Laws of Nature, Laws of God?

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Proceedings of the Science and Religion Forum Conference, 2014

Edited by

Neil Spurway

Cambridge Scholars Publishing

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THE SCIENCE AND RELIGION FORUM

Growing out of informal discussions which began in 1972, around the key figure of Revd Dr Arthur Peacocke, the Science and Religion Forum was formally inaugurated in 1975. Its stated purpose was "to enable and encourage further discussions of the issues which arise in the interaction between scientific understanding and religious thought". These issues, together with the social and ethical decisions demanded by scientific and technological advances, have remained the subject of the Forum's meetings since that date.

In 2005 the Forum merged with the Christ and the Cosmos Initiative. This had been founded by the Revd Bill Gowland, a past President of the Methodist Conference, with the intention of bringing the latest knowledge of scientific thinking within the orbit of the enquiring layperson.

Thus enlarged, the Forum is open to all, of any personal faith or none, who are concerned to relate established scientific knowledge and methodology to religious faith and theological reflection. Implementing its broad objectives, it seeks:

1) to encourage scientists with limited knowledge of religion, and religious people with limited knowledge of science, to recognise and appreciate the contributions of both disciplines to human understanding of life in the world

2) to provide an interface between academics active in science-religion work, and public communicators – notably teachers, clerics, and those training future members of these professions.

At every point, the Forum strives to extend recognition that science and religion, properly understood, are not antagonists, but complementary in the quest for truth.

The Forum holds a regular annual conference, plus occasional smaller *ad hoc* meetings, and publishes a twice-yearly journal, *Reviews in Science and Religion.* Since 2008 it has also published edited proceedings of its annual conferences, under the series title *Conversations in Science and Religion.*

At the date of publication, the Forum's President is Prof John Hedley Brooke (Oxford) and its Chairman Revd Dr Michael Fuller (Edinburgh).

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The Science and Religion Forum warmly acknowledge the highly efficient and outstandingly friendly welcome given to it by the staff of Leeds Trinity University, when they hosted the conference of which these chapters are a product. The architectural and practical qualities of the University's facilities deserve comparable commendation.

As Editor, I owe my own thanks to all thirteen contributors, for meeting a fairly short deadline, and in several instances tolerating a succession of follow-up editorial demands. Particular appreciation is due to Professor Nancy Cartwright, for agreeing to work with an edited transcript of her exhilarating talk as the basis of her chapter, and Dr Jonathan Topham for honouring (splendidly) a commitment which he did not realise, until inconveniently late, that he had implicitly accepted.

I warmly acknowledge also the guidance about various aspects of my Introduction (Part Two), received from Drs Michela Massimi and Fraser Watts, and Miss Danielle Adams.

—Neil Spurway

CONTRIBUTORS

Editor

Neil Spurway studied in Cambridge, but has worked in the University of Glasgow ever since, and is now Emeritus Professor of Exercise Physiology. He has chaired that university's Gifford Lectureships committee, as well as the present Forum, been President of the Royal Philosophical Society of Glasgow and Vice-President of the European Society for the Study of Science and Theology. He co-authored *The Genetics and Molecular Biology of Muscle Adaptation*, but also initiated the present series and edited its first two volumes, *Creation and the Abrahamic Faiths* and *Theology, Evolution and the Mind*.

Invited Contributions

Nancy Cartwright, FBA, currently holds simultaneous Professorships in Philosophy in the Universities of Durham, UK, and San Diego, California. Her immediately previous chair was at the London School of Economics, where she co-headed the project on *God's Order, Man's Order and the Order of Nature*, funded by the Templeton Foundation and run jointly between LSE and San Diego. She is a Past President of both the Philosophy of Science Association and the American Philosophical Association (Pacific Division). Her many books include *How the Laws of Physics Lie, The Dappled World: A Study of the Boundaries of Science* and, most recently, *Evidence: For Policy, and Wheresoever Rigor is a Must*.

John Henry is Professor of the History of Science in the University of Edinburgh. Graduating from Leeds, and obtaining his doctorate from the Open University, he joined Edinburgh's Science Studies Unit in 1986, and has stayed there ever since. His interests include the histories of both science and medicine, and philosophy from mediaeval times to the Enlightenment. Resultant books have been *The Scientific Revolution and the Origins of Modern Science, A Short History of Scientific Thought* and a new translation of Jean Fernel's *On the Hidden Causes of Things (1548)*.

Tom McLeish, FInstP, FRS, Professor of Physics and Pro-Vice-Chancellor (Research) at the University of Durham, has previously held academic appointments in Cambridge, Sheffield and Leeds. He has won awards for his research on the molecular theory of complex fluid flow, and currently works on applications of physics to biology, as well as on matters of science policy and history. He gives time to science communication via radio and TV, and the face-to-face contact of schools lectures. His recent book, *Faith and Wisdom in Science* (on which his contribution here is based) has made considerable impact.

Eric Priest, FRSE, FRS, Emeritus Professor in the School of Mathematics and Statistics, University of St Andrews, has devoted his scientific life to theoretical studies of solar physics, and the interactions of magnetic fields with plasmas more generally. He has published two books, more than 30 years apart, on *Solar Magnetohydrodynamics* and *Magnetohydrodynamics of the Sun.* He is committed also to communicating, in lectures, discussions, and both TV and press interviews, his conviction that science and religion are parallel, not conflicting, human quests, with certainty no part of either.

