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## How the Laws of Nature were Naturalised

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*When the notion of laws of nature first arose in the early modern period, it was an undisputedly theistic idea. Descartes and Newton believed there were laws because there was a divine Lawgiver. Today, the laws of nature have been thoroughly naturalized, but this shift away from a theistic understanding did not come about by accident. It was instead part of a larger programme to naturalise science in the nineteenth century. The most successful driver of this programme was a British group known as the X-Club, whose most prominent member was zoologist Thomas Henry Huxley. After briefly considering why the laws of nature became a foundational idea in science, we will trace how this reconceptualisation came about.*

**Key words:** laws of nature, X-Club, Huxley, Newton, Darwin, uniformitarianism, catastrophists, Divine Lawgiver, les philosophes, Hume, scientific naturalism

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How and when the notion of laws of nature arose in modern science is well-documented. For seventeenth-century natural philosophers such as Descartes and Newton, laws played a key role in their rejection of Aristotelian metaphysics. Their thinking was intrinsically theistic: There were laws for the whole of nature because there was a divine lawgiver.

Today, of course, matters are far different. Scientists and science educators no longer recognise any relation between the laws of nature and theism. That long-dead philosophers once thought there was one can be written off as an artifact of a more religious time. If anything, explanations that appeal to laws are now set in opposition to theism, as if once something is explained in terms of the laws of nature there is no need for God.

How did a theistic notion of laws come to be naturalised? One might think it was the inevitable evolution of language; concepts are as prone to drift in science as anywhere else. That, however, is not the full story in this case. In the Anglo-American world, the reconceptualisation of law was part of a larger programme to secularise science in the nineteenth century. The most successful driver of this programme was a British group known as the X-Club, whose most prominent member was zoologist Thomas Henry Huxley.

This paper starts with laws and their relation to theism in the early modern period, moving quickly through two centuries to focus on Victorian England. The main question will be how the idea of laws of nature was successfully ap-

propriated from theism by naturalists. Note that this was not a linear progression and there was never one uniform view held by philosophers or scientists at the time.<sup>1</sup> Moreover, not all writers seemed to have a clear sense of what they meant by 'law'. As we look back at them with the taxonomy of philosophical options we have in hand today, many appear to equivocate. For those looking to naturalise the laws, however, precision and clarity merely got in the way.

## From Aristotelian essences to laws of nature

The early modern period, starting with Descartes, is marked by its rejection of Aristotelian substantial forms/essences in favor of laws.<sup>2</sup> Attitudes ranged from scepticism to hostility. Pierre Gassendi argued that even if substantial forms exist, we do not have epistemic access to them.<sup>3</sup> Robert Boyle thought they were simply unintelligible.<sup>4</sup> Newton was typical:

Such occult Qualities put a stop to the Improvement of natural Philosophy, and therefore of late Years have been rejected. To tell us that every Species of Things is endow'd with an occult specifick Quality by which it acts and produces manifest Effects, is to tell us nothing. . . . (*Opticks*, Query 31)

Note that 'occult qualities' are unobservable, not necessarily supernatural.

Many philosophers also complained that substantial forms were useless intermediaries between God and physical entities.<sup>5</sup> God needs no viceroys to govern the world on his behalf, not Aristotelian essences, not the revamped world-soul of the Cambridge Platonists, and not a reified 'Nature' that some writers were carelessly referring to.<sup>6</sup> The overall trend was to replace metaphysically sus-

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1 Brooke, J.H. 'Natural law in the Natural Sciences: the origins of modern atheism?', *Science & Christian Belief* (1992) 4 (2), 84.

2 Harrison, P. 'Laws of nature in seventeenth-century England: from Cambridge Platonism to Newtonianism', in Watkins, E. (ed.) *The Divine Order, the Human Order, and the Order of Nature: Historical Perspectives*, New York: Oxford University Press (2013), pp. 127-148.

3 Fisher, P. 'Pierre Gassendi', in Zalta, E.N. (ed.) *Stanford Encyclopedia of Philosophy*, Stanford: Metaphysics Research Lab, Stanford University (2014), sec. 3, <http://plato.stanford.edu/archives/spr2014/entries/gassendi/>.

4 Anstey, P.R. *The Philosophy of Robert Boyle*, Routledge Studies in Seventeenth-Century Philosophy, London: Routledge (2002), pp. 23-24.

5 Henry, J. 'Voluntarist theology at the origins of modern science: a response to Peter Harrison', *History of Science* (2009) 47 (1), 93.

6 Boyle was most explicit on this point. See Davis, E.B. 'Boyle's Philosophy of Religion', in Jones, J-E. (ed.) *The Bloomsbury Companion to Robert Boyle*, London: Bloomsbury (2020), p. 274. As one anonymous referee rightly notes, Boyle's influence on British natural philosophers in the late seventeenth and early eighteenth centuries has not been fully appreciated, especially his rejection of intermediaries that govern on God's behalf and the ordaining of the laws of nature.

pect, unobservable entities with laws of nature.<sup>7</sup> This is not to say that British early moderns considered laws to be ontological powers. They were often understood as patterns within God's direct governance of creation.<sup>8</sup> 'God uses no other means, instruments or applications in these productions, than his bare word or command,' wrote Isaac Barrow, Newton's predecessor as Lucasian Professor of Mathematics.<sup>9</sup> Samuel Clarke, one of Newton's chief defenders, argued that the regularities we note are 'truly and properly speaking, . . . nothing else but the will of God producing certain effects in a continued, regular, constant, and uniform manner'.<sup>10</sup> Some early Newtonians believed that gravity was the clearest manifestation of lawful divine action. As William Whiston put it, gravity just is God's 'general, immechanical, immediate power'.<sup>11</sup> Such ideas would lead some to embrace occasionalism, the doctrine that God is the sole efficient cause in nature.

The shift away from substantial forms to freely chosen divine laws had important implications for experimental philosophy and empiricism in general.<sup>12</sup> For our purposes, the most important point is that laws were not considered to be independent powers or, as we now often think, a naturalistic alternative to theism. Unlike substantial forms or their Platonic counterparts, laws of nature were intrinsically theistic. Many early modern scientists took laws to simply be divine decrees for how nature shall run.

