The Cultural Values of Science
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A NOTE ON ASPECTS OF CLASSICAL PHYSICS IN THE TWENTIETH CENTURY

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Preamble

If 'culture' is the general state of intellectual development in society as a whole then 'science' is an important and distinctive component of culture. Herein must surely lie the main cultural value of science, the subject with which this meeting of the Pontifical Academy of Sciences is concerned.

A systematic way of dealing with experience, science is [1] 'the creation of the human mind, with its freely invented ideas and concepts.

– (Scientific theories) try to form a picture of reality and establish its connection with the wide world of sense impressions.

– (Thus) we find our way through a maze of observed facts, to order and understand the world of sense impressions.

– (Without) this belief in the inner harmony of the world there would be no science'.

But the scientist is no stranger to ignorance and doubt [2], 'being fully aware that scientific knowledge is a body of statements of varying degrees of certainty – some most unsure, some nearly sure, but none *absolutely* certain. Great (scientific) progress comes from a satisfactory philosophy of ignorance'.

Science swallows its past! Unlike all other forms of knowledge, scientific knowledge is such that [3] 'the insights of the past are digested and incorporated into the present in the same way that the genetic material of our ancestors is incorporated into the fabric of our body'. No person now alive [4] 'could understand Shakespearean experience better than Shakespeare (himself), whereas (within the foreseeable future) any decent eighteen-year-old student of physics will know more physics than Newton'.

Science [5] ‘makes great demands on the purely cognitive side of human nature, (but) it also speaks to the affective side. To achieve a significant advance in science makes just as great a demand on the intellect, imagination and personality as does the work of creative writers, poets, painters, sculptors and composers’.

Aspects of Classical Physics

Physics is the scientific discipline that is concerned with matter and energy and their interactions. Possibly the most stupendous development ever to have occurred in science was the rise of *modern* physics in the twentieth century [6]. Less impressive though still very significant were concomitant advances in most areas of *classical* physics, which is based on laws applicable to processes on length scales and time scales where both quantum and relativistic effects are negligible.

These laws are concerned with (i) forces and their relation primarily to the motion of bodies of matter (‘dynamics’), (ii) relations between heat and other (e.g. mechanical, electrical) forms of energy (‘thermodynamics’), and (iii) the effects arising from the interactions of electric currents with magnets, with other currents, or with themselves (‘electrodynamics’).

The laws were well established by the end of the nineteenth century, but, to paraphrase a prescient warning issued by Maxwell three decades earlier at a meeting arranged to discuss the problem of free will [7], the traditional preoccupation of physicists and applied mathematicians with phenomena that are simple, stable and insensitive to boundary conditions and initial conditions had created over-confidence in the ‘all-encompassing influence of the laws of Nature’. Thus, knowing that the general circulation of the gaseous atmosphere of the Earth under the influence of differential solar heating must be governed by the laws of dynamics and thermodynamics, and emboldened by the success of physicists in establishing these laws, one leading scientist when asked in the year 1900 to predict likely developments over the next half-century was rash enough to suggest that little more than routine efforts by meteorologists trained in physics and mathematics would soon lead to highly accurate weather forecasts! Evidently unaware of Maxwell’s warning he clearly overlooked the serious mathematical difficulties which still beset physicists and engineers in their attempts to apply the laws to real systems [8-14].

These difficulties are especially severe in theoretical research on turbulent fluid flows and other complex processes encountered in the study of continuous media. The governing partial differential equations in terms of which the physical laws are expressed mathematically certainly provide valuable theorems and other useful diagnostic relationships between key variables. But the essential nonlinearity of the equations makes them virtually impossible to apply directly in most prognostic work, where all the multiple solutions of the equations would have to be found and their stability thoroughly investigated.

Classical physics understandably declined in popularity as modern physics advanced, although some talented practitioners pursued fruitful careers in the subject [15]. Others kept a foot in both camps, at least to start with, including scientists of the calibre of Heisenberg whose well-known contributions to the theory of stability of parallel shear flow and turbulence in fluids [16, 15] were outshone by his great work in quantum mechanics [6]. With many new problems to be tackled in modern physics there was no strong temptation to spend time seeking explanations of natural phenomena such as the Gulf Stream in the Atlantic Ocean and the Great Red Spot in Jupiter's atmosphere. And other phenomena now investigated under the heading of 'geophysical and astrophysical fluid dynamics' such as the magnetism of the Earth and the corona of the Sun would remain enigmatic until pioneering work by Alfvén and others [17, 18] had created the new subject of 'magnetohydrodynamics' (MHD).

MHD involves the application of all the laws of classical physics, for the (pre-Maxwell) equations of electrodynamics are also needed when treating the flow of an electrically-conducting fluid. Much material in the cosmos is both fluid and electrically conducting and on the scale of cosmical systems MHD phenomena abound. But most underlying processes are impossible to reproduce on the very much smaller scale of the terrestrial laboratory, owing mainly to the difficulty with available fluids of achieving high enough values of the 'magnetic Reynolds number' $UL\mu\sigma$ (where U is a characteristic flow speed, L a typical length, μ the magnetic permeability of the fluid and σ its electrical conductivity). Significantly, this obstacle to progress is now being overcome to some extent by the increasing use of powerful computers for integrating the governing equations.

