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Dialectical Critical Realism in Science and Theology: Quantum Physics and Karl Barth

In order to illuminate the similarities and differences between science and theology, we consider an epistemology and methodology for each that can be characterised as a dialectical critical realism. Our approach is deeply indebted to the work of the great Swiss theologian, Karl Barth. Key points are (i) that the object under study determines the method to be used, the community of investigators and the nature of the possible knowledge to be gained; (ii) the necessity of a posteriori, rather than a priori reasoning; and (iii) that the dialogue between theology and science should account for both the similarities and differences between the two disciplines. The counterintuitive nature of quantum physics is used to illustrate how in science (i) the dialectic element should lead to a critical dimension to realism, and (ii) one is forced to engage with reality on its own terms.

Keywords: Critical realism, dialectic, quantum physics, epistemology, Karl Barth

Defining critical realism and dialectic

Critical realism is a philosophical or epistemological perspective that was clearly defined and developed only in the second half of the twentieth century. According to realism, there is an objective world that is independent of our perceptions of it, and we can obtain some reliable knowledge of this world. Such a position stands in contrast to idealism, the view that reality is identified with or determined by our ideas about it. But *critical* realism also acknowledges that knowledge is constructed by fallible humans in particular social contexts, and that our knowledge of the world is at best approximate. This view is critical because it allows knowledge to change when confronted with more evidence about the nature of reality itself. It is critical also because it claims that theoretical concepts are only approximate and provisional representations of reality, rather than exact representations that correspond intrinsically to reality.

In philosophy, the concept of *dialectic* is most commonly associated with G. W. F. Hegel (1770-1831). He introduced a system of understanding history in which new movements and ideas develop as syntheses of the inherent contradictions in preceding movements or sets of ideas. Hegel considered that all reality is dialectical; history itself is nothing other than a dialectical movement towards unity, so that every contradiction and antithesis becomes only a single moment that is later relativised and included in a higher synthesis. In contrast to Hegel's position, the Danish philosopher Søren Kierkegaard (1813-55) later developed a dialectical method in which there is no overarching synthesis, but only the paradoxical tension between a statement and its counter-statement. In the twentieth century, Karl Barth's theology also utilised a 'dialectical method' that was closer to Kierkegaard than to Hegel.[1] Barth called 'for every theological statement to be placed over against a counter-statement, without allowing the dialectical tension between the two to be resolved in a higher synthesis'.[2] For Barth, the truth itself cannot be articulated directly; rather, it 'stands in the middle' between statement and counter-statement.[3] The purpose of dialectics in theology, therefore, is to 'leave empty the place where the decisive Word [may] be spoken'[4]- to say both 'Yes' and 'No' so that authentic knowledge may arise in the space between these two opposing statements. In spite of such different approaches to dialectic, Hegel, Kierkegaard and Barth all held that knowledge is itself dialectical: 'truth' cannot be predicated of single statements in isolation, but only of the dynamic relationship between different statements and items of knowledge.

Critical realism in recent scholarship

Several authors have previously considered the role of critical realism in the dialogue between science and theology. The theological implications of quantum physics have also received considerable attention. We briefly mention some previous work in order to situate the present paper in this context and to clarify the distinctiveness of our own approach. In particular, the distinctiveness of our approach lies in its emphasis on the *dialectical* character of critical realism, an aspect that is seen especially in the theology of Karl Barth.

Ian Barbour, Arthur Peacocke, and John Polkinghorne have all suggested that some form of critical realism can provide a common epistemological and methodological framework for science and theology.[5] In their view, since critical realism is the most appealing framework for the natural sciences, it should also form the basis of theological and interdisciplinary scholarship. Alister McGrath has, however, criticised these authors for invoking critical realism

1 For Barth's early programmatic announcement of his dialectical method, see Barth, K. 'Das Wort Gottes als Aufgabe der Theologie', in *Das Wort Gottes und die Theologie*, Munich: Chr. Kaiser Verlag (1924), pp. 156-178. Unfortunately the English translation of this important paper is unreliable: 'The Word of God and the Task of the Ministry', in Horton, D. (trans.) *The Word of God and the Word of Man*, London: Hodder & Stoughton (1928), pp. 183-217.

2 McCormack, B.L. *Karl Barth's Critically Realistic Dialectic Theology: Its Genesis and Development 1909-1936*, Oxford: Clarendon Press (1995), p. 11.

3 Barth, *op. cit.*, (1) p. 171.

4 Barth, K. 'Church and Theology', in Smith L.P. (trans.) *Theology and Church: Shorter Writings, 1920-1928*, London: SCM (1962), p. 302.

5 See for example Barbour, I.G. *Myths, Models and Paradigms: The Nature of Scientific and Religious Language*,London: SCM (1974); Peacocke, A.R. *Intimations of Reality: Critical Realism in Science and Religion*, Notre Dame: University of Notre Dame Press (1984); and Polkinghorne, J. *Belief in God in an Age of Science*, New Haven: Yale University Press (1998), chapter 5.

without engaging with the broader scholarship on critical realism in the academic and philosophical community. Drawing on the work of the sociological philosopher Roy Bhaskar, McGrath develops an impressive critical realist methodology which rejects the sharp Kantian distinction between phenomena and noumena, and emphasises the stratification of reality and the determination of epistemology by ontology.[6] According to this approach, then, different methods must be used for the investigation of different objects and strata of reality. For McGrath, a properly 'scientific' theology therefore involves a posteriori reflection, rather than reflection grounded on any prior methodological commitments. Although his approach is deeply influenced by the theological realism of Barth, McGrath does not attempt to draw Barth explicitly into dialogue with the epistemological challenges posed by quantum physics, nor does he explore the specifically *dialectical* character of critical realism.

