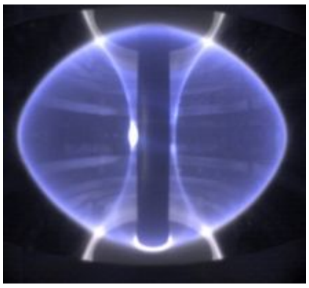
Introduction

When the great American physicist and bongo-drums player, Richard Feynman, was asked to think of a single sentence that would convey the most important scientific knowledge, he answered simply: ‘Everything is made of atoms.’

Richard Feynman having fun.

Our understanding of matter at the atomic scale has made possible much of modern life, with its the mobile phones, computers and communications technology. Technologies from semiconductors, lasers, displays, and materials developments all require knowledge of how atoms behave and interact. The fundamentals of chemistry, drug development and biochemistry all rely on that fundamental insight. But we also know that atoms are not fundamental, and not indivisible; smaller structures exist inside.

The discovery of the atomic nucleus within the atom had profound consequences. The implications were not initially obvious; indeed the pioneering New Zealand nuclear physicist, Ernst Rutherford, reportedly said that the idea of getting practical energy out of the atomic nucleus was ‘moonshine’.[1] Later in the $20^{\rm th}$ century, theory and experiment on nuclear structure allowed us to understand the energy source of stars (including the sun), the most violent supernovae, the heating of the earth, and even the method of formation of the chemical elements around us. More immediately, fission power stations continue to provide the greatest contribution to low-carbon electricity in the UK, generating 18% of electricity in the UK and as much as 75% in France.



The plasma inside the MAST tokamak reactor runs at temperatures of up to 3,000,000 K.

Like fission, the physics of nuclear fusion (combining nuclei) has been understood for decades. The nuclear physics is not an area of current research in the field of nuclear physics, but future developments in controlling the plasma in which fusion occurs will be needed if we are to unlock the potential of this almost inexhaustible source of energy. Large-scale experimental facilities at the Culham Laboratory in Oxfordshire and the ITER fusion prototype plant in France are investigating ways to control high-energy plasmas for long times.

Today the physics questions about the fundamental make-up of forces and matter have moved on. We observe the most basic building blocks of nature to be point-like constituents . the quarks, leptons, making up matter, and with gauge bosons as the force-carrying particles. The experimental observations are described to amazing accuracy by the Standard Model of particle physics, a theoretical triumph of relativistic quantum field theory that correctly predicts the gyromagnetic ratio of the electron to an accuracy of one part in a trillion.

Laboratory measurements, together with a mathematical formalism, let us enquire into the nature of the vacuum, and into the dense and hot conditions of the universe a fraction of a second after its birth. They are also providing insights into the reasons why matter dominates over anti-matter, and the origins of mass. Performing

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[1] He turned out to be right, in a way, since the moonlight has since been understood to originate from fusion of hydrogen to helium inside the sun. It’s perhaps unlikely that this is what he intended.

experiments length scales and higher energies than ever before requires the invention of new technologies. The technologies of the future will, no doubt, grow out of our current areas of research. At the same time, spin-offs are already affecting the wider world. Perhaps the most remarkable invention of our era, the World Wide Web, was developed by Queens college graduate Tim Berners Lee when working at CERN in order to help physicists collaborate on designing and building the LHC. The technologies developed for current particle physics experiments have been used in medical imaging, climate forecasting, decoding the human genome, nuclear anti-proliferation, cancer treatment, information analysis and drug development.


The first web server. When Tim Berners Lee wrote his proposal for the World Wide Web it was annotated by his manager 'vague but interesting'.

Recently the LHC has opened up a new field by discovering a completely new type of particle. Observations suggest it is remarkably similar to the 'Higgs boson' of the Standard Model. This apparently fundamental spin-0 particles, and is only just starting to be investigated and understood. It is almost certainly the manifestation of entirely new fundamental force of nature, different from all of the others observed until now. Much about that force has not yet been investigated. To understand the properties of that force will require a long programme at a high-energy LHC and most likely new facilities and new ideas.

Many other experimental and theoretical questions remain open. The properties of neutrinos, are only now starting to be probed with precision. Soon we may know whether or not neutrinos are their own anti-particles. Other crucial differences between matter and anti-matter, differences essential to our existence, are being studied with ever greater detail in the decays of hadrons.


Not dark matter.

The 'Dark Matter' particle, believed to be responsible for the missing 80% of the matter in the universe, is being hunted by astroparticle and underground direct detection experiments. And it is hoped that future theories or experiments may throw light onto the enormous difference in strength between the forces.

New theories exist which can solve these problems. All predict the existence of new particles or phenomena, often within reach of either operating or proposed facilities. The close interplay of theory with experiment at the cutting edge of knowledge will be required if these new phenomena are to be predicted, measured and added to the canon of human knowledge.