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The Unseen World

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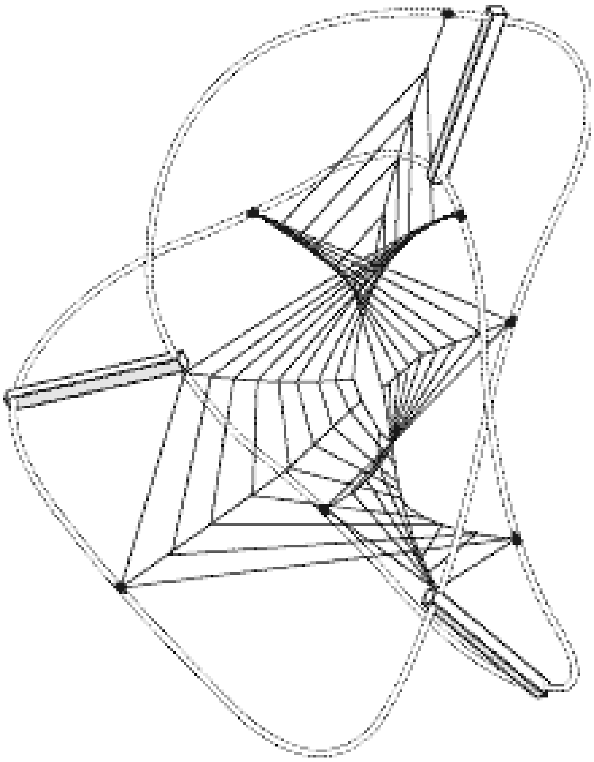

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Science deals with many things we cannot directly observe. By directly I mean with the unaided senses. For example there are the elementary particles such as electrons and quarks which are supposed to provide the microscopic building blocks of matter, but also the mysterious photons and gluons etc. which mediate interactions between the microscopic building blocks. And then of course in molecular biology there are the proteins and genes and so on which explain the processes underlying living organisms. But also there are more abstract entities such as energy and entropy which are not part of our immediate sensory experience, and still more abstract entities, like numbers and mathematical points, not just indeed in physical space, but in still more abstract mathematical spaces, such as Hilbert space in quantum mechanics.

So much of modern science seems concerned with what I will call the Unseen World (using sight as a generic term covering all the senses). Indeed the Unseen World effectively constitutes what we may call the scientific world-view. This was famously illustrated by Eddington with his talk of 'the two tables', the table of everyday experience, firm and solid in front of him, and the scientific table, mostly empty space permeated by the force-fields of elementary particles. Which is the 'real' table? And which is the true story, the scientific story or the everyday story?

In this lecture I want to explore the cognitive credentials of the Unseen World from both an historical and a modern perspective. Hume famously warned that "the ultimate springs and principles are totally shut up from human curiosity and enquiry". But science seems not to have heeded Hume's warning, and let me begin by reminding you of a famous medieval woodcut, in which a curious person peers beyond the vault of the heavens to learn of the hidden mechanisms and contraptions that lie beyond.

But my first question is: what can we directly observe with the unaided senses? Macroscopic objects in our immediate vicinity perhaps, such as the table in front of me or the chair next to me. But is it the table we see, or the light reflected off the table, or is it the electrical stimulation in the retina caused by the light, or in the optic nerve, or what is it exactly that we see?

Naively we can think of a sort of homunculus inside our brains (our conscious selves) reading out and interpreting the input signals, but if our brains (and minds?) are just part of nature, then the whole idea of a homunculus, or the ghost in the machine, as the philosopher Gilbert Ryle called it, seems patently absurd. This is the problem of consciousness, but it is not the problem I am going to consider today, interesting and important though it is.

Let us start with the assumption that we do, in some sense, SEE tables and chairs in a good light possessing normal eyesight and so on. Even if we don't actually see them, i.e. they are not actually being observed, nevertheless they are observable in the sense that it is possible to see them.

Some philosophers of science, and indeed historically many scientists, have thought that science is concerned with discovering regularities in the behaviour of observable entities. Such people are generally called positivists. Scientific knowledge can be checked out in a positive fashion by direct observation. Labels such as 'positivist', and more particularly its cognate 'empiricist', are used with many shades of meaning in philosophy. I shall use such terms with a broad brush, just to give you the general idea.

At first blush the positivist position sounds attractive. The scientific attitude has progressed by getting rid first of supernatural spirits and gods controlling the world, then of theoretical metaphysical concepts like dormative virtues and other

mysterious substantial forms beloved of the Aristotelians, and finally arriving at the culmination of what the nineteenth century philosopher Auguste Compte called positive (i.e. non-speculative) knowledge.

