Science Fiction and Popular Science from Ancient to Modern Times: Scientists Versus Laymen

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I have, on occasion, been asked to write a popular science article or review some popular science (PS) book. In particular, I was asked to write a review of "The Emperor's New Mind" by Roger Penrose. While working on that review I tried to find out how others had found it. Despite being on the best seller list, it appeared that few people had actually read it, of whom few had read it cover to cover. Of those, even fewer had actually followed all of it. I had a head start, having been a student of Roger's. It is an odd fact fashion that has evolved to keep such books on the shelf -- and even dip into it a bit -- but seldom to actually try to follow it. This despite the fact that there is much more popular science available than ever before, and often written by the experts in the field. This was far from being the case earlier. There has been an increasing trend for practicing scientists to write science fiction (SF) and PS. For example, the famous astronomer and astrophysicist, Fred Hoyle, wrote some remarkable SF and the physics Nobel Laureate, Steve Weinberg, wrote a PS best seller. Stephen Hawking's "A Brief History of Time" is probably one of the most popular unread books. At one time such activities on the part of serious scientists would have been viewed askance. How much and why has this attitude changed over recent times? For that matter, why did they arise in the first place? I will be unable to address these questions in the depth they deserve, within the space limitations for this article, but will try to explore them somewhat.

1. What *Is* Science?

Though there is no generally accepted *definition* of SF, it clearly has the expectation of some *science* associated with it. As such, we need to discuss what "science" is first. This discussion is even more relevant for PS, where liberties are often taken to nourish the imagination of readers who may be more attuned to fictional discourse.

There may be minor differences about what science is but, by and large, Sir Karl Popper's definition[1] can be used for our purposes. Science is the activity of formulating and testing scientific theories. A "scientific theory" is a set of assumptions that lead to (in principle) falsifiable predictions. Thus the claim "the Earth is round", is a scientific theory. It could, in principle, be proved false by going off the Earth and looking at it. When we find that it *is* round, the theory is proved. (Of course, this theory is of very limited generality, but that is not relevant for the present purpose.) The claim that "2 + 2 = 4" is *not* a scientific theory, as it can never be proved false (even in principle), being true by definition. Scientific theories of greater generality require a greater background of concepts to be understood. Even for the round Earth, there is the concept of "roundness" to be properly formulated. (How "round" must the Earth be, for the theory to be found correct?) For more profound theories, of greater applicability, there will be higher levels of abstraction required. For example, for mechanical theories we have the concept of "force", which is abstract but more easily apprehended than the concept of "energy", as that is more abstract. Still more abstract is the thermodynamic concept of "entropy". Quantum concepts are even more esoteric. The further removed the concept is from ordinary experience, the more abstruse it appears to those not familiar with it. Einstein pointed out[2] that the development of scientific theory is, perforce, from the more concrete to the more abstract.

This abstractness of modern science becomes a problem for the non-scientist who wants to understand what the new theories are all about. A separate problem associated with science is that its practitioners tend to get "bogged down" with the details and lose sight of the "broad picture". The non-scientists, faced with the outpourings of such scientists, find themselves floundering in a sea of jargon whose relevance continues to elude them. Yet another problem is the tendency of some scientists to *mystify* their work in an attempt to make it seem more profound, rather than *clarifying* it to make it more intelligible. Unfortunately, many lay people like to praise such works, because they feel that they gain reflected glory by "comprehending the incomprehensible". All these problems are relevant for our later discussion of the attitude of scientists to their colleagues writing SF.

Since the attitude of the practitioners of science to SF and PS depends on the nature of the scientific discussion in the work, it becomes necessary to categorise the science used in SF, or explained in PS. There can be various categorisations. I will choose only those relevant for my discussion here.

2. Categorization of Science

There is the most common, currently accepted, division of sciences into *natural* and *social*. The former is what was regarded as "science" from the *Renaissance* to the first half of the twentieth century. (As with all historical statements of this type, it must be taken with caution. In this context dates cannot be exact and must be taken only as giving *rough estimates*.) It was assumed that there are "natural laws" (which can not be doubted) waiting to be "discovered". There is obviously no room in this view for social sciences. During Greek and Muslim times that was not the view of "science". Matters pertaining to human behaviour were very much part of "science". In the latter part of the twentieth century, the "science" dealing with collective human behaviour was developed along the lines of what had become accepted as "science" in modern times and again entered the purview of "science" under the title of "social sciences". Natural sciences can be further divided into the *physical sciences* and the *life sciences*. At the border between natural and social sciences lie *medical science* and *psychology*, which deal with individual human beings and groups of human beings. The former of these subjects deals with humans as biological organisms, which are studied more thoroughly because of our special interest in them. The latter is complicated by the fact that it deals with consciousness. This complication is fundamental because it changes our concept of scientific laws. The usual assumption that stating a scientific law cannot change the subject of that law, no longer applies. In this case, as with human laws, there *will* be changes in the behaviour of the subject of the "laws". To the extent that we deal with humans as living organisms, to be studied as such, these subjects can be regarded as branches of the natural sciences. To the extent that we have to take account of their *ethical* and *moral* aspects, they become branches of the social sciences. These aspects are obvious for psychology but are also relevant for medicine. For example, we can perform experiments on animals with only minor twinges of conscience, but would be stopped by law from doing so on human beings, even if our consciences were dormant[3]. (Ethical problems can arise even with natural sciences where testing a theory may have serious consequences for people or for animals. There are some interesting SF stories that explore such possibilities.)

At the base of both varieties of science is *philosophy*, which deals with the basic reasoning process used in science. Of course, philosophy itself needs to use psychology and other branches of science. It is often identified with unnecessary hair-splitting. This is because of the tendency of philosophers to get bogged down in details. As providing a perspective for understanding, however, it is most important for science. Another area not so easily classifiable is *mathematics*. As would be clear from the earlier discussion, it does not satisfy Popper's definition of "science". It is, nevertheless, essential as a *language for science*. It is usually taken as synonymous with definiteness. That is a misapprehension. It is a precise and a quantitative language, but the claim that "in mathematics, every statement can be proved to be either true or false" is not valid. One can construct arithmetical languages by providing an alphabet (as a set of symbols) and rules of syntax for putting the alphabet together in the form of words. Axioms (statements taken to be true, *a priori*) can then be made in those words. Kurt Godel[4] proved that, in a given finite arithmetical language (i.e. with a finite alphabet), statements can always be made which are not derivable from any finite set of axioms. More or less as a consequence of this theorem, one finds that Aristotle's "law of the excluded middle" does not hold. In fact, there are multi-valued logic systems, which allow for possibilities beyond a statement being either "true" or "false". There is worse to come, *one can not even prove, in general, that the arithmetical system is internally consistent*.

There is another common misapprehension about science, namely that it is totally objective. With the advent of quantum theory, we began to realise that there may be an inherent subjectivity at the base of science. According to the Copenhagen interpretation of the quantum formalism[5], the very *nature* of the fundamental quantum entities depends on how we choose to observe them. An electron may be a wave or a particle, depending on the experiment performed, in which it is detected. The total objectivity in science is further suspect because of the fact that the science of a time and a place bears a strong cultural imprint. It has been realised that science is a matter of *describing* nature, not of finding "immutable laws" for it. The description is culture dependent, as is the choice of phenomena being studied. There is a strong influence of economic needs on this choice, which is determined in its turn by social and cultural considerations. Of course, there is the reverse impact of science on the culture of the time. My point is not that one is prior to the other but that we can not divorce one from the other, as was commonly believed in the Victorian view of science.