Dr Jonathan Topham is a Senior Lecturer in History of Science at the University of Leeds. His research relates mainly to the history of printed communication in science, especially in late Georgian Britain. Among his co-publications are *Science in the Nineteenth-Century Periodical: Reading the Magazine of Nature* and *Culture and Science in the Nineteenth-Century Media.* He is currently completing a monograph about the Bridgewater Treatises entitled *Reading the Book of Nature: Science, Religion and the Culture of Print in the Age of Reform*.

Shorter Contributions

Paul Beetham, BSc (London), completed a Ph.D in Microbiology in Aberystwyth. Post Doctoral work in Germany, environmental consultation and teaching followed. Entering the Ministry he studied Theology at Durham and is now Superintendent Minister of the Birmingham (West) & Oldbury Methodist Circuit. He has served on the committees of both the Christ and the Cosmos initiative and the Science & Religion Forum.

Geoffrey Cantor is Emeritus Professor of the History and Philosophy of Science at the University of Leeds and Honorary Senior Research Associate at UCL Department of Science and Technology Studies. He has had a life-long interest in figures at the interface between science and religion, and two of his most notable books are *Michael Faraday, Scientist and Sandemanian,* and (with John Hedley Brooke) *Reconstructing Nature: The Engagement of Science and Religion.*

John Emmett recently retired as a Methodist Minister in the Bristol area and Tutor in Christian Doctrine at Wesley College. Before that he worked as a research physicist. He has a BSc in Physics, a PhD in Nuclear Power Physics, both from Imperial College, London, and an MA in Theology and Ministry from Bristol University. He is currently working on a book comparing models used in Trinitarian theology and Quantum Physics.

Richard Gunton, MA (Cambridge), PhD (Leeds), is a Research Fellow in ecology at the University of Leeds. He has he conducted research on plant community ecology in South Africa, Australia, Portugal and France, and contributed to a recent book on *Scaling in Ecology and Biodiversity Conservation*. He is also coordinator of the Faith-in-Scholarship initiative and an advisory board member for the Jubilee Centre.

Gavin Hitchcock (BA, Oxford; PhD, Keele), a mathematician, has worked for a number of years in Africa, mostly at the University of Zimbabwe, where he developed an interest in mathematical talent search and pedagogy. Currently he is Assistant Director (Training) in the South African Centre for Epidemiological Modelling and Analysis at the University of Stellenbosch. His pure mathematical researches have been in topology, and he now writes dialogues in the history of algebra.

John Lockwood, Fellow of the Royal Meteorological Society, a retired Senior Lecturer, University of Leeds, holds a B Sc (Geography with Pure Mathematics) and a Ph D. (Climatology), both from Queen Mary College, London. He researched energy/water exchanges between land surfaces and the atmosphere by numerical modelling. His books include *World Climatology, Causes of Climate*, and *World Climatic Systems*.

Juuso Loikkanen Juuso Loikkanen is a Junior Researcher at the University of Eastern Finland. He holds degrees in mathematics, theology, and economics and is currently working for two PhDs, respectively in Systematic Theology and in Mathematics. His contribution to this book is his first publication in English.

Fabien Revol is Assistant Coordinator, Chair in Science and Religion, and coordinator of the "Jean Bastaire" Chair for a Christian Approach of Integral Ecology in the Université Catholique de Lyon, from which he holds doctorates in both Theology and Philosophy. He is the author of *Le Temps de la Création*, and is writing a book on the question of novelty in nature. He is the only Committee Member of the Science and Religion Forum not based in Britain.

Fraser Watts is Reader Emeritus in Science and Religion in the University of Cambridge, and a past President of the International Society for the Study of Science and Religion. Amongst earlier positions he was Senior Scientist in the MRC Applied Psychology Unit in Cambridge. His publications include books (with co-authors) on *The Psychology of Religious Knowing*, *Psychology for Christian Ministry* and *Evolution, Religion and Cognitive Science.*

INTRODUCTION

NEIL SPURWAY

Part One: Subject-matter of this Book

As far as we can tell, when science as we now know it took off in the 17th C, every investigator thought of himself as probing some aspect of divine Creation – and every law enunciated was perceived as having been ordained by God for the governance of that Creation. In the more secular ethos of the 21st C, such a position is much less common. In consequence, the philosophical status of "laws of nature" – scientific laws – has become a lot more controversial. The Science and Religion Forum's 2014 conference, in the most congenial surroundings of Leeds Trinity University, was devoted to this topic, and the essays in this book result from talks given at that meeting.

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The five chapters in **Section One** derive from plenary talks, by invited speakers. In the first, Professor Eric Priest, FRS (St Andrews), intertwines an account of mathematical and experimental studies of the sun with his personal and religious response to the phenomena he encounters – a kind of response which was almost universal among scientists before the so-called "Enlightenment", and is (as he demonstrates) by no means dead today.

In Chapter Two, another FRS physicist, Professor Tom McLeish (Durham) aligns scientific research, over many centuries, with the biblical stance toward nature, especially as expressed in the Book of Job:

> Where were you when I founded the earth? Tell me, if you have insight.

