See the symmetries
by Simon Saunders

Book Review: *Symmetry and the Beautiful Universe*, by L. Lederman and C. Hill, Prometheus, New York (2004)

This is H.G. Wells, writing in his *Experiment in Autobiography*, in 1934:

> I heard about and laid hold of the idea of a four dimensional frame for a fresh apprehension of physical phenomena, which afterwards led me to send a paper, 'The Universe Rigid', to the Fortnightly Review (a paper which was rejected by Frank Harris as 'incomprehensible'), and gave me a frame for my first scientific fantasia, The Time Machine. If there was a Universe rigid, and hitherto uniform, the character of the consequent world would depend entirely, I argued along strictly materialist lines, upon the velocity of this initial displacement. The disturbance would spread outward with ever-increasing complication. But I discovered no way, and there was no one to show me a way to get on from such elementarystruggles with primary concepts, to a sound understanding of contemporary experimental physics." (H. G. Wells, "Experiment in Autobiography", 1934, p.172)

Wells would have read *Symmetry and the Beautiful Universe* with keen interest. Here Leon Lederman and Christopher Hill attempt to explain all about such matters to the beginner. The book is a *tour de force* of physics made simple: example by example the authors show how symmetries underlie the laws of physics; from ancient astronomy to high energy particle physics - and how the violation of symmetries can be unexpected too, as Lederman (a Nobel prize-winner) himself demonstrated back in the '50s with the violation of mirror symmetry. (He showed that the looking-glass world is not in fact possible, by the lights of the laws of the actual world.) The achievement of the book is to present such a broad spectrum of examples in such an accessible way. And the authors are on to something: there is no question that symmetry principles have dominated fundamental physics throughout the twentieth century. Why? And just what is a symmetry principle?

Think of the symmetry you might find in a Bach cantata; think of Aristotle's "music of the spheres", the hidden harmonies the Greeks were discovering in the motions of the planets. A symmetry principle says there is a certain pattern, whether in a description we make of things or in the things themselves. But aren't physical laws or equations also about patterns? What distinguishes a pattern involving symmetries from any old pattern? The answer is best seen in examples, case by case. The fact is that certain kinds of pattern just obviously do have some sort of symmetry about them, looked at it in the right way - say that a shape is repeated over and over again, or reappears (as in the Mandlebrot set) at every scale. And one of the key notions here is the idea of a transformation, that a symmetry principle says that there is a variety of ways of looking at the equations, or the description, or whatever, under which it is the same. For example, that when you change which part of the picture you look at, or the scale that you look at it, you see the same shape over and over again. Increasingly we find that all the laws of physics are like this. Moreover – patterns within patterns! - they often have the same symmetry in common, so investigating the symmetry directly becomes a way of finding new laws. Recognizing this has changed the way physicists go about looking for their equations.

But here Lederman and Hill offer a rather special insight on the matter. They consider symmetry from the point of view of a particular mathematical theorem, namely Noether's theorem. Emily Noether has a chapter of her own; her theorem has another, separate one. The authors' appreciation for her is heartfelt, and with reason: Noether was in the front rank of German mathematicians in the interwar years, whilst facing great adversity, both as a woman and as a Jew. She died in 1935, at the age of 57.

Noether's theorem comes into play whenever a certain mathematical expression, related to the equations of motion, is left unchanged by some set of transformations (a set which must be neither too small nor too large). It says that in such a case a corresponding quantity (that normally has a physical interpretation) is conserved, and vice versa. Total energy is an example; indeed, the statement 'energy cannot be created or destroyed' is itself viewed as a law, 'the first law of thermodynamics'. Other examples, familiar from schoolbook physics, include momentum, electrical charge, and mass. The 'conserved quantities', then, are quantities *conserved in time*. The suggestion that these are the key to all of physics now comes as a surprise: one would have thought that equations of motion are typically about how quantities *change* in time. So, indeed, they are, and in fact this theorem of Noether's has nothing to say about changeable quantities. Moreover, the cases where there are either too few or too many symmetry transformations for the theorem to come into play are also important to physics. As a result, and because the book does cover so much ground, this theorem of Noether's soon fades into the background. It does not bear on the second half of the book at all.

For a theme one could hope to do better. There is in fact a good deal of history of physics contained in the book as well, including one of the truly epic stories of the modern era, the history of the 'relativity principle'. In Galileo's hands this was the principle that the equations of motion look the same, not on going from one place to another, or from one scale to another, but from one velocity to another. 'Galileo's ship', in the magnificent thought experiment of the thinker who did so much to jump-start the scientific revolution, is an on-board laboratory teeming with contraptions, chemical experiments, flying birds – you name it – all of which behave in exactly the same way whether the ship is at rest or is gently in motion. The undetectability of the 'true' state of motion of a system, unrelated to anything else (its absolute motion), was thereafter built in to Newton's theory of gravity (where it caused Newton a great deal of heartache – his project was after all to distinguish the 'true' from merely 'apparent' motions of the stars). Subsequently it was thought that such a quantity simply did not exist (that there is no such thing as absolute velocity). And this, in Einstein's hands, was the key to the discovery of the theory of relativity, now in its centennial year. In fact the theory was a consequence of this and only one other principle (which was then also widely accepted): that the speed of light is a constant independent of the speed of the source from which it is emitted. This principle followed from the idea that light was a vibration in a medium, like sound. In just the same way, the speed of the sound emitted from an aircraft is always the same, whatever the speed of the plane.