Another commonly used classification is of *the hard sciences* in contradistinction to *the soft sciences*. This is often taken to imply a value judgement, the "hard sciences" being regarded as "superior", in some sense, to the "soft sciences". It is necessary to dispel this common misapprehension. Where the level of abstraction is high, and consequently the subject matter gets further removed from common experience, the science becomes "hard" for the non-practitioner. Where there is not so much abstraction involved, the subject is more easily accessible to all and the science may be regarded as "soft". It is well to remember that what the "hard" sciences gain in *depth* they lose in *breadth*. With the increasing modern trend towards inter-disciplinary studies, which need greater breadth, there is an increasing need for the "soft" sciences. However, there is an unfortunate tendency of workers in the "soft" sciences to avoid rigour in their discussions. (There is no inherent necessity for work in the soft sciences to be non-rigorous and the lack of rigour weakens the standing of the "soft" sciences.)

3. What *Is* Science Fiction?

Let us revert to the question of what SF is. Science can come into a story as a means of escaping the limited and well-charted Earth. In earlier times, stories could be set in strange lands and provide believable adventures. Even in the early twentieth century, Edgar Rice-Burroughs could set Tarzan in the African jungles without stretching credulity too far. Further, he could still follow Jules Verne into the "center of the Earth". None of these areas of the Earth are available to the modern SF author. Alternatively, his hero, John Carter, could simply *wish* himself on Mars[6]. That, again, stretches modern credulity. To escape from the dreary Earth, one simply takes a space ship off the Earth and then proceeds to introduce strange creatures with strange habits, piracy on the "space-ways", etc. on a grand scale, as is done by Rice-Burroughs in his John Carson of Venus[7]. This is what has come to be known as "space opera". The science content is negligible and unbelievable, merely providing a gloss of realism to escapist fantasies. There are, however, more serious SF attempts. Nevertheless, one must remember that SF *is* fiction and the main purpose of fiction is to *entertain* and not to *instruct*.

It is difficult to decide exactly when SF started. There have been fantasy (fairy) stories since time immemorial. These have involved demons and magic and strange beasts and people. The strange beasts and people are known to come from distorted tales of imperfectly understood observations. Thus the *centaur* originated in times when people who did not ride horses saw invaders riding horses, from a distance. The *unicorn* comes from stories of the rhinoceros seen by African travelers. *Headless men* carrying their heads in their arms are the Indonesian orangutans and so on. In all probability the stories of magic can be traced to people coming into contact with a relatively advanced civilization. Thus there is probably a grain of truth in many of these stories, folk-tales, myths and legends. Quite often it is an imperfectly understood science which lies at the base of the stories. Who can say that the current understanding of science is "correct", much less "perfect"? From the point of view of some future observer, should our SF also be regarded as fantasy? Clearly not. Nevertheless, those myths do *not* qualify as SF.

The point is that there was no intention of being "scientific" in those earlier stories. In the Greek story of *Daedalus and Icarus*[8] there is a definite attempt to provide a method for a human being to fly. Daedalus fashions wings for flying and attaches them to his son, Icarus, with wax. In the euphoria of flight, Icarus soars too close to the Sun, and the wax melts. Though the world-view is hopelessly flawed, it would be unfair to exclude *this* story from SF, as it *is* a serious attempt to provide a scientific and technological development and its consequences in a story. There was a later attempt to get a man to the Moon by goose-power. However weak the science content, it *is* SF.

More clearly recognizable SF comes from the time of Edgar Allan Poe. He regarded working scientists as mere tinkerers with "details" and his "broad view" as genuine science. By disregarding all scientific facts as "mere details", he was ready to deem any of his ideas to be workable and "scientific". Thus, in *The Unparalleled Adventure of One Hans Pfaall*, he had a flight to the Moon in a balloon[9], despite the fact that the science of the time already knew that this was not possible. In fact, he spent some effort in trying to reconcile his idea with known science. It is this attempt that makes the story undoubtedly SF (however much his attitude to science may irritate a working scientist). Much of his SF is, as may be expected, fantasy and horror, such as *The Colloquy of Monos and Una* and *The Fall of the House of Usher*. However, his insistence that his is the truly scientific view and the working scientist's view is sheer prejudice, coupled with some reasoning to justify his ideas (however unreasonable that "reasoning" may be) makes its classification as SF acceptable.

The later SF of Jules Verne[10] and H.G. Wells[11] is, again, based on misconceptions -- we know that the Earth is *not* hollow and there are no *blood-sucking Martians* -- but is perfectly acceptable as SF, as it is consistent with the scientific views of the time. At this point, one can appreciate that it is not necessary that the scientific theory on which the story is based be generally accepted. So long as there is *some* scientific theory on which the story is based, it is perfectly acceptable SF. Thus, "Atlantis stories"[12] can be perfectly good SF, as the idea of Atlantis comes from a scientific theory based on the similarity of flora and fauna on both sides of the Atlantic, explaining it as due to their transportation across the ocean via Atlantis.

In SF a technological change, or a change in natural conditions, may be postulated, and its social and cultural consequences be explored. The changes may be beneficial or, more often, harmful. SF stories are frequently based on natural calamities. Again, alien visitations are a recurrent theme. Alternatively, human visits off the Earth are also an SF staple. In the more serious SF, there is an attempt made to provide a believable scientific base for these changes, or these visits. In view of the distances involved and the speed of light limit, visits normally remain restricted to the Solar system. With our present knowledge, there can be no serious claim of aliens coming from *within* the Solar system. This fact limits the range of speculation enormously. To avoid this limitation, some way around the known limitations is postulated. This procedure presents a problem to the serious SF writer. Once one gives up realistic limits there are no holds barred. To avoid this dilemma, Asimov proposed the criterion that *one* known scientific error be permitted -- an "SFic license" analogous to the well-known "poetic license". This license provides the flexibility required to make the fiction interesting, while retaining some limitations and a semblance of realism.

It may happen that some SF is almost indistinguishable from "fantasy". For example, Robert Heinlein's *Glory Road* or Philip Jose Farmer's series, *A Private Cosmos, The Gates of Creation* and *The Makers of Universes*, are at the border between the two. In fact, one may often find SF bracketed with "fantasy" in libraries and bookstores. Why? The reason for this "unification" of the two branches of fiction may stem from the claim of Arthur C. Clarke[13] that a sufficiently advanced technology will be indistinguishable from magic. Thus, an author who wants to write fantasy that is believable, only has to assume that there is (or has been) a sufficiently advanced technology developed, which provides validity to the use of magic. From there on the story can go ahead as a "justified fantasy". If this fiction is not to be of the space opera variety (which it generally is), it tries to concentrate on exploring ethical, moral and philosophical issues. Most of all, it tries to push the ideas of "good" and "evil", and of "ultimate goals", to their limits. In this type of SF, human interest has to be stressed. Of course, to make any fiction attractive there is need to have human interest, but that need not be the major thrust of the story in general.