From this he argues that "theology and science" is an inappropriate juxtaposition – we should be striving toward a theology *of* science.

These two splendid essays prepare the ground for what might well be considered the core lecture of the symposium, an account (Chapter Three) by Professor John Henry (Edinburgh) of the theological view of a Law of Nature – a divine injunction to matter as to how it should deport itself – and its subsequent, imperfectly comfortable, secularization. Not only linguistically but, it can be argued, metaphysically the laws discovered by the scientist still carry the implicit connotation of being laws laid down by God, yet the majority of modern practitioners would reject that connotation, and some would question its very meaning.

Chapter Four, by Dr Jon Topham (Leeds) is an account of a series of 19th C lectures, the “Bridgewater Treatises”, which were designed to show that the science of the day was wholly compatible with a theistic outlook. It is interesting to consider how the contribution by Professors Priest and McLeish would have fitted, *mutatis mutandis*, into the Bridgewater corpus: I suggest that they would have been amongst the most widely-quoted contributions!

This part of the book ends with a highly-personal philosophical discussion (Chapter Five), by Professor Nancy Cartwright, FBA (Durham and San Diego), of latter-day thinking about scientific laws. This was delivered as the Forum’s prestigious Gowland Lecture, open to the public, and is the one contribution to the book which is not an essay re-written entirely after the meeting. We were only able to include a text from this eminent but heavily-committed speaker by transcribing her lecture, and asking her to correct an edited version of that transcript. Accordingly, the printed text includes verbatim elements of the extensive discussion which the lecture aroused. Every other essay embodies, within the continuous written account, such elements of subsequent discussion as the speaker chose to incorporate.

The philosophical level of Professor Cartwright’s treatment was sufficiently high that I have judged it appropriate to present an essay of my own, attempting to introduce the modern philosophical thinking about scientific laws upon which she is commenting, for readers unfamiliar with the field. It is embodied in Part 2 of this Introduction.

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Section Two consists of contributions offered by registrants at the conference. I have placed first (as Chapter Six) a fine essay by Dr Fraser Watts (Cambridge), questioning whether complex biological systems – especially now that they are recognized as embodying massive epigenetic, not just Mendelian influences – will ever be describable by laws, as traditionally understood. Some background to this paper (including a definition of “epigenetic”!) is also included in Part 2, below.

In Chapter Seven Dr Gavin Hitchcock (Stellenbosch) takes us in what might be considered an almost-opposite direction, to consider laws in mathematics. He offers a lovely historical reconstruction to show that, in that discipline, the very concept of law is remarkably recent; and that, insofar as it is now accepted, it has not only an aesthetic but a moral dimension which is hard to detect elsewhere.

The remaining four chapters have more specifically theological themes. As becomes a Frenchman, Dr Fabien Revol (Lyon) builds his paper (Chapter Eight) on the writings of Descartes, and urges the importance of the latter's concept of "continuous creation". This term does not refer to the steady drip-feed creation of new matter, as in the cosmological hypothesis initiated by Hoyle, Bondi and Gold in the 1940s, but to the essentiality of divine immanence, sustaining the Universe in being. It seems appropriate to remark that this was a theme central to the thinking of Rev Dr Arthur Peacocke, the effective founder of the Science and Religion Forum.

Chapter Nine, by Mr Juuso Loikkanen (University of Eastern Finland), argues that there is no need to set divine design and natural causes against each other, and that Intelligent Design, despite raising the hackles of almost every experimental scientist alive, need really not be considered incompatible with their approaches.

In Chapter Ten Dr Richard Gunton (Leeds) raises questions about the validity of "Fine-tuning" arguments for the existence of God. Awe at the lawful appearance of the Universe remains a radically Christian and entirely appropriate stance but, he contends, it would be better expressed without citing "Anthropic" cosmological principles.

Next Dr John Emmett (a retired Methodist minister with a PhD in Physics) contends that dualist thinking, even as suggested by the juxtaposition "Laws of Nature, Laws of God", should be replaced wherever possible by Trinitarian thought-forms. They are, he contends, not only more Christian, but more constructive.

The section concludes, not actually with prayer (as do many religious meetings) but with a chapter *about* prayer. This (Chapter Twelve) is by Dr John Lockwood (Leeds), who considers prayer in the context of weather. As a mathematician, he is well placed to offer some guidance about the mathematics of complex – and even chaotic – systems along the way. Whether such systems will ever be describable in law-like terms it would be rash to predict: they certainly cannot now.

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Section Three (Coda) consists of just two pieces. The first (Chapter Thirteen), by Professor Geoffrey Cantor (Leeds), was the after-dinner speech at the conference. It returns to the theme of the first two chapters, urging that the only appropriate reaction to the majesty of Creation is reverence.

Finally, Dr Paul Beetham (another Methodist Minister with a science PhD – this time in microbiology) gives an overall, and again very personal reflection on the preceding contributions.

