeal thanks largely to its applications to technologies such as telecommunication, transportation, radio and television, ^{computers} electrical kitchen gadgetry, and ever increasing number of applications which bring comfort and luxury and relief from drudgery for a larger and larger number of human beings around the world. To be sure, there has also been a dark side of the applications

of science, namely the production of the instruments of annihilation of the human kind* if the human being inhabiting this planet so ~~desires~~ desires.

Many well meaning people ~~but~~ This has also led to an anti-science wave among ^{some} ~~some~~ of the social ~~enthusiasts~~ ^{social scientists} society ~~enthusiasts~~. But is science to

blame if ~~some~~ ^{some} ~~agents~~ ^{agents} of power ambitious people ~~not~~ ~~excluding~~ ~~some~~ ~~scientists~~ helped by ~~equally~~ ~~power~~ ~~ambitious~~ ~~scientists~~ to hijack ~~have~~ hijacked and vulgarized science for their own ~~reflexion~~ ^{reflexion} ambitions?

So long there exists that dark side of the character of the human being such exploitation and distortions of the will continue to occur.

To day we ~~to~~ tend to put "science and technology" together. They have become inseparable in the minds

the whole creation - the animal and the vegetation kingdom -

* may

as if almost ^{by a single} ~~one~~ word. Science and technology ^{with each other} appear almost synonymous ^{at least} as inseparable. ~~While technology~~ ~~is not~~ While technology cannot exist without science, it is also true that deeper advancement in science require ~~technological~~ ^{technological} innovations what one may call technological innovations. Yet science is ~~something~~ ^{something} different. ~~or~~ ^{or} something entirely different in spirit from technology and therefore ^{therefore} What then is Science?

What is Science?

Science is nature itself and ~~the~~ doing science means ~~the~~ appreciation of ~~see~~ the marvels of nature happening all around us. The study of science means trying to understand the ways of nature, ~~or~~ by making inquiries. ~~The~~ ~~very~~ Inasmuch as any living being is a product of nature, and has to learn to live with it after its birth, ~~the~~ it is ~~see~~ begins to ~~make~~ learn about the ways of nature and how to adjust itself with the environment provided to it for its habitation. The inquiry could be intuitive as most of us are constantly doing and learning about ~~the~~ ~~nature~~ nature. To that extent ^{there} in everyone of us. is a scientist, ~~and~~ perhaps the greatest of all ~~scientist~~ ^{scientist} intuitive scientist is the "Child".

we should fully realize and grasp the true
 we will stand above blame if we ~~are~~
 spirit of science

Its restless hands and eyes and its ~~sharp~~ alert ears and other sensory ~~perceptions~~ ^{organs} are the most furious inquirers and explorers. They are constantly seeing and feeling the nature and its ~~ways~~ learning about its ~~ways~~ (the laws). The inquiry is the essence of the learning process. When the child begins to talk,

~~When the inquiry on the other hand, explicit and more systematic and quantitative ~~is~~ than 'it constitutes what one ~~means~~ by 'science''. If a child is properly ~~the~~ ^{an} inquiring mind of the child is properly channelled it can ask meaningful questions at high levels of perception. As many of us grow out of our childhood, we begin to accept~~

~~his inquiries become more explicit. ~~He~~ begins to ~~verbosise~~ ^{verbalise} his inquiries. They become more explicit and specific. He asks a variety of questions about ~~the natural~~ ^{among other things} processes around him. Most of ~~the~~ ^{the} adults ground him, however find his ~~enquiries~~ ^{enquiries} including his parents and teachers ~~usually~~ ^{may} find ~~these~~ ^{these} inquiries "bothersome" and ~~if not~~ ^{if not} ~~irritating~~ ^{may} and ~~discourage~~ ^{discourage} him from asking questions. Then the killing of the spirit of inquiry begins for they ~~is~~ ^{is} either do not have the time or the patience to ~~or~~ ^{or} even listen to them. ~~The~~ ^{The} Conformism becomes the guiding spirit. Moreover~~

His ~~its~~ restless eyes and hand are the most furious ^{and energetic} ~~inquiries~~ ^{are} ~~They are constantly~~ feeling the nature and learning about ~~the~~ its ~~laws~~ ways (or laws) of nature. The inquiry is ~~the~~ essence of the learning process.