We broadly see, then, the kind of issues SF deals with and the type of science that would be involved in such fiction. There must be some science content, and the primary purpose of the story (apart from entertainment) is the exploration of issues raised by the science or associated technology, not the development of plots or characters, as in other kinds of fiction. It is necessary to look at each type of SF separately to examine the principal questions raised at the beginning of this article.

4. Scientists' Attitude to Science Fiction

Initially, it may be useful to address attitudes that are less prevalent now than they were when SF was less respectable, and the views of hard scientists were more rigid. This will bring into clearer focus the changes in attitudes that have already occurred and the scope for further improvement in them.

The view of authors such as Poe probably has a lot to do with the negative attitude that scientists developed towards SF and SF authors. Without caring to learn about the details they so casually dismiss, such writers proclaim their understanding of the "inner workings of science". They continue to maintain untenable views by insisting that they not be "confused by facts". Such a closed mind and bigoted attitude is sure to alienate persons with even a modicum of understanding of science. Whereas dilettantes may be tolerated, when they condemn the workers in the field as bigoted, by being totally bigoted themselves, they bring their more reasonable colleagues into disrepute as well.

As mentioned earlier, there is a tendency among many scientists to try to make their study more abstruse than necessary. There is a feeling that this makes their work seem more profound. They purport to be all the wiser for comprehending matters that appear beyond the ken of ordinary mortals. This tendency has particularly pervaded mathematics. Teachers of this subject tend to make it appear so difficult that it discourages most students. Often scholars, who like mathematics, do so because it puts them in a "superior" category. Those who are unable to attain this superior category suffer from what is generally termed "math anxiety". The same attitude has marked academics in earlier times. When this is the motivation of a scientist, any action that reduces the mystery of his subject will, naturally, be resented. (This is not to say that all scientists have this motivation.)

Another factor is that some scientists resent people being able to pick up easily, what they had learned with so much difficulty. Having invested years in learning about some topic, it may begin to seem futile when a lay person at a party, can sound as knowledgeable as an expert. This does not trouble the soft scientist so much, as the width required there is not so easily acquired, and the matter *can* be simply explained. The hard scientist is more committed to his terminology and, unless previously exposed to the popular presentation of the subject, finds it more difficult to explain it in simple terms accessible to lay people. As such, the lay person may even sound *more knowledgeable* than the expert. That hurts the scientist.

Even with the best motivation possible, scientists may still resent lay-people dabbling in their concerns. Not only does this dabbling tend to "trivialize" their study, the major worries of the scientists are ignored. Matters that need care in presentation are presented superficially, so that the deeper points are lost. The problem here is that a matter of interest and excitement for the scientists may leave the non-specialist cold. The scientists do not want to miss out, what they regard as, "the most interesting part". When the SF writer, or the PS author, manages to get people interested in the subject *without* "the most interesting part", the scientists feel frustrated at not being able to do so. The lay presentation seems a sham, and the scientists feel that if they were ready to dispense with the scruples of intellectual integrity, they could do a better job.

The problem is enhanced when the authors of the popular work, or fiction, are members of the scientific community. According to conservative working scientists they become "traitors to science", who have "sold out" and "prostituted the subject". The added factor of professional jealousy creeps in. Such authors are perceived as "having the best of both worlds", using their scientific standing to gain "cheap popularity". As a scientist myself, I have to be constantly on my guard against developing the same attitudes. Trying to formulate objective criteria to assess the worth of any work -- SF or PS -- helps in this struggle.

The scientist must bear in mind that modern education has brought science to a much wider audience in any case. Subjects that were considered fit only for "the highest level of studies", like quantum mechanics and relativity, are now included in school and under-graduate curricula. It is not only in modern times that abstruse subjects have been trivialized. There was a time when multiplication and division were taught as advanced techniques of calculation. With the development of the so-called "Arabic numerals" in India, it became possible for children to learn how to perform these computations.

5. Scientists Versus Lay SF Authors

It is by no means clear that practicing scientists should necessarily be better SF writers. While one may expect that they would be more accurate in their SF, that may not be so either. Serious scientists can still make serious mistakes. An example is E. E. "Doc" Smith. He was an engineer by profession. In his *Skylark* series, his hero discovers some rays that have a speed equal to the square of the speed of light. That is *nonsense*! Speeds can not be equated with squares of speeds. Thus, if we measure speed in kilometers per second, the speed of light is 300,000 and its square 90,000,000,000. The incompatibility shows up clearly if we choose to measure speed in "billion meters" (million-kilometers) per second. In these units, the speed of light is 0.3, and its square is 0.09, i.e. *less* than the speed of light. Thus saying that a speed is equal to the speed of light squared can mean that it is greater than *as well as* less than the speed of light!

It must be admitted however that, by and large, scientists *will* be more accurate in their science than lay people. Authors such as Isaac Asimov and Arthur C. Clarke are famous examples of scientists who write hard SF. Others, like Sir Fred Hoyle and Robert L. Forward are less well known as SF authors, though more famous as scientists. In the case of Arthur C. Clarke, his area of specialization was his main theme of SF -- space travel. In the case of Isaac Asimov that is not so. Though his Ph.D. was in Biochemistry, none of his SF dealt with developments in that area. One might have expected that his stories would be about cloning and genetic engineering developments. However, his major contributions in hard SF were in the areas of robotics, artificial intelligence and space travel. Despite the vast quantities he wrote, and the great variety of subjects he covered in his writing, *none* of his fiction dealt with his field of specialization. (His PS writings will be mentioned in section 9.)

Hoyle is a famous astronomer with major contributions in that field. He was also one of the main proponents of the Steady State theory of Cosmology. With the observation of the cosmic microwave background radiation (CMBR), that theory essentially died. Hoyle tried to resuscitate it by arguing that the CMBR was due to small iron needles that pervade space. Where did these needles come from? Hoyle and Chandra Wickramasinghe have argued[14], in their book *Evolution From Space*, that there is sentient life somewhere, sending seeds of life to other planets in these iron needles. In a further flight of fancy, they propose that not only primitive and simple life forms are being sent, *but even insects* in larval form. They go on to claim that these repeated invasions have driven evolution! (This is not his SF but his *science*!) Most of his SF is very realistic by comparison[15]. No part of most of his SF is beyond the bounds of possibility. There is a somewhat weird SF by him, entitled *The First of October is Too Late*, but that is the exception to prove he rule. Even that is used to present some of his more speculative philosophical-scientific ideas. Forward is a theoretical physicist, working primarily in Relativity theory (my own major field of specialization). His is definitely hard SF. To me much of his science seems more speculative than his SF. Though the SF *does* take some assumptions that are not valid, they are clearly taken under SFic license.

