# *The Pointsman: Maxwell's Demon, Victorian Free Will, and the Boundaries of Science*

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The railway pointsman was the vigilant employee shifting tracks and posting signals to route hurtling trains safely on their way. In a twelve-hour shift in 1880, a pointsman might pull two thousand levers.[1] Their daily life was governed by "reliability, service, and coolness."[2]The power of the railway pointsman began in his disciplined mind and ended in the placement of his hands on the correct levers. In this, he replicated a critical assumption of Victorian religious and social thought: conscious free-will. As the human body would only act when prodded to do so by the soul, the signalman would move physically only after deliberate decisions.[3]

But the Victorian period also saw tremendous advances in science that made many doubt the truth of the pointsman's power. The march of physics through the conquered territories of mechanics, thermodynamics, and electricity, and biology's beachhead in the nervous system and mind, all seemed

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[1] Frank McKenna, *The Railway Workers 1840–1870* (London: Faber and Faber, 1980), 65–78.

[2] Ibid., 76.

[3] The terms "pointsman," "switchman," and "signalman" were all "broadly interchangeable." P. W. Kingsford, *Victorian Railwaymen: The Emergence and Growth of Railway Labour 1830–1870* (London: Frank Cass and Co., 1970), 91.

to herald the victory of a materialist, mechanical worldview. In this view all phenomena can and should be explained solely with recourse to matter and motion, implying a harsh determinism: the behavior of everything made of atoms, including humans, was strictly determined only by their current physical state. The appropriate railway metaphor here was not the pointsman, but rather the train itself, carried forward by momentum and uncaring for trivialities such as humans in its way. Like the future events of a materialist universe, the path of the train was fixed by the shackles of the track.

Whether or not the success of science demanded humans forfeit their intuition of individual volition was a major intellectual crisis of the Victorian period. Both Christian doctrine and simple social responsibility needed humans to be able to control their own actions and accept responsibility for them. But was this tenable in light of daily leaps forward in science? Much hope rested in the metaphor of the pointsman, a tiny figure who through cunning and forethought could master the overwhelming force of physical determinism.

One of its chief proponents was the devout Christian physicist James Clerk Maxwell, best known for his epochal work in electromagnetism and statistical mechanics.[4] In one letter he invoked it thus:

> There is action and reaction between body and soul, but it is not of a kind in which energy passes from one to the other,—as . . . when a pointsman shunts a train it is the rails that bear the thrust.[5]

This was in the context of theological problems surrounding the nature of the soul. But note that Maxwell uses nearly identical language here:

> In this way the temperature of B may be raised and that of A lowered without any expenditure of work, but only by the intelligent action of a mere guiding agent (like a pointsman on a railway with

[4] For other scientists' use of railway metaphors, see David B. Wilson, "A Physicist's Alternative to Materialism: The Religious Thought of George Gabriel Stokes," in *Energy and Entropy*, ed. Patrick Brantlinger (Bloomington: Indiana University Press, 1989). Max Weber invoked railways to explain how religion could make large-scale changes in history. Max Weber, "The Social Psychology of the World Religions," in *From Max Weber: Essays in Sociology*, eds. Hans Gerth and C. Wright Mills (New York: Oxford University Press, 1946), 280.

[5] James Clerk Maxwell to Lewis Campbell, April 21 1862, in *Scientific Letters and Papers of James Clerk Maxwell,* ed. P. M. Harman (Cambridge: Cambridge University Press, 1990) (hereafter *SLP*), 1: 711–12.

> perfectly acting switches who should send the express along one line and the goods along another).[6]

This was in a quite different context, a discussion of the laws of thermodynamics. The pointsman as described here would receive the peculiar name of "Maxwell's demon," a thought experiment that has survived to this day as a tool in statistical mechanics.[7] The image of the pointsman was used by Maxwell to solve not just religious difficulties but scientific ones as well.

Other work has noted this parallelism but this essay will consider this shared metaphor in detail, particularly in light of Maxwell's religious context and personal religiosity.[8] What was the overlap of conceptual space that made this a reasonable project in both religion and science? I will argue both instantiations of the pointsman indicate a deeper concern of Maxwell's: the danger of mistaking observed regularity for a true scientific law. And more generally, the danger of solely materialist explanations in science. The pointsman was a tool by which Maxwell hoped to remind investigators to tread carefully in declaring something to be proven by science.

To Maxwell a correct understanding of free will, as personified in the pointsman, was essential to clear conceptions of both man as a religious creature and of the limits of science. Understanding human volition, then, was not an end unto itself. It was a foundation on which one could build reliable theories of man and matter.

## I. THE PROBLEM

Born in Scotland to a family of mixed religious heritage, Maxwell was raised in both the Anglican and Presbyterian traditions.[9] His religious atti-

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[6] Maxwell to John William Strutt, December 6 1870. *SLP*, 2: 582–84.

[7] The general story of the demon is also told in Martin J. Klein, "Maxwell, His Demon, and the Second Law of Thermodynamics," *American Scientist* 58 (1970): 85–97; Edward Daub, "Maxwell's Demon," *Studies in History and Philosophy of Science* 1 (1970): 213–27; and P. M. Heimann, "Molecular Forces, Statistical Representation and Maxwell's Demon," *Studies in History and Philosophy of Science* 1 (1970): 189–211.

[8] Theodore Porter, *The Rise of Statistical Thinking 1820–1900* (Princeton: Princeton University Press, 1986), 194–208; Crosbie Smith, *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain* (Chicago: University of Chicago Press, 1998), 249–51; and P. M. Harman, *The Natural Philosophy of James Clerk Maxwell* (Cambridge: Cambridge University Press, 1998), 197–208.

[9] Paul Theerman, "James Clerk Maxwell and Religion," *American Journal of Physics* 54 (1986): 312–17, 312. Also Smith, *The Science of Energy*, chapter 11.

tudes early in life appeared quite conventional, if somewhat more tolerant. Maxwell was a student in primary school during the aftermath of the Disruption, a massive split in Scottish Christianity driven by the swelling ranks of those with evangelical outlooks.[10] The struggles around the emergence of the Free Church were a prominent issue in the Maxwell household and young James' father chose his teachers carefully lest the young boy be swept up in the ferment.[11] They were quite literally in the heart of the religious schism: the Maxwells attended St. Andrews Church, the very building that sheltered the General Assembly that led to the Disruption.[12] We do not know how much direct exposure Maxwell had to evangelicalism in his early life but it is clear such ideas began to exert a strong influence on him soon after his arrival as a student at Cambridge in 1850.