Part Two: Laws in Science

Alister McGrath has said (2005) that what drew him back, from schoolboy atheism towards a religious position, was reading some philosophy of science. This gave him his first awareness of the limits to both the range and reliability of scientific knowledge. Probing just one stage deeper, into the structure of such knowledge as science does provide, one realizes that the nature and role of scientific laws ("laws of nature") has become one of the major questions: and it is, of course, the underlying question of this book. However, we are able to publish here only one chapter dealing frontally with that question from the standpoint of the philosophy of science – Prof Nancy Cartwright's Gowland lecture, asking "How could laws make things happen?" (Chapter Five). This is a brilliant, individualist challenge to a number of widely-held assumptions, but it is not an elementary introduction to the topic! Here, I try to provide such an introduction. It is aimed most directly at sketching some of the background to Nancy Cartwright's chapter, but it should provide an only slightly less direct foundation for parts of several other contributions.

a) Kant and Newton

One talk, given at the conference, cannot be published in this book because it was already in press elsewhere (Massimi, 2014). The speaker, Dr Michela Massimi, is a Senior Lecturer in Philosophy of Science in the University of Edinburgh. Her topic was Newton's conception of natural laws, and Kant's critical reappraisal of Newton's view, undertaken relatively early in his own philosophical life – well before such great works as the *Critique of Pure Reason*. At first glance this early thinking of Kant's might seem to the non-specialist a recherché detail, but it in fact takes one straight to the heart of our conference theme.

In Newton's mind, laws of nature, such as those he himself so majestically expounded, were "laws" in essentially the same sense as laws of the realm – injunctions, prescriptions, given by God to the matter in His creation, dictating how it should behave. That was why they were *called* laws! To this cast of mind, as physical science developed it was making evident the jurisprudence governing the natural world. Newton was by no means the first to think in this way, as John Henry's contribution to this book (Chapter Three) makes clear: Descartes was a particularly important predecessor. But Newton was immensely admired by Kant, whose world-view was substantially founded on Newtonian physics. So for Kant to have detected weaknesses in Newton's outlook upon natural law is striking and significant: essentially, Kant was initiating the modern philosophical debate about the nature of scientific laws, which I presume to sketch below. But before this let me outline the key point which Michela Massimi made about Kant's critique of Newton.

The views she was presenting were those of the pre-1770 Kant, the "pre-critical" Kant, expressed particularly in *The Only Possible Argument* (1763). A key quote is:

> "Something is subsumed under the order of nature if its existence or its alteration is sufficiently grounded in the forces of nature. The first requirement for this is that the force of nature should be the efficient cause of the thing; the second requirement is that the manner in which the force of nature is directed to the production of this effect should itself be sufficiently grounded in a rule of the natural laws of causality."

Reading this attentively, one sees that, for Kant, orderliness, lawfulness, arises "bottom up" from the capacities inherent in nature. It is "sufficiently grounded" there, and not imposed from above, or outside – "top-down" – by Divine will, as Newton's thinking implied. (Historians of Philosophy recognise that Kant was taking the notion of natural "ground" from his older contemporary, Christian Wolff.) Newton's equations brilliantly described what was happening, but his underlying metaphysics involved God too directly for Kant.

b) Modern philosophical thinking about scientific laws

Nowadays, the most basic philosophical suggestion about the nature of scientific laws is that they are, at root, no more than observed regularities. I doubt whether any established philosopher of science actually upholds this "Naïve …" (Armstrong, 1983) or, less pejoratively, "Simple" Regularity Theory (SRT: Bird, 1996), but it makes a good starting-point for such textbook discussions. The SRT is also consonant with the outlook of Francis Bacon, the first writer who attempted to prescribe, at book length, how science should be done. With the overall aim of persuading people to study the world themselves, and not consider it necessary – let alone sufficient – to read what Aristotle had said about a topic, Bacon spelled out the process of generalising from repeating trends in observation, and proceeding on the working assumption that regularities which had been observed so far would continue to apply – an assumption, we may note, which every other living creature, animal, plant or microbe, is continually making too (though this is a 20th/21st C point, not a 17th C one). For this process of generalisation and projection, conducted consciously by human beings, Bacon coined the term "Induction". The inductive search for regularities is clearly an essential first stage in any science, but science is much more than this, and scientific laws are usually more than statements of those regularities.

However, to pin down what more they are is harder. Part of the problem is that there is a diversity of laws, and they do not all do the same things. If we start, as philosophers of science almost always do, with examples from physics, Kepler's Laws of Planetary Motion (the First Law being that the planets move in elliptical orbits, with the sun at one focus of each planet's ellipse) could be regarded as statements of observed regularity: they are wonderfully economical mathematical formulations of the regularities, yet in essence they are regularity-statements, arguably compatible with the SRT. But Kepler's Laws cry out for explanation, for the elucidation of the mechanism which leads to the regularities. That elucidation, of course, was provided two generations later by Newton's Law of Gravitation, building on those of Motion. These are most certainly not just summaries, however elegant, of a massive number of observations. Their statement, verbal and mathematical, implies processes, the intuiting of which constituted huge leaps forward in human understanding. Though Kepler's Laws came first in historical sequence, they are logically derivative from Newton's, and thus secondary to them. Whatever philosophical account we give of one of these groups of laws cannot apply to the other.

