

Nature of the subject

Physics is the most fundamental of the experimental sciences, as it seeks to explain the universe itself, from the very smallest particles—quarks (perhaps 10^{-17} m in size), which may be truly fundamental—to the vast distances between galaxies (10^{24} m).

Classical physics, built upon the great pillars of Newtonian mechanics, electromagnetism and thermodynamics, went a long way in deepening our understanding of the universe. From Newtonian mechanics came the idea of predictability in which the universe is deterministic and knowable. This led to Laplace's boast that by knowing the initial conditions—the position and velocity of every particle in the universe—he could, in principle, predict the future with absolute certainty. Maxwell's theory of electromagnetism described the behaviour of electric charge and unified light and electricity, while thermodynamics described the relation between heat and work and described how all natural processes increase disorder in the universe.

However, experimental discoveries dating from the end of the 19th century eventually led to the demise of the classical picture of the universe as being knowable and predictable. Newtonian mechanics failed when applied to the atom and has been superseded by quantum mechanics and general relativity. Maxwell's theory could not explain the interaction of radiation with matter and was replaced by quantum electrodynamics (QED). More recently, developments in chaos theory, in which it is now realized that small changes in the initial conditions of a system can lead to completely unpredictable outcomes, have led to a fundamental rethinking in thermodynamics.

While chaos theory shows that Laplace's boast is hollow, quantum mechanics and QED show that the initial conditions that Laplace required are impossible to establish. Nothing is certain and everything is decided by probability. But there is still much that is unknown and there will undoubtedly be further paradigm shifts as our understanding deepens.

Despite the exciting and extraordinary development of ideas throughout the history of physics, certain things have remained unchanged. Observations remain essential at the very core of physics, and this sometimes requires a leap of imagination to decide what to look for. Models are developed to try to understand the observations, and these themselves can become theories that attempt to explain the observations. Theories are not directly derived from the observations but need to be created. These acts of creation can sometimes compare to those in great art, literature and music, but differ in one aspect that is unique to science: the predictions of these theories or ideas must be tested by careful experimentation. Without these tests, a theory is useless. A general or concise statement about how nature behaves, if found to be experimentally valid over a wide range of observed phenomena, is called a law or a principle.

The scientific processes carried out by the most eminent scientists in the past are the same ones followed by working physicists today and, crucially, are also accessible to students in schools. Early in the development of science, physicists were both theoreticians and experimenters (natural philosophers). The body of scientific knowledge has grown in size and complexity, and the tools and skills of theoretical and experimental physicists have become so specialized, that it is difficult (if not impossible) to be highly proficient in both areas. While students should be aware of this, they should also know that the free and rapid interplay of theoretical ideas and experimental results in the public scientific literature maintains the crucial links between these fields.

At the school level both theory and experiments should be undertaken by all students. They should complement one another naturally, as they do in the wider scientific community. The Diploma Programme

physics course allows students to develop traditional practical skills and techniques and to increase facility in the use of mathematics, which is the language of physics. It also allows students to develop interpersonal skills, and information and communication technology skills, which are essential in modern scientific endeavour and are important life-enhancing, transferable skills in their own right.

Alongside the growth in our understanding of the natural world, perhaps the more obvious and relevant result of physics to most of our students is our ability to change the world. This is the technological side of physics, in which physical principles have been applied to construct and alter the material world to suit our needs, and have had a profound influence on the daily lives of all human beings—for good or bad. This raises the issue of the impact of physics on society, the moral and ethical dilemmas, and the social, economic and environmental implications of the work of physicists. These concerns have become more prominent as our power over the environment has grown, particularly among young people, for whom the importance of the responsibility of physicists for their own actions is self-evident.

Physics is therefore, above all, a human activity, and students need to be aware of the context in which physicists work. Illuminating its historical development places the knowledge and the process of physics in a context of dynamic change, in contrast to the static context in which physics has sometimes been presented. This can give students insights into the human side of physics: the individuals; their personalities, times and social milieux; and their challenges, disappointments and triumphs.