Evangelical Christianity was not a separate sect, but rather a cross-denominational movement reconceptualizing the relationship of God and man through individual reflection and action.[13] In evangelicalism man was naturally depraved via original sin and was wholly other from the divine. Life was the opportunity to prove one's morality through the exercise of free will to choose a godly life over a worldly one. The individual conscience was the critical element: evangelicalism discarded Calvinist predestination in favor of an emphasis on man's free ability to accept God's offered grace.

During the summer of 1853 Maxwell prepared for the rigors of the Mathematics Tripos exam at the residence of a friend's uncle (an evangelical rector).[14] He fell ill and collapsed while studying, leading to an intense conversion experience. Maxwell emerged from this with a fierce evangelical faith. Writing to his host afterward, he described his new religious outlook:

> [A]ll the evil influences that I can trace have been internal and not external, you know what I mean—that I have the capacity of being

[10] See Stewart Brown and Michael Fry, eds., *Scotland in the Age of Disruption* (Edinburgh: Edinburgh University Press, 1993).
[11] Lewis Campbell and William Garnett, *The Life of James Clerk Maxwell* (London: Macmillan, 1882), 420. Hereafter *Life*.
[12] C. W. F. Everitt, "Maxwell's Scientific Creativity," *Springs of Scientific Creativity*, eds. Rutherford Aris et al. (Minneapolis: University of Minnesota Press, 1983), 71–141, 114.
[13] On evangelicalism see David W. Bebbington, et al., eds., *Evangelicalism: Comparative Studies of Popular Protestantism in North America, the British Isles, and Beyond, 1700–1990* (Oxford: Oxford University Press, 1994). On evangelicalism's relation to science, see David N. Livingstone et al., *Evangelicals and Science in Historical Perspective* (Oxford: Oxford University Press, 1999).
[14] *Life*, 169–71

> more wicked than any example that man could set me, and that if I escape, it is only by God's grace helping me to get rid of myself, partially in science, more completely in society,—but not perfectly except by committing myself to God as the instrument of His will, not doubtfully, but in the certain hope that that Will will be plain enough at the proper time.[15]

Maxwell's newfound evangelical stance was quite clear: a depraved human nature and a complete reliance on divine grace. The dominant thought of this passage was the statement of Maxwell's acceptance of the overwhelming importance of a correct understanding of God's will. The evangelical outlook required a God who provided grace as a free choice and humans who acknowledged that free choice through exercise of their own will.

That summer Maxwell threw himself into reading to better understand his new faith. He devoured sermons of all kinds, including F. D. Maurice's *Theological Essays*, which were soon accused of heresy.[16] He did not, apparently, agree with all of Maurice's ideas, but the controversial theologian's emphasis on social activism resonated with Maxwell's own paternalist attitudes.[17]

Of particular significance was Maurice's emphasis on the role of human will. The exercise of the choice between love and selfishness was always a reflection of the divine will—volition was a route to submission to God's higher plan.[18] The ability to choose to trust God was a critical element in Maurice's scheme, and was also an important aspect of Maxwell's own understanding of his conversion experience.[19] This choice freed Christians from their worldly prison of "mere Fate or Necessity," giving them the power to live extraordinary lives as agents of God.[20] On this specific issue Maurice fit well with the Victorian religious mainstream which celebrated will as a source of both human strength and weakness, but always as a path to submitting to a higher power.[21]

An important part of Maxwell's religious development was his time as

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[15] Maxwell to C. B. Tayler, July 8 1853, *SLP*, 2: 220–21, on 221. On February 20 1853 Maxwell wrote that he could not apprehend evil with rational means, which suggests a more emotional approach to religion. See *Life,* 182–83.
[16] *Life,* 191–92.
[17] Maxwell to Lewis Campbell, September 15 1853, in *Life,* 192.
[18] John R. Reed, *Victorian Will* (Athens, Ohio: Ohio University Press, 1989), 21, 42.
[19] Maxwell to C. B. Tayler, July 8 1853. *SLP*, 2: 220–21, on 221.
[20] Frederick Denison Maurice, *Theological Essays* (Cambridge: Macmillan, 1853), 424–25.
[21] Reed, *Victorian Will*, 11–16, 38–39.

a member of the Cambridge discussion group known as the Apostles. One of his first essays for the Apostles revealed his earliest thinking on the impact of scientific developments on the Christian doctrine of free will.[22] One of the difficulties in maintaining the idea of an independent soul capable of guiding human action was the problem of determinism. In its modern form this problem goes back at least to David Hume, and appears under several different names. Briefly, it states that all events in the world are caused by physical causes (or natural laws), which admit of no exceptions, and thus all future events are in principle pre-determined by the current state of the world.[23] The difficulty rests in whether this applies only to physical phenomena or to mental and spiritual phenomena as well. Victorian society's basic assumption was that the soul, divinely created and endowed, was qualitatively different from the crude matter around it and was thus exempt from determinism. That is, the soul and the will could act freely without being conditioned by prior causes.[24] The mystery of how the soul drove the body gave rise to detailed analyses, but was accepted as obviously true.

Retaining faith in this simple exceptionalism became increasingly difficult for Maxwell's generation. Previously, the danger of materialism and mind was seen as largely a political issue stemming from the French Revolution.[25] But this threat took on a new cast with the impressive success of natural philosophy, particularly physics, in the middle of the nineteenth century. This made the idea of inescapable natural laws even more convincing. There were specific dangers as well. From Maxwell's essay:

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[22] Jordi Cat, "On Understanding: Maxwell on the Methods of Illustration and Scientific Metaphor," *Studies in the History and Philosophy of Modern Physics* 32 (2001), 395–441.

[23] Reed, *Victorian Will*, 31–35. "Determinism" has several possible meanings, the distinctions among which are beyond the scope of this paper. See *The Empire of Chance: How Probability Changed Science and Everyday Life*, eds. Gerd Gigerenzer et al. (Cambridge: Cambridge University Press, 1989), 276–82.

[24] For the free will debates in Victorian culture and thought see Reed, *Victorian Will*; L. S. Jacyna, "The Physiology of Mind, the Unity of Nature, and the Moral Order in Victorian Thought," *British Journal for the History of Science* 14 (1981): 109–32; Rick Rylance, *Victorian Psychology and British Culture 1850–1880* (Oxford: Oxford University Press, 2000), 25–45; Lorraine Daston, "The Theory of Will versus the Science of Mind," and Kurt Danziger, "Mid-Nineteenth Century British Psycho-physiology: A Neglected Chapter in the History of Psychology," in *The Problematic Science: Psychology in Nineteenth-Century Thought,* eds. William Woodward and Mitchell Ash (New York: Praeger, 1982), 88–118, and 119–46, respectively.

[25] See the statement of William Hamilton (one of Maxwell's teachers) in Rylance, *Victorian Psychology and British Culture*, 45.