In a 1992 study, James Loder and Jim Neidhardt compared Barth's theological method with Niels Bohr's interpretation of quantum mechanics, with particular emphasis on the concept of 'complementarity'.[7] Loder and Neidhardt point out that both Barth and Bohr argued that the phenomena they were trying to understand (God's self-revelation and quantum phenomena respectively) must be interpreted on their own terms. This was an important study, since it was a sophisticated attempt to draw connections between Barth's theology and the epistemological implications of quantum physics. Nevertheless, the focus on Bohr gives rise to significant weaknesses, especially since Bohr's approach is only one way of interpreting quantum physics. Besides the Copenhagen interpretation (associated with Bohr), there are the Bohmian, many-worlds, consistent histories, 'no interpretation', and decoherence interpretations. Further, the credibility of Bohr's philosophical perspective is undermined by his uncritical application of concepts from quantum theory to the humanities and social sciences.

In the present paper, we will thus seek to move beyond these existing studies by offering a sustained engagement with Barth's theological realism in the context of contemporary quantum physics.

Critical realism in theology: Karl Barth

The Swiss theologian Karl Barth (1886-1968) was arguably the most influen-

6 McGrath, A.E. *A Scientific Theology*, 3 vols., London: T&T Clark (2001-3).
7 Loder, J.E. & Neidhardt, W.J. *The Knight's Move: The Relational Logic of the Spirit in Science and Theology*, Colorado Springs: Helmers & Howard (1992); 'Barth, Bohr and Dialectic', in Richardson, W.M. & Wildman, W.J. (eds.) *Religion and Science: History, Method, Dialogue*, New York: Routledge (1996), pp. 271-289. An evaluation can be found in McGrath, A.E. *The Foundations of Dialogue in Science and Religion*, Oxford: Blackwell (1998), pp. 198-205. Prior to the work of Loder and Neidhardt, Günter Howe and Hermann Timm had also brought Barth's theology into dialogue with Bohr: see their book, *Die Christenheit im Atomzeitalter*, Stuttgart: Klett (1970).

tial theological thinker of the twentieth century.[8] His *magnum opus* was the thirteen volume *Church Dogmatics*, a work whose scope, originality, exegetical engagement, and historical depth make it a model for scholarship in any field.[9] Dialogue on the relationship between science and theology has been deeply indebted to Barth, as is clear especially in the work of the British theologians T. F. Torrance [10] and Alister McGrath.[11]

Barth argued that theology is a discipline in its own right, and so should not be subservient to any external philosophy. He was opposed to natural theology, and he declined to participate in the formal dialogue between science and theology.[12] Yet the opening pages of the *Church Dogmatics* give careful consideration to the question of the respects in which theology is a 'science' (*Wissenschaft*).[13] As the present article will aim to show, Barth's approach to the 'scientific' character of knowledge can contribute significantly to the contemporary dialogue between science and theology.

Bruce McCormack has persuasively argued that the best way to characterise Barth's theology is to say that it is both critically realistic and dialectical.[14] McCormack's approach has also been developed by Paul La Montagne, who has specifically compared Barth's theological method with scientific criti-

8 For an accessible introduction to Barth's thought, see especially Barth's own works *Evangelical Theology: An Introduction*, Foley, G. (trans.), Grand Rapids: Eerdmans (1963); and *Dogmatics in Outline*,Thomson, G.T. (trans.), London: SCM (1949).

9 Barth, K., Torrance, T.F. & Bromiley, G.W. (eds.) *Church Dogmatics*, Edinburgh: T&T Clark (1956-75). For general overviews of the *Church Dogmatics*, see Busch, E. *The Great Passion: An Introduction to Karl Barth's Theology*, Bromiley, G.W. (trans.), Grand Rapids: Eerdmans (2004); and Webster, J. *Barth*, 2nd edn. London: Continuum (2004).

10 See especially Torrance, T.F. *Theological Science*, Oxford: Oxford University Press (1969); *The Ground and Grammar of Theology*, Charlottesville: University Press of Virginia (1980); and *Reality and Evangelical Theology: The Realism of Christian Revelation*, Philadelphia: Westminster Press (1982).

11 See McGrath, *A Scientific Theology; and The Order of Things: Explorations in Scientific Theology*, Oxford: Blackwell (2006).

12 On Barth's decision not to engage in dialogue with natural science, see his preface to *Church Dogmatics* III/1, pp. ix-x. See also the discussion in Sherman, R. *The Shift to Modernity: Christ and the Doctrine of Creation in the Theologies of Schleiermacher and Barth*, London: T&T Clark (2005), pp. 48-61.

13 Barth, *Church Dogmatics* I/1, pp. 8-11. Here Barth is speaking not of 'natural science' but of 'science' in the broadest sense, since the German term *Wissenschaft* means 'academic discipline' or 'field of study'. On Barth's view of the scientific character of theology, see the major study of Anderson, C.B. 'The crisis of theological science: a contextual study of the development of Karl Barth's concept of theology as science from 1901-1923' (PhD diss., Princeton Theological Seminary, 2005); and McCormack, B.L. 'Theology and science: Karl Barth's contribution to an ongoing debate', *Zeitschrift für dialektische Theologie* 22 (2006), 56-59.

