What's the use of physics?

C. H. Llewellyn Smith

Physics appears in the title of this talk because it was addressed to physicists* and I have taken most of my examples from physics, but much of the talk applies to science generally, particularly basic science. The use of basic science may appear obvious to working scientists, but it is not obvious to others. We must be prepared to put the case for our subjects and defend them from the various attacks to which, in the UK at least, science has been subjected.

Science in general, and physics in particular, are in danger for a number of reasons. Children are turning away from science, apparently because they consider it soulless and mechanical. Among adults, science is under fire from many directions. A recent book by Brian Appleyard[1], which has attracted considerable attention, argues that science has inflicted '*appalling spiritual damage*' on society because the former holds the latter in a sway of '*seductive effectiveness and persuasive power*'. Some adherents of the Green Movement appear to think that science is responsible for all the ills of mankind, spiritual and material. More specifically, the importance of physics in industry may not be as apparent as that of chemistry, which boasts a Chemical Industry. Furthermore, the view that the leading scientific opportunities are currently in the life sciences, rather than the physical sciences, is currently being promulgated by some senior European science advisors.

Here I shall deal with these anti-science/physics arguments, in the reverse order to which I have introduced them, before presenting the positive case.

Anti-physics/science arguments

'The leading opportunities are now in life sciences'

There has been enormous progress in the life sciences in the last few decades and the opportunities are enormous, but I would argue that they are no greater than the opportunities in physical sciences, which range from those opened up by the discovery of high temperature superconductivity, to those likely to be generated by a new generation of optical telescopes. In passing, I note that the differences in techniques and approach between the different sciences have diminished greatly within the last two decades, and I also observe that the great progress in the life sciences has been based largely on techniques and instrumentation derived from physics.

'There is no physics industry'

This is, of course, simply wrong. A large part of industry is physics based, and the electronics industry could justly be called the quantum physics industry.

'Science does more harm than good'

I do not understand the argument that science does spiritual harm (I deal with the slightly different charge that it is soulless or mechanical below). I suspect that it is based on ignorance of science and how science progresses, and the fear that ignorance engenders. I note, however, that those who speak against science are happy to use electricity, be inoculated, listen to hi-fi and enjoy other benefits of science.

There are those who consider that science has done more material harm than good, usually throwing nuclear weapons and pollution into the balance. This confuses science itself with the use of science. It is impossible to prevent the misuse of anything. Religion, for example, has been used to justify war in most regions of the world. But these misuses are criticisms of human nature, not of science or religion. If, nevertheless, we examine the use of science in war, we find that it is as often defensive as offensive.

Perhaps the earliest large scale use of science in warfare was by Archimedes, whose many inventions are said to have withheld the Roman siege of Syracuse for three years. To give just one more example, the invention of radar undoubtedly played a major role in saving Britain from invasion by Hitler. Furthermore, the scientific 'spin-off' of technical developments with military origins has often been considerable. For example, the ability to launch satellites was undoubtedly accelerated by decades by the arms race, with benefits which include: improvements in agriculture resulting from better surveillance, improvements in weather forecasting, a revolution in communications, and improved military surveillance which has greatly lessened the chance of accidental war.

Should science be blamed for pollution? It is true that great environmental damage has been done by industrial/science-based processes, and the depletion of the ozone layer resulting from the use of aerosols illustrates the potential dangers of introducing new products — a lesson which is now being learned. However, there is probably more low-tech than high-tech pollution, and the deforestation of ancient Greece owed nothing to science. Again it is the misuse of science which is to blame, not science itself which holds the keys to controlling pollution. The root cause is, arguably, the growth of population, which can indeed be 'blamed' on improvements in the ability to control disease and thereby postpone death, but this is hardly a cause for criticism of medical science.

'Science in general, and physics in particular, are soulless and mechanical'

This view derives partly, I expect, from the teaching of physics — balls running down inclined plains, pulleys and levers, laws of thermal expansion, etc. This is all very important of course, but children need to know that physics

*Based on a talk delivered at The Institute of Physics in Bhubaneswar, India, on Founders Day, 4 September 1992.

explains why stars shine, why people do not grow to be ten feet tall, and how the TV works, and to be told how science progresses.