## Britain before Darwin

The decretal view of laws remained prominent well into the nineteenth century.<sup>13</sup> One notable change was that while Descartes and others derived their

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7 See Koperski, J. *Divine Action, Determinism, and the Laws of Nature*, New York: Routledge (2020), chap. 4, <https://doi.org/10.4324/9780429029110> for more. Leibniz was a prominent exception to this rule. His account of natural necessity was based more the intrinsic powers of substances rather than imposed laws. See Psillos, S. 'Laws and powers in the frame of nature,' in Ott, W.R. & Patton, L. (eds.) *Laws of Nature*, New York: Oxford University Press (2018), sec. 6.

8 Given the imprecise way that law language was often used, it is difficult to say exactly how prevalent this rejection of intermediaries was. Nate Rockwood argues (private correspondence) that some theists in this era clearly did take laws as ontologically real. While there was widespread agreement that laws were theistic, the metaphysical details varied quite a bit.

9 'Maker of Heaven and Earth (Sermon XII),' in *Theological Works*, vol. 2, Cambridge: Cambridge University Press (1885), p. 303.

10 Harrison, P. *op. cit.* (2), p. 143.

11 Brooke, J.H. *Science and Religion: Some Historical Perspectives*, Cambridge: Cambridge University Press (1991), p. 146.

12 Henry, J. *op. cit.* (5)

13 Numbers, R.L. 'Science without God: natural laws and Christian beliefs,' in Lindberg, D.C. & Numbers, R.L. (eds.) *When Science & Christianity Meet*, Chicago: University of Chicago Press (2008), pp. 265-285. From Scottish physicists Balfour Stewart and P.G. Tait, 1875: '[The] will of man is accomplished in conformity with the laws of the universe, while on the other hand

belief in laws from a broader theistic philosophy, laws would instead become the basis for a kind of design argument for the existence of God. This was true for both theological conservatives and those leaning more towards deism.<sup>14</sup> Mathematician Baden Powell could speak for many:

And this is, perhaps, of all others the reflection which, to a thinking and philosophic inquirer, tends most to exalt his ideas of the Divine perfections – the regulation of all the varied and complicated actions of the material world by an unvarying system; . . . the sufficiency of a few simple laws to regulate the entire complexity of the vast mechanism; the first constitution of the world upon a principle which, without further interposition, contains within itself the means of perpetual renovation and stability.<sup>15</sup>

Note Powell's claim that all this happens 'without further interposition'. Many theists at the time had come to accept Leibniz's intuition that an omnipotent, omniscient designer would never need to intervene in his creation, at least to keep nature on its course.<sup>16</sup>

A controversy in geology at the beginning of the nineteenth century dominated the debate about how laws operated. Charles Lyell sided with James Hutton and *uniformitarianism* to explain geological phenomena against its rival *catastrophism*.<sup>17</sup> The latter appealed to geological forces that changed over time and argued for an observable progression in the development of life in the fossil record. Biblical literalists also fell into this camp, pointing to unique events such as Noah's flood to explain discontinuities in the geological strata. Uniformitarian explanations were instead limited to the slow, ongoing action of mechanisms like erosion and sedimentation – continuous, presently observable, and law-governed changes. They dismissed both one-off events and varying, unobservable powers at work in previous ages. As Lyell argued,

Many appearances, which had for a long time been regarded as indicating

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the will of God . . . constitutes in itself the laws of the universe', Smith, C. *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain*, Chicago: University of Chicago Press (1998), p. 254.

14 Ruse, M. 'The relationship between Science and Religion in Britain, 1830-1870', *Church History* (1975) 44 (4), 505-522, <https://doi.org/10.2307/3163829>.

15 *The Connexion of Natural and Divine Truth*, London: J.W. Parker (1838), pp. 155-156.

16 Leibniz, G.W. & Clarke, S. *The Leibniz-Clarke Correspondence: Together with Extracts from Newton's Principia and Optics*, Alexander, H.G. (ed.) (1717), repr., Manchester: Manchester University Press (1956), p. 29.

17 Whewell coined the terms 'uniformitarianism' and 'catastrophism' to describe the two approaches. While the terms are now considered imprecise, there are no ready alternatives. See Cannon, W.F. 'The Uniformitarian-Catastrophist debate', *Isis* (1960) 51 (1), n. 1, and Rudwick, M.J.S. 'Uniformity and progression: reflections on the structure of geological theory in the age of Lyell', in Roller, D.H.D. (ed.) *Perspectives in the History of Science and Technology*, Norman: University of Oklahoma Press (1971), pp. 209-226.

mysterious and extraordinary agency, were finally recognised as the necessary result of the laws now governing the material world; and the discovery of this unlooked-for conformity has at length induced some philosophers to infer, that, during the ages contemplated in geology, there has never been any interruption to the agency of the same uniform laws of change.<sup>18</sup>

Proper geological explanations, in Lyell's view, could only appeal to observable processes still currently at work. Discontinuous, purely historical causes – including supernatural ones – violated the norms of good science.

Surprisingly perhaps, uniformitarians were against evolutionary explanations for biological change over time while catastrophists supported it. Evolution, including Lamarck's recently published view, entailed progression – change with a noticeable direction and so a sense of teleology. Uniformitarians resisted any hint of progress or directionality in the development of life.<sup>19</sup> In their view, what we observe today is what has always been: one set of unchanging laws working through the same, familiar mechanisms over long periods of time. Any appearance of directionality in the fossil record, Lyell argued, was due to it being incomplete. He predicted that fossils resembling mammals would be discovered in the earlier epochs, which of course did not occur.<sup>20</sup>

Catastrophists such as Adam Sedgwick believed that the extant fossil record indicated a direction in the development of life from the simple to the more complex as well as large discontinuities from one era to the next, with new species and environments appearing wholly formed.<sup>21</sup> While mechanisms responsible for these changes within the strata were as yet unknown, many appealed to the acts of a 'creative power'.<sup>22</sup> Whewell made it clear that in his view the 'creative power' was 'Creative Power' itself, or more briefly 'the Creator'.<sup>23</sup>

Darwin, a close friend of Lyell, supported uniformitarianism in name. More accurately, he selected key ideas from both camps. Darwin's theory appealed to gradual processes still at work in nature, but accepted the catastrophist view of directional, biological change over time as revealed in the fossil record. Given the power of Darwin's arguments and the lack of morphologically advanced

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18 Lyell, C. *Principles of Geology*, 11th edn., (London: D. Appleton (1889), 88; 1<sup>st</sup> edn. published 1830.

19 Rudwick, M.J.S. *op. cit.*, (17), p. 212.

20 Lyons, S.L. 'Thomas Huxley: fossils, persistence, and the argument from design', *Journal of the History of Biology* (1993) 26, no. 3, 548-549.