> When we consider voluntary actions in general, we think we see causes acting like forces on the willing being. Some of our motions arise from physical necessity, some from irritability or organic excitement, some are performed by our machinery without our knowledge, and some evidently are due to us and our volitions. Of these, again, some are merely a repetition of a customary act, some are due to the attractions of pleasure or the pressure of constrained activity, and a few show some indications of being the results of distinct acts of the will.[26]

By the late 1850s, it seemed perhaps the human will was not quite so different from the material world than had been supposed. The work of Hermann Helmholtz and colleagues (which Maxwell was quite familiar with) began to provide dramatic evidence the human mind was subject to the same laws as the material world.[27] It seemed that animals, including humans, were constrained by the same energy laws that explained steam engines and waterwheels.

At the same time, a number of philosophical systems began to appear explaining the workings of the human nervous system and mind, and they made no recourse to the traditional freely-acting soul. Maxwell read widely, and there were a handful of figures who likely stimulated his thinking on the problem of volition. First was Herbert Spencer, who in 1855 challenged a number of classic assumptions about the will: "all actions whatever must be determined by those psychical connections which experience has generated . . . in his constitution."[28] Second, Maxwell's reference to pleasure and repetition suggests familiarity with Alexander Bain's early work which argued for volition being dependent on actual physical changes to the brain caused by a repeated activity seeking pleasure or avoiding pain.[29] It is well known that during this period Maxwell read Henry Buckle, who sought to explain all of human history by appeal to natural laws and denied that

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[26] [ author: please fill in the title of Maxwell's essay] *Life*, 240.
[27] On Helmholtz, see *Hermann von Helmholtz and the Foundations of Nineteenth Century Science*, ed. David Cahan (Berkeley: University of California Press, 1993) and Robert M. Brain and M. Norton Wise, "Muscles and Engines: Indicator Diagrams and Helmholtz's Graphical Methods," in *The Science Studies Reader*, ed. Mario Biagioli (New York: Routledge, 1999).
[28] Herbert Spencer, *Principles of Psychology* (London: Longman, Brown, Green, and Longmans, 1855), 617. See also Reed, *Victorian Will*, 119, 500–504.
[29] On Bain see Rylance, *Victorian Psychology and British Culture*, chapter 5.

consciousness was an exception to the uniformity of nature. While his analysis was only applied to large groups, his assumptions were quite deterministic: "If . . . I had a complete knowledge both of [a man's] disposition and of all the events by which he was surrounded, I should be able to foresee the line of conduct which, in consequence of those events, he would adopt."[30] And although he denied that his work circumscribed the will, William Carpenter's arguments that the reflex action could work without conscious intervention seemed to suggest that many of the higher functions of the mind were automatic.[31] These figures were not alone, and the 1850s marked the beginning of decades of vigorous debate on the subject of the will.

Maxwell had no doubts about the reality of the will, but he acknowledged contemporary developments in psycho-physiology and reflex action made it no longer tenable to claim that only the will was responsible for human behavior. "Some had supposed that in will they had found the only true cause, and that all physical causes are only apparent. I need not say that this doctrine is exploded."[32]

Near the end of the essay Maxwell cautioned that a natural philosopher must be careful not to generalize so broadly as to mistake one thing for another. His warning was one that reappeared several times in his career in different forms, and in different contexts. "[I]f we are going to study the constitution of the individual mental man, and draw all our arguments from the laws of society on the one hand, or those of the nervous tissue on the other, we may chance to convert useful helps into Wills-of-the-wisp."[33] The physiology of nerves and the behavior of societies were important topics that Maxwell thought deserved serious investigation, but they were incomplete. Without including the human will as a real and efficacious entity, one could mistake those scientific approximations for absolute truth and be led down a dangerous path.

## II. ESCAPING THE DETERMINIST PRISON

However, Maxwell had no interest in circumventing the conservation of energy or the breakthroughs of experimental physiology. This was a genu-

[30] Henry Thomas Buckle, *History of Civilization in England* (London: J. W. Parker and Sons, 1857), 17–18, and Reed, *Victorian Will*, 97–102.
[31] William Carpenter, *Principles of Human Physiology* (London: John Churchill, 1842), and "The Automatic Execution of Voluntary Movements" (1850), in William Carpenter, *Nature and man* (London: Kegan Paul, Trench and Co., 1888), 164–68.
[32] [ essay title] *Life*, 240.
[33] Ibid., 243.

ine dilemma with which he would grapple for the rest of his life. He was searching for some synthesis that would acknowledge the power of natural laws while retaining the possibility of man's free choice of God over sin. In an 1857 letter to his friend Lewis Campbell he described how he presented this issue to his students:

> I have to tell my men that all they see, and their own bodies, are subject to laws which they cannot alter, and that if they wish to do anything they must work according to those laws, or fail, and therefore we study the laws. You have to say that what men are and the nature of their actions depends on the state of their wills, and that by God's grace, through union with Christ, the contradictions and false action of those wills may be settled and solved, so that one way lies perfect freedom, and the other way bondage under the devil, the world, and the flesh, and therefore you entreat them to give heed to the things which they have heard.[34]

Another letter to Campbell in 1862 shows Maxwell's initial attempts to deal with the problem without discarding established science. Praising Helmholtz, Maxwell admitted that it was now clear that human bodies could be thought of as machines running on food for fuel. These implications of the conservation of energy showed that "the soul is not the direct moving force of the body. If it were, it would only last till it had done a certain amount of work, like the spring of a watch, which works till it is run down. The soul is not the mere mover."[35] He was careful to distinguish the soul from a mere reservoir of energy. Once this was made clear, the concern that it could be "used up" was negated and the possibility an eternal existence in heaven was retained.[36]

The problem of how a non-energetic soul could meaningfully guide the body remained, though. If it could not exert force, how could it intervene in the body's actions? Having disposed of the crude notion that the soul powered the body, Maxwell argued that the solution was to be found in a more subtle model of the mind-body relationship:

> There is action and reaction between body and soul, but it is not of a kind in which energy passes from one to the other,—as when

[34] Maxwell to Lewis Campbell, December 22 1857, in *Life*, 294.
[35] Maxwell to Campbell, April 21 1862, *SLP*, 1: 711–12, 712.
[36] This concern was widespread. See John Ruskin, "Unto this Last" (1862), in *The Works of John Ruskin*, eds. E. T. Cook and A. Wedderburn (London: George Allen, 1903–12), 1: 29–30.