14 See especially McCormack, *op. cit.*, (2); and McCormack, B.L. 'Der theologiegeschichtliche Ort Karl Barths', in Beintker, M. Link, C. & Trowitzsch, M. (eds.) *Karl Barth in Deutschland* (1921-1935): *Aufbruch – Klärung – Widerstand*, Zurich: TVZ (2005), pp. 15-40. On the dialectical character of Barth's theology, see also Beintker, M. *Die Dialektik in der 'dialektischen Theologie' Karl Barths*, Munich: Chr. Kaiser Verlag (1987); and Chalamet, C. *Dialectical Theologians: Wilhelm Hermann, Karl Barth and Rudolf Bultmann*, Zurich: TVZ (2005).

cal realism.[15] La Montagne stresses that Barth's critically realistic perspective about the knowledge of God was a response to revelation, and was not based on any a priori commitment to the nature of human knowledge. For Barth, realism means that the object of theological inquiry – God's self-revelation in Jesus Christ – is independent of our own ideas and thoughts about God. Barth emphasised that God is what he is, and not merely what we might wish him to be. Thus theological inquiry must begin not with any presuppositions about the nature of God or of the possibility of human knowledge of God, but only with God himself in the sheer actuality of his own living reality. Because the reality of God is the object under study in theology, the methods of theology must be wholly constrained by this unique object. And it is in exactly this sense that theology can be described as a 'science'. As Barth writes:

> Theology is one among those human undertakings traditionally described as 'sciences'. Not only the natural sciences are 'sciences'. Humanistic sciences also seek to apprehend a specific *object* and its environment in the manner *directed* by the phenomenon itself; they seek to understand it on its own terms and to speak of it along with all the implications of its *existence*.[16]

There is therefore no generally valid scientific theory that can be established in advance of actual knowing; we can theorise about methods of knowing only after knowledge of the object has already arisen. In McCormack's words: 'Sciences are human *practices* whose norms emerge only through carrying them out.'[17]

But Barth emphasised not only the realism of theological inquiry; he also argued that this realism must be *critical*. He was well aware that even in the best cases there remains a gulf between reality as we represent it conceptually and reality as it is in itself. He was aware of the problematic relationship between knowledge and 'the social, historical and political investments in knowledge'.[18] More importantly still, he was acutely aware of the fact that the object of theology itself is not something that can be pinned down or brought under our 'scientific' control – it is a living, moving object, or rather a living *subject* who actively encounters those who study him.[19] Thus for Barth, theology 'is an eminently *critical* science, for it is continually exposed to judgement and never relieved of the crisis in which it is placed by its object, or rather to say, by its living subject'.[20] Theology's transcendent object is always living and active, always encountering us as a genuine Other, as a personal agent whom we cannot grasp or control. Our knowledge of this object is therefore at best a

15 La Montagne, D.P. 'Barth and rationality: critical realism in theology' (PhD diss., Princeton Theological Seminary, 2001).
16 Barth, *op. cit*., (8) p. 9.
17 McCormack, *op. cit*., (13) p. 58.
18 Ward, G. 'Barth, Modernity and Postmodernity', in Webster, J (ed) *The Cambridge Companion to Karl Barth*, Cambridge: Cambridge University Press (2000), p. 286.
19 On Barth's view of God's 'objectivity', see Busch, *op. cit*, (9) pp. 72-76.
20 Barth, *op. cit*., (8) p. 16.

knowledge in crisis: it is precarious and unstable, 'set on the edge of a knife'.[21] Hence, theology can never adopt a simplistic realism which identifies our knowledge of the object with the object itself.

Indeed, several of the biblical writers offer warnings against placing too much confidence in one's own understanding of what God is really like. The name which God reveals to Moses, YHWH, can be translated 'I am who I am' or 'I will be what I will be' (Exod. 3:14), and this name highlights God's refusal 'to put himself at the disposal of humanity or to allow humanity to comprehend him'.[22] And God confronts righteous Job with the question: 'Who is this that darkens my counsel with words without knowledge?' (Job 38:2). To Isaiah, God declares: 'For my thoughts are not your thoughts, neither are your ways my ways. As the heavens are higher than the earth, so are my ways higher than your ways and my thoughts than your thoughts' (Isa. 55:8-9). In the New Testament, Jesus is depicted as consistently challenging Israel's assumptions about the will of God and the nature of God's kingdom, while Paul contrasts the 'wisdom' of human beings with the 'foolishness' of a God who allowed his Son to be executed on a cross (1 Cor. 1:18-25).

While realism is essential, then, it must be shaped and moderated by a *critical* dimension. Since in theology we have to do with the infinite and living mystery of God himself, we must always be ready to revise our ideas and concepts as they are challenged and critiqued by the reality of God. This, then, is what 'critical realism' entails in theological study, and this is the kind of approach that Barth sought to develop. But how does such an epistemological approach relate to the study of the natural sciences?

