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The Interplay of Science and Culture

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We shall begin by considering two questions:

i) what is the cultural value of science?
ii) what is the scientific value of culture?

When approaching the first question I was immediately reminded of a set of four lectures on the topic "Science as a Constituent of Humanism" given forty years ago in Dublin by the late Academician Erwin Schrödinger. He was a well-read man with wide cultural interests. As a boy he obtained a good grounding in Latin and Greek and when a young man he became keenly interested in philosophy. Apart from inventing the wave equation that bears his name he made significant contributions to other aspects of quantum theory, general relativity, nonlinear electrodynamics, statistical mechanics, unified field theories, nuclear chemistry, biophysics and probability theory. He was therefore in a strong position to answer the question proposed in the first sentence of the published version of the "Science as a Constituent of Humanism" lectures; namely, what is the value of scientific research?

Schrödinger immediately rejected the utilitarian reply that the value of scientific research resides chiefly in its application to advances in technology like speed of travel and ease of communication. He questioned whether the happiness of the human race has been enhanced by the technical and industrial developments that followed in the wake of rapidly progressing natural science and he pointed out that such advantages in technology often bring with them serious disadvantages like the spread of artificial radioactivity.

Schrödinger's reply to the question "What is the value of scientific research?" might be epitomized in the words "The value of scientific research is chiefly cultural", though the reply is not couched by him in precisely these terms. Schrödinger put the study of the natural sciences on the same footing as the study of literature, philosophy, history of music, archaeology, painting, etc., and these have no immediate utilitarian value. Their value consists in helping man to know himself and his place in the universe. This does not imply that the scientist has no need of specialization; indeed specialization is essential in order that he may be able to make an original contribution to preexisting knowledge. While he specializes, he should keep himself informed of other disciplines and so be in a better position to make both intellectual and moral judgements.

What is to be said about Schrödinger's views on the value of scientific research? It is up to each individual to hold his own opinion but I would imagine that the chief value set by a scientist on a result of his researches is estimated by the contribution that it makes to scientific knowledge. The cultural side often appears when the scientist is preparing lectures or is reading a new subject as a preparation for research activity in a new field. Then he may detect gaps in the logical presentation of the subject or may find that accepted models of a physical or chemical system are rather crude. He may question himself as to whether such a model has any physical meaning. It is also important for him to remain aware that having employed a model on a number of occasions he may have lost sight of the misgivings that were entertained when it was first employed.

I refer to such difficulties as being related to culture because they lead the scientist to some heart-searching regarding the extent to which the human mind is capable of comprehending the physical world. A phrase that used be in vogue to justify the acceptance of a physical theory was "I feel it in my bones that it is correct". In order that such a discipline as theoretical physics may exist it is presupposed that there is order in nature and that this order may be expressed by mathematical equations. I propose now to give two examples of physical results that are true but were first deduced from incorrect physical theories.

We first consider the Bohr theory of the hydrogen atom. Rutherford had assumed that the electron revolves about the proton as a planet revolves about the sun. Bohr assumed that the electron travels in a circular orbit with the proton at the centre of the circle, that the atom can exist only in certain discrete energy states and that energy is radiated only in a transition between two such states. In going between two states the atom emits or absorbs energy equal to the difference between the energies of the two states, and this energy difference divided by the Planck constant h gives the relevant frequency of emission or absorption. Lastly Bohr postulated that, if q is a generalized coordinate describing the motion and p is the corresponding momentum

$$\int p \, dq = \frac{\ell h}{2\pi} ,$$

where ℓ is a positive integer and the integral is taken over one complete range of values of q. The integer ℓ labels the states of the atom. It is found that in going from a state where $\ell=n$ to a state when $\ell=n'(<n)$ the atom radiates energy with frequency

$$\nu = \frac{2\pi^2 m e^4}{h^3} \left(\frac{1}{n'^2} - \frac{1}{n^2}\right) ,$$

where m is the mass of the electron. The equation for ν is the Balmer formula which had previously been found experimentally for the case of $n'=2$.

The Bohr theory is based on a classical model of an orbiting electron and according to classical electrodynamics the electron should lose energy at a rate proportional to the square of the acceleration of the electron. As a consequence it should very quickly spiral into the nucleus. Thus the Bohr theory is incorrect and it remains a mystery why it yields the Balmer formula. In fact this resulted later from Schrödinger's wave mechanical theory of the hydrogen atom.

We now move on from Bohr to Sommerfeld. The latter introduced special relativity into the Bohr theory of the hydrogen atom and obtained the fine structure of the Bohr spectrum which had been detected experimentally by Paschen. Dirac later deduced the fine structure theoretically from his relativistic equation of the electron, in which the electron has a spin which the electron in the Bohr atom had not. Thus it seems that two errors in the investigations of Sommerfeld, namely, the use of the Bohr model and the neglect of electron spin cancel out one another. It is not clear why this should be so.

So far I have spoken of the ways in which different physical theories lead to the same experimental result. I shall now give an example of how widely diverging theories may lead to a similar theoretical result which has not yet been compared with experiment. I refer to the mutual scattering of electromagnetic rays. This does not occur in Maxwell's electrodynamics which is linear but Maxwell's theory has its own difficulties. Thus the electric intensity arising from a charge e at a point distant r from the charge is e/r^2, and this goes to infinity as r tends to zero. To obviate this difficulty Born and Infeld replaced Maxwell's equations in free space by

$$\frac{1}{c}\dot{\underset{\sim}{D}} = \text{curl}\,\underset{\sim}{H}\ , \quad \text{div}\,\underset{\sim}{D} = 0$$

$$-\frac{1}{c}\dot{\underset{\sim}{B}} = \text{curl}\,\underset{\sim}{E}\ , \quad \text{div}\,\underset{\sim}{B} = 0\ ,$$