A very famous example of a strong reaction by scientists to a dilettante is their response to Immanuel Velikovsky. He was originally a psychologist and hence something of a scientist already. As a dilettante he studied Astronomy, Physics, Chemistry and Egyptology on his own. This led to a series of books[16]: *Worlds in Collision; Ages in Chaos; Earth in Upheaval; Oedipus and Akhnaton; Peoples of the Sea;* and *Ramses II and his Time*. His starting point is that the planet Venus was ejected out of the planet Jupiter *as a comet* and then settled into its present orbit. In the process, it passed near Mars and the Earth repeatedly. These occurrences led to the Greek myths about the goddess Venus being born out of the head of the god Jupiter, the Greek and Roman myths about the god of war, Mars, etc. He further claims to "explain" the miraculous occurrences recounted in the Old Testament of the Bible (which originates with the Jews). In particular, he postulates a major near-collision of the comet Venus with Earth during the Jewish captivity in Egypt, which led to the various plagues, the parting of the sea and the manna that fell from the sky. He claims to support this reconstruction by writings from ancient Egypt. He further argues that the accepted chronology of ancient Egypt is erroneous, and that his reconstruction clears up the major confusion of the Egyptologists. When astronomers and physicists protest that his claim of a "comet Venus" are clearly fallacious, he points to his successful explanation of manna by his chemistry and clarification of the historical confusion by his Egyptology, and charges the physicists and astronomers with prejudice and bigotry. The chemists and Egyptologists protested in vain about his mauling of the facts related to their subjects, because he proclaims his successes in explaining astronomical and physical facts, again with accusations of prejudice and bigotry. As pointed out in the book[17] *Scientists Confront Velikovsky*, edited by Donald Goldsmith, Velikovsky starts with an acceptance of all the Biblical stories as *gospel*, and proceeds to try to make all other branches of knowledge consistent with them. When it can not be managed, he is ready to mangle the science and twist it to come out in support of his reconstruction of the story. Before this book by SF and PS writers, scientists had continued to deride his theories but lay people were impressed. It was only when sufficiently broad-minded scientists, who had been involved with the popularization of science and SF, such as Isaac Asimov, David Morrison and Carl Sagan, came out clearly in opposition to Velikovsky, that his theories could finally be laid to rest.

The lesson to be learned from the story of Velikovsky is that the general public can be confused by self-proclaimed scientists, because the general run of regular scientists are too rigid in their resistance to novel ideas. (Remember that Chandrasekhar had provided his explanation for white dwarf stars in the early 1930's, but the establishment, consisting of Sir Arthur Eddington and A. E. Milne, would not accept it. As such, he and Fowler were awarded the Nobel Prize 50 years after the work was done!) How can the public know when the scientists are being bigoted and hide-bound, and when they are validly rejecting ridiculous ideas? The answer is that they will trust those who can make the critique intelligible to them. *This can only be done by the* *scientist who is a PS author and the scientist who is an SF author*. Thus they have an important role to play in society. While the scientists are rejecting their colleagues who bring science to the public, they should bear in mind the valuable role that these colleagues play.

Another writer whose claims have caught the public imagination, but scientists reject, is Erich Von Daniken. He has written a series of books[18], following on his *Chariots of the Gods*, purporting to provide evidence that the myths of gods, from various areas, were based on some early extra-terrestrials. It appears that they resembled the humans present on Earth enough for them to be regarded as superior humans. They seem to have tried numerous experiments in developing and modifying humans in whimsical ways. Von Daniken uses any new ideas that he can get to "explain" myths. For example, he claims that they had black holes in which they threw criminals, which led to the idea of Hell. Though fun to read, it is difficult to take at all seriously. There is always the fascination with what Carl Sagan calls "pseudo-science" that people who desire to delude themselves seem to have. This, and the fact that it *is* fun, explains the popularity that such books enjoy.

6. The Impact of SF on Popular and "Academic" Science

One major impact of SF on science is that many young people have been attracted into working in science because of an early interest in SF. Of course, many of the enthusiasts of SF have found that serious science was not for them. However, the initial resistance to science of the pre-SF era, has disappeared.

SF has contributed to the development of hard-core science in many ways. It has occasionally provided a *goal*. For SF purposes, there is need to go faster than light (FTL). Scientists who have been reading SF start thinking about possibilities for FTL travel. They come up with *tachyons*. Other scientists criticize the idea. The original proponents try to find errors in the critique, or ways around it. Finally, the idea is killed but has led to the development of a better understanding of why the speed of light limit applies. Then some one comes up with the idea of *hyperspace*. Again, the process of progress occurs. Though the idea of hyperspace, *per se*, does not work out, it weakens the fixed view of three space and one time dimensions. The old suggestion of Kaluza and Klein, for a five dimensional theory gets revived with still higher dimensions. (It became such an accepted part of theory that Jim Hartle, a relativist, started his talk at the Sixth Marcel Grossmann Meeting in Kyoto, Japan, in July 1992, with the statement "I am going to make a very daring proposal[19]. I am going to suggest that we live in a four-dimensional world!") Though said facetiously, it does represent the present thinking among a large section of theoretical physicists.

Or again, take the idea of *wormholes* in the Universe. They arise from considerations about *black holes* (regions of such strong gravitational fields that even light can not escape from them). Relativity explains the change of the path of an object, from a straight line to a curve, as being due to "the curvature of the space" instead of a "force". To make the theory of general relativity consistent, it is necessary to postulate a copy of the Universe with a "mirror image" of the black hole in it. The two copies are joined by the so-called "Einstein-Rosen bridge". We can think of two regions of a curved Universe connected together as analogous to two antipodal parts of an apple. (The apple comes into the picture because it gave Newton the idea of gravity, so Wheeler recalls the apple whenever gravity is involved.) The Einstein-Rosen bridge gets stretched out to a path connecting the two regions, such as would be created by a worm eating through from one part to the other. An ant wanting to go from one end to the other could, now, take the short-cut through the *wormhole*, as Wheeler called it, and arrive faster than an ant going around the long way. As such it would be able to beat the "ant speed" limit on the apple. This idea certainly gained currency due to its SF utility, by providing a way around the light speed limit.

Yet again, SF themes require unlimited energy. Robert L. Forward provides a *vacuum energy battery*. The paper is published in the prestigious *Physical Reviews*. I am not convinced that it is sound science. However, neither I, nor any one else that I know of, have proved the idea wrong. When it is proved wrong, science will have progressed. (Of course, if it turns out to be right and I am wrong in my expectations, science would have progressed even more.)

Another SF contribution to the development of science is the use of *scenarios* for developing scientific theories. This is extensively used in the new ideas on *cosmology* with, what is called *inflation theory*. The consequences of a theory in a complicated situation are explored by taking typical choices, where a range of possibilities appears. By constructing various possibilities one gets an idea of a *likely*, if not definite, outcomes are anticipated.

7. Popular Science

I now come to PS. It is obviously *not* SF (since the "F" has been dropped from it) but it provides many of the same functions that SF does and used to carry the same stigma for the author. I do not know when it started. Perhaps there was no need for it in the days before science became too abstract, and books more common. Certainly, Plato's *Dialogues* can be thought of as popular philosophy and Galileo's *Dialogues*[20] as PS. However, the first attempt to popularize the study of science that I am aware of, rather than the author's own particular view in his subject, is by the great logician and mathematician, Bertrand Russell[21], during the period 1923 to 1925.