But has science really followed the positivist programme? There are all kinds of difficulties. If we are restricted to direct observation then what is the point of scientific instruments like telescopes and microscopes? Surely these are supposed to enable us to see things that we can't directly observe?

There is a significant difference here between the telescope and the microscope. The optical telescope enables us to see things that we could see directly if we were differently located, i.e. moved closer to the distant tower or close up to the moons of Jupiter or whatever. But for the microscope it is not a matter of relocating ourselves. For the virus or the cell to become directly visible to us we would have to change our normal sensory apparatus or adopt the perspective of the Incredible Shrinking Man. So to count the virus or the cell as observable needs rather more science fiction than the case of the telescope.

Historically the first practical versions of the telescope and the compound microscope were employed by Galileo at the beginning of the seventeenth century. The telescope revealed all sorts of oddities in the heavens, from mountains on the moon to the satellites of Jupiter, announced by Galileo in his famous book The Starry Messenger (1610). What was the reaction of Galileo's Jesuit opponents? Some refused even to look through the telescope, averring that if God had intended us to inspect the heavens so closely he would have equipped us with telescopic eyes! Others claimed Galileo's observations were artefacts of the instrument.

With the microscope amazing detail was exposed. For example, the famous drawing dated 1625 of a bee made by Francesco Stelluti looking through an early

microscope. But sometimes people saw what they wanted or expected to see. Preformationists, like Nicholaas Hartsoeker, in embryology at the end of the seventeenth century claimed to see the homunculus sitting perfectly preformed in the head of the spermatozoa!

What we see is largely determined by the overall theoretical background of our thinking. The slogan here is the theory-ladenness of observation.

We have already had occasion to question whether the table or chair is directly observable. Is not observation always a case of probing or interacting with the physical world, and don't we always observe things by the effects they produce ultimately in our conscious minds. We often talk loosely of observing fundamental particle reactions, for example, with a bubble chamber or suchlike, but it's only when we look at the photographic plate recording the tracks that the observation is translated into positive knowledge for us.

From this perspective electrons, quarks, genes and viruses are after all observable. So do they really belong to the Unseen World, and on that account should they be eschewed by the scientist? This debate was carried on particularly vigorously at the end of the nineteenth century in respect of the reality of atoms. For Mach, Ostwald and others, the atoms of the physicist and the chemist were just fictional entities introduced as speculative mechanisms for explaining empirical regularities about chemical combination or the properties of gases. They were not to be thought of as 'real' in any robust philosophical sense.

To the modern scientist it is usually assumed that these debates have long been settled in favour of a realist conception of so-called theoretical entities rather than their positivist dismissal. But again things are less simple than they seem.

If we look at the history of science we can see it as a series of U-turns about the explanatory theoretical structure that lie behind or beneath the world of macroscopic experience. Entities like phlogiston or the luminiferous aether or caloric have simply disappeared from the scientific vocabulary and the nature of atoms and molecules is quite different from the modern perspective of quantum mechanics than the billiard ball conception of the nineteenth century. This leads to the famous pessimistic induction. If we have been so often wrong in the past, is it not pure hubris to believe that our present scientific theories won't look equally ridiculous a hundred years from now?

To defuse the pessimistic induction philosophers have tried to read the history of science in a more continuous and progressive fashion. It has been argued by John Worrall, for example, that although the ontology of physical theory changes abruptly, nevertheless there may be what might be called structural continuity in the sense that in many cases the mathematical equations survive, only the <u>interpretation</u> of the quantities entering into the equations changes. There are two versions of this structuralist philosophy. In an extreme, even bizarre, ontological version, it is only structure which really exists. Everything else is just imaginative fiction. In a more prosaic epistemic version, structure is all that we can claim reliably to <u>know</u>. We don't deny that atoms or quarks exist, just that we never know what their true natures are, only the <u>mathematical</u> description of how they are constructed, related to one another, behave in various experimental contexts and so on. The basic argument here is that the continuity of mathematical structure defeats the argument of the pessimistic induction. There are various comments I would like to make. Does it make sense to talk about things we can <u>never</u> come to know? This line of thought would drive us towards ontological structuralism. This of course is linked to the verificationist theory

of meaning espoused by the old logical positivists. Statements that cannot be verified are simply meaningless. Of course any strict interpretation of such a principle would arguably render every statement in science, just as much as, for example, in theology, meaningless. We never know anything for certain except perhaps in logic or mathematics. I say 'perhaps' because even these claims are not entirely clear but that is another story.... So, if there are so many things I am not certain about, by the same token I personally am quite happy to accept that there are things I am ineluctably ignorant about.