21 'Presidential Address', *Proceedings of the Geological Society of London (1826-1833)* 1 (1830), 304-306.

22 Cannon, W.F. 'The problem of miracles in the 1830s', *Victorian Studies* (1960) 4, no. 1, 8.

23 *Of the Plurality of Worlds: An Essay*, 4th edn., London: John W. Parker and Sons (1855), p. 349.

fossils in the deeper strata, Lyell reluctantly came to agree.<sup>24</sup>

Whewell and John Herschel also influenced Darwin's thinking. Herschel first made a useful distinction that will become important when we turn to Huxley: fundamental and empirical laws. A paradigm example of the former is Newton's laws, which could be used to derive models for many different special cases.<sup>25</sup> Ideally such laws would be included in a theory that explained the causes or mechanisms involved.<sup>26</sup> The latter were mere generalisations from data, what Whewell would call 'phenomenal laws' such as those discovered by Kepler.<sup>27</sup> While empirical laws were in no way metaphysical, fundamental laws *ensure* that events go the way they do, given the conditions. Universal, uniform laws that applied to all possible circumstances were the means by which the 'Divine Author' governed.<sup>28</sup>

Whewell agreed, arguing in his *Bridgewater Treatise* that the study of laws brings people to believe in a Divine Lawgiver:<sup>29</sup>

Hence we infer that the intelligence by which the law is ordained, the power by which it is put in action, must be present at all times and in all places where the effects of the law occur; that thus the knowledge and the agency of the Divine Being pervade every portion of the universe, producing all action and passion, all permanence and change. The laws of nature are the laws which he, in his wisdom, prescribes to his own acts; his universal presence is the necessary condition of any course of events, his universal agency the only origin of any efficient force.<sup>30</sup>

This is essentially the same decretal view of laws defended by the early Newtonians, although not all would have endorsed the nod toward occasionalism in the last clause.

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24 Cannon, W.F. *op. cit.*, (22), 39.

25 Herschel, J.F.W. *A Preliminary Discourse on the Study of Natural Philosophy*, new edn., London: Longman, Brown, Green & Longmans (1851), chap. VII, paras. 212-213.

26 Ruse, M. 'Darwin's debt to philosophy: an examination of the influence of the philosophical ideas of John F.W. Herschel and William Whewell on the development of Charles Darwin's Theory of Evolution', *Studies in History and Philosophy of Science Part (June 1975) A 6*, no. 2, 161, [https://doi.org/10.1016/0039-3681\(75\)90019-9](https://doi.org/10.1016/0039-3681(75)90019-9).

27 Herschel, J.F.W. *op. cit.*, (25), chap. VI, para. 187.

28 *ibid.*, 36-37.

29 Snyder, L.J. 'William Whewell', in Zalta, E.N.(ed.) *Stanford Encyclopedia of Philosophy*, Spring 2019, Stanford: Metaphysics Research Lab, Stanford University (2019), sec. 4; <https://plato.stanford.edu/archives/spr2019/entries/whewell/>.

30 Whewell, W. *Astronomy and General Physics Considered with Reference to Natural Theology*, *Bridgewater Treatises on the Power, Wisdom, and Goodness of God, as Manifested in the Creation*, London: William Pickering (1834), pp. 361-362.

Darwin accepted the distinction between fundamental and empirical laws<sup>31</sup> and included this quotation from Whewell at the front of the *Origin of Species*:

With regard to the material world, we can at least go so far as this – we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws.

Darwin also endorsed some of Whewell's conclusions about laws and design in his 1860 letter to Asa Gray:

I cannot anyhow be contented to view this wonderful universe, and especially the nature of man, and to conclude that everything is the result of brute force. I am inclined to look at everything as resulting from designed laws, with the details, whether good or bad, left to the working out of what we may call chance. . . . Certainly I agree with you that my views are not at all necessarily atheistical.<sup>32</sup>

Darwin would change his mind about this design inference in favour of explicit agnosticism, but not his belief in laws.

Given the strong connection between laws of nature and theism, one might wonder how Darwin could continue to affirm one without the other. How can scepticism about the existence of God *not* entail scepticism toward the laws of nature? The groundwork for such a move was laid some decades earlier.

## **Philosophes, Practitioners and Hume**

By the mid-eighteenth century, physicists<sup>33</sup> began to appeal to principles with less obvious dependence on theism. These included Leibniz's law of continuity, the principle of sufficient reason, and the principle of least action, all of which played important roles in the development of differential equations.<sup>34</sup> While Leibniz himself provided a theological foundation for the first two, others simply invoked them as settled matters of metaphysics. So while Pierre-Simon Laplace would use such principles as guides to discover and apply dynamical laws, he would reportedly declare that he had no need to posit God in doing so.<sup>35</sup>

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31 Ruse, M. *op. cit.*, (26), 179-180.

32 *The Life and Letters of Charles Darwin: Including an Autobiographical Chapter*, ed. Francis Darwin, vol. II, *The Life and Letters of Charles Darwin: Including an Autobiographical Chapter*, London: D. Appleton (1888), p. 105.

33 'Physicist', like 'scientist', is an anachronism here, as those terms were not coined until the 1800s.

34 Their precise content is not particularly relevant here.

35 Herschel, W. *The Scientific Papers of Sir William Herschel: Including Early Papers Hitherto*

During this same period, deists and philosophical naturalists began to recast Newton as one of their own. This was especially true in France, where a completely secularised view of both Newton and his physics was in play by the time of French Revolution. Physicists such as d'Alembert and philosophes like Voltaire proclaimed that physics was independent of metaphysics, especially those systems influenced by theology.<sup>36</sup> Given its theistic roots, one might think that the language of law would have been replaced or at least downplayed in more naturalistic circles. It was, however, too useful to ignore. Not even strongly anti-metaphysical movements like Auguste Comte's positivism could do without it.<sup>37</sup>

Whewell offered his own diagnosis of the deteriorating association between theism and laws in some circles.<sup>38</sup> Physicists and mathematicians made significant advances in the development of differential equations in the generation after Newton. As research became more specialised, many turned their full attention to physics and away from philosophical questions about the nature of laws themselves.<sup>39</sup> One could – unfortunately from Whewell's point of view – start with mathematical laws and the principles of physics and fail to recognise their divine origin:

Such persons are not led by their pursuits to any thing beyond the general principles, which form the basis of their explanations and applications. They acquiesce in these; they make these their ultimate grounds of truth; and they are entirely employed in unfolding the particular truths which are involved in the general truth. Their thoughts dwell little upon the possibility of the laws of nature being other than we find them to be, or on the reasons why they are not so.<sup>40</sup>

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*Unpublished*, Dreyer, J.L.E. (ed.), vol. 1, Cambridge: Cambridge University Press (2013), lxii. Although Herschel witnessed the famous exchange between Laplace and Napoleon, he does not include the claim 'I had no need of that hypothesis' in his diary entry for 8 August 1802.