Computational fluid dynamicists strive for breakthroughs in understanding turbulence and other fundamental processes characteristically involving many different length scales and time scales [19]. As in laboratory studies, basic general theorems and dimensionless parameters play a central role in the formulation of crucial investigations and the interpretation and application of experimental results. Dimensionless parameters (such as the magnetic Reynolds number) are readily identified by expressing the governing equations in dimensionless form, but their successful use is less straightforward and remains something of an art [20].

Fortunately, experience shows that it is not always necessary or even desirable to insist on complete geometric and dynamic (and, where appropriate, thermodynamic and electrodynamic) similarity. We now see, for instance, albeit with twenty-twenty hindsight, that if physicists in the late nineteenth century and early twentieth century had made simple but systematic 'curiosity-driven' laboratory investigations of flow phenomena in spinning fluids, unexpected dynamical processes, including deterministic chaos, of direct relevance in meteorology, oceanography and other areas of science and engineering would have been discovered much sooner [12]. Whilst it is impossible in the laboratory to simulate a planetary atmosphere in all its details, much of our knowledge of fully developed 'sloping convection' – a process which underlies many natural phenomena such as highly irregular waves and jet streams seen in the Earth's atmosphere and the more regular large and durable eddies in the atmospheres of the major planets – comes from laboratory experiments on thermal convection in rotating cylindrical (rather than spherical) fluid systems no more than several centimeters in size. These were eventually started half a century ago, long before computers became powerful enough to play a significant role in such research.

At the beginning of the twenty-first century we can be sure that all branches of science will continue to benefit from improving computer technology [19] and fundamental advances in mathematics [10]. But in forecasting detailed future developments scientists in the past have shown little more than modest skill [21], even with the benefit of fascinating insights provided by the imaginations of non-scientific colleagues. We can look forward to many surprises.

REFERENCES

[1] Einstein, A. & Infeld, L., *The evolution of physics*, (re-issue of 1961 second edition), Cambridge University Press. (1971).

[2] Feynman, R., *What do* you *care what other people think*?, Bantam Books, New York (1989).

[3] Burstyn, H.L., 'Tradition and understanding', *School and society*, (November 1969).

[4] Snow, C.P., 'The case of Leavis and the serious case', pp. 81-97 in *Public affairs*, Macmillan, London (1971).
[5] Dainton, F., *Doubts and certainties*, Sheffield Academic Press (2001).
[6] Brown, L., Pais, A. & Pippard, B. (eds.), *Twentieth century physics* (three volumes), Institute of Physics, Bristol (1995).
[7] Barrow, J.D., *Theories of everything*, Oxford University Press (1990).
[8] Poincaré, H., *Les méthodes nouvelles de la mécanique celeste*, Gauthier-Villars, Paris (1892).
[9] Lighthill, J., 'The recently recognized failure of predictability in Newtonian dynamics', pp. 35-50 in *Predictability in science and society*, (eds. Mason, J., Mathias, P. & Wescott, J.H.), Cambridge University Press (1986).
[10] Arnold, V., Atiyah, M., Lax, P. & Mazur, B. (eds.), *Mathematics: Frontiers and perspectives*, American Mathematical Society (2000).
[11] Sussman, G.T. & Wisdom, J., *Structure and interpretation of classical mechanics*, M.I.T. Press, Cambridge, Massachusetts (2001).
[12] Lorenz, E.N., *The essence of chaos*, University of Washington Press (1993).
[13] Bjerknes, V., Bjerknes, J., Solberg, H. & Bergeron, T., *Hydrodynamique physique avec application à la météorologie dynamique*, Les Presses Universitaires, Paris (1934).
[14] Norbury, J. & Roulstone, I. (eds.), *Large-scale atmosphere-ocean dynamics*: *Analytical methods* (vol. 1); *Geometric methods and models* (vol. 2), Cambridge University Press (2002).
[15] Batchelor, G.K., *The life and legacy of G.I. Taylor*, Cambridge University Press (1996).
[16] Heisenberg, W., 'Über Stabilität und Turbulenz von Flussigkeitsströmung', *Ann. Phys. Lpz.* (4) 74, 577-627 (1924).
[17] Alfvén, H., 'On the existence of electromagnetic-hydrodynamic waves', *Arkiv. f. Mat. Astron. Fysik*, 29B, no. 2, 7 pp. (1942); *Cosmical electrodynamics*, Oxford University Press (1950).
[18] Davidson, P.A., *An introduction to magnetohydrodynamics*, Cambridge University Press (2001).
[19] Catlow, R., Burke, P., Goodfellow, J., Tildesley, D. & Wilson, M. (eds.), 'New science from high performance computing', *Phil. Trans. Roy. Soc. London* A360, 1073-1294 (2002).
[20] Birkhoff, G., *Hydrodynamics: A study in logic, fact and similitude*, Princeton University Press (1960).
[21] Thomas, J. Meurig, 'Predictions', *Notes Rec. Roy. Soc. London* 55, 105-117 (2001).