But how can one embrace both of these principles of Einstein's, the relativity principle and the light-speed principle? Taken together, they imply that the speed of light is the same independent of the motion of the emitter *and* of the receiver (this may take a little while to see). But that seems impossible. If I run away from something fast enough, I must reduce the speed of anything it emits relative to me! Einstein's marvellous solution to this puzzle was to see that lurking in all our thinking in these matters is a certain assumption about time, but one that is in fact unfounded – the assumption that any two events, no matter how distant from each other, occur in a definite order in time. Giving this up, except for the special case in which a pulse of light from one event can reach the other – only possible if they are not too distant! - was the key to Einstein's subsequent discoveries. Such an ordering, for sufficiently remote events, does not exist, any more than absolute velocity does.

The authors of *Symmetry and the Beautiful Universe* go over this history at length. They make this last point clearly enough, but the further implication, that the frame of the world is better thought of as *four* dimensional (it is 'spacetime') – with space (three dimensions) and time (one dimension) replaced by a kind of blending of the two – gets barely a mention. But this is the way to understand Einstein's bombshell: the old way of thinking amounted to the view that there is only one way to slice up spacetime into three-dimensional spaces, arranged in a sequence of times. Einstein showed us how it can be done in *many different* ways. Think of a block of wood, sliced up into wafers, like playing cards; now slice it differently at an angle. On one slicing you get some whorls in the grain on a single card, whilst on another they are on different cards. That is how the order in time of two distant events can be made whatever you like, by choosing one slicing rather than another. Going from one slicing to another is the symmetry transformation, the four-dimensional way of looking at the change from one absolute velocity to another. There is in reality no slicing, but only the block of wood.

There is more. A choice of absolute velocity is a choice of slicing: it can be thought of as a direction in the block of wood at each point (a perpendicular to a playing card containing that point). And now the fact that only *relative* velocities are physically real is the statement that it is only *relations* between these directions that are physically real, as opposed to the directions themselves. It is those relations (the relative velocities) that are unchanged – 'conserved' – under the symmetry transformation, on setting Gallileo's ship in motion. But this has nothing whatsoever to do with Noether's theorem! It is also more general - one can say something similar about every other kind of symmetry in physics (with no restrictions to 'not too few' and 'not too many'). Take the simplest and most familiar symmetries, rotations and translations. The angle between two lines in space are unchanged when they are both rotated; the relative distances between points of a rigid body are unchanged however it is moved about. Does it make sense to suppose the universe was created ten years earlier than it was? No: it is only the time interval, between the one instant and the other, that is physically real.

The authors' emphasis on Neother's theorem obscures these simpler insights. And the further truly astounding implication of the four-dimensional frame of the world, that position in time is not so different from position in space – that talk of 'now' (in time) has exactly the same character as talk of 'here' (in space), as a sort of gesture, or act of pointing ('this is now', or 'here I am in time', like 'this is here' and 'here I am in space') - gets barely a mention. This was what had caught H.G. Wells' eye, with his idea of a 'Universe rigid'. But insofar as Lederman and Hill consider the matter (in a footnote, appended to a different chapter), the problem of 'the now' in physics is supposed to have something to do with *consciousness.* It is a dishonourable tradition to make unwanted questions in physics into questions about consciousness; consciousness is the one thing that physicists are happy to leave unexplained.

Their lack of interest in this, and other ways in which physics raises fundamental questions - but conceptual questions, philosophical questions, that physics does not seem out to answer - raises an issue in its own right. Who, exactly, are the authors trying to reach, and for what purpose? Women, so they learn of Emmy's life and work? - in part. The young and the curious, to bring physics to life for them? - undoubtedly. The gullible, so they are armed against superstition? – these too; the book is peppered with admonitions against astrology, alternative medicine, and creationism. But the time is long past when audiences like this could be relied on to pay deference to scientific authority. To all of them one might do better to acknowledge the cracks and rough edges to reason than to pretend they are not there. Questions of symmetry expose them, and yet, for want of a dialogue of another kind, with *philosophy*, physicists are at a loss as to what to say.

There was plenty of dialogue in the ancient and early modern period on our place in the cosmos, in the light of the ideas of Copernicus and Galileo. On this topic the authors speak with clarity and assurance. But in later chapters, with each setting of the stage, we are expected to look away: look away from the Universe rigid, as without any 'now'; look away from the reversibility of the laws supposed to underlie heating and cooling, which manifestly are *not* reversible; look away from cats that are neither alive nor dead, or live and dead at once, in quantum mechanics. Acknowledge the strangeness of physical theories, yes, and even delight in it, but not when it poses simple, unanswered questions, that are troubling as well as profound. Good for H.G. Wells for keeping his eyes open, and from the idea of a four-dimensional frame to write *The Time Machine* - and thereby to rudely revitalize interest in physics. Alas, it is doubtful that the authors of *Symmetry and the Beautiful Universe* will achieve as much.

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