If the natural learning process of the child is allowed to ~~of mature~~ through the making of ~~the~~ inquiries to allowed to develop and to have its full play, and the inquiries are properly responded to and answered, the scientific faculties of the child will develop fully, and he may evolve into a creative scientist, an engineer, or even a at least a scientifically tempered member of the society.

Unfortunately most of the adults around him ~~seem~~ including his parents ~~and~~ ~~(and even many teachers)~~ may find his inquiries bothersome, and discourage him from asking questions. ~~Thereby they~~ ~~are~~ learning process is ~~not~~ thereby curtailed.

At school also, the process of education is information rather than inquiry oriented. Inquiries are by and large discouraged while information is acquisition and ~~storage~~ ^{quick retrieval} of information is accorded high premium. The examination system is also information oriented and the acquisition of high percentage of marks is ~~the only one~~ regarded as the ~~only~~ sole index of high performance. ~~Even~~ T.V. programmes which glorify the retrieval of

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if any one dares to persist in being different he may well be "chastized" and to behave in a normal disciplined manner. Conformism becomes the guiding spirit for these youngsters. Thus begins the process of the ~~spirit of inquiry~~ ^{stifling} ~~stifling~~ ^{stifling} of the spirit of inquiry. Perhaps the process is complete by the time he ~~leaves~~ ^{leaves} school. The percentage of marks obtained in the science subjects is ~~the~~ ^{the} ~~sole~~ ^{sole} ~~measure~~ ^{measure} regarded as the sole measure of his ~~being~~ ^{aptitude} ~~aptitude~~ ^{aptitude} for science. It is however, possible, and indeed ~~there~~ ^{there} are many well known cases, that some do manage to keep their spirit of inquiry alive despite the ~~system~~ ^{system} ~~which~~ ^{which} they have to pass through. What then should be ~~science~~ ^{science} education a proper science education?

Science Education:

When we talk of a science education we must in the ~~present~~ ^{present} ~~context~~ ^{context} we cannot ~~ignore~~ ^{ignore} the practical aspects. We cannot ignore the fact that a large number of students who take science courses do so with a view to a ~~career~~ ^{career} in engineering, medicine and other ~~applied~~ ^{applied} fields. These ~~are~~ ^{are} important aspects which professional applied

as encyclopaedic information only ~~rein~~ further
 reinforce the ~~wrong~~ wrong values of the information
 culture. Any departure from adherence to these ~~sets~~
 standardized, and socially applauded sets of values ~~is~~
~~not~~ would be regarded as a queer behaviour, ~~it~~
~~only~~ ~~the~~ ~~brain~~ and ~~the~~ strongly ~~conformist~~ ~~a~~
 and may even be regarded as dull wittedness.
 This ~~is~~ ~~the~~ beginning of the ossification of creativity in
 a child. Yet, there exist many ~~and~~ well known
 cases who ~~have~~ refused to be subdued by the stifling
 forces of the system and have managed to keep
 their spirit of inquiry alive as also their
 creativity. What should then be a proper science
 education which brings out the best of creative
 talents of a student to the fore?

Science Education:

When we talk of a science education in the
~~present~~ day context of the present day imperatives,
 we cannot ignore the pragmatic aspects. We
 cannot, for instance, ignore the fact that a
 large number of students who take science
 courses do so with a view to a career
 in engineering, medicine and other professional →

applied fields. These are important aspects which

have implications for the evolution and development of the society at large. But these are not the issues that I ~~would like to~~ I would ~~not~~ like to address at the present juncture. I would like to emphasize the ~~mode~~ Suffice it to say that a ~~good one~~ proper science education should be ~~would be~~ ~~only help~~ those ~~also~~ those ~~planning to take~~ be ~~also~~ to also those planning to ~~take~~ take up professional courses, ~~for~~ It is the encouragement of creativity that should be the aim of science education, and the creativity is ~~to be~~ ~~must~~ be ~~the~~ ought to be valued in all professions.

I would however like to address the question of science education from the point of view of creativity in science ~~itself~~. the pursuit of ~~science~~ of science itself.