Kepler's generalisation from observations and Newton's theorising about mechanism do not represent the gamut of scientific laws. Later, I shall acknowledge some others. However, Kepler and Newton will be enough to have before us as we look at three other philosophical accounts of scientific laws, all more sophisticated than the SRT.

Systematic or Necessary?

The first more sophisticated account was spelled out most fully by David Lewis (1973), following earlier thinking by John Stuart Mill in the 19^{th} C and Frank Ramsey in the mid-20th. Lewis's main concern was to exclude chance regularities from appearing to be laws. He proposed that a regularity represented a law of nature only if it could be construed as an axiom in an overall deductive system which combined simplicity with strength. Simplicity and strength are both, of course, subjective notions, which seems at first sight to be a weakness. However, reading Thomas Kuhn (1962) on the role of training and textbooks in modern science, one must surely recognise that the education of the upcoming scientist these days will align his/her mind to the accepted criteria – it will align subjectivities! So that aspect of Lewis's account, although uncomfortable, is probably true to life. To my mind less comfortable, however, is that the follower of this so-called "systematic approach" must conclude that Kepler's formulations only achieved the status of laws in the wake of Newton's proposals. By contrast, these latter are clearly Lewissian laws in their own right, for they are the axioms of the Newtoniansystem.

Ten years after Lewis's book was published, David Armstrong (1983) used the long-standing philosophical concept of "universals" – properties, such as redness or largeness, which an infinite number of existing or potential things may have in common. For Armstrong, a scientific law is "a necessary relation between universals"[1]. One can get some feel of this in the situation which Bird uses to illustrate it: "If we see various different pieces of magnesium burn in air, we can surmise that the one property, being magnesium, necessitates the other, combustibility." I cannot imagine any practicing scientist gracing this very simple regularity with the title "law", but philosophers, having decided that the detection of regularities must be at the root of all laws, generously apply the term to almost any regularity. Substantively, one must surely wonder what Armstrong's account has added to the regularity that burning is observed in all instances where magnesium is exposed to air? We may intuit necessitation, but its objective meaning is elusive. I am reminded of Hume's critique of the concept of "cause": we may see that B always follows A, but what objective additional information have we added by saying that A *causes* B? Returning to Armstrong: even if we're happy that "necessitation" is meaningful, it is less than obvious how laws such as Newton's law of

[1] Briefer but similar analyses had been presented a few years earlier by both Fred Dretske and Michael Tooley.

gravitation can be fitted into the schema: massiveness and distance are universals, but quantitatively particular masses and distances are not, and the counterpoint with particulars is an essential aspect of the traditional concept of what is “universal”.

Proponents of necessitation, such as Armstrong, therefore espouse an additional “Principle of Instantiation”, whereby universals are instantiated by real particulars in the world. Whether this has done anything more than pinpoint our ignorance, I suspect most of my fellow-scientists will doubt. Other philosophers have doubted too. David Lewis, for instance, insisted (1983) that “necessitation” could not just be postulated: it could not enter into the relations between particulars just by bearing a name, “any more than one can have mighty biceps just by being called ‘Armstrong’”. (I owe this quote, together with some of the previous understanding, to a widely-helpful overview of which Prof Cartwright was the lead author: Cartwright *et al*, 2005.)

Essentialism

I am content to leave the debate between Systematists and Necessitarians there, because the third account of scientific law is to my mind the most promising. Certainly it is in several ways closer to the way practicing scientists think. Of course, it is expressed in philosophical language, in this case that of Essentialism, a mediaeval concept recalled to serve a modern function. The “essence” of an entity is the sum of its properties or “dispositions” (its “powers”, in Nancy Cartwright’s terms – Chapter Five). It is through these properties/dispositions/powers that entities interact. Laws such as Kepler’s recount our observations *that* they do so, and those such as Newton’s our formulations of *how* they do so. Things, out there in the world, have their essential properties, and many of these entail interactions with other things. Modern Essentialism is represented by the work of Mumford (1998), Ellis (2001) and Bird (2008); simpler accounts from the first two authors are Mumford (2005) and Ellis (2008). Essentialist thinking prepares us to accept the conclusion to which Nancy Cartwright comes in her paper here: laws don’t make *anything* happen – they aren’t causal agents! It’s the properties of material entities, and hence the mechanisms to which they contribute, that cause things to happen. What the laws we have formulated do is allow us to predict and explain these happenings.

Explanation

Explanation is, for the scientist, among the crucial roles of scientific law. However, what we mean by “explanation” is also, in philosophers’ eyes, not obvious. Half a century ago, the leading account of the role of laws in explanation was that of Karl Hempel, with his “covering law” account (Hempel, 1966, *et prec*.). According to this, a phenomenon is explained if there is a law or laws “covering” the situation, and the observed phenomenon can be deduced from the law(s), together with facts concerning the relevant circumstances – the “antecedent conditions”. The occurrence of the phenomenon can therefore be deduced from the law. “Nomological” being philosophical parlance for “having to do with laws”, this account is designated the “Deductive-Nomological” (D-N) model of explanation. A variant, encompassing the situation where the law is statistical and the resulting explanation or prediction probabilistic, was an important extension of essentially the same outlook.