Of course, truth *is* stranger than fiction. *Whereas human imagination is bounded by experience, experience is not bounded by human imagination.* A proper *comprehension* of that experience may have to wait for the imagination to catch up, but there will inevitably be surprises in store for us, in that occurrences will not always match our expectations (however rationally based). In earlier days, the pace of change in scientific concepts was so slow that there was ample time for expectation to catch up with observation. It was only a matter of intellectual inertia on account of religious dogma that created problems. From the time of Sir Isaac Newton, the level of abstraction went beyond common observation, and there was need for re-adjustment. However, except for a very few, there was rapid acceptance of Newtonian physics. The physics of James Clerk Maxwell was considerably more abstruse. While Newton's "action at a distance" could be swept under the rug, having been proposed much earlier by Al Kindi, Maxwellian "action at a distance" rubbed one's nose in it. The force could be directly *seen*. Close a switch *here* and a needle moves *there*. Here we had "magic without magic" (with due acknowledgement of the *J. A. Wheeler Festschrift* title[22]). Truth had become at least as strange as fiction! With the even more abstruse general relativity of Einstein and the downright *spooky* observed non-local quantum effects, truth has totally outstripped fiction. So many of the modern facts and theoretical expectations are totally counter-intuitive. These later developments have brought about the need for PS writing.

As mentioned before, one of the earliest popularizers of science was Lord Bertrand Russell. His hallmark was the extreme lucidity of his writings, be they on philosophy, science or social and ethical matters. He is one of the people primarily responsible for bringing the social sciences into the purview of science on account of his extensive writings on subjects that would nowadays be so called. However, it is not clear that he should be regarded as a scientist himself. Most other people who wrote about scientific subjects took a more *historical* tack. These were seldom scientists themselves, but were more likely to be popularizers and historians of science.

One of the earliest *scientists* who wrote PS, that I am aware of, was George Gamow, who was a nuclear physicist to start with and later developed an understanding of stellar evolution. He went on to formulate the so-called "hot big bang" model of the Universe, which is the standard model at present. Though he was a "serious scientist" in that he did provide serious and significant contributions to science, he was a "non-serious scientist" in another sense. He had a tremendous sense of humor. Having written a paper with a student named Alpher, he inserted the name of another student, Hans Bethe, so that the authorship should read *Alpher, Bethe, Gamow*. This paper[23], as he had intended, became famous as the *Alpha-Beta-Gamma* paper. He had strong disagreements with Hoyle about the theory of the Universe. Whereas Hoyle supported the Steady State Theory (according to which the Universe is eternal), Gamow was a proponent of the Big Bang Theory (according to which the Universe started at an instant of time, not with a whimper but with a bang.) He had pointed to the observed abundance of primordial elements as evidence for his theory. When Hoyle refused to accept the argument, he wrote a "New Genesis" in which he made fun of Hoyle's theory. In it he wrote "And God said `Let there be Hoyle.' And there was Hoyle. And God looked at Hoyle … and told him to make elements in any way he pleased." He went on with "And so, with the help of God, Hoyle made heavy elements in this way, but it was so complicated that nowadays neither Hoyle nor God, nor anybody else can figure out how it was done." His PS was genuinely *fun* to read. While much of his PS[24] was of an astronomical nature: *A Planet Called Earth; Birth and Death of the Sun;* he also wrote one of my favorite popular mathematics books: *One, Two, Three, Infinity*.

One of the earliest famous popularizers of science was Sir Lancelot Hogben, who wrote a series of books for adults and children[25]. Among them are, *Science for the Citizen* and *Mathematics for the Million* for adults and *Mathematics in the Making*, *Man Must Measure* and *Men, Missiles and Machines* for children. The first two books took England (and its colonies) by storm, so that all non-scientists with pretensions to intellectualism took the former two books as required reading. They did much towards developing public interest in the subject. However, this was merely the dawn of the age of PS. It is worth mentioning here that this and some other similar works, have been undertaken with a view to improving the understanding of the lay public. Unfortunately, there are far too many other PS attempts which try to glorify the works of the scientists rather than to inform the reader about the subject.

It was when the SF authors Isaac Asimov and Arthur C. Clarke entered the PS field that it really got started[26]. (In fact, it is not clear whether Asimov should be regarded as essentially an SF or a PS writer. Though he started as an SF writer, even before he became a scientist, the bulk of his writings are on PS.) With them it was no longer a matter of *dabbling* in it, but of using it as a moneymaking proposition. The earlier attempts were all of *amateurs* while their work was *professional*. However one might decry commercialism entering into academic pursuits, it is the commercial (and only the commercial) demand that can bring professionals into the field. And it is only the professional who will really do the job. Later, scientists like Carl Sagan (who also wrote such SF classics as *Contact*) entered the field as semi-professionals in popular science[27].

(Incidentally, Sagan's PS books such as *Broca's Brain* or *The Dragons of Eden*, are less well known than his TV series for popularizing science *Cosmos*.) Meanwhile full-time professional PS writers also came forward.

The next major development was that some of the best serious scientists started writing popular expositions of the subject that they had been working on. The first PS "best seller" that I know of was *The First Three Minutes* (in 1977) by Stephen Weinberg[28], who later shared the Nobel Prize for his work on the Unification of the Weak Nuclear with the Electromagnetic force. This book told the story of the birth of the Universe, explaining how we get to know about it, and to what extent we can be sure of what we know. Like Asimov and Clarke, he *clarified* the subject instead of mystifying it (as so many PS writers have done). However, he seemed to be apologetic about having "deserted" the serious science field and entered the popular arena. He talked about "returning to the pages of *The Physical Review*", where he "felt more comfortable". However, he returned repeatedly to PS writing, as will be discussed later.

The next that comes to mind is Stephen W. Hawking's[29] *Brief History of Time* in 1985. It deals with the same subject as *The First Three Minutes*, but goes into speculations about a still earlier time. It does not distinguish clearly between speculation and that which is more definitely known. It is based on Hawking's ideas. Some of them (like radiation from black holes due to quantum effects) are more generally accepted, some are less widely believed (like quantum cosmology) and some (like the "no-boundary boundary condition" of Hartle and Hawking, in the Euclideanised version of space-time) are still more speculative. There is nothing that can be regarded as established. He ended up with a suggestion that the Universe might be thought of as having no beginning and no end, through the mathematical trick of Euclideanisation, *without* further clarification of how it should be understood. Although this work was widely acclaimed, I feel that it did *not* make the ideas more comprehensible. Instead, it made the reader feel that Hawking had deep and profound thoughts that were beyond the reader. This fact may be apparent if you think of the above terms presented with little more explanation. However, he was *not* apologetic about entering the popular arena. This is a major difference in attitudes that has developed recently. In the decade between the two PS books mentioned, academia adopted a more flexible attitude to PS. Even SF-writing became much more acceptable. He then wrote a sequel entitled *Black Holes and Baby Universes* (which is a collection of essays similar in style and content to his first book).

