Chapter 1

Theories Come and Theories Go

It's all kinds of old defunct theories, all sorts of old defunct beliefs, and things like that. It's not that they actually live on in us; they are simply lodged there and we cannot get rid of them.

Hendrik Ibsen (1828–1906), *Ghosts*

1.1. What is Science?

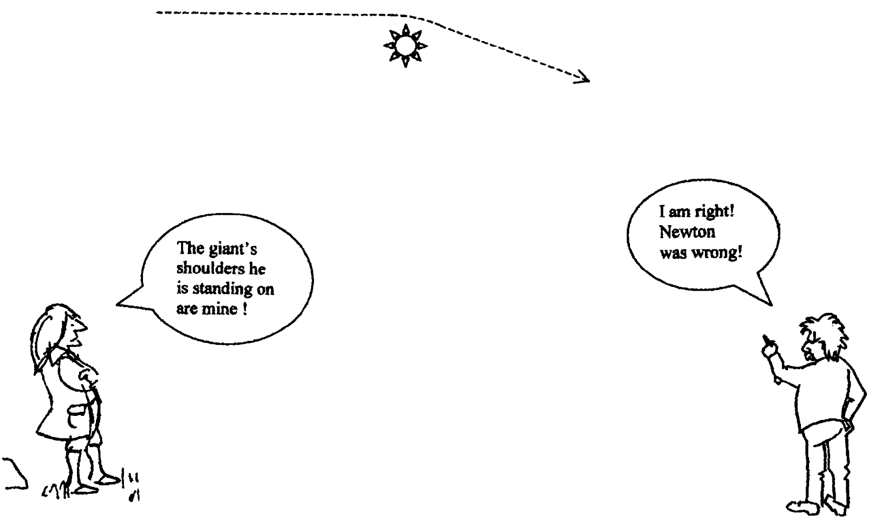
Science is a quest for knowledge and an understanding of the Universe and all that is within it. Individual scientists learn from those that have preceded them and their work guides those that follow. Arguably the greatest scientist who has ever lived, Isaac Newton recognized this debt to his predecessors by saying "If I have seen further it is by standing on the shoulders of giants."

All that Newton discovered is so much the accepted background of scientific endeavour today, at least in astronomy and physics, that what he did may now seem to be obvious and humdrum. Yet, in its day, it was spectacular. It was as though humankind, or at least those who could understand what Newton had done, had a veil moved from before their eyes so that all that was previously obscure was seen with a crystal-like clarity. The forces of nature that caused the Moon to go around the Earth and the Earth to go around the Sun were quantified. Forces that operated in the same way, but with different causes, could explain the way that electric charges attracted or repelled each other and also the behaviour of magnets. While all agree that Newton was a great man and his discovery of the law of gravity was a great discovery, can it be said that it was truth in some absolute sense? Apparently not, because three hundred years later another famous scientist, Albert Einstein, showed that Newton's law of gravitational attraction was just an approximation and, to be *very* precise, one should use the Theory of General Relativity instead. It turns out that Newton's way of describing gravity is good enough for most purposes and the calculations that send spacecraft to distant solar-system bodies with hairline precision use Newton's equations rather than those of Einstein.

The example of gravitation is a good one for portraying one aspect of scientists' attitude to their work. Some of them are purely interested in theoretical matters, in that they just try to understand the way that nature works without necessarily having some practical motive to do so. One of the early deductions from the Theory of General Relativity is that light from a star, passing the edge of the Sun, will be deflected twice as much as would be suggested by Newton's gravitational theory. It was realised that if this could be shown to be true, then General Relativity would get a tremendous boost in credibility. This prediction about the deflection of light was made by Einstein in 1915 while he was working in Berlin during the First World War. The observational confirmation that Einstein was right was made in 1919 by British teams of scientists, led by Sir Arthur Eddington and the Astronomer Royal, Sir Frank Dyson. They travelled to South America and West Africa to make observations during a solar eclipse, when starlight deflected by passage close to the Sun could be seen. The expedition was planned in 1918 while Britain and Germany were on opposite sides of a vicious and destructive war but their scientists could come together in their search for knowledge.

The demonstration that Einstein's prediction was right excited the scientific community, and even members of the general public who realised that something important had happened even if they did not quite know what it was. Although scientifically important, this demonstration was *not* important in making a great impact on everyday life. However, the life that we live today *is* very much shaped by the science that has been done in the last 200 years. Experiments with 'Hertzian waves' in the latter half of the 19th century eventually led to radio, television and the mobile telephone. Einstein's Special

Relativity Theory suggested the idea that matter can be turned into energy (and vice-versa) through the famous equation $E = mc^2$. The world has not been the same since the first large-scale demonstrations of the validity of that equation when atomic bombs were dropped on Hiroshima and Nagasaki in 1945. Curiosity about the way that electrons behave in semiconductor materials led to the electronics revolution that so dominates world economics. In fact, rather oddly, it sometimes seems that curiosity-driven research seems to outperform utility-driven research in terms of the usefulness of the outcome. When, in 1830, Michael Faraday waggled a magnet near a coil of wire and produced an electric current he was not conscious of the fact that he was pioneering a vast worldwide industry for generating electricity.