> a man pulls a trigger it is the gunpowder which projects the bullet, or when a pointsman shunts a train it is the rails that bear the thrust. But the constitution of our nature is not explained by finding out what it is not. It is well that it will go, and that we remain in possession, though we do not understand it.[37]

The human will can act, not like an engine pushing a load, but as a delicate force that initiates a larger process, like a pebble starting an avalanche. Critically, both of the metaphors Maxwell uses here are events initiated by a conscious actor—a man pulls the trigger, a pointsman shunts a train. Note the ending statement of simple faith in his own experience of volition, perhaps an indication of the influence of his education in the Common Sense philosophy.[38]

Maxwell was aware that all he had done was find out "what [free will] is not," and had not found a positive solution to exactly how the will can act. But his strategy for solving the problem was made clear: find a process that begins with consciousness but does not require a significant investment of energy. This was the pointsman, though Maxwell did not yet understand how it might work. Interestingly, this letter to Campbell in which he first formulated the pointsman metaphor also mentions Rudolf Clausius's work on heat that had stimulated Maxwell to begin revising his kinetic theory of gases. Thus the pointsman was in focus just as he tackled anew the problems of molecules and statistics, the context in which the pointsman would appear again later.

Enthusiasm for molecular explanations was not limited to those defending free will. The later part of the 1860s and 1870s saw an explosion of attempts to explain wide ranges of the natural, biological, and mental worlds through materialistic hypotheses. From T. H. Huxley's insistence on the material basis of life, to Henry Maudsley's reduction of the mind to the reflex action, to Bain's argument that the mind is inescapably subject to the laws of cause and effect, the independence and reality of human volition were under sustained attack.[39] Many of these same scientists were also be-

[37] Maxwell to Campbell, April 21 1862, *SLP*, 1: 711–12.

[38] Richard Olson, *Scottish Philosophy and British Physics 1750–1880* (Princeton: Princeton University Press, 1975), chapter 12, discusses the influence of the Common Sense school of philosophy on Maxwell's science.

[39] T. H. Huxley, "On the Physical Basis of Life," *Fortnightly Review* 5 (1868): 129–45; Henry Maudsley, *The Physiology and Pathology of Mind* (London: Macmillan, 1867); Alexander Bain, "On the correlation of force and its bearing on the mind," *Macmillan's Magazine* 16 (1867): 372–83. See also Danziger, "British Psycho-Physiology," 134–38 and Rylance, *Victorian Psychology and British Culture*, 164–75.

coming more aggressive in explicitly challenging the truths and structures of religion. And while iconoclasts such as John Tyndall denied that they had explained away the mind, his strong determinism ("with the necessary molecular data . . . the chick might be deduced as rigorously and as logically from the egg as the existence of Neptune from the disturbances of Uranus") and claims that consciousness had an "invariable" relationship to physics were taken to be direct blows against the soul.[40] Even Emil Du Bois-Reymond's 1872 concession that the true nature of consciousness would never be understood scientifically was cloaked in a celebration of determinism.[41] His separation of the mind into transcendental-but-impotent and material-but-active portions only reinforced the problem of how the mind could influence the body.

Maxwell's response to these developments appeared in an 1873 essay.[42] His argument was that philosophy, religious or otherwise, must take into account the progress of physics to understand free will.[43] His foundation was again the pointsman model, which stated that the soul's power was not "motive" but rather to "regulate and direct the animal powers."[44] The progress of physical science had caused one difficulty (humans obeyed energy physics), but that progress might also have created the solution. The steering effect of an immaterial soul—the pointsman—was made more plausible by the innovative concept of instability, which Maxwell credited to Balfour Stewart.[45]

Stewart had argued that there were two kinds of mechanical systems, stable and unstable. Both could be considered as machines and obeyed the laws of mechanics, but because they were regular and calculable only stable systems had been studied closely. However, there were also unstable sys-

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[40] John Tyndall, "Scope and limit of scientific materialism," in *Fragments of Science* (New York: D. Appleton and Company, 1871), 109–22.

[41] Emil Du Bois-Reymond, "Ueber die Grenzen des Naturerkennens," *Reden* (Leipzig: Veit, 1886). Ernst Cassirer, *Determinism and Indeterminism in Modern Physics* (New Haven: Yale University Press, 1956), points to this speech as framing the determinism problem for the late nineteenth century. See also Keith Anderton, "The Limits of Science: A Social, Political, and Moral Agenda for Epistemology in Nineteenth Century Germany" (PhD dissertation, Harvard University, 1993).

[42] J. C. Maxwell, "Does the Progress of Physical Science Tend to Give any Advantage to the Opinion of Necessity (or Determinism) Over That of the Contingency of Events and the Freedom of the Will?", dated February 11 1873, *SLP*, 2: 814–23 (also in *Life,* 434–44). Hereafter "Freedom."

[43] "Freedom," 815.

[44] "Freedom," 817.

[45] Balfour Stewart and J. Norman Lockyer, "The Sun as a Type of the Material Universe. Parts I & II," *Macmillan's Magazine* 18 (1868):_246–57, 319–27.

tems where an infinitesimal amount of energy could set a system in motion, such as when a balanced egg tipped over. Unlike deterministic stable systems, here there was "freedom of action."[46] Stewart made a connection between the ability of an unstable system to magnify tiny forces and the problem of the will. If the human nervous system was arranged in an unstable fashion, the will could influence the entire structure with a microscopic effort. As he put it later, the inherent "incalculability" of unstable systems forced back the determinist specter: "In truth, is there not a transparent absurdity in the very thought that a man may become able to calculate his own movements, or even those of his fellow?"[47]

Maxwell was delighted with this development. He argued in an anonymous review that the stable/unstable division called into question many of the fundamentals of determinism, including the notion of an unbroken causality that can be precisely understood. "In unstable systems, like antecedents do not produce like consequents; and as our knowledge is never more than an approximation to the truth, the calculation of what will take place in such a system is impossible to us."[48] Maxwell argued that determinism was thus only plausible in processes that were stable at all times, which had been the only systems studied by physics. Science had advanced to the point where instability could be comprehended, and this tended "to remove that prejudice in favour of determinism."[49] This was a large step toward the pointsman, but was not a complete solution. While Stewart had reduced the amount of energy needed for volition to a tiny amount, *some* was still needed, thus still requiring the soul to be either energetic or impotent. Free will remained an experiential reality, but its justification remained complicated.

The situation became even more complicated at the 1874 British Association for the Advancement of Science meeting, the site of some of the century's most devastating attacks on free will. At this Belfast gathering Tyndall delivered his infamous naturalistic manifesto and Huxley declared that animals, including humans, should be thought of as automata—that

[46] Balfour Stewart, *The Conservation of Energy* (New York: D. Appleton, 1875), 159–60.
[47] Stewart, *Conservation*, 160–62.
[48] Anonymous, [Maxwell], "The Conservation of Energy," *Nature* (Jan 15 1874): 198–200, on 199. Maxwell's authorship of this review is argued for in Philip Marston, "Maxwell and creation: Acceptance, criticism, and his anonymous publication," *American Journal of Physics* 75 (2007): 731–40.
[49] "Freedom," 823.

is, machines governed solely by natural laws.[50] As with Tyndall he denied subscribing to fatalism, but his claim that "there is no proof that any state of consciousness is the cause of change in the motion of the matter of the organism" was unmistakable in its rejection of free will.[51] Instead of being the mark of an active soul, consciousness became a mere epiphenomenon of the functioning of mechanical bodies.