where $\underset{\sim}{D}$ is the electric displacement, $\underset{\sim}{E}$ the electric intensity, $\underset{\sim}{B}$ the magnetic induction and $\underset{\sim}{H}$ the magnetic intensity. In Maxwell's theory $\underset{\sim}{D}$ is a constant times $\underset{\sim}{E}$ and $\underset{\sim}{B}$ is a constant times $\underset{\sim}{H}$. This is not true for the Born-Infeld theory, which is nonlinear. As a consequence electromagnetic waves scatter one another. If we consider two colliding linearly polarized antiparallel rays of wavelength λ scattering through an angle ϕ, then the probability that there will be scattering into a small cone of solid angle $d\Omega$ is $d\Phi$ given by

$$d\Phi = 5.77 \times 10^8\, r_o^8 (3 + \cos^2\phi)^2 \lambda^{-6}\, d\Omega\ ,$$

where $r_o = 3.48 \times 10^{-13}$cm.

In 1936 Hans Euler, a student of Heisenberg, studied the scattering problem by using the Dirac "hole theory" which envisaged a photon imparting its energy to an electron in a negative energy state and so creating an electron-positron pair. There is a number of ways in which the scattering process could be viewed as a sequence of production and annihilation of pairs.

Euler had not at his disposal the techniques developed by physicists like Feynman and Dyson in the late 1940's (indeed he died in combat in 1942), and so his calculations are very lengthy. The result was

$$d\Phi = 10^8 r_o^8 (3 + \cos^2\phi)^2 \lambda^{-6} d\Omega \ ,$$

which is just about one sixth the previous value of $d\Phi$. "This is nothing short of a miracle" was the comment of Max Born, who could see no way how two so very different sets of presuppositions could have led to comparable results.

We now turn to the second question, namely, what is the scientific value of culture. By culture we understand such pursuits as the study of language and literature, philosophy and other disciplines previously mentioned by Schrödinger as being on the same footing as the study of the natural sciences. Not all of these cultural pursuits have the same importance for the promotion of scientific knowledge and pride of place is due to the study of the ancient Greek language and of the Greek philosophers. These philosophers disputed among themselves as to whether physical theories are to be obtained by applying pure reason or are to be deduced from observation. The latter view was held by Aristotle and by Thales of Miletus, who introduced the basic assumption that the physical world can be understood. Thales is also credited with recognizing that all matter of which the world is composed is intrinsecally the same. This would be expressed today by saying that all matter is composed of atoms of the chemical elements.

The idea that all matter is composed of atoms goes back to Democritus according to whose theory atoms are invisibly small, they all consist of the same stuff though they differ in size and shape, they are impermeable and the space outside them is empty; the atoms are in perpetual motion and the behaviour of all atoms inside a living body is determined by the physical laws of nature.

The influence of the ancient Greeks on scientific theory was paramount; indeed peoples who did not come directly or indirectly under the influence of Greek thought never had science as we know it. The basic advance in the thinking of the Greeks was the assertion that the physical world can be understood. This attitude is generally accepted nowadays in spite of objections by Kirchoff and Mach, who maintained that science can do no more than provide a complete and economical description of observed facts; in other words theoretical science is a bookkeeping exercise. Another feature of Greek science was that it isolates the observer from the system under examination. This is done in order to simplify the examination.

We shall now consider another, and perhaps less obvious, way in which cultural activities can further the progress of scientific thought. What I have in mind is the maintaining of an active interest in painting, sculpture, music etc., which will engender the feeling that in spite of human frailty, a beauty prevades the universe. Such an attitude of mind has proved valuable over the centuries for the creation of scientific theories. It provides a criterion for the validity of a physical theory, viz., that the theory is beautiful.

This beauty will be interpreted in every epoch in a manner related to the culture of the epoch. Pythagoras and his disciples believed that the motion of the planets is accompanied by musical sounds and that the heavens resound with harmonies. Kepler accepted this, and he concluded that God's purpose in creating the planetary system was that harmonies might resound in heaven. Now the various notes constituting the harmonies are related to the lengths of sounding strings, as Kepler had discovered, and so the planetary orbits should manifest certain whole-number relationships. In the course of searching for these relationships he came upon his three laws of planetary motion.

The criteria of beauty is not something established logically from experimental results. It is a metaphysical conviction. Another such conviction is the criterion of simplicity. One may be permitted to see in the beauty and simplicity of the workings of the universe a reflection of the beauty and simplicity of its Creator. The criterion of simplicity was employed by Einstein in his search for unified field theories and when Dirac was formulating in 1942 a combination of relativity and quantum theory he was led by the criteria of beauty and simplicity to start off with the physical theory of special relativity and the mathematical theory of functions of a complex variable. His exposition of how these theories were to be combined was itself a masterpiece of simplicity and beauty.

As a summary I recall that having accepted from the Greeks that the physical world can be understood we are also inclined to accept that a great order is present in the physical world and that this order may be expressed by mathematical equations. Some of these equations may not be logically deducible from earlier premises but they are justified by applying them to physical situations and making a comparison with experimental findings. A notable example is Schrödinger's wave equation which has been applied successfully on hundreds of thousands of occasions.

The insight into the beauty and order that exists in nature is one of the cultural benefits of the pursuit of scientific studies. On the other hand the inadequacy of the human intellect to explore fully the secrets of nature is a reminder to the scientist of his intellectual limitations. However it should not lead him into defeatism or scepticism. In the words of Schrödinger "scepticism alone is a cheap and barren affair". To proceed further in his quest of the truth which is veiled from us the scientist is often compelled to make an act of faith in his own educated guesses or in results previously obtained by other researchers.

Finally I realise that much of what I have said is open to discussion. My hope is that this communication will provide food for thought.