Nothing could be more misleading than the popular image of a scientist as a man in a white coat who goes round with a clip board painstaking recording readings, and then mechanically reaches a conclusion by following the 'scientific method' (except that, unfortunately, it is still true that most scientists are men). In fact, tremendous imagination is required to see things in the new ways needed to discover new scientific laws. The well-known Harvard physicist Sidney Coleman, who reviews science fiction, was once asked to describe the difference between the imagination needed by a successful scientist and by a successful writer of science fiction, and replied that the scientist needs much more imagination because he (or she!) is constrained by the facts. The ancients found it easy to imagine mechanisms which might move the planets across the sky, but the facts inconveniently kept calling for additional epicycles; it took millennia to make the imaginative leap to the heliocentric system and simplify the picture again. Enormous imagination was required to discover the theory of evolution. Einstein was the master of the 'gedanken' or thought/imaginary experiment, and was led to special relativity by trying to imagine travelling with a ray of light, and to general relativity by imagining doing experiments in a free falling lift.

Science is therefore certainly not mechanical: it needs great imagination. It is also not soulless and can even address semi-philosophical questions, such as why we can understand nature one layer at a time, or more grandiosely, why is science possible? We know that we can understand the macroscopic properties of (e.g.) water, using the Navier–Stokes equation etc., in terms of two parameters — the density and viscosity. The values of these parameters can in principle be understood using molecular and atomic physics in terms of further parameters, namely the charge and mass of the nuclei of hydrogen and oxygen, the fine structure constant and the mass of the electron. These parameters can in turn be understood, at least in principle, in terms of the physics at a 'deeper' level, and this process will continue until perhaps one day we find an ultimate and final 'theory of everything'. This theory would — ultimately — determine the properties of water, but luckily we can understand hydrodynamics without understanding the theory of everything. However, it is certainly possible to imagine a world in which this was not the case, and we could not understand anything without understanding everything — which would make science impossible! This is the situation which would obtain if nature was described by a 'non-renormalizable field theory'. However, in the last ten years, field theorists have shown that non-renormalizable theories almost certainly make no sense and thus, although they might be surprised to hear it, explained why science is necessarily possible!

Science can therefore address and answer semi-philosophical questions. I myself prefer the old title 'natural philosophy' which is still used to describe physics in Scotland, and persists in the title of a chair at Oxford, to the newer terms physics or science.

Pro-physics/science arguments

Fundamental science i) has great cultural importance, ii) produces enormous direct long term economic benefits, iii) generates important spin-offs, and iv) has a crucial role in education and training. I shall deal with these points in turn, taking (ii) and (iii) together.

The cultural value of science

Our lives are enriched by knowledge of the genetic code, how the sun works, why the sky is blue or why it gets colder when we go up mountains. A major reason for supporting science is that scientific knowledge ennobles mankind. Scientists seem reluctant to say this, and apparently always have been as this extract from Plato's Republic in which Socrates is considering the appropriate university syllabus in a well ordered state shows:

> Socrates: Shall we set down astronomy among the subjects of study?
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> Glaucon: I think so, to know something about the seasons, the months and the years is of use for military purposes, as well as for agriculture and for navigation.
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> Socrates: It amuses me to see how afraid you are, lest the people should accuse you of recommending useless studies.

I think we scientists should be prepared to assert the cultural value of science more forthrightly, and emulate Bob Wilson, the first Director of the Fermi National Accelerator Laboratory near Chicago, who when asked what his laboratory contributed to the defence of America, replied 'nothing, but it makes it worth defending'.

The direct long term economic value of science and spin-off

Direct benefits include, for example, the enormous benefits which have flowed from understanding the laws of electricity, or the benefits of understanding astronomy referred to by Plato (incidentally, the importance of astronomy for navigation led to the foundation of the Royal Greenwich Observatory, which was probably the first example of public patronage of science in England). There is no doubt that these benefits, although generally very long-term and unpredictable, have repaid the total investment in fundamental scientific research many times over[2]. This investment must come from the public purse because basic scientific research is a 'public good', i.e. an item (lighthouses and national defence are archetypal examples) which is costly to produce but which, having been produced, can be made available to all at little or no cost, and from which it may be difficult to exclude people even if they are unwilling to pay.

The classic (and apocryphal?) example of spin-off is the development of non-stick frying pans as a product of the US space programme. More substantial examples range from the development of computers which was provoked by the needs of research (and made possible by the development of thermionic valves and then transistors, which count as direct benefits of fundamental research) and the use of large superconducting magnets (developed by particle physicists) in body scanners. The value of spin-offs should be subtracted when estimating the cost of fundamental research. Incidentally, when considering the value of individual areas of science, we should not forget 'interdisciplinary spin-offs' such as the provision of nuclear magnetic resonance for research in chemistry and biology as a result of research in physics.