36 Shank, J.B. 'Between Isaac Newton and Enlightenment Newtonianism: the "God question" in the eighteenth century', in Harrison, P. & Roberts, J.H. (eds.) *Science without God? Rethinking the History of Scientific Naturalism*, Ian Ramsey Centre Studies in Science and Religion, Oxford: Oxford University Press (2019), pp. 93-95.

37 Brooke, J.H. & Cantor, G. *Reconstructing Nature: The Engagement of Science and Religion*, Gifford Lectures, Oxford: Oxford University Press (2000), pp. 48-49.

38 Ducheyne, S. 'Whewell, necessity and the inductive sciences: a philosophical-systematic survey', *South African Journal of Philosophy* (2009) 28, no. 4, 340-343.

39 See Lyssy, A. & Leduc, C. 'L'économie de la nature - Maupertuis et Euler sur le principe de moindre action', *Philosophiques* (2015) 42, no. 1, 31, <https://doi.org/10.7202/1032216ar> for a case study of what Whewell had in mind. The authors show how a theistic 'principle of efficiency' articulated by Leibniz was formalised into the much less philosophically significant principle of least action by Maupertuis and Euler.

40 Whewell, W. *Astronomy and General Physics Considered with Reference to Natural Theology*, New York: Harper and Brothers (1856), p. 206.

Unlike the Enlightenment *philosophes*, these researchers had no intention here to divorce metaphysics from science. The narrowing of concerns was, Whewell thought, a regrettable consequence of specialisation. By analogy, mathematicians today can spend their whole careers without considering the metaphysics of mathematical objects. Are they Platonic entities, human constructs, ideas in the mind of God, or something else? One can obviously use mathematics and make advances in mathematical knowledge without ever asking the question. The same applies to physics and the laws of nature.

The British philosopher David Hume had little to say about the laws except when he was attacking miracle claims. His focus was instead on causation. Others would eventually take his analysis and apply it elsewhere. According to Hume, causation is a fiction. Everyone could observe that water froze when the temperature fell below 32 °F, but Hume denied that low temperature *makes* water freeze. There is no such thing as causation itself. There is just the observed regularity between events. Any sense that one causes the other or that there is a necessary connection between the two events is a psychological projection on our part. While this idea would play a central role in Immanuel Kant's system, Hume's analysis would not have much influence in science for several decades. When it did, it would be reinterpreted as a doctrine about the laws of nature, a view that continues to be popular in analytic philosophy today.

All told, naturalised interpretations of laws were more prevalent in continental Europe than in Victorian England. Change there required a more strategic approach.

## Huxley, the X-Club and 'Scientific Naturalism'

Huxley plays the central role in what follows, but he was only one member of an influential group known as the X-Club.<sup>41</sup> As Ronald Numbers writes,

The relatively smooth passage of naturalism turned nasty during the last third of the nineteenth century, when a noisy group of British scientists and philosophers . . . began insisting that empirical, naturalistic science provided the *only* reliable knowledge of nature, humans, and society. Their anticlerical project . . . had little to do with naturalizing the practice of science but a lot to do with creating positions and influence for men such as themselves. They sought, as the historian Frank M. Turner has phrased it, 'to expand the influence of scientific ideas for the purpose of secularizing

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41 The others were George Busk, Joseph D. Hooker, Herbert Spencer, William Spottiswoode, Edward Frankland, Thomas A. Hirst, and John Lubbock. See Barton, R. *The X Club: Power and Authority in Victorian Science*, Chicago: University of Chicago Press (2018) for a recent and comprehensive history of the group.

society. . . . Secularization was their goal; science, their weapon.<sup>42</sup>

The X-Club's strategy was both rhetorical and political. By championing reforms in the British educational system, they successfully put fellow 'scientific naturalists' in charge of the university teacher examinations in new state schools.<sup>43</sup> Students would be trained to see science as fully naturalistic, effectively pushing theism out of the discussion in Anglo-American science departments.

Huxley's offensive began in earnest with a review of an anonymous book, later attributed to the journalist Robert Chambers.<sup>44</sup> *Vestiges of the Natural History of Creation* first appeared in 1844 and became a sensation in both England and America. Huxley published his review in 1854, five years before Darwin's *Origin of Species*. Here he quotes from *Vestiges*:

Law, I have over and over again said, is merely a term of human convenience to express the orderly manner in which the will of God is worked out in external nature; and He must be ever present in the arrangements of the universe, as the only means by which they could be even for a moment sustained.<sup>45</sup>

This view of the laws of nature goes back to beginning of the scientific revolution. God has ordained discoverable regularities and it is by his power that they do not change. Many of Chambers's contemporaries would have agreed. Huxley continues:

But what does this amount to, he asks? Ans: 'Creation took place in an orderly manner, by the direct agency of the Deity,' which is no different from what Jews and Christians had been saying for millennia. As such, a very poor scientific explanation.

What then is this real proposition of the 'Vestiges'? It is simply, exhibited in all its naked crudeness, the belief that a law is an entity – a Logos intermediate between the Creator and his works – which is entertained by the Vestigarian in common with the great mass of those who, like himself, indulge in

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42 Numbers, R.L. *op. cit.*, (13), p. 281.

43 Stanley, M. 'God and the uniformity of nature: the case of nineteenth-century physics', in Harrison, P. & Roberts, J.H. (eds.) *op. cit.*, (36), p. 106.

44 Stanley, M. *Huxley's Church and Maxwell's Demon: From Theistic Science to Naturalistic Science*, Chicago: University of Chicago Press (2015), pp. 52-53. See also Secord, J.A. *Victorian Sensation: The Extraordinary Publication, Reception, and Secret Authorship of Vestiges of the Natural History of Creation*, Chicago: University of Chicago Press (2000), pp. 498-506.