Maxwell evaded automata with a development in French mathematical physics known as "singular states," which provided a sophisticated explanation for how a particle could be diverted without energy. It was found in the 1870s that for certain differential equations (the equations which govern the motion of particles) there were sometimes peculiar points where an entire family of solutions "overlapped" and it was impossible to tell which trajectory a particle would take. Many of the mathematicians involved used these results to deal with difficult issues regarding their Catholic context in France, including free will.[52] Maxwell quickly connected it to his own religious concerns. He interpreted these singular states to be the mechanism for his pointsman: at such a state, the laws of motion made no determination which track the metaphorical train might follow. No forces or energy would be required to affect the path of a particle:

> While [the particle] is on the enveloping path it may at any instant, at its own sweet will, without exerting any force or spending any energy, go off along that one of the particular paths which happens to coincide with the actual condition of the system at that instant.

This was a dramatic improvement that removed the need for even the small amount of "trigger-work" that Stewart needed the will to perform.[53] At a singular state "a strictly infinitesimal force may determine the course of the

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[50] T. H. Huxley, "On the Hypothesis that Animals are Automata, and its History," in *Science and Culture* (London: MacMillan, 1881), 199–245; Adrian Desmond, *Huxley: Evolution's High Priest* (London: Michael Joseph, 1997), 2: 51–80; Rylance, *Victorian Psychology and British Culture*, 93. On Victorian automata see M. Norton Wise, "The Gender of Automata in Victorian Britain," in *Genesis Redux*, ed. Jessica Riskin (Chicago: University of Chicago Press, 2007), 163–95.

[51] Huxley, "Automata," 244.

[52] Mary Jo Nye, "The Moral Freedom of Man and the Determinism of Nature: The Catholic Synthesis of Science and History in the *Revue des questions scientifiques*" in *British Journal for the History of Science* 9 (1976): 274–92. Also Ian Hacking, "Nineteenth Century Cracks in the Concept of Determinism," *JHI* 44 (1983): 455–75, 464–65.

[53] Maxwell to Francis Galton, February 26 1879, *SLP*, 3: 756–58, 757.

system to any one of a finite number of equally possible paths, as the pointsman at a railway junction directs the train to one set of rails or another."[54]

This was truly the fulfillment of the promise of the pointsman. The motion of particles *could* be influenced by an entity not involved with the transfer of energy. Dynamical theory had now shown that entire future courses of events were only predictable "*in general*," and there was clear ontological space for conscious influences.[55] Best of all, this space fell directly out of the equations of motion and thus maintained the strict validity of physics. It was "much better than the insinuation that there is something loose about the laws of nature."[56]

It seems that by this point Maxwell's views of free will had reached a comfortable maturity, and we can now see the full message that is embodied in the pointsman. First, he reminded even his allies that the days of a completely unrestrained will were far in the past. The conservation of energy and psycho-physiology had forcefully demonstrated that humans do not have unrestricted control over their bodies.[57] The pointsman does not have complete control over the train—he can only deflect it at certain times and under certain circumstances. The train really does run on rails. Nonetheless, the pointsman is needed to get the train to a particular destination.

The problem, Maxwell said, was that investigators had not been careful about applying results from one domain of knowledge to another:

> Many cultivators of the biological sciences have been impressed with the conviction that for an adequate study of their subject a thorough knowledge of dynamical science is essential. But the manner is which some of them have cut and pared at the facts in order to bring the phenomena within the range of their dynamics has tended to throw discredit on all attempts to apply dynamical methods to biology.[58]

This was particularly dangerous in the case of investigating "sensation and voluntary motion" through purely psychological or neurological means. It was sloppy science to treat "a fact of consciousness as if it were an electrical

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[54] Maxwell, "Review of *Paradoxical Philosophy*," *SLP*, 3: 760.
[55] "*Paradoxical,*" 760.
[56] Maxwell to Galton, February 26 1879, *SLP*, 3: 756–58, 757–58.
[57] "*Paradoxical,*" 760. See also Maxwell, "Hermann Ludwig Ferdinand Helmholtz," *SLP*, 2: 592–98.
[58] "Helmholtz," 593.

current."[59] The application of one kind of scientific idea to another could be immensely fruitful, but it could also be disastrous.

There were two extremes on which one could err. The first was to try to explain the emergence of consciousness from material processes. Maxwell commented satirically on such attempts: "I was dimly aware that somewhere in the vast System of Philosophy this question had been settled, because the Evolutionists are all so calm about it: but in a hasty search for it I never suspected in how quiet and unostentatious a manner the origin of myself would be accounted for."[60] He mocked those, such as Du Bois-Reymond and von Nägeli, who postulated a continuity of consciousness beginning with the pleasure felt by the simplest entities as making the error of naïve personification.[61] The problem with theories of this kind (such as Herbert Spencer's) was that they explained away the soul.

The second extreme was to accept the existence of the soul, but then try to justify its properties in material terms. These sorts of "gross materialisations" of the soul were misguided attempts at objectivity, but were fundamentally flawed:

> Science has, indeed, made some progress in clearing away the haze of materialism which clung so long to men's notions about the soul . . . No anatomist now looks forward to being able to demonstrate my soul by dissecting it out on my pineal gland, or to determine the quantity of it by the process of double weighing.[62]

Maxwell's targets on this end were usually other Christians, such as John Drysdale.[63] He argued that such attempts either resulted in absurdities such as Isaac Taylor's energy-producing soul or a will trapped in a materialist prison not so different from Du Bois-Reymond's. Maxwell attacked both sides equally—anyone who argued that the soul was explainable imperiled its divine nature and role in God's plan. He mocked the claim that the human body and soul could be treated as isolated entities: "I often catch myself, when thinking about my body or my mind, supposing that I am thinking about myself."[64]

Instead, he said, we should return to our own introspective experience

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[59] "Helmholtz," 595–96.
[60] Maxwell, "Psychophysik," *SLP*, 3: 604.
[61] "Psychophysik," 602.
[62] "*Paradoxical*," 760, 756.
[63] "Psychophysik," 606–7.
[64] "Psychophysik," 598–99.