Then my one-time Ph.D. supervisor, Sir Roger Penrose, wrote his attempt at a PS book[30], entitled *The Emperor's New Mind*. I may be biased, but I think that it is *much* clearer than Hawking's PS book. However, it is not a book that can be taken as casual reading. Though all concepts discussed are explained in the book, it is certainly not light reading for those unfamiliar with the mathematics and science discussed there. It deals with the question of whether artificial intelligence (AI) has, or can, be achieved. In the process he appeals to various results from the foundations of mathematics and physics, from Gödel's theorem to general relativity and quantum theory; to various aspects of biology, physiology and psychology; and then tries to develop a theory of consciousness. He arrives at the conclusion that, not only has AI not been achieved, it can not really be achieved, in that the AI will only have a semblance of intelligence but can never be *the real thing*. His problem is *not* of trying to mystify the subject. He *does* explain *everything*. However, there is a level of maturity required in all the subjects, which is not likely to have been reached by most of his readers. As such, he is likely to lose the reader's interest.

From my discussions with most lay readers, I find that they have tended to skip much of the material and skim through the book. This applies even to many experts in one or two of the fields used in his *tour de force*.

Roger Penrose has, since, written a sequel to his book, which will be discussed later. The fact that sequels to "best sellers" have appeared, and been "best sellers", demonstrates the enormous increase in acceptability of PS and semi-PS writing. Does the fact that there have not been so many SFs written by the best scientists mean that it is *less acceptable*? In my view the answer in "No." It is not that scientist-SF writers are currently facing so much resistance, as, that there have not been so many top scientists who have tried SF writing seriously. The few working scientists who have, have done well enough in both fields.

One of the areas of Physics that has generated a lot of recent PS is the *quantum theory* and its applications to understanding the fundamental constituents of matter and the forces acting between them. The reason for the enormous outpourings on the subject is that it is one of the theories most misunderstood by the public (and most popularizers of science), and one least understood by the experts. The problem with it is that it *is* weird! Let me try to explain why.

Quantum theory started with Max Planck's explanation of the laws of radiation by assuming that it is absorbed by matter in discrete *quanta*. Albert Einstein explained how light caused currents to flow in metals by taking the postulate more seriously and treating light as *consisting of discrete quanta*. Then Niels Bohr used the same idea to explain how an atom can be stable despite the fact that it contains electrons that must be accelerated, while they would have been expected to spiral into the nucleus as they radiated away energy. These general ideas were formalized more fully by Erwin Schrodinger and Wehrner Heisenberg, in two apparently opposite ways. There were a number of questions raised by the formalism. It seemed to say that objects were to be described by a "wave function" but on the other hand that the wave function only gave the probability of finding the object at some place. *How could one, then, deal with individual objects?* Probability, after all, only applies to collections of objects. Again, it seemed to require that both the position and the momentum of a particle could not be simultaneously known. *Should this be taken as a limit of our knowledge, of the nature of particles or of "knowability"?* There were endless debates on this matter between Einstein and Bohr, which ended with the vast majority of working scientists in agreement with Bohr. Later Paul Dirac showed that Schrodinger's and Heisenberg's descriptions are in fact equivalent. If any single scientist is to be credited with inventing quantum theory, it would have to be Dirac.

Two of the strange conclusions that Einstein objected to were, that objects only exist to the extent that they are observed and that there is an inherent randomness in the laws of Nature. It is in this context that Einstein made his oft-quoted aphorisms: "I can not believe that the Moon will change because a mouse looks at it"; and "I do not believe that God plays dice with the world". With Boris Podolsky and Nathan Rosen, he tried to demonstrate that the ideas of Bohr would lead to the unacceptable conclusion that signals could be sent faster than light, in contradiction to his special theory of relativity. They claimed that quantum theory is an incomplete description of nature. Bohr's attempt to refute this argument led David Bohm to suggest a way to show that Bohr was wrong. In itself, the idea was not testable. However, John Bell formulated it in a way that could be experimentally verified. The test, performed by Aspect and by Fry, led to the vindication of the predictions of quantum mechanics. It turned out that it is not necessary to suppose that signals travel faster than light but one must give up the idea that quantum objects can be regarded as particles with no spatial extent. Instead, they have to be thought of as extended (*non-local*) objects.

More recently there has been a fresh development that, again, caught the public imagination: the so- called theory of “chaos”. It shows that while, in principle, classical physics is fully predictable, in practice that predictability has no relevance. The point is, that with very minor changes in the situation at a given time, there can be drastic changes in the outcome. Since one can never know the situation at a given time precisely, one is unable to meaningfully predict subsequent events. The classic example of this limitation is the weather. As they say, if a butterfly flaps its wings anywhere in the world, the prediction could change from “calm” to a “hurricane” at the antipodal point in three days.

Of course science is limited. There are many things worth knowing, discussing and enjoying, which have no scientific content. Aesthetics is an example of a relevant non-scientific field. Of more relevance for our purposes is the fact that it often fails to make predictions. This fact appeals to the mystics, who like to use it to argue that science is useless. Many popularizers of science like to further mystify science through quantum theory and chaos, so as achieve greater popularity. I will ignore this vast majority of works on quantum theory and concentrate on the PS writings of the serious scientists.

Penrose’s *The Emperor’s New Mind* dealt to a large extent with his view of how general relativity can solve one of the mysteries of quantum theory -- namely non-locality. The problem is that an individual quantum object can be spread over meters, and even kilometers. Then, when a measurement is made on it, it suddenly collapses to a point. There is, at present, no understanding of what makes this collapse possible and how to know when it will occur. Also, at present, there is no valid theory that incorporates both general relativity and quantum theory. It should be borne in mind that these two theories have been found to be incredibly precise in their respective domains of applicability. So far there have been no situations where both would be expected to give significantly different predictions from classical theory. However, we can visualize such situations (and in fact know that at some stage in the history of the Universe they did prevail). Penrose’s view is that there will exist some theory different from both, which gives both as an approximation. Most quantum theorists take it for granted that it will be general relativity, and not quantum theory, that will be modified. To me it seems that this “quantum chauvinism” is unjustified. Penrose returns to this theme in his *Shadows of the Mind* and *The large, the Small and the Human Mind*. As before, his explanations are very clear. In fact, he seems to have adapted to the requirements of PS better. He has certainly refined his arguments in the light of various criticisms of his first book (and the second).

Weinberg also returned to PS writing, this time in connection with application of quantum theory to understanding the fundamental constituents of matter and the forces acting between them. Some of the work was expository, but some of it was directed to building public support for the enormous financial outlay required for building a particle accelerator which would achieve much greater energies than could have been expected before. The new technology to be used was of superconducting wires that could produce much more powerful electromagnets. In his *Dreams of a Final Theory* he declared this goal. Despite its popularity (though not equal to his best seller), the US Congress decided to drop the project. I felt that this book lacked the precision and focus of *The First Three Minutes*. Perhaps partly because it had an element of advertising in it.