The case for scientific realism

Others have offered detailed accounts of the subtleties of scientific realism.[23] In this section, we do not wish to add to this earlier work, but only to emphasise why so many practising scientists find critical realism so appealing. Ultimately, the case for scientific realism rests on the sheer success of science; as Wentzel van Huyssteen observes, it is 'an empirical thesis' which rests 'on experiential grounds'.[24] What follows is a series of specific examples from

21 Clough, D. *Ethics in Crisis: Interpreting Barth's Ethics*, Aldershot: Ashgate (2005), p. 14.
22 Zimmerli, W. *Old Testament Theology in Outline*, Green, D.E. (trans.), Louisville: John Knox Press (1978), p. 20. For Barth's own discussion of the significance of the name of God, see Barth *op. cit* (9) I/1, pp. 316-324.
23 See for instance Bricmont, J. & Sokal, A. 'Defense of a Modest Scientific Realism', in Carrier M. et al. (eds.) *Knowledge and the World: Challenges Beyond the Science Wars*, Berlin: Springer-Verlag (2004), pp. 17-45.
24 van Huyssteen, J.W. 'Critical Realism and God: Can There Be Faith after Foundationalism?' in *Essays in Postfoundationalist* Theology, Grand Rapids: Eerdmans (1997), p. 44. In *Faith, Science, and Understanding*, New Haven: Yale University Press (2000), J. Polkinghorne has suggested that all scientists are critical realists. On the question of whether this is true, see Crease, R.P. 'This is your philosophy', *Physics World* (April 2002) http://physicsweb.org/articles/world/15/4/2.

physics which illustrate why the success of science is best explained by a realist understanding of knowledge: these examples would be remarkably difficult to explain if scientific theories were viewed according to any non-realist model.

(i) High precision tests

Due to advances in technology over the past few decades, it has been possible to make experimental tests with remarkably high precision of the predictions of fundamental theories such as quantum mechanics, special relativity, general relativity, and quantum electrodynamics (QED). For example, QED predicts the value of the magnetic moment anomaly of electrons that agrees with experiment to within a few parts per billion.[25] Einstein used his equations for general relativity to predict the gravitational red shift of light, yet experiments in the period 1920-1960 failed to observe the predicted effect. However, the predicted effect has now been observed with a precision of seventy parts per million.[26]

(ii) The testing of unforeseen predictions

When Schwinger, Tomonaga, and Feynman developed the theory of QED they did not anticipate that it would be tested to such precision. In a similar vein (as emphasised by Weinberg),[27] other theories have led to predictions that were not at all anticipated when the theories were originally developed. One hundred years ago Planck introduced the concept of the quantum in order to explain the spectrum of black body radiation. He did not anticipate that this result would describe the spectrum of the cosmic microwave background, which is a remnant of the big bang, to an accuracy of better than 0.005%.[28] When Einstein wrote down his field equations for gravity (general relativity) he did not realise that they would lead to the prediction of gravitational radiation which was subsequently observed (albeit indirectly) in binary pulsar systems to an accuracy of 0.4%.[29]

(iii) Diverse and independent methods of measuring the same physical quantity give the same result

The reality of atoms and molecules was finally accepted in the early part of the

25 Mohr, P.J. & Taylor, B.N, 'CODATA recommended values of the fundamental physical constants: 1998', *Reviews of Modern Physics* (2000)72, 351, Appendix B.
26 Vessot, R.F.C., et al. 'Test of relativistic gravitation with a space-borne Hydrogen Maser', *Physical Review Letters* (1980) 45, 2081.
27 Weinberg, S. 'Sokal's Hoax', *The New York Review of Books* (1996) 43:13, 11.
28 Fixsen, D.J., et al., 'The Cosmic Microwave background spectrum from the full COBE FIRAS data set', *Astrophysical Journal* 473 (1996), 576-587.
29 Taylor, J.H. Jr., 'Binary pulsars and relativistic gravity', *Reviews of Modern Physics* (1994) 66, 711.

twentieth century because of several independent measurements of Avogadro's number (which is defined as the number of atoms in 12 grams of carbon).[30] McGrath[31] reviews the five different ways of measuring Avogadro's number. It can be measured from Brownian motion, electrochemistry, alpha radioactive decay of nuclei, oil drops on Langmuir Blodgett films, and X-ray diffraction from crystals. The results of these independent and diverse experiments on a diversity of materials are consistent with the value of $6.02214199(47) \times 10^{23}$.

A more recent example concerns the fine structure constant α. It was originally determined from the splitting of atomic spectral lines but can be determined with greater precision from QED. In 1980, von Klitzing found that α could also be determined with similar precision from the Quantum Hall effect which occurs in semiconductor heterostructures.[32]

(iv) Limitations of theories are well defined

Although classical Newtonian mechanics is only an approximation to more general theories such as special relativity and quantum mechanics, we know precisely under which conditions it can give a quantitative description of particle dynamics and these more encompassing theories can give quantitative estimates of the inaccuracy of classical mechanics.

(v) Unification and universality

Many disparate phenomena, which at first seem unrelated, can be described by the same set of 'simple' equations. For example, when first studied, electrostatics, magnetism, light waves and radio waves appeared to be unrelated and needed to be described by separate and distinct theories and laws such as those of Coulomb, Ampere, Gauss, Faraday and Biot-Savart. However, Maxwell showed that all these laws could be described by just four equations. Furthermore, Einstein used relativity to show that Maxwell's equations could be reduced to just two equations. Similarly, quantum mechanics, which can be reduced to just a few equations and postulates, can quantitatively describe diverse systems ranging from atoms to molecules to nuclei to crystals.[33]

30 See the discussion in Briggs G.A.D. & Fisher, A.J. 'STM experiment and atomistic modelling hand in hand: individual molecules on semiconductor surfaces,' *Surface Science Reports* (1999) 33, 3; and Haw, M.D 'Colloidal suspensions, Brownian motion, molecular reality: a short history', *Journal of Physics: Condensed Matter* (2002) 14, 7769.
31 McGrath, *op. cit*., (6) 2:158-160.
32 von Klitzing, K. Dorda, G. & Pepper, M. 'New method for high-accuracy determination of the fine-structure constant based on quantized Hall resistance', *Physical Review Letters* (1980) 45, 494.
33 Laughlin, R.B. & Pines, D. 'The theory of everything', *Proceedings of the National Academy of Sciences* (USA) (2000) 97, 28.