as the basic evidence for volition: "I know that I exist now, and that I act, and that what I do may be right or wrong, and that whether right or wrong, it is my act, which I cannot repudiate."[65] This reminds us of the high stakes of free will for the Victorians—only a people who could freely choose their actions could be held responsible for them (both in the eyes of God and those of society). Maxwell leveled this criticism against Du Bois-Reymond's conclusion that humans had two minds, one material, deterministic, and active, and one immaterial, conscious, and impotent. "We might ask Prof. Du Bois-Reymond which of these it is that does right or wrong, and knows that it is his act, and that he is responsible for it. . . ."[66]

This all left the soul in a liminal position. It was outside the *explanatory* range of science:

> But as soon as we plunge into the abysmal depths of personality we get beyond the limits of science, for all science, and indeed, every form of human speech, is about objects capable of being known by the speaker and the hearer. . . . The progress of science, therefore . . . has rather tended to deepen the distinction between the visible part, which perishes before our eyes, and that which we are ourselves, and to shew that this personality, with respect to its nature as well as to its destiny, lies quite beyond the range of science.[67]

But this did not mean that mind and will should be *ignored* by science. Rather, the lesson of the pointsman was that considerations of the will were crucial for keeping one from making incorrect conclusions about the application of science to humans (i.e., automatism). The will was a reality about the world that changed what conclusions were valid—if you ignore the pointsman you won't understand where the train is headed—and thus the will needed to be taken into account, not explained away.

Maxwell's understanding of the human will was not a simple import of religious dogma into his natural philosophy. He was clearly not uncritical about these issues: he rejected unsatisfactory solutions to the free will problem; accepted that humans were subject to some natural laws; and strongly condemned any naïve pairing of Christian doctrine with the sci-

[65] "Psychophysik," 607.
[66] "*Paradoxical*," 760–61.
[67] "*Paradoxical*," 762.

ence of the day.[68] Rather, the pointsman was a way of thinking about the basic experience of volition in a world of natural laws. He continually reconsidered it in light of new findings in physics and physiology, and it was modified over time. Even when incomplete, it was a resource he drew upon to shape his understanding of the problems of the limits of science. And these problems were not limited to the mysteries of volition—they were found in the realm of pistons and engines as well.

## III. MOVING METAPHORS

I have traced the development of Maxwell's pointsman largely in the realm of considerations driven by his evangelical Christian values. I will now examine the other context in which the pointsman emerged: the laws of thermodynamics. Maxwell was one of the pioneers of the kinetic theory of gases, which sought to demonstrate that the observable characteristics of gases could be deduced from the hypothesis that all matter was made up of molecules in motion.

Maxwell's great innovation in this field was his application of statistical methods. He learned these techniques from social statistics, particularly Thomas Buckle's historical works. He explained that "the limitation of our faculties" made tracing individual molecules hopeless. In his earliest uses of statistical methods he emphasized the incompleteness of this kind of knowledge, although it could still provide the "moral certainty" that would be accepted by reasonable persons.[69]

Maxwell achieved significant successes with his theory, notably deriving many of the observed properties of gases and providing some explanation for the interchange of heat and macroscopic movement described by the conservation of energy (also known as the first law of thermodynamics). But here I will focus on Maxwell's thinking on the second law of thermodynamics.

The second law as it was understood at the time was expressed in sev-

[68] "*Paradoxical*," 761; "Analogies," *SLP*, 1: 380; and Maxwell to C. J. Ellicott, November 22 1876, in *Life*, 393–95, 394.

[69] P. M. Harman, *The Natural Philosophy*, 124–29, and Theodore M. Porter, "A Statistical Survey of Gases: Maxwell's Social Physics," *Historical Studies in the Physical Sciences* 12 (1981): 77–116. For Maxwell's approach to kinetic theory see Theodore M. Porter, *The Rise of Statistical Thinking 1820–1900* (Princeton: Princeton University Press, 1986), 111–26; Stephen Brush. *The Kind of Motion We Call Heat* (New York: Elsevier, 1986); and Elizabeth Garber, et al., eds., *Maxwell on Heat and Statistical Mechanics* (Bethlehem: Lehigh University Press, 1995).

eral different forms: useful energy tended to dissipate; in the absence of external work heat flowed from hot to cold; or that entropy always increased in a closed system. These statements were generally based on macroscopic entities like steam engines and Maxwell was unconvinced that the microscopic perspective of kinetic theory could be fully reconciled with them.[70]

He sought "to pick a hole" in the law with a novel thought experiment. In an 1867 letter he described two vessels placed in physical contact, each filled with gas at different temperatures. The second law normally predicted that the two vessels would adjust to an equilibrium temperature. Maxwell thought he had evaded this straightforward result based on a conceptual resource developed in a very different context.

Maxwell first slightly altered the setup. A diaphragm would be placed connecting the two vessels, able to open and close. "Now conceive a finite being who knows the paths and velocities of all the molecules by simple inspection but who can do no work, except to open and close a hole in the diaphragm, by means of a slide without mass." This being would watch the motion of individual molecules and when a fast molecule approached, it would open the diaphragm and allow the molecule into the adjacent vessel. The door would be closed to prevent the passage of slow molecules, resulting in the build-up of faster molecules on one side and slower molecules on the other. The kinetic theory of gases interpreted this asymmetry as a difference in temperature, meaning heat would have flowed from cold to hot. The second law was violated with no work or energy, "only the intelligence of a very observant and neat fingered being has been employed." There was nothing qualitatively distinct about this being, it was simply very perceptive and quick. Humans were unable to do this only due to "not being clever enough."[71] The moral of the tale was that the second law was true only in a statistical sense, and that a being with access to better measurement could circumvent it casually.

This finite being became known as "Maxwell's Demon," a strange but

[70] For instance, see Maxwell to J. W. Strutt, December 6 1870, *SLP*, 2: 582–83. William Thomson was particularly interested in the temporal directionality of thermodynamics. See Crosbie Smith and M. Norton Wise, *Energy and Empire* (Cambridge: University Press, 1989), 612–33. The social and cultural significance of thermodynamics is discussed in Stephen Brush, *The Temperature of History* (New York: Burt Franklin and Co., 1978); Bruce Clark, "Allegories of Victorian Thermodynamics," *Configurations* 4 (1996): 67–90; and Greg Myers, "Nineteenth-century Popularizations of Thermodynamics and the Rhetoric of Social Prophecy," *Energy and Entropy*, ed. Patrick Brantlinger (Bloomington: Indiana University Press, 1989).

[71] Maxwell to P. G. Tait, December 11 1867, *SLP*, 2: 328–33, 331, 332.

perhaps not implausible creation.[72] The demon may seem more familiar to us in a later description of the same thought experiment, with the two vessels named A and B:

> Provide a lid or stopper for this hole and appoint a doorkeeper, very intelligent and exceedingly quick, with microscopic eyes but an essentially finite being. . . . In this way the temperature of B may be raised and that of A lowered without any expenditure of work, but only by the intelligent action of a mere guiding agent (like a pointsman on a railway with perfectly acting switches who should send the express along one line and the goods along another).[73]

The same metaphor that Maxwell constructed to explore the human will reappeared here inside containers of gas. Why? It is clear that in the crudest sense his use of the pointsman was, as in his discussions of the will, meant to circumvent objections that energy would be needed to achieve the desired effects. The pointsman's tasks were thus expanded to explain both volition and heat flow. But as with free will, the pointsman metaphor also signaled much larger questions about the nature of scientific explanation.

