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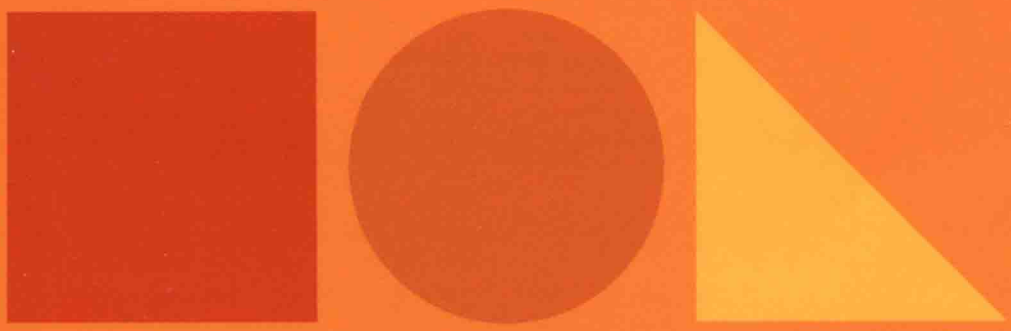
Order from Force

A natural history of the *vacuum*

Jeffrey H Williams



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For BTC, for all his encouragement and support.

Preface

This book concerns the forces of nature and what investigations of these forces can tell us about the world we see about us. The story of these forces is long and complex, and contains many episodes that are not atypical of the bulk of scientific research, which could have achieved greater acclaim 'if only...'.

My intention is to introduce ideas of how the visible world, and those parts of it that we cannot observe either because they are too small or too large for our scale of perception, can be understood by consideration of only a few fundamental forces. My subject will be authority. In particular, what is the absolute authority that binds all humanity and which will brook of no disagreement or amendment. We will see that this authority is the corpus of, commonly termed, laws of physics arising from the forces of nature, and the corresponding constants of nature (for example, the speed of light, c, the charge of the electron, e, or the mass of the electron, m_e).

Some may choose to ignore man-made laws and attempt to avoid the consequences, but no one can ignore nor circumvent the fact that to every action there is an equal and opposite reaction; Sir Isaac Newton's third law of motion *Actioni contrariam semper et æqualem esse reactionem.* Nor is it possible to avoid the inevitability of the force of attraction that exists between neutral atoms, which is responsible for condensation, i.e. the attractive force between atoms and molecules described by Dutch physicist Johannes Diderik van des Waals in his doctoral thesis of 1873 *Over de Continuiteit van den Gas-en Vloeistoftoestand.*

These laws of nature are valid and inescapable everywhere on Earth, just as they would be if we could measure them on the surface of a planet orbiting a distant star. These laws and their associated numerical constants convey a total authority. Whether we know it or not, and irrespective of whether we like it or not, these laws govern every aspect of our lives. In addition, these laws are capable of creating complexity and order; they generate ordered structures through application of a force, and we will in this volume explore this ability. We will see how the electromagnetic force leads to the condensation of gases to form solids and liquids. How a gas which is devoid of any order or structure, being merely an ensemble of particles in thermally driven chaos, endless energy without design, can condense to form a liquid that has some localized internal order, or to form a solid that has extended internal order. In the same way, the force of gravity takes random pieces of debris in space and is able to fashion planets and stars arranged in solar systems and galaxies.

The laws of physics govern our lives, and the constants of nature define our very morphology. The separation and orientation of the molecules which compose our bodies are determined by subtle intermolecular electromagnetic forces, whose magnitude is determined by the various constants of nature and whose operation is dictated by the laws of physics. We are merely living representations of these immutable physical laws.

Author biography

Jeffrey H Williams

Jeffrey Huw Williams was born in Swansea, Wales, on 13 April 1956, he gained his PhD in chemical physics from Cambridge University in 1981. His career has been in the physical sciences. First, as a research scientist in the universities of Cambridge, Oxford, Harvard and Illinois, and subsequently as a physicist at the Institute Laue-Langevin, Grenoble, one of the world's leading centres for research involving neutrons and neutron scattering. He has published more than sixty technical papers and invited review articles in the peer-reviewed literature. However, he left research in 1992 and moved to the world of science publishing and the communication of science by becoming the European editor for the physical sciences for the AAAS's *Science*. Subsequently, he was the Assistant Executive Secretary of the International Union of Pure and Applied Chemistry, the agency responsible for the advancement of chemistry through international collaboration. Most recently, 2003–2008, he was the head of publications at the *Bureau international des poids et mesures* (BIPM), Sèvres. The BIPM is charged by the Metre Convention of 1875 with ensuring world-wide uniformity of measurements and their traceability to the International System of Units (SI). It was during these years at the BIPM that he became interested in, and familiar with the origin of the Metric System, its subsequent evolution into the SI, and the coming transformation into the Quantum-SI.