(vi) Although social influences play a role in theory development and acceptance, these influences are not determinative

Non-scientific factors within the scientific community such as culture, politics, personalities, and funding may play a role in the development, promotion and acceptance of theories, particularly in the short term. Yet in the long term it is empirical evidence and not social influences that determine which theories are accepted by the scientific community. To illustrate, here are three examples:

a) In 1905, a physicist who could not obtain a university position worked at the Swiss patent office and published three research papers in his spare time. If politics, status, influence, power and personal connections determined the acceptance of new theories, these three papers would be long forgotten. However, Einstein's papers on Brownian motion, the photoelectric effect and the special theory of relativity attracted considerable interest and launched his career *because of their explanatory and predictive success*.

b) In 1962, Brian Josephson, a PhD student at Cambridge, proposed the possibility of observing a new effect in superconductors. However, this idea was rejected and actively opposed by John Bardeen, who had already received a Nobel Prize in physics for being a co-discoverer of the transistor, and who received even more prominence for leading a team that created the theory of superconductivity in 1957 (for which work he shared a second Nobel Prize in 1972). Given this considerable mismatch in power, prestige and influence between Josephson and Bardeen, one might have expected Josephson's ideas to have little chance of acceptance.[34] But they were accepted because the Josephson effect was *observed*, and it is now the basis of technology for making high precision measurements of fundamental constants, and of small magnetic fields (to a precision of 1 part in 10^{19}), including those associated with brain activity.

c) In the 1950s, the Soviet theoretical physicist Lev Landau developed a theory for collective excitations in various quantum many-body systems, including liquid Helium and metals. It has been suggested that a key to this development was Landau's commitment to Marxist ideas about 'collective' politics.[35] However, this argument overlooks the fact that similar theoretical ideas were developed independently at the same time in the United States, at Bell Telephone Laboratories, a bastion of capitalism and individualism.

(vii) Emergence, consilience and reductionism

Philip W. Anderson is one of the most influential theoretical physicists of the

34 McDonald, D.G. 'The Nobel laureate versus the graduate student', *Physics Today* (July 2001) 54, 46.

35 See Kojevnikov, A.B. 'Freedom, collectivism and quasiparticles: social metaphors in quantum physics', *Historical Studies in the Physical and Biological Sciences* (1999) 29:2, 295; and 'Landau, physicist and revolutionary', *Physics World* (June 2002), 35.

second half of the twentieth century. He has argued that an even greater problem for postmodernism than the predictive and explanatory success of science is the concept of emergence.[36] Emergence is the phenomenon whereby unanticipated macroscopic properties arise from the microscopic properties of the constituent atoms and molecules.[37] For example, gold is soft, metallic and shiny, yet individual gold atoms are not. In molecular biology, an example of emergence is the way in which a particular sequence of nucleotides in DNA leads to a cell being susceptible to attack by a particular virus.

'Consilience', a concept popularised by the evolutionary biologist E. O. Wilson, suggests that the universe can be organised in terms of a few fundamental laws or principles that underlie every branch of learning. Anderson suggests that emergence is the mechanism for consilience, and that reduction is the evidence for it. Theories may be underdetermined, since there may be many possible theories that can explain what is actually known. Hence, a successful theory may not actually correspond to what is happening. If there are only a few constraints (hypotheses, observations) that a theory must satisfy, it has sometimes been the case that more than one satisfactory theory can be provided. However, as the number of constraints increases, acceptance of a theory is more likely and it becomes hard to conceive of alternative theories that could satisfy these constraints. Reduction can greatly increase the number of conditions that a theory must satisfy. For example, any alternative to quantum theory must be able to explain all known principles of atomic physics and of chemistry. Such a large body of knowledge places extremely strict constraints on any alternative theory.

Dialectical science

A detailed study of the material world confronts us with results that challenge our classical conceptions of what is 'obvious', 'reasonable' or 'common-sense'. Presuppositions or axioms that seem to be self-evident sometimes turn out to be inappropriate to the description of physical reality. The earth rotates round the sun, not the converse. Modern theoretical physics has turned upside down 'obvious truths' such as the ideas that parallel straight lines do not cross, that time and space are separate, that electricity and magnetism are different and that particles and waves are distinctly different entities. While Kant took Euclid's axioms of geometry as self-evident, it is now clear that these axioms are not universally true.

36 Anderson, P.W. 'Emergence, reductionism and the seamless web: when and why is science right?', *Current Science* (2000) 78:6, 1.

37 For an introduction to emergence, see Laughlin, R.B. *A Different Universe: Reinventing Physics from the Bottom Down*, New York: Basic Books (2005); and see also the interdisciplinary essays collected in Clayton, P. & Davies, P. (eds.) *The Re-Emergence of Emergence: The Emergentist Hypothesis from Science to Religion*, Oxford: Oxford University Press (2006).