45 Huxley, T.H. 'Review of *Vestiges of the Natural History of Creation*', in Foster, M. & Lankester, E.R. (eds.) *The Scientific Memoirs of Thomas Henry Huxley*, vol. Supplementary (1854), repr., London: Macmillan and Company (1903), p. 3.vol. Supplementary (1854; repr., London: Macmillan and Company, 1903

science at second-hand and dispense totally with logic.<sup>46</sup>

Contrary to Chambers's own words, Huxley portrays his view of law as an independent power that governs nature, rather than God's decrees.<sup>47</sup> Some of Chambers's contemporaries did hold a fully reified view of law, in contrast those early moderns who explicitly rejected governing intermediaries between God and nature. Others were simply careless in giving the laws themselves a causal role. Huxley highlights the latter, quoting phrases in *Vestiges* in which the laws 'produce winds', including storms and hurricanes.<sup>48</sup> Given the entire work, though, it seems clear that when Chambers slips into causal language in which the laws themselves govern or bring about some change, the laws in his mind can be further reduced to regularities of divine will for creation. At one point, he explicitly states his position:

We advance from law to the cause of law, and ask, What is that? Whence have come all these beautiful regulations? Here science leaves us, but only to conclude, from other grounds, that there is a First Cause to which all others are secondary and ministrative, a primitive almighty will, of which these laws are merely the mandates.<sup>49</sup>

Laws as divine decrees would be a familiar view to his readers.

Having just attributed a strong, realist view of law to Chambers, it is odd that Huxley shortly thereafter paints him as kind of occasionalist, whereby every event is due to the direct agency of God.

If the author of the 'Vestiges' really means by law, simply the mode in which the 'Will of God'—who is ever present in the arrangements of the universe—takes effect, . . . what meaning is there in the passages we have just quoted? If every thing is the direct result of the Will of God, what does his theory differ from that of the 'learned,' at whom he sneers? If the Deity be ever present, and phenomena are the manifestation of his will – law being simply a name for the order in which these occur – what is every phenomenon but the effect of a 'creative fiat,' an 'interference,' an 'interposition of creative energy?'<sup>50</sup>

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46 *ibid.*

47 As he wrote some years later, "The only hypothesis which gives a sort of mad consistency to the Vestigiarian's views is the supposition that laws are a kind of angels or demiurgoi, who, being supplied with the Great Architect's plan, were permitted to settle the details among themselves." Huxley, T.H. 'Science and Pseduo-Science,' in *Collected Essays, Volume V: Science and Christian Tradition* (1887; repr., New York: D. Appleton and Company (1902), p. 79.

48 Huxley, T.H. *op. cit.*, (45), p.3

49 Chambers, R. *Vestiges of the Natural History of Creation*, 1st edn., London: John Churchill (1844), pp. 25-26.

50 Huxley, T.H. *op. cit.*,(45), p. 5.

Huxley sees this as little more than creationism, the author having views 'not a whit in advance of the notions entertained by our grandmothers'.<sup>51</sup> Here we see the beginning of a dichotomy that would be used for decades to come. The reader is given a choice between believing either in science or in direct divine action, between laws in the learned sense or the folk knowledge of earlier times. Huxley's charge is ironic given that Chambers was a deist. There were many published attacks on *Vestiges*, but most came from theological moderates and conservatives, not scientific naturalists.<sup>52</sup>

It is likely that Huxley's vitriol surprised Chambers given that both affirmed uniformitarianism. *Vestiges* describes a grand cosmic process in which not even the construction of the Earth required 'any immediate or personal exertion on the part of the Deity'.<sup>53</sup> The problem was that Chambers only followed Lyell in part, seeing a progression in the fossil record:

The whole train of animated beings, from the simplest and oldest up to the highest and most recent, are, then, to be regarded as a series of *advances of the principle of development*, which have depended upon external physical circumstances, to which the resulting animals are appropriate. I contemplate the whole phenomena as having been in the first place arranged in the counsels of Divine Wisdom.<sup>54</sup>

To the purer uniformitarians like Lyell, talk of development and progression was the language of catastrophism. Huxley believed that progressive change indicated teleology, which was to be strictly barred from naturalistic science along with any appeal to theism.

This would prove to be a problem after the publication of the *Origin of Species*.<sup>55</sup> On the one hand, Darwin's account helped to fill out the naturalistic programme. On the other, while Darwin was a close friend of Lyell and self-proclaimed uniformitarian, his theory supported some of the same objectionable doctrines found in *Vestiges*. Strictly speaking, Darwin argued for the transmutation of species without any intrinsic directionality. If the conditions were right, however, such change over time could produce increasing complexity. Moreover, his theory of variation plus natural selection looks suspiciously like a *law* for how species transmute from one to another. For some, this was a celebrated advance for biology as a discipline. Newtonian mechanics had supplied the paradigm of good science. Darwin had finally extended the idea of law into biology and eliminated the need for divine intervention. But in Huxley's mind,

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51 *ibid.* p. 3..

52 Smith, C. *op. cit.*, (13), pp. 25, 115-117.

53 Chambers, R. *op. cit.*, (49), p.154.

54 *ibid.*, p. 203

55 Lyons, S.L. *op. cit.*, (20), pp. 556-557.

progressive, lawlike change was itself an indicator of teleology which in turn implies theism. Some catastrophists had argued just that point.<sup>56</sup> Huxley could endorse natural selection if restricted to competition between mostly fixed species. He could not endorse transmutation and directionality that allowed humans to develop from far simpler species.

Huxley initially split the difference, promoting Darwin's theory as a triumph of naturalism while downplaying those parts that could be used to support directionality. This initially caused some tension between the two – surprising given Huxley's later reputation as 'Darwin's bulldog'. The success of Darwin's theory was too much to deny in the end. Lyell's prediction that a more complete fossil record would refute its *prima facie* directionality had failed. By 1869, Huxley came to endorse 'Evolution' which leans heavily towards uniformitarianism with allowance for some ideas associated with catastrophism – an apt description of Darwin's own approach. In general, though, directionality in science was still highly suspect.