1.2. The Problem of Cosmogony

Although by no stretch of the imagination could one envisage any practical outcome from the deflection of a beam of light passing the Sun, at least it was possible to do the experiment to show that the prediction was true. There are other areas of science where there is limited opportunity for experimentation and one of those is the subject we deal with here — technically referred to as *cosmogony*. The question we address is 'How was the Solar System formed and how has it evolved since it formed?' While there are various ideas in this field, everyone agreed that the Solar System formed some 4,500 million years ago and that, since that time, it has undergone many changes of an irreversible kind. The concept of reversible and irreversible changes is quite fundamental in science. For a reversible change the system could, at least in principle, run backwards so that the past states of the system can be deduced from its present state. For example, we know where the Earth is in its orbit around the Sun and the laws of mechanics that govern its motion. We now imagine that the direction of motion of the Earth reversed so that it retraced its path or, in practice, we do the calculation corresponding to that reversal of motion. This enables us to find exactly where it was at times in the past — but not too far in the past as even the Earth in its motion has undergone some irreversible processes. As an example of an irreversible process, we imagine a large cubical evacuated chamber with a tap at each of its eight corners leading to a cylinder of gas. The tap is turned on at one of the corners and the chamber fills with gas. Once the gas has occupied the whole chamber there is no way of telling from which of the corners the gas came in. The event was irreversible and one cannot make the molecules of the gas reverse their motions and re-enter the cylinder from which they came. For an irreversible change, the past state cannot be deduced from the present state.

If we cannot work backwards to find out how the Solar System began then what *can* we do? The answer is to try various models that are scientifically plausible to see whether or not they can give rise to a system like the Solar System today, or even one that might have evolved to give it. Taking this approach runs the risk that there would be a huge number of models that lead to the Solar System as we know it — but this turns out not to be the case. As we shall see, finding a model that gives anything like the Solar System has proved to be a very difficult exercise.

1.3. New Theories for Old

The history of science is peppered with ideas that have held sway, that were eventually found to be flawed and were then replaced by some new ideas. The lesson to be learnt from this is that no theory can ever be regarded as 'true'. There are two categories of theory — those that are plausible and those that are implausible and therefore probably wrong. Any theory in the first category is a candidate for the second whenever new observations or theoretical analysis throw doubt upon its conclusions. There is no shame in developing a theory that is eventually refuted. Rather, the generation and testing of new ideas must be regarded as an essential part of the process through which scientists gain the knowledge and understanding they seek. The Earth-centred theory of the structure of the Solar System due to Ptolemy, a 2nd Century Alexandrian Greek astronomer (Section 3.5), was a useful model for the 1,400 years of its dominance and it agreed with what was known at the time. People's everyday experience suggested that the Earth was not moving because there was no sensation of movement such as one would have when walking or riding a horse. If the assumption that the Solar System was Earth-centred gave complicated motions of the planets with respect to the Earth then so be it — after all there were no laws of motion known at that time that forbade such complication. When Copernicus introduced his heliocentric (Sun-centred) theory in the 16th century there were still no known laws of motion but the attraction of his idea was that, in terms of the planetary motions, it gave simplicity where the previous theory had given complication. It complied with a philosophical principle, known as *Occam's razor*, enunciated by the 14th century English Franciscan monk, William of Occam. The Latin phrase loosely translates as "If there are several theories that explain the facts then the simplest is to be preferred".

A seeker after knowledge and understanding must be cautious about accepting ideas because they seem 'obvious' and fit in with everyday experience. That, after all, was the basis of Ptolemy's model. Other scientists of great stature have made similar errors.

For example, Newton wrote in his great scientific treatise *Principia* as one of his 'Rules of Science':

"*To the same natural effects, the same causes must be assigned.*"

As an example he gave the light of the Sun and the light of a fire but we now know that these lights have very different causes. The heat of the Sun is produced by nuclear reactions while that of a fire comes from chemical changes produced by ignition. Again, Einstein never accepted quantum mechanics, especially the uncertainty principle, a recipe for defining the fundamental limits of our possible knowledge. An implication of the uncertainty principle is that we can never precisely define the state of the universe at any time and therefore we cannot predict what its future state will be. As Einstein wrote in a letter to Max Born "I, at any rate, am convinced that *He* is not playing with dice." By *He*, Einstein meant God.

The watchword in science is "caution". All claims must be examined critically in the light of current knowledge. Any acceptance must be that of the *plausibility* of an idea since the possibility of new knowledge and understanding to refute it must be kept in mind. We must beware of bandwagons and be prepared to use our own judgements; history tells us that bandwagons do not necessarily travel in the right direction!