Maxwell used metaphors repeatedly in his scientific career.[74] The pointsman fits well with Jordi Cat's argument that Maxwell used metaphors primarily for illustrative, not explanatory purposes.[75] What aspects of real pointsmen was Maxwell trying to evoke, and what was he hoping to illustrate? A pointsman's job was about information (where was the train, when would it clear the tunnel) and then acting immediately on it (shift the points, pull the lever). Incredible precision and unflagging attention were

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[72] The name "demon" came from Thomson, not Maxwell. See Maxwell, "Concerning Demons," *SLP*, 3: 185–86. "Demon" has become the default title for this entity, and I will use it here. Further significance of the name "demon" is discussed in S. Schweber, "Demons, Angels and Probability: Some Aspects of British Science in the Nineteenth Century," *Physics as Natural Philosophy,* eds. Abner Simony and Herman Feshbach (Cambridge, Mass.: MIT Press, 1982), 319–63.

[73] Maxwell to J. W. Strutt, December 6 1870, *SLP*, 2: 582–83.

[74] On Maxwell's metaphors see Jordi Cat, "On Understanding: Maxwell on the Methods of Illustration and Scientific Metaphor," *Studies in the History and Philosophy of Modern Physics* 32 (2001): 395–441; Mary Hesse, *Models and Analogies in Science* (Notre Dame, Ind.: University of Notre Dame Press, 1966) and *Revolutions and Reconstructions in the Philosophy of Science* (Bloomington: Indiana University Press, 1980).

[75] Cat, "On Understanding," 424.

required, but they were still, in the end, human and finite.[76] This was exactly the image Maxwell wanted to conjure both with his demon and with volition: conscious awareness and actions based on that awareness could allow a small action (pulling a lever) to have huge consequences (the train goes south instead of west). The benefit of using a metaphor here was a straightforward one, in that it helped describe the unfamiliar in terms of the familiar. The conscious observations and actions of the pointsman were intimately familiar to any human being, providing a way for Maxwell to illustrate the strange processes involved in psycho-physiology and thermodynamics.[77]

The pointsman was not intended to show the unrestricted force of the will. It showed that the will could act even within a wide range of restrictions. The real pointsmen were restricted by the structure of the tracks, the momentum of the train, and the rules of the rail company. But even if an observer understood all of those things, they would still not understand how the train got from place to place without appreciating that consciousness, observation, and volition were necessary to the process. Similarly, a man of science who understood conservation of energy, the reflex action, and the dynamical theory of heat would still not be able to understand the true nature of either humans or entropy. Without an awareness of consciousness, observation, and volition they would come to incorrect conclusions about scientific laws.

Maxwell did not mean the pointsman to be a literal explanation of what was happening in either the mind or a thermodynamic chamber. Maxwell did not think that the demon was an actual human or divine intelligence. It has been claimed that the demon was a microscopic Laplacian calculator that was omniscient about the motions of molecules (i.e., God).[78]

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[76] See Norris Pope, "Dickens's 'The Signalman' and Information Problems in the Railway Age," *Technology and Culture* 42 (2001): 436–61. The assertion that the demon's effectiveness relies on information becomes key to many of the twentieth-century attempts to refute the demon. See John Earman and John Norton, "Exorcist XIV: The Wrath of Maxwell's Demon. Part I: From Maxwell to Szilard," *Studies in the History and Philosophy of Modern Physics* 29 (1998): 435–71, and "Exorcist XIV: The Wrath of Maxwell's Demon. Part II: From Szilard to Landauer and Beyond," *Studies in the History and Philosophy of Modern Physics* 30 (1999): 1–40. Some of these attempts note that the demon only functions if free will is real: Orly R. Shenker, "Maxwell's Demon and Baron Munchausen: Free will as a 'perpetuum mobile'," *Studies in History and Philosophy of Modern Physics* 30 (1999): 347–72.

[77] Cat, "On Understanding," 425.

[78] Edward Daub, "Maxwell's Demon," *Studies in History and Philosophy of Science* 1 (1970): 213–27, 224.

Maxwell anticipated this accusation and stated that he was willing to dispense with the intelligent aspects of the demon and turn it into a sophisticated valve.[79] Based on these passages Peter Harman states that the demon had no supernatural connotations for Maxwell.[80] Harman is clearly trying to anticipate the claim that the demon was a direct divine agent. I agree with him on this specific point, but I believe Crosbie Smith and M. Norton Wise are also correct in arguing that Maxwell did not object to *all* supernatural implications of the demon.[81] That is, I think it is the case both that Maxwell did not intend the demon to be a literal description of divine actions and he did think the results of the demon thought experiment could have implications for matters that could be called "supernatural" (e.g. free will). The pointsman was not intended to provide a concrete explanation of an actual process, since there could be multiple explanations for what was going on (an intelligence or a valve). Rather it was the illustration that was important: considering carefully what intelligence can do *shows* the errors of certain kinds of reasoning.[82] Maxwell thought that metaphors could play an important part in science, but the scientific function of the pointsman was critical, not constructive.[83] Instead, its job was to warn against drawing unwarranted scientific conclusions.[84]

The demon was an elaboration of the pointsman model originally developed to shed light on human volition in a deterministic universe. The pointsman was, at root, an attempt to understand correctly the nature of the human will as something that could process information and act on it.[85] Maxwell was committed to such a correct understanding due to his evangelicalism, but this was not solely a religious issue. Rather, he argued that a correct understanding of free will helped us understand better both the world and our conceptions of it. In the case of the demon, understand-

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[79] Maxwell to J. W. Strutt, December 6 1870, *SLP*, 2: 582–83 and "Concerning Demons," *SLP*, 3: 185–86. Exactly how anthropomorphic the demon needs to be in order to function remains a matter of contention. See N. Katherine Hayles, *Chaos Bound: Orderly Disorder in Contemporary Literature and Science* (Ithaca, N.Y.: Cornell University Press, 1990), 43.

[80] P. M. Harman, *Energy, Force, and Matter* (Cambridge: University Press, 1982), 140.

[81] Smith and Wise, "Muscles and Engines: Indicator Diagrams and Helmholtz's Graphical Methods," 623.

[82] Cat, "On Understanding," 424, 428–29.