This suspicion prompted another conflict, this time with mathematical physicist William Thomson (Lord Kelvin), co-author of the highly influential *Treatise on Natural Philosophy* (1867). Thomson believed in uniformity in the sense that the laws of nature are unbroken. God does not intervene. But he believed that physics, not geology, most clearly showed that the past was very different from the present. Given the second law of thermodynamics, the sun could not be infinitely old. While it is not impossible that the sun was directly created by God, a far better and more probably explanation appealed to 'certain actions going on before us at present, which, if sufficiently abundant at some past time, must have given the sun heat enough to account for all we know of his past radiation and present temperature.'<sup>57</sup> By Thomson's calculations, the Earth could have been present for only the last 100 million years or so, putting a much shorter cap on the amount of time uniformitarians might use. To some in geology and biology, this was the unwelcome imposition of an outsider, and Huxley devoted his 1869 presidential address to the Geological Society to debunking Thomson's criticism. In the end, the physicist's worries were dismissed as 'superfluous.'<sup>58</sup>

The absolute uniformity of laws was obviously in tension with a belief in miracles. One popular way of dealing with miracle claims was to say that any *prima facie* miracle was just a matter of ignorance on our part, an argument that goes back at least as far as Spinoza. As historian Matthew Stanley notes,

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56 *ibid.*, p 562

57 Thomson, W. 'On the age of the sun's heat', *Macmillan's Magazine* (5 March 1862) 5, pt. III.

58 Huxley, T.H. 'Geological Reform', in *Lay Sermons, Addresses, and Reviews*, London: Macmillan (1874), p. 254.

many theists at the time agreed.<sup>59</sup> Some thought that there are unknown laws that God had put in place whose conditions are rarely met, hence the infrequent events that followed.<sup>60</sup>

The compatibility of theism and uniformity was a problem for Huxley. Only a certain type of uniformity and a certain type of law fitted his larger programme. Those like Thomson failed on both counts. His uniformity was not sufficiently uniform and his laws were theistic. As one of Thomson's biographers put it,

The laws of nature envisaged by Kelvin were *real* in the universalist sense of the term. They were not merely formulated by scientists; they were discovered by science through investigation and proper reasoning. He was confident, moreover, that these laws were ultimately the work of a creative intelligence and that they governed the universe according to the design of a Creator.<sup>61</sup>

Laws were undoubtedly a powerful idea, but one that was persistently associated with theism. Huxley would need a different interpretation to break that linkage. Ironically, as John Hedley Brooke notes, it was the prominence of the laws of nature that would allow for just the sort of separation that Huxley had in mind: '[A] natural theology of the material world in which the concept of physical law had a high profile could easily become the Trojan horse for a subversive scientific naturalism.'<sup>62</sup>

## Co-option and a revised history of laws

Uniformitarians claimed to be more scientific than catastrophists by positing that the past was shaped by the same observable mechanisms at work today: sedimentation, erosion, and so forth. Hume had shown that these empiricist restrictions could be applied to causation. There are no causes in a metaphysical sense, only repeatable sequences of observations. Huxley agreed, but applied Hume's reasoning to the laws.<sup>63</sup> One could consider nature to be nothing more than the 'totality of all laws,'<sup>64</sup> by which Huxley means regular, observable events.

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59 Stanley, M. *op. cit.*, (44), p. 75.

60 Such views persist. See physicist George Ellis's 'Ordinary and Extraordinary Divine Action', in Russell, R.J. (ed.) *Chaos and Complexity: Scientific Perspectives on Divine Action*, Berkeley, CA: Center for Theology and the Natural Sciences (1995), p. 386.

61 Burchfield, J.D. *Lord Kelvin and the Age of the Earth*, London: Macmillan (1975), p. 49.

62 Brooke, J.H. *op. cit.*, (1), 87.

63 "In truth, every one who possesses the least real knowledge of the methods of science, is perfectly aware that "natural laws" are nothing but an epitome of the observed history of the phenomena of the universe . . ." Huxley, "Review of Vestiges of the Natural History of Creation," 6.

64 *ibid.*, p. 2.

When we have made out by careful and repeated observation that something is always the cause of a certain effect, or that certain events always take place in the same order, we speak of the truth thus discovered as a law of nature. Thus it is a law of nature that anything heavy falls to the ground if it is unsupported. . . . In fact, everything that we know about the powers and properties of natural objects and about the order of nature may properly be termed a law of nature. But it is desirable to remember that which is very often forgotten, that the laws of nature are not the causes of the order of nature, but only our way of stating as much as we have made out of that order. Thomas Henry Huxley, *Introductory Science Primer* (New York: American Book Company, 1890), 12–13.

Physical objects and systems undergo change, sometimes with absolute regularity, but the laws do not govern or guide them. Here then was a way of understanding laws with no reference to God or teleology, one that Humeans today would recognise.<sup>65</sup>

There is an interesting tension here. Huxley argued that divine intervention was incompatible with uniformity and science. The possibility of miracles would mean that one could never be sure that the future would look like the past.<sup>66</sup> Hume in contrast knew that his regularity view of law and denial of causation raised a deep problem for induction (*A Treatise of Human Nature*, Book 1, part iii, section 6). If nothing in nature ensures that events would continue to play out as they have thus far, there is no guarantee that observations can guide successful predictions – the same worry that Huxley pinned on miracles.

For a Humean interpretation of laws to displace the theistic one, more work would need to be done. Huxley's next step was to reject the distinction made by Herschel and Whewell between fundamental laws and mere empirical ones.<sup>67</sup> The former, once again, involve causal explanations or proposed mechanisms that go beyond observable events.<sup>68</sup> Not content to argue that a Humean approach was superior, Huxley began to attack the notion of fundamental laws as

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65 Huxley did occasionally talk about laws in a distinctly non-Humean sense, but in a completely different context. When arguing against free will, he was happy to adopt a necessitarian view:

Let us suppose . . . that we do know *more* of cause and effect than a certain definite order of succession among facts, and that we have a knowledge of the necessity of that succession – and hence, of necessary laws – and I, for my part, do not see what escape there is from utter materialism and necessarianism. Huxley, T.H. 'On the physical basis of life,' in *Collected Essays*, Cambridge Library Collection-Philosophy (1868), repr., Cambridge: Cambridge University Press (2011), p. 158.