But is it true that mathematical structure really survives in tact? In the most revolutionary episodes in modern physics, relativity theory and quantum mechanics, that is just not right. The new mathematics involves parameters like the velocity of light c in the case of relativity, or Planck's constant h in the case of quantum mechanics. It is only by letting c tend to infinity or h to zero that we recover something like the old mathematics of classical physics. But these limits are in general highly singular. A world in which h is actually zero is qualitatively quite different from a world in which h is different from zero, however small in magnitude it might be. To illustrate what I have in mind, consider squeezing a circle so as to try and turn it into a line. But a line just is not a very elongated circle -- it has no inside and whether a curve is open or closed is an all or nothing matter. This is what mathematicians mean when they talk about singularities.

As another example, which is relevant to quantum mechanics, let us consider the limit of the classical wave equation of an elastic string for example, as the velocity of the waves tends to infinity. The character of the equation changes dramatically from what mathematicians call a hyperbolic equation to what they call a parabolic equation.

Suppose the two ends of the string, of length L, are fixed, then the solution for the displacement y of the 'limit equation' is just y=0. But for any finite velocity c, the solution of the original wave equation at an antinodal point is $y=\sin 2\pi\nu t$, where $\nu = c/2L$ for the fundamental mode of the string. Consider the time average $\bar{y} = 1/T \int_0^T \sin 2\pi\nu t.dt$ over a time interval T

Then $\bar{y} = 1/2\pi\nu T\ (1-\cos 2\pi\nu T)$

$= L/\pi cT\ (1-\cos \pi cT/L)$

For fixed T, however small, $\bar{y} \rightarrow 0$ as $c \rightarrow \infty$. But for fixed c, however large, we can always chose a T small enough to keep $\bar{y}$ unequal to zero. So the oscillatory behaviour of the string can always be revealed by averaging the motion over sufficiently short resolution times.

So in structural terms relativity and quantum mechanics genuinely involve new structure, not just the preservation of old structure. So is this not another example of a U-turn, like the abandonment of caloric or phlogiston? The best I can do here is to say that the way mathematical structures 'develop' in physical theory has a certain natural, although not of course inevitable, aspect to it -- natural that is to say to a mathematician.

There is of course a long tradition in natural philosophy that the physical world is constructed according to mathematical principles. This has a certain mystical appeal about it. For Plato, in the Timaeus, everything is constructed out of two sorts of triangle, a kind of mathematical atomism, and Galileo famously remarked that "the book of nature is written in the language of mathematics". For the cosmologist James Jeans, God was a mathematician. So in this vein, in discovering the new mathematical structures are we learning to read the mind of God, as Stephen Hawking claimed in his famous best-seller *A Brief History of Time*?

Let us pursue this question of the role of mathematics in physics for a moment. There are two quite distinct cases to consider. In the first case mathematics provides a language to represent physical reality or at any rate some emasculated, idealised version of physical reality. We translate a physical problem into a mathematical problem and then when we get the mathematical answer just translate back into physics again. But in other cases we embed the physics in a wider mathematical framework, involving what I call surplus structure, which controls the bit of mathematics actually used to represent the physical world itself. What do we mean by one bit of mathematics controlling another bit? In pure mathematics this is a familiar idea. Let me give two simple examples.

To prove Desargues's theorem in plane projective geometry, the usual method is to introduce a point which does not lie on the plane, i.e. move to a three-dimensional geometry. In this setting we need only to assume the axioms of incidence to prove the theorem in the plane. If we restrict ourselves entirely to the plane we have to invoke a more powerful principle such as Pappus's theorem concerning properties of hexagons in the plane to get the proof. In a sense the third dimension is controlling, i.e. explaining, what is going on in the plane.

Or again consider the binomial expansion of the function $1/1-x^2$, i.e. $1 + x^2 + x^4 + ...$ This only converges for $|x|<1$, and the reason is clearly related to the singular behaviour of the function at $x = \pm 1$. But what about the binomal expansion of $1/1+x^2 = 1 - x^2 + x^4 -\ldots$? This function is perfectly well behaved for $x = \pm 1$, but the convergence properties of the series are now controlled (explained) by the singularity at $x = \pm \sqrt{-1}$, i.e. by the extension of the real line to the complex plane.

All this is familiar in pure mathematics. The surprising thing is that this sort of thing is also going on in modern theoretical physics. In particular in modern gauge

theories of elementary particle interactions, the explanatory principles all operate in the realm of surplus structure! Let me quote from a well-known monograph by Henneaux and Teitelboim.