[83] Maxwell, "Address to the Mathematical and Physical Sections of the British Association," Liverpool, September 15 1870, *SLP*, 2: 215–29.

[84] Cat, "On Understanding," 430.

[85] Smith and Wise, "Muscles and Engines: Indicator Diagrams and Helmholtz's Graphical Methods," 625, argue that the demon was intended to show what was *distinctive* about conscious creatures, which is certainly an important part of Maxwell's reasoning.

ing the power of free will showed how to question the universality of the second law. The demon itself did not have to be a supernatural being and it was intended to solve a technical problem in thermodynamics. But its function was based on a metaphor that was also part of a chain of reasoning based on manifestly religious premises. Thus the pointsman was both a scientific and religious entity, and in both realms it was intended to raise difficult questions about the knowledge available from the current state of science.

More specifically, the pointsman questioned what *level of knowledge* was available, and how that level affected the conclusions one could draw. Maxwell was concerned throughout his career with ensuring that physical laws and claims were understood properly: were they a description of a real entity, a hypothesis, a metaphor, or simply a mathematical convenience? The correct understanding of free will, as manifested in the pointsman, was one more tool for properly calibrating the level of knowledge in both science and society.

Molecular investigations appear to have particularly stimulated Maxwell's thinking on these issues. He claimed that the kinetic theory "forces on our attention the distinction between two kinds of knowledge, which we may call for convenience the Dynamical and Statistical." Dynamical knowledge could produce certainty and exact prediction, whereas statistical investigations could only address probabilities and general assertions.[86] He did not denigrate the powerful results of statistics but he did want to make clear that it generated certain "peculiarities" different from "exact science." These peculiarities were responsible for such apparent anomalies as the reversibility of astronomy while thermal phenomena remained irreversible. This meant, fundamentally, that human knowledge via statistics could only be approximate, not absolutely accurate in the manner of astronomical predictions.[87]

The physical world, then, could sometimes present both puzzles and solutions that were only apparent, and that were dependent on our abilities rather than nature. In the case of the second law, processes of the natural world appeared to show regularity that the lens of statistics revealed was illusionary.[88] The intent of the demon was to demonstrate just such a situation. Maxwell asserted that the second law was "undoubtedly true as long as we can deal with bodies only in mass, and have no power of perceiving

[86] "Freedom," 818.
[87] "Freedom," 819.
[88] James Clerk Maxwell, "Molecules," *Nature* 8 (1873): 437–41. Also in *SLP*, 2: 361–78.

or handling the separate molecules of which they are made up,'' and used the demon to show how useful heat could be restored to a system by a being with precise, but finite, awareness.[89] Human misunderstandings of their own awareness and volition could lead to erroneous conclusions:

> It follows from [the activity of the demon] that the idea of dissipation of energy depends on the extent of our knowledge. . . . A memorandum book does not, provided it is neatly written, appear confused to an illiterate person, or to the owner who understands it thoroughly, but to any other person able to read it appears to be inextricably confused. Similarly the notion of dissipated energy could not occur to a being who could not turn any of the energies of nature to his own account, or to one who could trace the motion of every molecule and seize it at the right moment. It is only to a being in the intermediate stage, who can lay hold of some forms of energy while others elude his grasp, that energy appears to be passing inevitably from the available to the dissipated state.[90]

The demon, as an application of the concept of the pointsman, showed dramatically how we can be fooled into seeing laws of nature where they do not truly exist.

Similarly, Maxwell thought materialists such as Huxley had fooled themselves into seeing laws of nature where there were none. He was concerned with the consequences of their ideas in the religious realm, but the wider application of the pointsman shows us that his critique was a deeper one. He was arguing that they had mistaken some regularities of nature (e.g., the function of the nervous system) for absolute laws (human automatism). This error came from paying too much attention to energy and motion and not enough to personality and the experience of the divine. With the pointsman he argued that understanding how volition could work even in a world of natural laws would have prevented the materialists from reifying erroneous conclusions based on their limited agnostic perspectives. Maxwell asserted that thinking of humans simply as machines was a choice: ''Either be a machine and see nothing but 'phenomena,' or else try to be a man, feeling, your life interwoven, as it is, with many others, and strengthened by them whether in life or death.''[91] One could either accept the reality

[89] James Clerk Maxwell, *Theory of Heat* (London: Longmans, 1872), 308–9.
[90] Maxwell, ''Diffusion,'' article for the *Encyclopaedia Britannica*, *SLP*, 2: 625–46, 646.
[91] Maxwell to R. B. Litchfield, September 23 1857. *Life,* 281.

of our experience of volition or discard it, but rejecting that reality was asserting a particular boundary to science. And to Maxwell, the materialists had picked the wrong one. They asserted that consciousness was an object to be explained, rather than a cause to be taken into account. This neglect of the everyday experience of consciousness poisoned their analyses and thus they became convinced of the absolute truth of biological laws (that humans were automata) that were only approximately true.

The parallel use of the pointsman in his analyses of the second law shows that Maxwell thought an incorrect understanding of the will could have consequences in physics as well. The pointsman performed an analogous task here to its role in religion. It was a call to observers that they were focusing on the wrong level of analysis. For Maxwell, a correct understanding of the mind and the will affected how one saw the world. In science, that determined which laws of nature one could see. In society, it determined whether man was moral and responsible for his own actions. Decision making was one of the fundamental problems of metaphysics, and misunderstanding it could have dramatic consequences in all aspects of human thought from molecules to morality. The pointsman did not just guide molecules in motion; he also guided the physicist to a better understanding of the world.

## CONCLUSION

Maxwell's pointsman was a reminder of the need to draw correct boundaries, in two related senses. First, the limits of science itself vis-à-vis human consciousness. Science cannot encompass consciousness, or it becomes explained away. Solely materialist approaches to the human mind might seem self-consistent but were ultimately self-defeating. But science cannot ignore consciousness either, or it wanders into philosophical dead-ends. Thus consciousness and free will sit precisely on the boundary of science. Science must acknowledge the existence and possible effect of consciousness, but cannot seek to explain it.

This leads directly to the second type of boundary, the one between different kinds of scientific explanation: statistical versus dynamical, or limited versus absolute. Some scientific conclusions were true only in an approximate sense, not a fundamental one. Humans do obey some of the same laws as machines, and entropy usually does increase. But we can be fooled into thinking those approximations are *really* true if we do not pay

proper attention to human consciousness. Maxwell worried that ignorance of this issue was misleading Victorian scientists into dangerous waters, and intended the pointsman to show them a way out.

The lesson of the pointsman was that consciousness matters, and that the physical world cannot be properly explained without considering how our role as conscious, willful beings might impact it. For the real men of the Victorian railway, this was a matter of life and death. For Maxwell, the stakes were even higher: the existence of the soul and the progress of science.

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