66 Stanley, M. *op. cit.*, (44), p. 75.

67 Huxley, T.H. *op. cit.*, (47), p. 76.

68 Here he criticises George Campbell, who was using the same examples offered by Herschel and Whewell:

‘pseudo-science.’ Believing in anything more than observed regularities is to ‘mix the black of dogma and the white of science into the neutral tint of what they call liberal theology.’<sup>69</sup>

One problem was that Herschel and Whewell had grounded their case for fundamental laws – those that go beyond Humean regularities – in Newtonian mechanics. To disprove the existence of such laws would require some revisionist history. Huxley seized on one passage from the General Scholium of the *Principia*. While Newton gave a mathematical description for the gravitational force between bodies, he famously did not offer a mechanism for its cause. ‘*Hypotheses non fingo*,’ he wrote, Latin for ‘I feign no hypotheses.’ No causal explanation would be forthcoming. Huxley portrays this as Newton’s support for empirical, Humean laws and the rejection of fundamental ones. ‘Newton assuredly lent no shadow of support to the modern pseudo-scientific philosophy which confounds laws with causes...’<sup>70</sup> We should note that Newton had far more to say about the laws of nature than Huxley suggests. This one sentence in the *Principia* does not capture the scope of his philosophy of science nor even the nature of gravity.<sup>71</sup> Ironically, the same quotation is still cited by scientific anti-realists today.<sup>72</sup> All sides paint Newton in their own image.<sup>73</sup>

The focus on laws and uniformity was a little too academic for the promotion of scientific naturalism.<sup>74</sup> Huxley turned to the warfare thesis for more rhetorical leverage. Audiences were given a forced choice: One could stand with the scientifically minded naturalists or with scriptural literalism and dogmatism. ‘Choose your hypothesis,’ said Huxley in a lecture to a popular audience, ‘I have

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The Duke of Argyll . . . affirms that the ‘law of gravitation’ as put forth by Newton was something more than the statement of an observed order. . . . [As he writes], ‘it contains an element . . . of causation, the recognition of which belongs to a higher category of intellectual conceptions than that which is concerned in the mere observation and record of separate and apparently unconnected facts.’ There is hardly a line in these paragraphs which appears to me to be indisputable. *ibid.*

69 *ibid.*, p. 82.

70 *ibid.*, p. 78.

71 For more see Janiak, A. ‘Newton’s Philosophy,’ in Zalta, E.N. (ed.) *Stanford Encyclopedia of Philosophy*, Stanford: Metaphysics Research Lab, Stanford University (2016), sec. 4.1-2, <https://plato.stanford.edu/archives/win2016/entries/newton-philosophy>. As Newton put it, ‘Gravity must be caused by an agent [acting] consta[ntly] according to certain laws, but whether this agent be material or immaterial is a question I have left to the consideration of my readers.’ Isaac Newton, ‘Letter to Bentley’, 25 February 1693, The Newton Project, <http://www.newton-project.ox.ac.uk/view/texts/normalized/THEM00258>.

72 McMullin, E. ‘The impact of Newton’s *Principia* on the Philosophy of Science’, *Philosophy of Science* (2001) 68, no. 3, 290.

73 See Shank’s discussion of William Blake’s painting *Newton* (<https://www.tate.org.uk/art/artworks/blake-newton-n05058>) for why this is not merely a metaphor, *ibid.*, 95-96.

74 As Barton notes, the members of the X-Club were not as wedded to the term ‘scientific naturalism’ as some scholars have portrayed; Barton, R. *op. cit.*, (41), pp. 23-24.

chosen mine.<sup>75</sup> Contra the conventional wisdom today, however, the wedge was not science versus religion, but science versus theology, especially the Catholic version.<sup>76</sup> Who would want to identify with antiscientific clergy given the shining alternative?

This was the foundation of Huxley's highly strategic construction of the military metaphor. Theology, not religious belief per se, was the enemy. Theology was the intruder on science. Slavish literal interpretation of the Bible was one of its weapons. And most dramatically, these absurd beliefs had *come to an end*, thus marking any further resistance as antiquated and ridiculous. Uniformity was proposed as synonymous with rationalism, progress, and naturalism.<sup>77</sup>

Huxley knew that there was no replacing the idea of laws of nature. But once the warfare metaphor had done its work, then one could effectively argue that the idea of laws fitted better with naturalism. Laws could be severed from their theistic roots.

Others had wielded the warfare claim with great effectiveness. For the American scientist and later historian John W. Draper, there were only two 'interpretations [that] may be given of the mode of government of the world. It may be by incessant divine interventions, or by the operation of unvarying law.'<sup>78</sup> John Tyndall made the same case in his Belfast address to the British Association for the Advancement of Science:

[As] science demands the radical extirpation of caprice and the absolute reliance upon law in Nature, there grew with the growth of scientific notions a desire and determination to sweep from the field of theory this mob of gods and demons, and to place natural phenomena on a basis more congruent with themselves.<sup>79</sup>

'Caprice' refers to God's intervention, which is then associated with other superstitions. Law, in contrast, belongs to naturalism. Tyndall went on to praise

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75 *ibid.*, p. 401. In one personal letter Huxley wrote, 'My screed was meant as a protest against Theology & Parsonism in general - both of which are in my mind the natural & irreconcilable enemies of Science.' *ibid.*, p. 424..

76 Ungureanu, J.C. *Science, Religion and the Protestant Tradition: Retracing the Origins of Conflict*, Pittsburgh: University of Pittsburgh Press (2019). Frankland became a Unitarian. Spottiswoode, Lubbock, and Hooker remained liberal Anglicans; Barton, R. *op. cit.*, (41), p. 107.

77 Stanley, M. *op. cit.*, (44), p. 70.

78 *History of the Conflict Between Religion and Science*, The International Scientific Series, XII: D. Appleton (1875), p. 228.

79 *Address Delivered before the British Association Assembled at Belfast*, New York: D. Appleton and Company (1874), p. 8. Bernard Lightman believes that Tyndall used Draper's work as source material for the lecture. See Lightman, B. 'The Victorians: Tyndall and Draper', in Hardin, J., Numbers, R. & Binzley, R. (eds.) *The Warfare between Science and Religion: The Idea That Wouldn't Die*, vol. 106, (2020), pp. 104-105.

those who were able to rise above the theistic hegemony of the past. 'Far in the depths of history we find men of exceptional power differentiating themselves from the crowd, rejecting these anthropomorphic notions, and seeking to connect natural phenomena with their physical principles.'<sup>80</sup> Scientific naturalism alone has the resources 'to raise life to a higher level.'<sup>81</sup>

Having sorted the two sides, the question becomes which makes a better claim to uniformity and laws. In his highly successful book *Physiography* (1877), Huxley began with observations about the Thames and traced his way through the water cycle to solar evaporation. The story ends with the explanatory sufficiency of the laws, in direct and intentional contrast to other science popularisers at the time who were arguing in favour of divine harmony.<sup>82</sup>

Through a systematic tracing of interconnected causes and effects, Huxley had brought the reader from the London Bridge to the sun, rather than to an appreciation of the wisdom, goodness, and power of God. He then concluded with a powerful image of the cosmos as subject to universal laws of nature similar to those on earth.<sup>83</sup>

Those who persisted in arguing from nature to the divine were disparaged for 'letting their theological beliefs influence their science [which became] a powerful rhetorical strategy for discrediting their views.'<sup>84</sup> Even those who still believed in the strong, theistic view of laws recognised the rhetorical power of this wedge strategy, as George Douglas Campbell (the Duke of Argyll) noted:

The Reign of Law in Nature is, indeed, so far as we can observe it, universal. But the common idea of the Supernatural is that which is at variance with Natural Law, above it, or in violation of it. Nothing, however wonderful, which happens according to Natural Law, would be considered by any one

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80 *Address Delivered before the British Association Assembled at Belfast*, p. 8.