When the legendary "apple" fell on Newton's head and ~~awakened~~ ^{literally} awakened him to the ~~existence of the~~ ^{idea} realization of the existence of a force that attracted it towards the earth, he ~~it~~ was not the first man who saw the apple fall, or the first time he ~~saw~~ saw the apple fall. But for surely it was ~~of~~ the

first time he ~~felt~~ ^{realized} the apple fall, for it did seem to have initiated in his mind the inquiry: why?

Or when Einstein while travelling by ~~train~~ streetcar in Bern was set into ~~motion~~ thinking about the ~~effects~~ of the relativity motion, which culminated at ~~later~~ into the formulation of the "relativity theory", he was not the first man to have travelled by the streetcar. ~~he was not~~ Or when Galileo performed his experiments from the tower of Pisa, ~~he~~ motivated by ~~some~~ observations ~~was~~ what then

distinguishes these ~~men~~ ^{men} from the others? It is their power ~~power~~ of observation and ~~the~~ inquisitiveness, which enables them to ~~see~~ ^{notice} things, phenomena or ~~and~~ processes which others ~~are~~ ^{pass} by, and to institute ~~is~~ inquiries about them. It is their ability to see astonishment in certain happenings which others take it for granted. It is their mental analytical ability which enables them to ~~an~~ analyse and classify observations into logical structures. It is ~~the~~ ^{the} ability which their sharpness of their perception of physical phenomena which gives ~~the~~ them delight in having ~~dis-~~ found something new and astonishing. It is

improvement, that ^{does} it give such an impression. Witness
 for example, the horrendous ^{science} text books that ~~are~~ ^{continue to be}
~~dist~~ prescribed for use of our students which
 are full of unpardonable howlers. Still ~~the~~ when
~~emphasis is~~ it is the observations of natural phenomena
 by direct visual ~~contact~~ perception that should be
~~encour~~ encouraged, it is only through pictures in
 black and white that a student is taught how
 beautiful a ^{a flower} plant, or a ^{colourful} rock is supposed to look like.

When the characteristics of a phenomena ~~are supposed~~ ^{ought}
 to be learnt by the student through
 observations, he is asked to exam these properties
 as a enumerated most ~~useful~~ and ~~dryly~~ in
 the colourless science text books. ~~One~~

~~could go on and on and on~~ These in turn are
 supposed to be reproduced in examination and
 a high percentage of marks ~~represented~~ obtained is
 all what is ⁺ important and relevant. What
 exists ~~there~~ ^{amounts to} an antithesis of creativity.

regarded as

It is amazing that this state of affairs has ~~gone~~ ^{been}
 allowed to go on year ~~and~~ year after year, ~~and yet~~ no
 one ~~Not~~ ^{or even though} the stifling effects of such a
 system have ~~not~~ ^{repeatedly} been mentioned. ~~pointed~~
~~out~~ yet the system ~~no one~~ ^{has} been ~~enough~~ enough to
 debated and pointed out. yet

for some inexplicable reasons the system continues. Is it therefore any surprise that our assets of creativity are as ~~small~~ ^{low} as they are?

A country which is credited with ^{having nurtured} a large number of creative physicists ~~until~~ ^{almost} during the first half of the present century, namely Germany had a ~~an~~ ^{rather free} academic environment. I quote from Max Born about the state of the ~~academic~~ educational system and associated academic environment prevalent at the time when ~~Max~~ ^{Bo} he got his education.

"In Germany at that ~~for~~ period (there was) complete "academic freedom" at the University. There was in most cases no strict syllabus, no supervision of attendance, no examinations except the final ones. Every student could select the lectures he liked best; it was his own responsibility to build up a body of knowledge sufficient for the final examination which were either for a professional certificate or for a doctor's ~~deg~~ degree or both. Thus I made up a rather mixed programme for my first year including physics chemistry, zoology, general philosophy and logic, mathematics and astronomy....."