To illustrate further the value of the direct benefits of science and spin-off, I cannot do better than quote Casimir[3], the distinguished theoretical physicist who joined Philip's research in 1946 and became a member of the Executive Board of Philip's in 1956:

> I have heard statements that the role of academic research in innovation is slight. It is about the most blatant piece of nonsense it has been my fortune to stumble upon.
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> Certainly, one might speculate idly whether transistors might have been discovered by people who had not been trained in and had not contributed to the quantum theory of solids.
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> One might ask whether basic circuits in computers might have been found by people who wanted to build computers. As it happens, they were discovered in the thirties by physicists dealing with the counting of nuclear particles because they were interested in nuclear physics.
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> One might ask whether there would be nuclear power because people wanted new power sources or whether the urge to have new power would have led to the discovery of the nucleus. Perhaps—only it didn't happen that way.
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> One might ask whether an electronic industry could exist without the previous discovery of electrons by people like Thomson and H. A. Lorentz. Again it didn't happen that way.
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> One might ask even whether induction coils in motor cars might have been made by enterprises which wanted to make motor transport and whether then they would have stumbled on the laws of induction. But the laws of induction had been found by Faraday many decades before that.
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> Or whether, in an urge to provide better communication, one might have found electromagnetic waves. They weren't found that way. They were found by Hertz who emphasized the beauty of physics and who based his work on the theoretical considerations of Maxwell. I think there is hardly any example of twentieth century innovation which is not indebted in this way to basic scientific thought.

A further striking example was given by Thomson[4], the discoverer of the electron, when as President of the Royal Society he spoke in 1916 on the importance of research in pure science by which he meant 'research made without any idea of application to industrial matters but solely with the view of extending our knowledge of the laws of nature'. His example was the use of X-rays in surgery, which had been brought into prominence by the Great War. Having enumerated the benefits, Thomson went on to say: 'Now, how was this method discovered? It was not the result of a research in applied science starting to find an improved method of locating bullet wounds. This might have led to improved probes, but we cannot imagine it leading to the discovery of the X-rays. No, this method is due to an investigation in pure science, made with the object of discovering what is the nature of electricity.'

The value of science in training and education

There is no doubt that many of those children who (unfortunately in insufficient numbers, in Britain at least) do choose to study science are attracted by the excitement of frontline research[5]—in physics, particularly by research in astronomy and particle physics, and by the glamour of black holes and quarks. Of course only a tiny percentage go on to become astronomers or particle physicists: the majority follow other careers where their scientific training is directly or indirectly useful. Besides providing the necessary training for those who will become physicists or work in physics-based industries, a degree in physics teaches general numeracy, including particularly an ability to make approximate estimates and an understanding of statistics, and a feeling for how to interpret evidence, which should be valuable in all walks of life.

Speaking to physicists on an occasion such as this, it is perhaps not over-indulgent to tell a story which physicists think illustrates the superior virtues of a physics education as a nursery for common sense. An astronomer, a physicist and a mathematician are travelling together to Scotland. None has been there before and they look eagerly around after crossing the border. Before long they see a black sheep. 'Oh, that's interesting' says the astronomer 'All the sheep in Scotland are black'. 'Oh dear' responded the physicist 'You astronomers always generalize absurdly from scanty evidence. The most we can say is that there are some—at least one—black sheep in Scotland'. At this the mathematician almost has apoplexy and says, 'You physicists have no sense of logic or rigour: the most we can say is that one side of one sheep in Scotland is black'.

Of course there are also jokes against physicists, such as the complete version of the well-known tale of how a physicist proves that all odd numbers are prime. 'One is prime, two is prime, three is prime, five is prime, seven is prime: obviously all odd numbers are prime'. At this a student asks 'But what about nine?', to which, after a pause, the physicist replies, 'Well, eleven and thirteen are prime, so nine must be an experimental error'. This, however, is really a joke only against theoretical physicists.

Concluding remarks

I hope I have convinced you that it is easy to demonstrate the use of science in general and physics in particular. I would like to end with two points.

First, I would like to stress again the unpredictability of the fruits of basic research and the consequences thereof. Not all scientists had the prescience of Faraday who, when Gladstone queried the practical worth of electricity, replied 'One day, sir, you may tax it'. Rutherford's observation in the 1930s that 'anyone who expects a source of power from the transformation of atoms is talking moonshine' is more representative. If Rutherford had no conception of the commercial potential of nuclear physics although he discovered the nucleus, it is unlikely that a research council assessing his application would do a better job. Another example is provided by Thomas J. Watson, the founder of IBM, who in 1949 wrote that although a single computer could solve all the important scientific problems of the world, he did not believe that computers had any commercial applications—quite wrong, of course, on both counts.