For at least two decades after Hempel’s view became common currency, discussions of scientific explanation mainly consisted in criticisms of one or another aspect of his D-N model. Among these criticisms was that the model was too tolerant. In cases where the covering law is a symmetrical relation, it does not distinguish between the correct deduction and its inverse. Consider Boyle’s Law for a given quantity of gas – that, under conditions of constant temperature, pressure times volume is a constant. The D-N model would give equal justification to a claim that reducing the volume had caused the pressure to rise, and to the claim that increasing the pressure had caused the volume to diminish. If one thrusts inward the plunger of a syringe containing air, the first of these is true; if one transports an air-filled balloon to a greater depth under water, the second applies. They are never simultaneously correct, but the law does not tell us which way round is right. Another instance, perhaps more telling, is the relation between the height of a flag-pole and the length of its shadow: taking Hempel at face value, one could conclude that the length of the shadow caused the pole to be of a certain height! (I owe these examples respectively to Bird, 1998, and Okasha, 2002).

If this aspect of symmetry clearly requires more than Hempel’s analysis can provide, another seems satisfying, at least for our purposes here: it is that, in terms of the D-N model, there is symmetry between explanation and prediction: explanation = prediction after the event, prediction = explanation before the event. I think most practising scientists will be happy with that.

More recently, other approaches to explanation have gained credence in the philosophy-of-science community. In particular, the Essentialist view, outlined above, circumvents the problem: according to it, events are brought about by the properties/dispositions/powers of the entities involved. However, while this seems highly persuasive philosophically, and I feel accords well with how my fellow-scientists think at the coal face, an account in terms of laws, and how we use them, is probably still more applicable to formal scientific writing. So the D-N model has not disappeared, and it is referred to again by Nancy Cartwright in Chapter Five, below.

c) Other categories of law in physics

The above impressionistic outline of philosophical thinking about scientific laws was tested against just two examples, the laws of Kepler and those of Newton. They were sufficient to show that no single account can cover the logical status of all scientific laws. A few paragraphs on, I shall begin to ask how well the ideas we have encountered fit the laws formulated in the biological sciences. But we have not quite finished with physics, even at the basic, classical level to which we have so far restricted ourselves.

I first propose a third category of scientific law, in some senses intermediate between the two kinds we have so far acknowledged. The modal instance of this category is Ohm's Law. Ohm's law applies with absolute precision to current flow in electric circuits: precision even greater than that with which Newton's Law of Gravitation applies to the motion of a single planet. It could be documented by an unlimited number of specific instances and, however far one increased the precision of one's instruments, inexactitudes would not be found. But the reason for this is of different kind from those applying either to Kepler's Laws or to the Law of Gravitation. The relation I=V/R can equally well, and more fundamentally, be written R=V/I. Algebraically, this is equivalent to the Gas Laws, but the equivalence is misleading. The Gas Laws' terms – pressure, volume and temperature – are defined independently of the laws, which state an empirical relationship between them. But Ohm's law is a *defining* law: voltage and current (rate of flow of charge) can both be independently defined from electrostatics, but resistance cannot. Electrical resistance is *defined* as R=V/I. Furthermore, the equivalent relation applies with equal precision to fluid flow in pipes. For "voltage" we now read "pressure", "current" is rate of fluid flow, but hydraulic resistance is, in turn, not merely measured but defined as the ratio of pressure to current.

Yet another category of law is that of Conservation Laws – those of the conservation of energy, momentum, etc.. These are surely different in kind from any of the preceding categories, making it more evident still that no single account can be given of the form or logical status of all laws, even within classical physics? I make no claim to construct a more widely-applicable account of scientific laws, but merely to point out that those so far offered do not look able to embrace all the laws even of their modal science, physics. And science is not coterminous with physics.

d) Laws in the Biological Sciences

> "The philosophy of biology should move to the centre of the philosophy of science – a place it has not been accorded since the time of Mach. Physics was the paradigm of science, and its shadow falls across contemporary philosophy of biology as well in a variety of contexts: reduction, organisation and system, biochemical mechanism, and the models of law and explanation which derive from the Duhem-Popper-Hempel tradition."

This wish (Cohen & Wartofsky, 1976) has not been fulfilled. Physics still dominates the thinking of philosophers about science, as the contributions to this book abundantly demonstrate. But there are a score or more of other sciences. Do laws have similar form in all? We could validly look at representative laws from chemistry, mineralogy or geology, or – more challengingly still – at the sciences of massively complex physical systems, such as geophysics, astrophysics or meteorology – in a degree of counterweight to the customary preoccupation with physics. However, limited for space, I propose to move even further away from physical science, to what one otherwise-admirable review (which shall, at this point, be left anonymous) call "the poor cousins of physics – the special sciences", and consider a sample of biological laws. The ground for this policy is the widely-held suspicion that biological questions differ from those of physics more radically than those of any of the sciences listed a few lines earlier; and if the questions differ in kind, so must the answers.

To start at the least remove, a biochemical or biophysical process may be describable in wholly chemical or physical terms. However, something would be missing from such accounts – namely, the biological significance of the process concerned. As one moves up the scale of biological complexity, through systems physiology, via ethology and psychology to ecology and sociology, this becomes ever more apparent; indeed, beyond physiology, any such attempt would be laughably ridiculous. The argument is closely related to the old, but ever-valid, one which asks whether any understanding of Beethoven's Appassionata sonata is gained by recounting the acoustics of vibrating strings.