81 *ibid.*, 64. In the full passages, Tyndall argues for the intellectual superiority and proper authority of naturalistic science:

All religious theories, schemes, and systems, which embrace notions of cosmogony, or which otherwise reach into the domain of science, must, *in so far as they do this*, submit to the control of science. . . . Acting otherwise proved disastrous in the past, and it is simply fatuous to-day. . . . When this truth has been thoroughly taken in, rigidity will be relaxed, exclusiveness diminished, things now deemed essential will be dropped, and elements now rejected will be assimilated. . . . [As] long as dogmatism, fanaticism, and intolerance, are kept out, various modes of leverage may be employed to raise life to a higher level. *ibid.*

82 Desmond, A.J. *Huxley: From Devil's Disciple to Evolution's High Priest*, Reading: Addison-Wesley (1997), pp. 484-485.

83 Lightman, B. *Victorian Popularizers of Science: Designing Nature for New Audiences*, Chicago: University of Chicago Press (2009), p. 377.

84 Lyons, S.L. *op. cit.*, (20), p. 562.

as Supernatural.<sup>85</sup>

In lecture halls and periodicals, natural law was being set against the supernatural as explanatory categories, and those driving this dichotomy were winning.

Why did it work? Why was there not more fight back from practising Christians and academics like Campbell? As Stanley stresses,<sup>86</sup> one reason was that the X-Club and their allies used all the same language that theists had used for two centuries.<sup>87</sup> Naturalists continued to affirm belief in the laws of nature, albeit not the same sort of laws if one were pressed for the details, and many theistic scientists including Lyell, Herschel, and Thomson believed in uniformity. In short, it didn't feel like a revolution. Had naturalists rejected laws outright as an intrinsically theistic idea, the change would have been obvious. By successfully incorporating the familiar language of laws into naturalism, it became possible to eliminate God as a useless metaphysical appendage.

## Conclusion

The shift from a theistic understanding of laws to a naturalistic one was a combination of unintentional slide and fully intentional attack. The slide, according to Whewell, was due to the success of mathematical physics. As natural philosophy evolved into natural science, mathematicians and physicists could begin their work with Newton's laws without considering why nature was law-governed. That there were laws of nature could be simply taken as a given, much as it is today.

The attacks came as part of the broader agenda of philosophical naturalism. On the Continent, Enlightenment *philosophes* and positivists argued against metaphysics in general and theism in particular. The reduction of laws to observed regularities allowed those in Anglo-American circles to continue to talk about the laws of nature but in naturalistic terms. Once the philosophical foundation had been laid, British scientific naturalists incorporated it into a highly successful political strategy. As Hooker noted in a letter to Huxley, 'we have sufficient command over the public, as examiners in London, and as confidential advisers of examiners and professors elsewhere, to ensure the cordial reception of such a system'.<sup>88</sup> Stanley sums up their campaign:

It may be too strong to say that the scientific naturalists engaged in a conspiracy to take over science – but it is close. . . . Members of the [X-]club

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85 Campbell, G.D. *The Reign of Law*, 16th edn., New York: John B. Alden (1884), p. 4.

86 Stanley, M. *op. cit.*, (44), p.249.

87 One of Huxley's tactics was to be 'evasive and manipulative; he redefined terms in order to bamboozle opponents'; Barton, R. *op. cit.*, (41), p. 34.

88 *ibid.*, p..150.

dominated the council of the Royal Society for the rest of the century and were well known for maneuvering to control scientific appointments, elections, and grants across Britain. Huxley's personal success in achieving leadership positions, as well as his ability to place students and allies, made him one of the most influential men of science of the time.<sup>89</sup>

Not even Thomas Kuhn thought that such change was completely sociological, but he was right that recognised authorities play an outsized role. We all trust others about areas in which we lack expertise. When those in high places said that science conflicts with theology and that laws belong to naturalism, that had an effect.

Which was more important in the long run, the many publications and speeches in favour of scientific naturalism or having influential people in positions of power? Stanley favours the former, especially the co-opting of the laws of nature in naturalistic terms and the rewriting of history as the long struggle to free science from theology.<sup>90</sup>

Inevitably there are loose ends. Who were the key influences on Huxley and the X-Club? Was it the more secular Continental thought of half a century earlier? Was it, as Nathan Bossoh suggests (private correspondence), biblical higher criticism and the rising tide of liberal theology? These are difficult questions to answer unless a given author comments on them directly. If there are such hints to be found, that is a project, as they say, for another time.

The laws of nature continue to play a foundational role in the mathematical sciences. For better or worse, they are now taken to be part of a naturalised landscape, unquestioned by students and scientists alike. But there are questions. Why are there laws of nature? Why are those bits of science so special? Why are we so confident that they won't change tomorrow? Only philosophers wonder about such things today.<sup>91</sup>

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89 Stanley, M. *op. cit.*, p. 30. See Barton, R. *op. cit.*, (41), sec. 4.3 for X-Club manipulation of elections in the Royal Society. Stanley continues:

[Huxley's] efforts to restructure the way science was taught ranged from exam standardization to running a school for workingmen to sitting on the first London School Board. In both popularization and education, Huxley struggled to enforce the authority of professionals such as himself – ill-informed amateurs with an attraction to religiously tinged natural history, particularly clergy, were to be excluded. Stanley, M. *op. cit.*, (44), p. 31.

90 Stanley, M. *op. cit.*, (44), p. 8. About Huxley's *Primer on Science*, one historian writes 'Every school child that read this introduction to science would be trained to reject the very premises of theologies of nature.' Lightman, B. *op. cit.*, (84), p. 395.

91 Thanks to Nathan Bossoh, Del Ratzsch, Nate Rockwood and three anonymous referees for comments on a previous draft.