Another book that acquired some fame is David Deutsch's *The Fabric of Reality*. Deutsch was the originator of the idea of *quantum computers*. He is a firm believer in the so-called *many worlds* interpretation of the quantum formalism. The original idea was put forward by Hugh Everett Junior III. It tries to resolve the problem of the collapse of the quantum wave function. Bohr had declared that the wave function collapsed only when an "observation" was made. It is in this collapse process that randomness enters into the quantum description of phenomena. If two outcomes of a quantum process are equally likely, they will occur equally often when the experiment is run repeatedly. According to the Nobel Laureate, Eugene Wigner, it is necessary for the information to enter some intelligence. To bring out the problem with, this requirement, Schrödinger developed a *thought experiment*, relating the outcome of a quantum process to the death of a cat in a box. Since the quantum process can only predict probabilistically and things that are not observed can not be taken to have occurred, till some one opens the box and sees the cat, it would be neither dead nor alive. Once the observation is made, it will either be dead or not. Everett pointed out that each person could doubt that another person qualified as an "intelligence". As such, the problem of observation would end up with an endless *regress*. Everett's suggestion was that at each collapse of a wave function, the universe splits into many copies, in some of which one outcome becomes real, while in others the other does. Thus, in half the universes produced Schrödinger's cat is dead and in the other half it is alive. We thus avoid the embarrassment of a "neither live nor dead" cat.

In his book Deutsch tries to explain, and explore the consequences of, this idea. When I met him in 1986, I had just been studying this interpretation and had felt that there was a very unsatisfactory aspect of this theory. One was going on producing universes with no eye to the cost. *Who pays the energy bill for all these universes?* I had put this point to him and added that it would no longer be a "universe" but a "*multiverse*". On picking up his book I was astonished to see this term used by him, not as a critique of the idea but as supporting its validity. It may be my personal prejudice against the theory espoused by Deutsch, but I felt that the book did not explain the ideas involved well, often mystifying instead of clarifying. One of the reasons for my reservations about the book is that it seemed more like an advertising brochure (for the chosen point of view) than an exposition. The one point that was *extremely* well explained, had to do with quantum computers. They could, if we knew how to construct them, perform calculations in a totally different way from ordinary computers, as they would follow a totally different logic. Deutsch claims that they would be very much faster for very large computations. (It may be mentioned here that Penrose regards the human brain as a quantum computer, possibly linked to an ordinary computer.)

Nowadays PS writing is not only acceptable but has become decidedly *fashionable*, specially among authors who would like to claim a certain standing. It may be that it has become a symbol of "having arrived". There are innumerable PS books by famous scientists such as Dyson, Gell-mann, Oppenheimer, Pauli, Polkinghorne[31], etc. The days when there was a stigma attached to it are definitely over! There is much more PS, in other fields, that should have been discussed but is omitted because of my lack of competence to do justice to it[32].

8. The Impact of Popular Science on Science

There is, of course, one very direct impact of PS on science. As with SF, more young people get attracted into the field. In fact, those who get attracted by SF, and have the potential for science, are likely to start reading PS fairly early. Thus, it also acts as a filter for those who will not go on to become scientists.

Another effect, deriving from the change in attitude to PS, is that many more scientists have started reading it, and have thus improved the presentation of their work. This change is particularly apparent in physics and least apparent in mathematics. Associated with this acceptability has come a tendency of regular scientists to be more speculative in their work. They are more likely to publish, and seriously consider, *outré* suggestions than they used to be. Part of the reason may have nothing to do with PS, but with developments in science and the "publish or perish" culture that has arisen in academia. With the acceptance of special and general relativity and of quantum theory, it is no longer clear what should be regarded as conservative and what as *outré*. Thus there has been much work done on black holes, wormholes and *baby universes*. At one time this would have been regarded as *extremely* far out, even for SF! Again, there is a serious debate about the violation of causality. Until recently, causality could only have been questioned in SF. It is much easier to be speculative than to stick to what is well known to be true and yet be original. Speculation, therefore, often provides *easier* publication than solid science does. Nevertheless, I am sure that PS has played a major role in developing more speculative ideas concretely in science. This is particularly true in the fields of cosmology and relativity.

An example of my claim above is provided by an instance from my student days with Roger Penrose. He, too, was a reader of SF. Having been interested, through his SF reading, in the need of some sufficiently technologically advanced society for endless supplies of energy, he pondered on the possibility of using black holes as an energy source. (This was *before* Hawking-radiation was proposed.) His first idea was of filling up a box with thermal radiation and lowering it by means of a spring into a black hole. On releasing the radiation into the black hole, the string could store some energy in it, corresponding to the unusable thermal radiation. This idea became much more concrete with Hawking-radiation, and has led to a lot of solid work in relativity on "mining energy from black holes". He went on to consider whether energy could be similarly obtained from rotating (Kerr) black holes. This led to his famous work with Roger Floyd on energy extraction from Kerr black holes, which lies at the base of Hawking radiation. The original work was entirely SF and PS based.

Another consequence of PS writing is that there is a greater demand for it. People *want* more serious explanations of recent developments in science. They *want* to know more about the validity of SF, or SF-like, ideas for technological developments. There is more scope for working scientists to enter into the field of PS writing, as there is now a market for it. One *can* write "best sellers" in PS. This trend is likely to continue. Already, there has been a marked change of attitude in academia, in favor of SF and PS writing. Academia will need to adjust further to this trend. Science is benefiting from these fields and there is a demand for them. Credit will have to be given for this work. When Asimov started as a scientist, he faced problems on account of his SF writing. Even his PS writing would not have counted to his credit at the University. By the end of his career, his School regarded his association with them as an asset. Nevertheless, his SF/PS writing did not lead to his appointment as full Professor. His PS has been useful for me in writing textbooks and research papers. The International Astronomer's Union has given him credit for some of his work. Should that not have been enough to get him a professorship? There is a problem with that, which I would like to expand on in the next section.

In my discussion, I have tended to concentrate on SF novels and PS books. There have been many other very significant vehicles for these two fields. The SF short story may even be *more* significant than the novel. Magazines for both certainly reach a larger audience. The magazines used to be the main vehicle for SF in the early days. However, most of the good SF from the magazines has appeared in anthologies -- quite often in different anthologies. Nowadays there are PS magazines at different levels. There are the more technical ones, such as *Physics Today*, the somewhat less technical ones, such as *Scientific American*, and popular ones such as *Omni*. Even the SF magazines, such as *Asimov's*, tend to have PS articles. Films, on the big screen and the small, must surely be even more effective in bringing science to the masses. To the best of my knowledge, PS is limited to the TV with occasional programs, such as *Cosmos*, and long running series, such as *Tomorrow's World*. There can be no need for me to dwell on the SF films. They are endless.

9. The Attitude of Academia to SF and PS

What should be the attitude of academia to scientists who are SF and PS writers? Should they be discouraged, tolerated or actively encouraged? Despite the foregoing discussion, this is not a simple matter. Let us consider it in more detail.

I do feel that it was unwise of academic institutions to *discourage* SF and PS writing. So long as the scientists are working at what is required of them, there can surely be no objection to their writing on other topics. Would there *ever* have been any objection to a scientist who wrote poetry? We know that the Persian Astronomer-Mathematician, Omar Khayyam, also wrote poetry. (In fact, he may currently be more famous on account of his Rubaiyat than for his solution of the cubic and quartic equations, or for his remarkably accurate calendar.) Why should SF or PS carry a stigma not shared by poetry or music, for example? The reason for this attitude was that there was no *remuneration* for that work, while there is for SF and PS. This attitude, against "commercialism', dates back to the time when science was in the purview of "gentlemen" and not "tradesmen". There should be no "smell of the shop" in their work. With the obsolescence of that attitude, the associated objection to SF and PS writing should have disappeared long ago. Even now, there may be those conservative elements that remain stuck to the traditional values in academics. They need to reconsider their view.