> "Physical theories of fundamental significance tend to be gauge theories. These are theories in which the physical system being dealt with is described by more variables than there are physically independent degrees of freedom. The physically significant degrees of freedom then re-emerge as being those invariant under a transformation connecting the variables (gauge transformation). Thus one introduces extra variables to make the description more transparent, and brings in at the same time a gauge symmetry to extract the physically relevant content.
>
> It is a remarkable occurrence that the road to progress has invariably been toward enlarging the number of variables and introducing a more powerful symmetry rather than conversely aiming at reducing the number of variables and eliminating the symmetry."

Gauge theories are complicated by so-called ghost particles associated with these unphysical degrees of freedom. This is how the famous physicist Steven Weinberg explains the role of ghost particles:

> "The ghost field represents something like a negative degree of freedom, these negative degrees of freedom are necessary because we are really over-counting. The physical degrees of freedom are the components of [the gauge field] <u>less</u> the parameters....needed to describe a gauge transformation."

So ghosts (and indeed antighosts!) play a vital role in modern non-Abelian gauge theories. But these ghosts are not intended to have a real physical existence. They belong to the Unseen World in a more extreme sense than electrons or photons. One cannot but be reminded here of the famous Tibetan ghost traps that were supposed to ensnare the, to us non-existent, ghosts!

But what sort of world is the Unseen World? There is an ongoing theme in writing about science that behind and beyond the complex, variegated, diverse world of sensory experience there lies a simple, unified, integrated world that science is gradually revealing, that the Unseen World knits together the patchwork structure of the world of appearances, and provides the true account of the reality referred to in Plato's famous simile of the cave. As T.H. Huxley put it: "The aim of science is to reduce the fundamental incomprehensibilities to the smallest possible number". This theme of unification has generally been expressed by a scheme of reduction in which the sciences are arranged in a hierarchy, with sociology and psychology somewhere at the top, below that biology and then chemistry, the whole tower resting on the bedrock of physics. And physics itself is reduced to a unitary theory of everything, a TOE.

Such is the rhetoric particularly espoused by Nobel prize winners in physics applying for huge government grants to work on problems in fundamental physics. You might be forgiven for believing that the ultimate aim of science is to achieve a sort of one-off Humperdinck's Law from which everything else would be accounted for and explained.

But a strong reaction against this sort of wild talk has set in recently in philosophy of science. The pendulum has swung strongly in the opposite direction, promoting the disunity of science and the virtues of the Dappled World, the title of

Nancy Cartwright's most recent book here at the London School of Economics. The arguments here look at detailed case studies of what science is really like, and not just, in moments of wishful thinking, how we would like it to be. The description of real science provided by this work is much closer to the experience of the research worker at the cutting edge of the sciences than the sanitised account given in much of the popular science literature.

To be sure warnings about the tendency of human beings to jump to conclusions about unification go back at least to the seventeenth century when Francis Bacon wrote:

> "The human understanding is of its own nature prone to suppose the existence of more order and regularity in the world than it finds. And though there may be many things in nature which are singular and unmatched, yet devises for them parallels and conjugates and relations which do not exist."

But has the pendulum swung too far? I would like to explain my own point of view on this question. The idea of unification is essentially a regulative ideal. We may even want to define a concept of scientific rationality as one which invokes the simplest, most unified theory, to explain empirical phenomena. On this account creationism, for example, is to be rejected, not because science shows it to be false, but 'because its acceptance would violate the canons of scientific rationality. This argument in defence of the scientific account is by itself clearly viciously circular. Its justification can, however, be provided in terms of the past record of scientific theories based on the pragmatic explanatory virtues of simplicity and unification, in producing successful novel predictions, the usual gold standard of scientific progress. So is it not rational to expect the same criteria to produce more successful science in

the future? But such meta-inductions are always liable to fallibility. Perhaps at some deep level of explanation physics will get more complicated rather than increasingly simple. But that is why I talk of a regulative ideal. It does not have to be indefinitely achievable, but its past successes provide justification for pursuing the ideal as a leading principle of scientific investigation.

The difference between myself and Cartwright is essentially that she likes the Dappled World *à la* Gerard Manley Hopkins, whereas I want to get out my needle and thread and try to stitch the whole thing together.

So, let me try to summarise the status of the Unseen World. In philosophy there have always been two attitudes to the senses. The first is that the senses are linked not to reality, but to mere appearances. In the words of Parmenides' poem they access the Way of Seeming, not the Way of Truth. The senses are in effect a barrier interposed between us and reality. Reality can only be known, if at all, by reason or rational insight. The other view, a liberal and relaxed form of empiricism, is that the senses link us in an admittedly tenuous and fallible way with reality, and that science, in pursuing that link has at any rate in part revealed to us the Unseen World that lies behind and beyond the world of everyday experience.