If we compare this system then prevalent in Germany
 (as I suppose it must also be now), with what exists
 in our country, the ~~implications~~ ^{contrast} is obvious. How
~~the students are made to swallow~~ Our system is
~~by contrast~~ ^{coercive} as ~~it is~~, in more than one sense, is
~~hardly conducive~~ to creativity. Students are
 coerced to study subjects which they may not
 relish; they are coerced by parents and society
 to secure high percentage of ~~marks~~ aggregate
 marks ~~regardless~~ ^{regardless} of ~~whether~~ ^{any} and
 oblivious of ~~the~~ ^{any} ~~learning~~ real learning in the
 process. All the students irrespective of their
 aptitude are coerced into a chosen few
 professional directions. At the end of ^{the} assembly
 line one thus gets only two ^{or three} kinds of
 objects 'round' ~~and~~, 'cubic', ~~and~~ and may
 be 'cylindrical'. Where is then the scope for
 creativity? Creativity requires that a student be
~~allowed~~ ^{encouraged} to develop his ^{innate} ~~innate~~
~~innate~~ ^{innate} desires and aptitudes and a choice
 should be available to him - a choice to
 develop his own personality and his own
 individuality: ~~I am strong of the belief~~

perhaps ^{in their own limited domain} that there exists a greater degree of creativity among the population who have not gone through this standard ~~been~~ 'blessed' with this kind of education and whom we may call "uneducated", because their power of observation has not ~~been~~ ~~or~~ ~~suppressed~~ ~~eroded~~ destroyed by the coercive effects of our education system.

It is therefore extremely urgent that we give ~~of~~ completely new directions to our science education if we wish to ~~compete~~ excel in the scientific fields and to compete at an international level in the creation of original ideas.

Scientific Research

Our ~~propensity~~ ^{ability} to do scientific research at the highest international level is intimately related to our training during the process of education and to our attitude to ~~research~~ science research.

Scientific research today has degenerated to the state of a profession, and ~~the~~ ~~decline~~ there is ~~thus~~ a ~~slow~~ steady decline of standards. ~~It was not so~~ It was not so during the

science a student must know the latest, otherwise he would be left behind. And if new ^{modern develop-} ~~things~~ ^{ments} have to be taught in B.Sc, then old things must be pushed down to XII standard, and so on. Moreover, ^{the panel of} mathematicians who design the mathematics courses see in every student a potential mathematician and so would want him to learn all the mathematics that they can teach. Likewise the panel of physicists and chemists do likewise and keep on enlarging the syllabi for the XII std students. ~~The~~ ~~that~~ ~~the~~ ~~process~~ ~~continues~~ ~~down~~ ~~the~~ ~~line~~ ~~to~~ ~~std~~ ~~I,~~ ~~where~~ ~~the~~ ~~little~~ ~~children~~ ~~The~~ ~~result~~ ~~is~~ ~~so~~ ~~is~~ ~~that~~

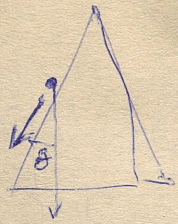
This is not only counterproductive ~~but~~ and counter-educative ~~but~~ ~~cruel~~ ~~in~~ ~~the~~ ~~extreme~~, but ~~and~~ amounts to subjecting the tender minds to a kind of academic violence and torture. The number of suicide cases that are reported during the examination time are not unrelated to this fact.

It is extremely urgent that we give completely new directions to not only our science education but ^{adopt} ~~have~~ entirely different approach to our ~~education~~ ~~system~~ itself.

Scientific Research:

~~Before we talk of scientific research we ought to define what we mean by scientific research in its general terms.~~ Scientific research means an advancement of knowledge over what is ~~known~~ exists at any given time. While science education is ought to aim at learning about the existing knowledge in a methodical way and ~~at~~ developing keen sense of observation and analytical ~~ability~~ mental ability, scientific research means a further exploration of nature beyond the present frontiers of knowledge, using the skills and the power of observation and analysis acquired in the process of learning science.

Thus our ability to do scientific research at the highest international level is intimately related to our training during the process of education and to our attitude to science research. Of course scientific research is in general, both basic and applied. ~~While applied research is~~ While ~~ex~~ Both types of research are extremely important for our country, it is not the type but the



mg cos θ =

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~~1~~

quality of research which is ^{of} the central issue.

Science research, ~~progress~~ has usually progressed by leaps which have ^{been} taken by individuals with ~~new~~ unusual powers of observation and insight. One can recall the names of Copernicus, ^{Kepler} Newton, Leibnitz, Euler, Lagrange, Hamilton, ~~Max~~ Kelvin, Clausius, ~~Max~~ Faraday, Maxwell, Einstein, Bohr, Heisenberg and Schrödinger, and Dirac. The list is, of course, not complete. * Among the classical physicists, the names of Copernicus, ^{Kepler} and Newton, on the one hand, and that of Faraday and Maxwell on the other stand out ~~as~~ ^{most prominently} giants, for while the former gave us the science of mechanics, the latter gave us the laws of electrodynamics, the two cornerstones of classical physics.