Some great insights and advances have been made in theoretical physics by focusing on paradoxes, tensions and inconsistencies within current theory. Einstein's discomfort with quantum theory led to formulation of the 'paradox', now known as the Einstein-Podolsky-Rosen (EPR) paradox.[38] Decades later this stimulated new experiments testing quantum theory and the new fields of quantum information and quantum computation. Despite these advances it is debatable whether the paradox has been resolved. This example counters a Hegelian view of science that considers advances to occur because paradoxes are resolved by new syntheses. Instead, as Barth's theology emphasises, encounters with reality give rise to *dialectics* which cannot necessarily be resolved by further advances of knowledge.

Einstein's theory of special relativity involves several counter-intuitive notions. The separation of space and time is not absolute but depends on the observer. This leads to strange effects such as the fact that two observers moving relative to one another will not agree about the lengths of objects or the time interval between two events. Einstein's theory of general relativity is a theory of gravitation which claims that space and time are not absolute and that space-time is curved, thus contradicting Euclid's axioms of geometry.

We now turn to the most counter-intuitive theory in all of science.

Quantum weirdness

Quantum physics is arguably the most successful (and most bizarre) theory of modern science. It describes everything from quarks and electrons to molecules and crystals. Many of its predictions have been tested to remarkable precision. However, the theory has a number of experimentally confirmed features which are very counter-intuitive and which challenge classical concepts. In spite of this, physicists do engage (albeit sometimes reluctantly) with quantum reality.[39] Here again, there are some highly suggestive parallels between the epistemological issues raised by quantum theory and those raised by Barth's dialectical critical realism in theology. Below we give a fairly thorough list of the strange features of quantum theory.[40] Our list is extensive, since many existing discussions of this topic in the theological literature[41] consider only one or a few of these strange features.

38 Einstein, A. Podolsky, B. & Rosen, N. 'Can quantum-mechanical description of physical reality be considered complete?' *Physical Review* (1935) 47, 777.

39 For a brief discussion, see Leggett, A.J. 'The quantum measurement problem', *Science* (2005) 307, 871. Leggett (who shared the Nobel Prize in Physics in 2002) makes the intriguing statement: 'Personally if I could be sure we will forever regard Quantum Mechanics as the complete truth about the physical world I think I should grit my teeth and plump for [the view that] Quantum Mechanics is the complete truth (in the sense that it always gives reliable predictions concerning the nature of experiments) but describes no external reality.'

40 For an introduction, see Rae, A. *Quantum Physics: Illusion or Reality?*, 2nd edn., Cambridge: Cambridge University Press (2004).

41 For a survey, see Worthing, M.W. *God, Creation and Contemporary Physics*, Minneapolis: Fortress (1996).

Discrete energies

A classical particle can have any possible energy. Energy can be added to it in any small amount. In contrast, particles such as the electrons in atoms can often have only certain well-defined discrete values for their energy. This leads to the atoms only being able to absorb or emit light of very particular wavelengths.

Tunnelling through a potential energy barrier

People cannot run through walls. They do not have enough energy. On a roller coaster one will only get over a hill if at the beginning one has enough kinetic energy to get to the top of the hill. In contrast, for an analogous situation involving atoms there is a finite probability that the atom can 'tunnel' through a barrier and escape. Such a process is responsible for radioactive decay of atoms and for rectification of electrical current by some electronic diodes in computers, and it contributes to proton transfer in some enzymes.

Wave-particle duality

Classically, one makes a clear distinction between particles (e.g. footballs) and waves (e.g. light waves or ripples on the surface of a pond). Such a clear distinction does not exist in quantum physics. One can observe wave phenomena (e.g. interference patterns) associated with electrons and particle-like phenomena (e.g. elastic collisions) with photons (quanta of light waves). This wave-particle duality led Bohr to hypothesise the principle of *complementarity*.

Heisenberg's uncertainty principle

For a classical particle it is possible simultaneously to measure the position and the speed of the particle to arbitrary precision. However, this is not possible in quantum physics. The uncertainty principle puts a lower bound on the uncertainty in both. The more precisely the speed is measured, the greater the uncertainty in the position, and vice versa.

Superposition states

Classically, particles or systems are in well defined states. For example, a bit in a computer is either a 0 or a 1. In contrast, in quantum physics one can have superposition states in which the bit is simultaneously in both states. A measurement will find the system to be in a 0 or 1. The relative probability of getting a 0 rather than a 1 depends on the original quantum state.

Does the wavefunction exist?

The fundamental object in quantum theory is the 'wavefunction' or quantum state of the system. There are many different interpretations of this wavefunction, as well as debates about its 'reality', since it cannot be measured directly. Measurements will have different outcomes with different probabilities. The square of the amplitude of the wavefunction gives the probability of the different outcomes. The phase of the wavefunction relative to another state can be measured via interference effects. However, the complete entity is not directly accessible to an experimentalist, and will always be altered by any measurement. This is in contrast to quantities in classical theories, such as position and velocity, which are all directly observable.

Berry's geometric phase

In most systems, if one varies a parameter that affects the state of the system and then returns the parameter value back to its initial value, the state of the system is the same as it was initially. However, if one does this for a quantum system, then cyclic variation of a parameter that affects the energy of the system can lead to the system's being in a different state from that it was in initially.[42] This is not a property that is completely unique to quantum systems, since classical systems such as Foucault's pendulum or polarised electromagnetic waves can also have this property. Yet, in quantum systems the geometric phase can have much more bizarre and non-local consequences.