Since retiring, he has devoted himself to writing; in 2014 he published *Defining and Measuring Nature: The make of all things* in the IOP Concise Physics series. This publication outlined the coming changes to the definitions of several of the base units of the SI, and the evolution of the SI into the Quantum-SI.

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Chapter 1

Science, science fiction and science fantasy

1.1 Setting the scene

History tells us that before there was science and its most useful offshoot, technology, there was magic. In the evolution of a culture, the scientific worldview is always one of the later developments, and it evolves along with magic. After all, both magic and science ask the same questions: why and how is the natural world the way we observe it to be, and how may it be tamed and controlled?

In this evolution of our culture, the 17th century supposedly marked the period when astrology, the burning of witches and folk magic yielded to Sir Isaac Newton's (1642–1726) rationalism, and the laws of nature were established as 'experience explained by reason'. Yet before there was reproducible and reliable science, there was unreliable or 'chancy' science, which is little different from magic. Even in the Renaissance, scientific work (what would then have been termed the exploration of natural philosophy) was very much a 'hit and miss' affair as few *savants* noted down the details of what it was they had done in their 'experiments'. As quantities of substances were not measured consistently or at all (most quantities could not even be defined precisely as they were so parochial) and the materials used were of varying degrees of purity, experimental science was the affair of each individual practitioner. Consequently, at this time both science and magic were acceptable and interchangeable ways of interpreting nature, as neither one nor the other was infallible or even reproducible; both appeared to work only on a statistical basis.

Indeed, the scientist or *savant* of that time dabbled in both natural philosophy and what we would today term the occult. Isaac Newton was himself something of a *magus* or, at least, a neo-Platonist. At the tercentenary of Newton's birth, John Maynard Keynes described him as the last of the magicians:

> Newton was not the first of the age of reason. He was the last of the magicians, the last of the Babylonians and Sumerians, the last great mind which looked out on the visible and intellectual world with the same eyes as those who began to build our intellectual inheritance rather less than 10 000 years ago.

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Sir Isaac Newton was a man with an immense, insatiable curiosity, for whom nothing could or should be taken at face value. Today we may consider ourselves as rational, coldly logical, non-superstitious, scientific beings with several degrees of separation from those who believe in magic and superstition. In the time of Newton, however, there were fewer degrees of separation between such individuals; perhaps there were none at all. But by the end of Newton's life the Enlightenment was underway and the triumph of science was more or less assured.

However, it is not only from magic that science can arise. There has always been a continuous, mutual nourishing of science and science fantasy. The science fantasists of the 19th century—for example, Jules Verne and H G Wells—produced convincing pseudo-scientific theories or stories about the near or even the far future. Their success in convincing their non-scientific readership was certainly due to their ability as writers and to well-explained principles of science, however, these stories (and the works of the science fantasist and *savant*, Anglican bishop and founder of the Royal Society of London, John Wilkins, 1614–72, who had an extraordinarily vivid imagination) were all tinged with a hint of the forbidden or of the occult, which intrigues us all the more. These books were also read and enjoyed by scientists, including scientists with impressionable imaginations. In this way, some part of the futuristic science stimulated ideas in the scientists who then went on to turn those ideas into real science. That is, the science in science fiction and science fantasy consists of a body of ideas, concepts and tropes that oscillate between narrator and reader with subsequent improvement, embellishment and, most importantly, refinements contributed by the scientists. Certainly, true science cannot advance as rapidly as fiction without the agency of a major scientist, an Einstein, a Dirac, a Newton or a Darwin, to act as a catalyst. But that does happen from time to time and it is true to say that a major advance in science also acts as a catalyst upon the quality of contemporary science fiction.

How much then separates science fiction from the science that preceded it or will come after it? Probably, not much. Given that the writers of science fiction certainly read those scientists who are able to write for a general readership, or who are so great as to be written about, it is evident that there is a symbiosis between the scientist and the writer of science fiction. It is likely that many scientists have nourished and excited their imaginations by reading science fiction. Then the question becomes: how much of today's imaginary science will remain imaginary and how quickly will some of it be transformed into reality? Science, science fiction and science fantasy were, still are, and perhaps always will be strongly coupled.

One of my favourite examples of this mutual influence on the development of science and science fiction is Isaac Asimov's psychohistory; a mathematical modelling of history, which forms the basis of his *Foundation* novels. We are informed by Asimov that when the number of humans approaches the number of gas molecules in a sample of air, then the purely statistical laws of the kinetic theory of gases will be applicable to human society. That is, history will become as predictable as the physical properties of an ideal or perfect gas[1].

[1] Asimov wished to consider a model of humanity reduced to non-interacting molecules. In section 9.2 of this volume, I give a list of the properties of the atoms and molecules that would give rise to an ideal gas, and we see that humanity will never be truly ideal.