After such leaps there still remains large amount of work to be ~~can~~ done which consists in ~~the~~ applying the laws so discovered to a large body of phenomena where these laws could be applicable. A large ~~of~~ number of first rate physicists ~~belong to this variety~~. Both experimental and theoretical belong to this

* These names stand enshrined in the annals of science

category. This is also a very important class of physicists because they are the ones who help establish ^{and expand} the regime of validity of the laws of nature ^{so far} probed ~~by~~ through painstaking experimental work and ^{in comparison} ~~theoretical~~ associated theoretical work.

This may not appear to be ^{so} glorifying ~~a job~~ at first sight, ~~as~~ and rewarding a job at first sight. However, every scientific investigation well done is important, for therein lies the opportunity of a new finding ~~or~~ which ~~it~~ may be defying the existing laws*. Thus the painstaking observations of the "black body spectrum" which ~~may~~ ~~have~~ appeared led to the birth of quantum had in them the germs of the most important discovery of the twentieth century, namely the "quantum theory." for it could not be explained in terms of the laws of classical physics.

What are the motivations of a person who opts for a career in scientific research? It cannot be the ~~monetary~~ riches because of the conventional kind, for ~~there~~ ^{there} are not ~~riches~~ in this career. ~~Any one~~ who have opted for such a career, in its true spirit ^{perhaps} ~~perhaps~~ ^{some day} ~~some day~~ so with a secret ^{wish} ~~belief~~ that, may ~~be~~ ^{their} name may be counted among those great physicists who have inspired them. In some

* and may be pointing to the existence of new ones. pointing

variety ~~of~~ ~~the~~ experimental physicists ~~will~~ ^{continue to} ~~rather~~ make
observations * which theoreticians attempt to explain or
describe in terms of the existing theories.
The ~~region of~~ ~~regime~~ of applicability and validity
of the theory ~~is~~ continues to expand. Conversely,
theoreticians also make predictions based on the
theory in vogue which experimentalists may look
for, and may find in

* on all accessible physical systems

They ~~is~~ ^{were} day dreamers. Whether ^{one} he succeeded or not is a different matter, but such a wish is a very human ^{sentiment} and does provide ~~the person~~ ^{himself} with a motivation to put his in his/her way best. And while ^{one} he is pursuing his ^{own} wish with this kind of wish and motivation, ^{one} he may discover yet another ^{kind of} motivation, for ~~doing science~~ pursuing science is namely for simply the pleasure of discovering something entirely ~~new~~ ^{new} and which nobody else besides him knows. Planck ~~had~~ ^{has} ~~his~~ ^{apparently} had this realization when ~~as~~ ^{is} reportedly he was walking with his son in a garden he is supposed to have told him that he "seems to have" discovered something as important as Newton's laws of motion." ~~On~~ ^{On} ~~the~~ ^{the} ~~other~~ ^{other} ~~hand~~ ^{hand}. To people ~~like~~ ^{of that class} ~~of that class~~ ^{of that class} science ~~is~~ ^{is} an ~~addiction~~ ^{obsession} which they would pursue even under the heaviest of odds ~~driven~~ ^{only} by the desire of learning about what lies beyond which may sometimes ~~be~~ ^{be} beyond their ^{own} capacities. ~~For~~ ^{For} ~~Marie Curie~~ ^{Marie Curie} it was ~~an~~ ^{in fact} ~~addiction~~ ^{addiction} indeed. →

What are the motivations in today's world of science? Times have of course, changed and with it our social ~~norms~~ ^{norms} and attitudes as well as the quality of motivations.

(reviewing the book, The Selfish Gene, by Richard Dawkins)

Hull David Hull has written (Nature 342 319-320, 1989)
"scientists give every appearance of being addicts and
science is their vice." ~~Marie Curie~~ "In the
addictum stakes," write John Galloway (Nature 343,
707, 1990). "Marie Curie was a 200-a-day
woman. Not for her a fellowship at a comfortable
Oxford College; she worked 12 hours a day in
a leaky hanger in the backyard" in
conditions that no self respecting heavy
labourer would have tolerated." And she worked
for nothing. That's what I call addiction."