So there is something fundamentally different about the subject-matter of biology. Does this mean that the very concept of laws, within biological sciences, is different from that in physical sciences? Discussion of laws, other than those concerning evolution and occasionally also development, is strikingly missing from entry-level textbooks on the philosophy of biology. Exceptions are to be found only in works at the most sophisticated level. To keep things simple, we must start from scratch.

Physiology

Physiology having been my discipline, I take my first example from it, and consider the Law of the Heart, formally enunciated by E.H. Starling, in a prestigious lecture delivered in 1915, though only published three years later. The law states that, over a very wide range, as a heart is more distended during filling so its subsequent contractile force increases, with the clearly desirable result that all the blood which has come in is soon pumped out. If we compare this law with our initial examples from physics, we must surely conclude that, at first sight, it is in the same category as Kepler's laws: they are each summaries of generalisations, crying out for mechanistic explanation. Starling's Law applies to a heart isolated from its nervous control, so it is a consequence of properties residing in the cardiac muscle cells themselves. Work half a century after Starling indicated that it is principally explained by the fact that the contractile force generated by each heart-muscle cell varies with the overlap of two different kinds of protein filament; within the range of lengths over which the cells operate in a healthy heart, the further the filaments are slid apart while relaxed, the greater the contractile force their subsequent interaction produces. Having already noticed the greater parsimony of scientists than philosophers in using the term "law", we should not be surprised that that regularity-statement about interacting filaments is not normally graced by being termed a "law". Nevertheless it surely has the same logical status *vis-a-vis* Starling's law as the Law of Gravitation has towards Kepler's?

However, physiology is only one step removed from biochemistry and biophysics, in the extent to which it seeks to bring physical and chemical thinking to bear on systems of matter which happen to be alive. Perhaps, therefore, there should be no surprise that the status of this representative physiological law seems analogous to that of one from physics.

Genetics

So let us turn next to population genetics, and the Hardy-Weinberg Law, separately enunciated by both its originators in 1908. It asserts that, in sexually-reproducing species, two different forms (“alleles”) of a given gene which do not differ in selective advantage will occur in the same proportions in successive generations: “In the absence of selective forces, the gene frequency will remain the same indefinitely”. (A human example of difference without evident selective advantage might be blue versus brown eyes.)

The basis of this law is algebraic logic: also, in real terms it is a statistical law, applying with reasonable precision only in large populations. There are two points here. The statistical aspect makes it different from the tiny sample of just three physical laws we have considered so far, but not from Statistical Mechanics, the theoretical analysis which underlies Boyle’s (and Charles’s) Gas Laws, nor from the empirical laws of Radioactive Decay, and not from countless other laws and law-like generalisations in electronics, astrophysics, meteorology …. Again, the fact that the Hardy-Weinberg formula results from the logical analysis of a conceptual model enables prediction and explanation, *provided* the circumstances fit the conditions assumed in the model, is a common enough situation in physics, too. The Hardy-Weinberg Law sets up a null hypothesis – no evolution – which, by its almost universal failure to tally with observation, demonstrates that there is hardly any real population which is not constantly evolving (Keeting, 1980); and the detailed respects in which a particular set of observations departs from the algebraic prediction give a good indication of the nature of the evolutionary trend in question. In terms of the SRT, the simple regularity this law describes is that of a theoretical model with which observations almost always fail to fit: it is virtually the opposite of Baconian induction! But this does not make it different in kind from model-based laws in the physical sciences. In classical physics, the Ideal Gas Laws, and Newton’s Law of Cooling, have comparable relations to the real world; and in current research fields, from particle physics to cosmology, such situations are commonplace.

However, Starling’s and the Hardy-Weinberg law still have one major feature in common: that the mechanisms underlying each can be analysed in material, essentially-molecular terms. In the first instance, these are the interactions of cytoplasmic proteins, in the second the trajectories of genes through the processes of cell division. As a last biological example, let us look at phenomena which are not objective but subjective, and the fundamental data are the reports of conscious human beings – psycho-physics – and the search for regularities in the intensity of sensation.

Psycho-physics

The original law, enunciated mathematically by G.T. Fechner in 1862, states that the experienced difference between the magnitudes of two stimuli varies as the ratio *(not* the arithmetical difference!) of the stimulus intensities. It follows that **S**, the experienced intensity of a sensation = **k.logR**, where **R** is the physical intensity of the stimulus and **k** a constant for the particular sense modality concerned. Thus to match the sensed effect of turning on a second light bulb (of the same wattage) when initially there was one, if we start with 50 bulbs we must turn on, not one more (the same arithmetical increment), but another 50. The equivalent has been found to apply, more or less closely, to at least thirty different sensory modalities, including sounds, smells and tactile pressures. And the logarithmic ratio is enshrined in the decibel scale by which engineers indicate sound intensities.