Sadly, we have a long way to go before we can approach this perfect state. As we will see later, the transition from the non-statistical behaviour of individual molecules (or humans in Asimov's fiction) to the more mathematically friendly statistical behaviour of large groups of molecules, i.e. solids and liquids (society in Asimov's fiction), is not so easily identified. However, the American historian Henry Adams (1838–1918), the grandson and great-grandson of American presidents, attempted such a modelling of human history at the beginning of the last century. In his *Degradation of the Democratic Dogma* (1919), Adams proposed two laws of history: 'All civilization is centralization' and 'All centralization is economy'. It is difficult to find fault with the first law; however, the second law says that resources—particularly energy sources—must be adequate to sustain the energy needs of the civilization or empire. Therefore all civilization is the survival of the most economic system. The nation that has an ample source of energy (coal, oil, gas, etc) and is able to control access to all major sources of energy for all other nations will dominate the world. We are a long way from the human domination of the Galaxy described by Asimov (and those 10^{23} humans), yet Adams' laws seem to be eerily familiar and anticipatory. There is a strange closeness between physics and history; a closeness that always moves out of focus when you seek to examine it. In both subjects, all is cause and effect; in history as in physics, there is no action without reaction. The problem is that in any predictive, quantitative estimation derived from history and from physics, the error bars are larger for the former than for the latter.

This classical or mechanistic view of history is not, however, a new idea. Asimov may well have obtained the idea for psychohistory from the great French astronomer and mathematician Pierre-Simon, *marquis* de Laplace (1749–1827) who thought in purely classical terms, and who maintained that from the known laws of mechanics and from a full knowledge of the present state of the Universe, every future state could, in principle, be predicted:

> We ought then to consider the present state of the Universe as the effect of its previous state and as the cause of that which is to follow. An intelligence that, at a given instant, could comprehend all the forces by which nature is animated and the respective situation of the beings that make it up, if moreover it were vast enough to submit these data to analysis, would encompass in the same formula the movements of the greatest bodies of the Universe and those of the lightest atoms. For such an intelligence nothing would be uncertain, and the future, like the past would be open to its eyes ...

This splendid conceit, based on the ideas of Isaac Newton, about predicting the future course of history comes from the introduction of Laplace's *Théorie Analytique de Probabilité,* (1812–20, volume 7). A century after the publication of this classical certitude, Werner Heisenberg put some fuzziness back into the Universe with his uncertainty principle and historians breathed a sigh of relief after the Enlightenment absolutism of Laplace. But in this process, both Laplace and Heisenberg had inspired some memorable science fiction and fantasy.

1.2 How should we look at nature? Asking the right question

In this volume, we will look at the many forces that shape nature and how this multitude of forces came to be distinguished as only four different forces. Like so much in science, the story of the forces of nature has its origins in philosophy and in magic. Speaking as someone who had only ever wished to be a research scientist, and who had the great privilege of having had his wish come true, I always find it useful to consider the impermanence of man's view of nature. This is why I believe the history of science is of importance to all of us. Knowing something of the origin and evolution of science allows us to put all our ideas and assumptions, and especially our achievements, into a clearer perspective. In particular, it is always worth considering the truth of the observation that the scientific facts we accept today, apparently without any second thoughts; i.e. the present-day dogma of science, would not so long ago have been considered the darkest magic.

Perhaps the most famous example of a magician in literature is Faust. In the earliest sections of Goethe's great poem (begun around 1772), the magician and his tempter correspond broadly to traditional mediaeval figures; the disillusioned old man manipulated by the Devil and the plot gives a somewhat traditional, Christian version of the concepts of salvation and perdition. However, by the time that Goethe finished his poem (1831), Faust had evolved; he is no longer a *magus* excited and led astray by his desire for 'forbidden knowledge', Faust has been transformed into the Romantic figure of everyman, a seeker for oneness with all nature. Between 1770 and 1830, our civilization had moved from the Classical world to the Romantic world. The later, holistic Faust has abandoned a Manichaean dualism of good and evil for a mystical sense of the unity of all things. This Romantic Faust would likely have been an early recruit to the green politics of environmentalism. Faust no longer embodies heterodox magic, but accedes to knowledge of the interconnections of all natural phenomena. In this way does the character of Faust follow the evolution of magical thinking: first there was magic and then there was physics; first there was the sorcerer and then there was the physicist.

The magic that predates and inevitably leads to physics is a force which follows processes and events that are inherent to consciousness and is something implicitly connected to constructive and imaginative thought, and therefore to the whole enterprise of artistic and scientific creation. Our imaginations, our dreams, our ability to use our consciousness to imagine and to describe, and then to transfer theories and fantasies, are inherently bound up with our facilities for reasoning. They are essential for making that great leap from observing and explaining a known phenomenon to going beyond into the realms of prediction. The fabulous and the fantastic are all around us. The more we examine a quantity or a phenomenon that was once deemed to have been fully described and comprehended, the more we may speculate and then, perhaps, realize that the fantastic is not entirely separate from the natural[2].

[2] Quantum mechanics arose from increasingly precise measurements of the quantity and qualities of the radiation emitted by hot bodies (Planck black-bodies).