Agreeing that, *at least*, PS and SF writing should be tolerated, the question arises about encouragement. For this purpose we need to distinguish between the two. Clearly, SF should be regarded as a branch of literature. To the extent that a scientist should be given credit for dabbling in literature, there can be no harm in giving the same credit for SF. However, unless the contribution to literature is serious, one would not feel tempted to give much credit for it. For sufficiently significant work in any other field than the main one, the general procedure is to give joint appointments. That could, and should, be done in my opinion.

If work in PS is encouraged, it may lead to a major shift in emphasis of the scientists. All said and done, serious science is *hard*. It would be much easier to reproduce what others have done. Would this be a bad idea? Though it may well not do any damage, such a major change needs to be approached with caution. We do not want to introduce a change that could become a real disaster. Care is required. Perhaps it would not be a bad idea for such changes to be tried out in some schools, and their impact assessed. If work in PS is encouraged, it may lead to a major shift in emphasis of the scientists. A *gung ho* approach in this matter should be avoided.

Another question to be considered is the nature of the encouragement to be given. The author already has a direct *monetary* incentive in the payment of royalties etc. Of course, the same consideration applies to science (text) books by scientists. They get royalties for them as well. The point is that one wants a “healthy mix” of science-for- scientists and science-for-lay people. It may be useful for scientists to learn to present their work in sufficiently simple terms, not only because of the reasons mentioned above, but also because it may improve their science. My father used to say, “if you can not explain some thing you have not understood it”. I found the truth of this saying when working with John Archibald Wheeler who says, “If I want to *learn* a subject I *teach* it. He insists on finding “the poor man’s way” of seeing any new principles, even the profoundest of them. One does not realize all that is contained in the principle till one follows Wheeler through his re-presentations of it. By the end of his working through it, one sees why he insisted on pursuing those simplifications and re-expressions. Mind you, he is not a PS writer in the usual sense, but he certainly does make regular science “popular”. (He is the man who invented the terms “black hole”, “wormhole” and “big crunch”.) That capability *needs* to be cultivated -- it *needs* to be encouraged. The way to encourage it might be to require some popular, and some regular, science publication by faculty at the time of promotion or tenure appointment.

There will surely be as many views as there are people to express them. There will be many ideas on whether SF and PS should, or should not, be tolerated or encouraged. Even for encouragement, there will be many differences about *how* to do so. I have given *my* suggestions. One needs to develop an informed consensus on the matter. The purpose of this article will have been served if it has provided guidelines of the type of considerations that need to be taken into account.

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Endnotes

[1] This subject is discussed in any modern text on the philosophy of science. A more easily accessible source is J. Passmore, 1994.

[2] See A. Einstein et al., 1947.

[3] The term "science" means different things to different people. Further, the general consensus on what it is to mean, has been changing over time. There is extensive literature available on this subject. A short article giving my views on the matter is available in A. Qadir, 1978. Again the philosophy of science is a well-developed branch of philosophy. My opinion is presented in (a relatively inaccessible article) A. Qadir, 1980.

[4] The original paper, K. Godel, (1931), is not very readable. The essential point made is available at various levels of popularization. Perhaps one of the simplest to follow is the explanation given in R. Penrose, 1989.

[5] The two main branches of modern physics are surprisingly different. While special relativity came more or less complete in Einstein's paper of 1905 (see A. Einstein, 1905 or for a more modern and simpler presentation, A. Qadir, 1989), the quantum theory has remained riddled with problems and continues to be a subject of research at the fundamental level. Though it provides rules in excellent agreement with experiment, there is strong disagreement about what the formalism should be taken to mean. This is the interpretation problem. A good account of the earlier debates is available in M. Jammer, (1989) and of the more recent discussions in J. A. Wheeler and W. Zurek, (?).

[6] See Edgar Rice-Burroughs' *Mars* series books mentioned in the Bibliography.

[7] See Edgar Rice Burroughs' *Venus* series books mentioned in the Bibliography.

[8] The reference to this myth may be found in any anthology of Greek mythology or in "dictionaries for classical literature, such as J. Warrington, 1978.

[9] See A. E. Poe, 1985.

[10] See, for example, J. Verne, (?).
[11] See, for example, H. G. Wells, (?).
[12] For example, there is Lin Carter's Thongor series about a land that is lost, see L. Carter (?) for example. This was taken to be even prior to Atlantis, called Gondwanaland. Atlantis itself comes from the authority of Plato, who refers to it, but possibly as a myth. The current belief, which has substantial scientific support through experiments and observations, is that due to *tectonic plate* movements, continents have been forming and breaking up. At some stage there may have been only one continent which broke up to provide all the present continents.
[13] This is quoted at various places by many people, including Isaac Asimov, but I have not seen the original A. C. Clarke statement.
[14] See F. Hoyle and C. Wickramasinghe, 1980.
[15] See the books of Fred Hoyle mentioned in the Bibliography or of Fred Hoyle and Geoffrey Hoyle.
[16] See I. Velikovsky, 1950, 1952, 1955, 1960, 1987.
[17] See D. Goldsmith, 1977.
[18] See for example, the first of the series, E. Von Daniken, (?).
[19] This quotation does not appear in his paper in the proceedings of the conference, H. Sato and T. Nakamura, 1993, as that is not the type of statement to be found in serious papers (unfortunately). However, it is by no means uncommon for scientists to display humor (and sarcasm, I might add) in serious talks.
[20] See Galileo's *Dialogues* given in the Bibliography.
[21] There are innumerable books and essays on various topics of natural and social sciences on which Bertrand Russell has written. I have only mentioned my favorite in the Bibliography.
[22] A book was put together in honor of the 60th birthday of John Archibald Wheeler, entitled *Magic Without Magic*. The reference is given in the Bibliography.
[23] See Alpher, A., Bethe, H. and Gamow, G., Phys. Rev. **25**(1946)783.
[24] There are many books of Gamow referred to in the Bibliography.
[25] See the books of Sir Lancelot Hogben, referred to in the Bibliography.
[26] It is impossible to try to even give representative references of all that these two authors have put out. I have just given a random sampling of some of them in the bibliography. As can be guessed, my favorite is Asimov. Apparently this was also the view of the two authors concerned, as Asimov dedicated one of his books "from the second best science fiction writer to the second best science writer" referring to "the Asimov-Clarke agreement".
[27] See, for example the books of Carl Sagan, mentioned in the Bibliography.
[28] See, S. Weinberg, 1976. He also wrote a textbook on General Relativity and Cosmology, by that name.
[29] See the books of Stephen Hawking mentioned in the Bibliography.
[30] See the books of Roger Penrose mentioned in the Bibliography.
[31] Representative books by each of the authors have been mentioned in the Bibliography. Some had not written these as popular books but as separate articles, which were later collected together and published in book form. This demonstrates that the time was ripe for PS when these books appeared -- all in the late 1980's!
[32] I am, nevertheless, unable to resist mentioning my favorite author on Biology, S.J. Gould, whose clear exposition of what the theory of evolution really means, as opposed to the common understanding of the phrase "survival of the fittest", really helped to reshape my thinking.