The story of this law, since its original statement, is not one of steady maturation but of challenge and revision. Fechner based his mathematics, as Weber before him had based the pioneering experiments, on minimum detectable increments – "just noticeable differences". When experimenters such as S.S. Stevens, in the mid-20th C, focused on subjects' judgements of "half", "double", etc., the strength of a primary stimulus, they found that the best approximation to a law was more accurately stated mathematically not as a logarithmic but as a power relation, $\mathbf{S = kR^x}$ where **x** varied rather widely with different modalities. In the medium range of intensities the values indicated by this kind of equation are often not very different from those predicted by the logarithmic law, but where the stimulus intensities differ widely the two formulations are far apart.

If we return to our comparisons with laws in physics, it seems clear that even the move to subjectivity has only reduced the precision of the formulation, it has not altered anything in principle as regards the possibility of discerning regularities and expressing them in laws. As regards explanatory potential, Stevens' law is no more mechanistic than Fechner's; each seeks to encapsulate the regularity, not to explain it. Nevertheless the mechanisms are coming to be understood, and evidently reside in molecular and electrochemical phenomena in the membranes of the various sensory and neural cells. The situation is closely comparable to the cardiac one, where Starling's law as such merely encapsulates the regularity, though subsequently we have seen that it can be explained molecularly. The Fechner, Stevens and Starling laws are all, therefore, at what we might call the Kepler level, not that of Newton, let alone Einstein. Yet even in this respect the honour of biology can be saved, for the Hardy-Weinberg law was derived precisely by theoretical consideration of the behaviour of the genetic particles postulated by Mendel. The word “gene” had yet to be coined, and the double helix was still two generations in the future, but the mathematics of Hardy and Weinberg embodies a mechanism just as much as Newton’s did.

The Evolutionary Perspective

I have argued, therefore, that there is no fundamental difference between the physical and the biological sciences, as so far examined, in respect either of the feasibility of encapsulating observed regularities in formal laws or of those laws being capable of being derived from an understanding of mechanism. Yet to my mind, and I believe those of the overwhelming majority of current biologists, there remains a respect in which all biological laws – those considered above, and the many others we have not sampled – differ fundamentally from all in the physical sciences, whether physics itself or any other in the range from chemistry to cosmology. Virtually every mechanism described by a biological law applies because it has enhanced the capacity, of the animals, plants or bacteria which display it, to survive and thence to reproduce. The Hardy-Weinberg law refers directly to reproduction, the other laws to the individual survival necessary for reproduction. Thus Starling’s Law demonstrates an elegant functionality in ensuring that blood circulates without wasteful accumulation in either the venous or the arterial system. He demonstrated it directly in dogs, but it, or something close to it, almost certainly applies to all animals which have hearts. And the laws of sensation, whether in Fechner’s or Stevens’ formulation, represent wonderful economy: the fine discrimination necessary for sensitivity to modifications in gentle stimuli would be astronomically wasteful at the high-intensity end of the response range: wasteful, that is to say, in terms both of the numbers of sensory receptors and nerve fibres required and the metabolic energy they would cost. Exactly equivalent laws apply to the nerves controlling muscles: finesse of control is highly desirable at the low-force end of the muscle’s range, but would be hopelessly wasteful at the upper end.

I conclude that the concept of adaptive evolution is truly fundamental to all biological thought, and underlies all biological laws. In the much-quoted dictum of Theodosius Dobzhansky, “Nothing in biology makes sense, except in the light of evolution”. It is not in their individual form, but in their unanimous embodiment of that underlying vision, that the laws of biology, of the kinds we have considered so far, differ fundamentally from those of physical science.

e) Evolution, Epigenesis and Complexity

I remarked near the beginning of Section (**d**) that entry-level books on the philosophy of biology make no reference to the sorts of law considered in that section, but all consider a range of problems which philosophers have claimed to find in evolutionary theory itself. Given the importance which I have just allocated to the evolutionary concept, I can clearly not question the appropriateness of the philosophers’ interest, though I confess to considering most of their concerns misplaced! However, no contributor to this book addresses these issues, so I must not air my criticisms here.

One contributor, however (Dr Fraser Watts, Chapter Six), considers another major problem which modern biology raises for the philosophy of science – that of seriously complex systems (where “complex” means more than merely “complicated”). The kinds of system at issue here are not individual hearts, but at very least the whole cardiovascular system, and more often the entire animal under stress; not the distribution of alleles in successive generations of a single species but the development over time of the competing populations in a complete ecosystem; and not the response of one sensory modality to variations of stimulus intensity, but that of the whole brain to its endlessly changing environment. These are massive challenges to biological theorists, and it is hard to imagine their work ever being satisfactorily treated by the kind of philosophy of science outlined earlier. The possibility of embodying such thinking in a deductive-nomological model, for instance, seems remote. Perhaps Nancy Cartwright’s “powers”, or the related Essentialism of other thinkers, can accommodate such problems linguistically, but I am as doubtful as is Fraser Watts that doing this will ever add significantly to our scientific understanding.

Dr Watts is not, of course, the first to have recognised the philosophical, as well as scientific, challenge of complex biological systems. Ayala & Dobzhansky (1974), Maturana & Varella (1980), Bechtel & Richardson (1993), and Mitchell (2003) are representative of those who wrote in earlier decades on this topic. One respect in which Fraser Watts’ chapter is invaluable alongside these predecessors is that he makes his case with remarkable simplicity and clarity – not always the case in the prior literature! Another is his specific, and very telling, theological orientation.