It follows from this unpredictability that, beyond perhaps some broad generalizations, governments cannot pick or choose which areas of basic science to support on the grounds of the relative likelihood of long-term benefits (the case of applied research is of course different). Supporting good people, and judging the opportunities in different fields by their ability to attract the best students, might be a better policy.

Second, basic research is not only in jeopardy from would-be planners because its benefits are unpredictable, but also tends to be in the firing line when governments wish to cut spending on research because the benefits are so long-term. 'The Endless Frontier', Vannevar Bush's visionary 1945 study, which set the framework for subsequent support of science in the US, contains a warning by a committee that included I. I. Rabi, professor of physics at Columbia, Oliver Buckley, President of Bell Labs, and Edwin Lane, President of Polaroid that 'Under pressure for immediate results, and unless deliberate policies are set up to guard against it, applied research invariable drives out pure'. We physicists have a duty to urge that such policies are adopted and to explain the use of science in general, and physics in particular, to the policy makers and the general public.

1. Brian Appleyard, *Understanding the Present, Science and the Soul of Modern Man*, Picador, 1992.
2. See Kay, J. A. and Llewellyn Smith, C. H., *Fiscal Studies*, vol. 6, no. 3, 1985, where the fact that fundamental science is a public good is also discussed at length.
3. Casimir, H. G. B., contribution to Symposium on Technology and World Trade, National Bureau of Standards, US Department of Commerce, 16 November 1966.
4. Quoted on p. 198 of *The Life of Sir J. J. Thomson*, Lord Rayleigh, Cambridge University Press, 1942.
5. Kalmus, P. I. P., *Phys. Bull.*, 1985, **36**, 168.

Received 7 October 1992; accepted 21 October 1992

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Appropriate research: unnecessary injections in India

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India has many scientists, but their impact on the world scientific literature is not in proportion to their numbers. Yet Indian scientists might investigate many problems which do not, at least initially, need elaborate equipment or even outside funding. Such a problem might be the effect of injections given by doctors or other people, on the health and wealth of their patients.

Everyone knows that injections are immensely popular among all classes in the Indian subcontinent, but there is scarcely anything in the medical and little in the anthropological literature. On injections given to babies and small children, there is virtually no literature although, for instance, injection abscesses are common. The Indian subcontinent is huge, it hosts diverse religions, philosophies, environments and social and hygeinic conditions. It is scarcely possible to make generalizations from the scattered papers which have been published. How many injections were given by whom, to whom? What is injected, for what conditions? How many of the injections are medically unnecessary and how many, necessary and unnecessary, might have iatrogenic consequences? What are the financial consequences of payments for injections by the poor who have the poorest health and nutrition and therefore may receive more injections? Any competent scientist could investigate these questions. Are they worth asking?

Unless the syringe and needle are sterile, bacteria may be injected and cause an infection, either locally as an abscess or systemically. A syringe or needle which is reused without sterilization may transfer the parasites of filariasis and malaria, hepatitis viruses (e.g. HBV), the human immunodeficiency virus (HIV) and the spirochaetes of syphilis from one person to the next. The material injected may be antigenic, poisonous, deleterious or just plain useless, perhaps even only dirty water. The Essential Drugs Programme of WHO has been concerned with drugs but not with their administration.

An infection with HBV or HIV will have a long incubation before disease as hepatitis or AIDS is apparent so that there will be no obvious link to an injection months or years earlier. However, twice as many patients receiving repeated injections had antibodies against hepatitis B virus as controls[1]. It is sad that unsuspecting patients can be misled: even an injection abscess may be explained:

'You had a poison all through your body. My injection caused the poison to be drawn into the injection site, leaving your body cleansed. Now if you go to the hospital, the doctor will be able to draw off all the poison'[2].

Health workers, doctors and mothers have all noticed that often a child who has received an injection for fever, will develop paralysis in the leg injected. When asked, health workers responded by saying: 'the leg was going to be paralysed and the doctor injected a medicine, but the illness was too strong and the medicine was unable to prevent the paralysis.' Paralytic poliomyelitis following injections was first reported in 1914 in children with congenital syphilis treated with Ehrlich's magic bullet. Other reports from tropical countries continued until 1950 when provocation poliomyelitis was recognized following injections of inflammatory materials in Britain and Australia[3]. If a child was incubating a wild poliovirus infection, an intramuscular injection of inflammatory material increased the risk of the child developing paralysis. In India doctors have noticed the coincidence of paralysis following 24 to 48 hours after an injection but have been unable to show that the paralysis was causal.