~~The choice~~
 The choice of problems that one ^{addresses} ~~undertakes to do~~ is ~~of~~
 therefore, of crucial importance in determining ~~the~~
~~what~~ the quality of research ^{work} that one is able to do.

~~Because~~
 And the emphasis on quantity leads to indiscrimination
 in the choice of problems
 because the quantity tends to ~~not~~ carry its own
 weight, and ~~leads~~ impresses in the absence of a
 critical evaluation of the work. But the emphasis
 on quantity ~~leads to~~ can lead to indiscrimi-
 indiscrimination in the choice of problems that one
 chooses to address. A fall in the standards
 of research is consequently a distinct possibility.

A scientist has thus a variety of choices of ^{the categories}
~~available to him~~ categories of ~~choice~~ available
 to him ~~at~~ which he can ~~choose~~ to one of
 which he can try to belong ~~to~~. Whether
 he can or not is a different matter, but
 can wish and dream and try his ~~best~~
 best. The choices ~~do~~ range from the ~~category~~
 category of Newton and Maxwell, or Einstein and
 Bohr, or of Debye and Schrödinger, or to any

~~How~~
 To guard against the falling of standards ~~and~~
~~and~~ and slippages in one's own value system one has
 to constantly remind oneself of the values that
 have been upheld by all those who have passed
 on to ~~give~~ us the magnificent scientific edifice built
 by them painstakingly brick by brick. We must
 not only try to preserve this magnificent heritage
~~we~~ but also contribute to it, if we can,
 by adding another ~~brick~~ piece somewhere. ~~But~~
 to enhance its structural beauty, but must
 certainly not do anything to tarnish it.

Once one sets for himself such a high
 standards of achievement, the life is certainly not
 easy. One tries hard ~~and~~ and is constantly
 haunted by a sense of failure, because the
 successes by their ~~own~~ yardstick is are few if
 at all and failures numerous.

7.4

has said:

We do not honour scientists for being correct, but
we honour them for being creative.

Sir C.V. Raman is reported to have said, that he has been a failure as a scientist! If one did not know the real meaning behind this statement one would be astonished at this statement coming from Raman, our only Nobel Laureate in physics science. But his sense of failure, if one were to believe it, came, according to him, when he compared himself with Lord Rayleigh and Lord Kelvin. ~~It is~~ and other physicists of that calibre. The point of the story is the level at which one wants to pitch one's efforts and achievement and one's level of satisfaction without being deflected by extraneous considerations.

Science has always been highly competitive, but it is much more so today than ever before. Really new fundamental discoveries are few and far between. But they are still there, and they still beckon us and challenge us. But we must listen to that their call and go in the right direction, and not be lost in the wilderness of ~~many~~ ^{the} little ^{trivial} and insignificant things. We may be able to do many ~~more~~ little ~~correct~~ ^{correctly} things. But as Herman Bondi

* it would be highly presumptuous to suggest that ~~26/2/20~~ 7

following,
We thus have to ask the questions -

- a. Should we do scientific research?
- b. What kind of scientific research we should aim at? Should we judge our scientific research more critically than ^{what} we have been doing?

~~Or to a class of 'also ran' or worse~~

~~of the other classes of well renowned physicists. X~~

~~Or to a class which is destined to be do not leave much impact. do have their names appear~~

~~many many times over in the pages of scientific journals, but~~ Of course * it is ~~not~~ in

one's hands to belong to any particular class

that one may desire to! One can only try one's best and that is the most important thing. **

As Chandrasekhar has quoted

While incessant quest and hard work, are essential ~~that~~ ~~short cuts to doing science~~ ~~achieving real success~~ ~~in doing science~~ a certain amount of intervention by luck seems to be helpful.

** and ^{even} implied to suggest by implication that one belongs to an "also ran" class because of one's choice. This is neither suggested nor implied. The only thing that is being suggested here is that there are pitfalls which one can try to avoid and there are

It is easier said than done. ~~Chandrasekhar~~ But
 still there are those who have the passion
 and strive endlessly to achieve their treasured
 goal:
 Chandrasekhar quotes T.S. Eliot in his
 address essay (Nature 244, 285 (1990)).

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