The Aharonov-Bohm effect

This is a specific example of the geometric phase, and it exhibits a strange non-local character. If a classical charged particle passes through a region of space containing a magnetic field, the motion of the particle is affected. However, if the magnetic field is confined to a region of space that the particle circles but does not enter, the field has no effect on the particle. This is not the case in quantum theory. The magnetic field will change the phase of the particle's wave function and change interference patterns, even though the electron never actually enters the region in which the magnetic field is present.

Entanglement

This is by far the strangest property of quantum physics and there is no known classical analogue. Entanglement occurs when two (or more) particles or systems become intertwined in an inseparable way so that the state of one of the particles completely determines the state of the other particle. Entanglement leads to Bell's inequalities, teleportation and the quantum measurement prob-

42 Berry, M.V. 'Anticipations of the geometric phase', *Physics Today* (1990) 43:12, 34.

lem, which is embodied in *Schrödinger's cat*, which is simultaneously dead and alive! We now discuss each of these specific consequences of entanglement.

Bell's inequalities

Motivated by the EPR paradox, Bell considered alternative theories to quantum mechanics which would have been acceptable to Einstein. Such theories would be consistent with our everyday intuitions about cause and effect, and especially with our intuition that an event at some point in time and space cannot influence another event at a different time and space if there has not been time for a light signal to travel between the two points. Bell showed that such theories would have to satisfy certain mathematical constraints (inequalities), which quantum mechanics would not. Experiments subsequently confirmed the predictions of quantum mechanics, violating our intuitions about what is 'reasonable'.

Teleportation

Teleportation is the process whereby, through a series of measurements, one can destroy a quantum state at one point in space and time and recreate that same state at a different point in space, instantaneously.

The quantum measurement problem

Measurements always yield definite outcomes. Yet the formalism of quantum theory suggests that this may not be the case.[43] This problem is well illustrated by Schrödinger's cat. It is simultaneously dead and alive, until someone observes it. This conflict between quantum theory and our everyday experience and intuition of 'reality' is the aspect of quantum theory that has caused the most debate, contention, and confusion. It has led to a plethora of different interpretations of quantum theory.[44] The existence of superposition states in microscopic (i.e., atomic and molecular) systems is well established experimentally. More recently, such states and the associated interference effects have been observed in some mesoscopic (i.e., intermediate between microscopic and macroscopic) systems. The quantum measurement problem arises because entanglement leads to a microscopic superposition state causing a measuring apparatus (which is by definition macroscopic) also to be in a superposition state.

We can see, therefore, that the most successful theory in all science – a theory that explains the structure and properties of matter – confronts us with a

43 Schlosshauer, M. 'Decoherence, the measurement problem, and interpretations of quantum mechanics', *Reviews of Modern Physics* (2004) 76, 1267.
44 *ibid*.

reality that is altogether different from what our reason and intuition would lead us to anticipate. At the very least, this should encourage us to be cautious about thinking that reality has to behave in a certain way. We should be open to the possibility that reality is quite different to what we might expect.

In theological study, the weirdness of the quantum world should not be taken as a mandate for crazy ideas or irrationality, but instead it should open us to a careful consideration of theological ideas in terms of their own internal logic. Quantum physics gives an example of a reality which is concrete and describable but also enigmatic, and which must be interpreted on its own terms. The paradoxes and counter-intuitive nature of quantum theory do not lead physicists to abandon realism, but rather the *dialectical* nature of our knowledge compels physicists to adopt a more *critical* realism. So too, in theology, the enigmatic character of the object of study should lead not to epistemological relativism but to a recognition of the *dialectical* and *critical* character of all theoretical formulations.

Similarities and differences between science and theology

As Barth emphasised, both science and theology are concerned with a specific object which defines the field of study: its central agenda, the appropriate methods of investigation, the nature of the knowledge attained and the limits of what can be known. As noted earlier, according to Barth, all sciences 'seek to apprehend a specific *object* and its environment in the manner *directed* by the phenomenon itself'.[45] In short, Barth argued that the essence of a science is the priority of 'being' over 'knowing' – the determination of knowledge by the object of knowledge. The scientific method is notoriously difficult to define, and we can agree with Feyerabend that there is no single scientific method. 'Anything goes' – scientists simply use whatever is effective and productive. Even within sub-fields of physics, the methods used differ significantly. The best methods produce new insights and coherence, and they unify rather than fragment fields. The methods used in mathematics, physics, chemistry, biology and psychology are distinctly different. As one moves from mathematics and physics to biology and psychology, the complexity of the objects studied and the number of variables and components increase. Consequently, the level of mathematical rigour and quantitative description also decreases.

The constraint of an objective reality, independent of the observer, plays a similar role in science to the constraining role of divine reality in Barth's theology. In scientific realism the world is viewed as what it *is* rather than what we wish it to be, or even what our current theories say it should be. If reality as found by experiment does not conform to our theoretical understandings of it, then theory must accommodate reality and not vice versa. Granted, one unexplained experimental result does not lead scientists immediately to aban-

45 Barth *op. cit*, (8) p. 9.

don a theory. Sometimes it takes the scientific community decades to accept that a once-successful theory must now be revised. But eventually the weight of experimental evidence determines what is accepted as a description of reality.

Both Dirac and Einstein were brilliant theoretical physicists who made extremely important discoveries in the first half of their careers. Yet Einstein was uncomfortable with quantum mechanics, and Dirac was uncomfortable with renormalisation in quantum field theory and felt he could only accept theories that were 'beautiful'.[46] Because neither could engage with the reality accepted by their contemporaries, the second halves of the careers of both Einstein and Dirac were relatively unproductive.

