IOP Concise Physics

Order from Force

A natural history of the *vacuum*

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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).

Before the 18th century Enlightenment, magic and fantasy were inextricably linked with man's attempt at understanding the forces of nature yet nonetheless led to considerable advances in technology and to many useful discoveries (in engineering, metallurgy, chemistry and pharmaceuticals). When thinking about the world in a magical sense, one considers the phenomena of nature to have arisen through the agency of certain secret forces of nature; forces which may reside uniquely in certain objects (for example, the loadstone of the flying island of Laputa in Jonathan Swift's *Gulliver's Travels*) or with certain inspired individuals (for example, Giordano Bruno, Leonardo Da Vinci, or Paracelsus). Such magical thinking structures the processes of imagination and imagining something can, and sometimes does, precede the fact or the act of discovery. This apparent breakdown in causality is something that we would today term intuition or instinct and is something that a great many people experience without thinking about it. Indeed, you do not have to investigate modern quantum mechanics and the quantum view of nature very deeply before concepts such as causality and non-causality, of cause and effect, become much more confused than one would have ever supposed. Such concepts become, essentially, metaphysical.

At the end of the Enlightenment, however, the fluidity or mobility of thought was restricted, the world had been measured and defined. The founders of the Metric System in revolutionary France decreed that in accordance with Isaac Newton, the circumference of the Earth was precisely 40 000 km. The field of experience had been surveyed, measured and delineated. Raw nature was tamed, restricted by a host of new disciplines (from medicine to geology) and by the study of language itself. These new disciplines classified, sorted and (importantly) separated the confusing complexity of the space that is human reason. Whether we like it or not, the epistemological earthquake that was the French Revolution of 1789—the apogee of the Age of Enlightenment—created our modern world, making us subject to the tyranny of number while freeing us from the tyranny of concepts and speculation.

1.3 The innocence of youth

Lightning flashes from an area of high electrical potential to an area of lower or zero electrical potential (see figure 1.1). This enormous pulse of electric current is made visible because it causes the molecules in the air through which it passes to become excited and some of these molecules will become so excited that they become ionized by ejecting electrons. These excited air molecules (nitrogen and oxygen) then emit visible light in the process of returning to their ground or unexcited state by collisions with neighbouring molecules; the invisible electrons that constitute the lightning bolt are made visible (or rather their route through the atmosphere is made visible) by the light emitted by the molecules excited by the bolt's passage. The lightning is made audible because of the sudden increase in pressure caused by the lightning bolt; there is a rapid expansion of the air surrounding the route of its passage. In turn, this expansion of air creates a sonic shock wave, similar to the sonic boom of an aircraft travelling faster than the speed of sound (about 767 miles per hour or 343 m s^{-1} at ambient temperatures at sea-level), which produces the sound of thunder.

Figure 1.1. Lightning or electromagnetism in action. Lightning is probably the most spectacular, frightening and immediate demonstration of one of the four forces of nature (electromagnetism). This extraordinary image of a lightning storm over Windy Point, South Australia, was taken by Anne Vu (*Anne Vu/@annedr0id*) who retains full copyright.

The sublime spectacle of lightning and the awesome sound of thunder are the most dramatic example we will ever see of one of the four forces of nature and it is the example of the electromagnetic force *par excellence*. Lightning, a bolt of electric current of many tens of thousands of amperes, flows when the physical conditions in the atmosphere are right; when the electrical potential between the point of origin of the bolt and the terminus of the bolt is high enough (a few million volts per metre) and when there is an accessible route to a much lower electrical potential or, better still, to the Earth at zero potential. Then, the bolt will flash downwards through the air, or through a tree, or through a church tower.

I can remember being told this in secondary school and I can also remember a friend asking the physics teacher how the lightning chose one particular route to earth. This is a perfectly reasonable question; of course, by asking the question in this way we are using anthropomorphic terms such as 'choice'. But electrons do not have free will and are not capable of thought. Neo-Platonists and our unenlightened ancestors might have said that the lightning bolt had been hurled in a particular direction by some vengeful super-being, but today we know differently. The pupil's innocent question is an example of the pre-scientific or magical approach to understanding or explaining natural phenomena. Of course, the lightning bolt could came down through the tree under which the pupil was sheltering, because some malign spirit wished to put him in fear of his life for something that he had done or

that he had left undone. This was the interpretation of nature in the, pre-scientific, magical world of the predecessors of Sir Isaac Newton and Sir Robert Boyle, where spirits dwelt among us and influenced our lives by warnings and signs involving the forces of nature. The pupil's question arose from a confusion about how we look at nature.

In the world of science, magic has been, and is still associated with inquiry and speculation. The change from a purely magical way of thinking to a more scientific form of thinking can be best thought of as a change from the inquisitive mind seeking to ask the right question as opposed to providing the right answer. The pupil was asking the right question, even though he was laughed at by the other pupils. So why does the flow of electrons 'choose' one particular route to earth, rather than another route?

Of course, the sheltering tree, the church tower and any object pointing upwards towards the reservoir of electrons in the sky (those large dark-grey clouds) would become electrically charged by the electrical potential present in the atmosphere (the immense electric field between the clouds and Earth). There would be tiny currents of electricity running down simultaneously to the Earth at speeds close the speed of light through all these objects. The route with the lowest electrical resistance, for example, the copper lightning-rod attached to the church tower (provided one end was securely embedded into the ground) would be the best conductor—the conductor with the lowest resistance to the flow of electrons. The sheltering tree and the boy would have a higher electrical resistance compared to a copper lightning-rod. So a large part of that reservoir of electrical charge in the sky would flash downwards through the copper lightning-rod and leave the boy and the tree unscathed.