In all this, there is a striking parallel between the development of scientific knowledge and the development of knowledge in theology. In both science and theology, reality often proves to be stranger and more surprising than we had ever imagined. In both fields, specialists are at times compelled to revise their own theories and assumptions in light of new counter-intuitive discoveries about the nature of reality. In patristic theology, for example, a deepening awareness that God himself was present in the historical appearance of Jesus gave rise to the unexpected and highly complex theoretical formulation of God's triunity, culminating in the confession that Jesus was '*homoousion* [of one being] with the Father'.[47] Although the doctrine of the Trinity remained relatively stable in medieval, reformation and post-reformation theology, it was again decisively reformulated and subjected to new conceptual sharpness when modern thinkers like Hegel, Barth and Karl Rahner uncovered startling new insights into the relationship between Trinity and revelation on the one hand, and between the 'economic' and the 'immanent' Trinity on the other.[48] As this example illustrates, theological knowledge as much as scientific knowledge can be subjected to drastic revision in the wake of new, counter-intuitive discoveries and insights. The ability of reality to surprise us is summed up in the famous statement that 'the Universe is not only queerer than we suppose, but queerer than we can suppose' (sometimes referred to as 'Haldane's law', after the distinguished evolutionary biologist and geneticist J. B. S. Haldane).[49] As John Polkinghorne also writes:

> [Scientists] have learnt that the world is strange beyond our prior expectation, but also rationally satisfying in its idiosyncrasy. The doctrines of a tripersonal God and of him making himself known in personal terms, have

46 H. Kragh, 'Paul Dirac: Seeking Beauty', *Physics World* (August 2002).

47 See Torrance, T.F. *The Trinitarian Faith: The Evangelical Theology of the Ancient Catholic Church*, Edinburgh: T&T Clark (1988).

48 On the influence of Hegel, Barth and Rahner, see Grenz, S.J. *Rediscovering the Triune God: The Trinity in Contemporary Theology*, Minneapolis: Fortress, (2004), pp. 24-71.

49 A similar statement is attributed to Sir Arthur Eddington, arguably the most important astrophysicist in the first part of the twentieth century: 'Not only is the universe stranger than we imagine, it is stranger than we can imagine.'

> about them those elements of surprise and intellectual profundity which are characteristic of the best scientific theory. Our investigation of the physical world has stretched our minds and enlarged our notions of the conceivable. It would be surprising indeed if our encounter with God did not do the same.[50]

But although there are significant parallels between scientific realism and theological realism, it is also important to note the differences between the two. In the first place, critical realism in the philosophy of science and Barth's theological realism have different origins. In the former, critical realism is a response to and interpretation of the history of science and the explanatory power of scientific discovery. In the latter, critical realism is a response to and interpretation of God's self-revelation in Jesus Christ. Barth's critically realistic epistemology was not an epistemological presupposition, but was developed a posteriori as an implication of God's self-revelation and the knowledge that it calls forth.[51]

Further, the value of a critically realistic perspective in either science or theology does not immediately imply the value or validity of such a perspective in the other field. The methods, mechanisms and prerequisites for gaining knowledge in science are very different from those in theology. In science, knowledge is gained by experimentation and theorising, which are in principle accessible to all who have the prerequisite technical training. Knowledge of God, in contrast, depends on God's own self-disclosure, along with the human response of faith. Michael Polanyi has rightly emphasised the 'fiduciary' character of scientific knowledge, and has shown that all scientific investigation rests on a series of basic epistemological commitments;[52] but since the object of such 'scientific faith' differs so radically from the object of 'faith in God', the similarities between these two forms of epistemological commitment should not be exaggerated. The truth about God is not equally accessible to all, since God's reality becomes visible only by the gift of God and in the act of faith. Thus the different objects in science and theology give rise to fundamental differences in the prerequisites for knowledge and the appropriate community of investigators.

Conclusion

Many discussions of the relationship between science and theology focus on the content of specific scientific theories (e.g. quantum theory, evolution, or cosmology), and their implications for theology and biblical interpretation. Our

50 Polkinghorne, J. *Reason and Reality: The Relationship between Science and Theology*, London: SPCK (1991), p. 98.
51 See McCormack, *op. cit*, (2) p. 464; and La Montagne, *op. cit*., (15) pp. 106-116.
52 Polanyi, M. *Personal Knowledge: Towards a Post-Critical Philosophy*, London: Routledge & Kegan Paul (1962).

approach has been distinctly different, as we have considered some of the methodological and epistemological parallels between theology and science. Our hope has been to contribute to a mutually productive dialogue between these two very different fields, by focusing on the way in which knowledge in both science and theology is shaped and determined by the different objects of inquiry. The determination of knowledge by its object can helpfully be described using the concept of dialectical critical realism, a concept that is profoundly embodied in the theological thought of Karl Barth. Just as Barth illustrates the importance of a method of dialectical critical realism in the field of theological knowledge, so the paradoxical and counter-intuitive findings of quantum physics illustrate the scientific importance of a dialectical critical realism in which knowledge about the physical world is shaped by the (often surprising) nature of reality itself. We hope this paper will also stimulate others who are interested in the interface between science and theology to engage fruitfully with Barth's distinctive approach to theological epistemology.

Finally, we suggest that the approach considered here makes it possible to take account of some of the legitimate problems raised by postmodern theory (such as the cultural and historical influences on theory development, and the constructedness of texts and discourses), while avoiding certain unnecessary postmodern conclusions, such as ontological anti-realism and epistemological relativism.

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