Migraine and Metaphysics: Sentinels of Science in Nineteenth-century Physics

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Abstract:

In an old boy network of nineteenth-century natural philosophers, all with a background in mathematics from the University of Cambridge, a conspicuous aversion ruled against metaphysics. Within these circles it produced a strong compulsion to define the limits of genuine scientific endeavour. These attempts were primarily directed against unfounded hypotheses trying to encompass the indefinite and all sorts of aprioristic knowledge, except mathematics. Either by emphasizing the formal aspects of science or linking the formalism to useful applications in the shape of physical models and demands for practical use, two ways in this crusade, not always consistent, were laid out. Nevertheless, the same natural philosophers were engaged in fundamental questions and manifest speculations about the constitution of matter, the age of the earth, the destiny of the universe, and so forth. How could that, if at all, yield a coherent worldview? In this article I will answer that question by looking at how a group of outspoken and influential Cantabrigian Wranglers were carving out intellectual, cultural and political space for themselves and their scientific endeavours while unremittingly patrolling their borders.

1. PATROLLING THE MATHEMATICAL BORDERS

Provoked by a question raised by the physicist Peter Guthrie Tait at a meeting at the Royal Society of Edinburgh May 17, 1869 the lawyer Clement Mansfield Ingleby send an open letter to the editor of the newly established scientific journal *Nature* in order to "clearing up a most unfortunate confusion of thought respecting the intellectual ranks of mathematicians and metaphysicians".[1]

In Scotland Tait had challenged the present adherents of metaphysics to produce a metaphysician who was at the same time a proper mathematician. Tait himself could not think of a single instance. Tait's challenge was interpreted by Ingleby as a mere badinage at the expense of "the science of metaphysics" displaying certain natural philosophers' general dismay of that branch of knowledge. Ingleby was trained in mathematics from Trinity College in Cambridge, but had upon graduation taken up a position in his father's law firm in Birmingham. He continued his academic interests at the Birmingham and Midland Institute—a young institution that provided adult scientific and technical education—teaching logic and metaphysics. In 1859 he moved to London to pursue an intellectual and literary career publishing, among other things, an *Introduction to Metaphysics* in two volumes during the 1860s.

Ingleby's response to Tait in *Nature* consisted in making a taxonomy of different levels of mathematicians and metaphysicians. Mathematicians, he argued, could be trichotomised into inventors, experts and readers or students of mathematics, where metaphysicians on the other hand could only be divided into the two groups of creators and students of metaphysics. He then went on to discuss who should be on the list of natural philosophers who fulfilled the criteria for being put in the first groups of mathematical inventors and metaphysical creators, believing that it must be such persons Tait was asking for. The German philosopher Georg Wilhelm Friedrich Hegel, thought to be a genuine metaphysician, was dismissed for being only a reader of mathematics. Galilei Galileo and Isaac Newton, though both considered mathematical inventors, failed to produce metaphysical systems of their own in Ingleby's opinion, which left only René Descartes and Gottfried Wilhelm Leibniz who truly fulfilled the criteria. Ingleby had taken up Tait's challenge and given him two prominent names in reply.

Tait, in his response to Ingleby in the following issue of *Nature*, completely dismissed the trichotomy of mathematicians. His argument was that either one was a mathematician or one was not. No intermediate class would be possible. Being a mathematician required more than just the mastery of integration and differential calculus. It was important to have at least some sort of creative faculty, even in a very small scale. But in order to be considered a mathematician it was not necessary to have devised an entirely new calculus. Less would do and so Tait's contemporary colleagues and fellow Cantabrigians George Gabrial Stokes,

[1] C. M. Ingleby, "Creators of Science", *Nature* 5: 62, (1869).

William Thomson (Lord Kelvin), James Clerk Maxwell and Arthur Cayley were included as mathematicians and not mere experts as they would have been in Ingleby's taxonomy. With respect to metaphysicians Tait agreed with Ingleby in his division of two groups. He did not, on the other hand, share Ingleby's attempt to drive the locus of the discussion into the field of "noble metaphysical endeavours". Those, not being specifically defined, were admitted by Tait as something applicable to all men worthy of the name of mathematicians and physicists. This was not, however, as Ingleby believed, the interesting class of metaphysicians. Tait maintained his repudiative attitude towards 'spurious metaphysics' as being the class of "stagnation, ropes of sand, bitter quarrels as to the meaning of unintelligible words", performed with pride by "dwellers in a sublimer sphere".[2]

The sarcasm Tait employed left no room for the peaceful reconciliation of the mathematicians and the metaphysicians Ingleby was hoping for. Rather, Tait sharpened the boundaries by ridiculing those Ingleby tried to advance as genuine metaphysicians. On that account Hegel was dismissed. Not on the grounds for not being a mathematician, but for being a bad metaphysician. Thereby Tait angled for supporters against a certain type of metaphysical thinking fairly popular at the time, through a common disdain for Hegel among the inner circle of natural philosophers in the Cambridge network.[3] Who could take seriously a German philosopher who tried to prove that Newton understood neither fluxions nor the law of gravitation?

2. DOWNRIGHT NONSENSE

Hegel was not popular among mid-Victorian men of science. Among those who shared Tait's feelings in that regard were William Thomsen. A former student, John Hutchinson, remembered Thomson's anger towards Hegel to exceed even his anger towards the Cambridge examination system and the British system of weights and measures:

> If you wanted to see an illustration of pure white heat you should have seen Sir William castigating Hegel for the audacity of his assaults on Newtonian philosophy. I remember on one occasion he sent over to the library for the learned volume containing Hegel's criticism of Newton, in order that we might hear the *ipsissima verba*, the downright nonsense, of this 'arrant impostor.'

The dislike of Hegel's way of thinking came forth on several occasions. Among them in a lecture on the tides held in 1882. Thomson, while explaining Newton's gravitational ideas, passed a remark on Hegel's speculations about the movement of planets like blessed gods

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[2] P. G. Tait, "True and Spurious Metaphysics", *Nature* 5: 81, (1869).

[3] For an introduction to the elite circles of mid-Victorian physicists see Peter Harman (ed.), *Wranglers and physicists: studies on Cambridge physics in the nineteenth century*, Cambridge: Cambridge University Press. 1985. For a more general discussion of Victorian hierarchies of knowledge see Peter C. Kjærgaard, "Competing Allies: Professionalisation and the Hierarchy of Science in Victorian Britain", *Centaurus* **44**, 248-288 (2002). For how *Naure* was used to channel and control scientific discussions see Peter C. Kjærgaard, "'Within the bounds of science': Redirecting controversies to *Nature*". In Louise Henson et al (eds.), *Culture and science in the nineteenth-century media*, Aldershot: Ashgate 2004, 211-222.

instead of stones: “If Hegel had any grain of philosophy in his ideas of the solar system, Newton is all wrong in his theory of the tides”; which, of course, Thomson did not believe was the case.[4]

Tait, in other words, had the necessary intellectual backup and Ingleby was left without a case when trying to propagate a positive and dynamical interaction between mathematicians and metaphysicians. The possibility of those two groups working together was effectively turned down by Tait, who accordingly placed himself as “an enemy of intellectual progress” by Ingleby’s definition in the concluding remarks of his letter to *Nature*.

Resting assured that he was not alone in his view of mathematics and metaphysics, “these two grand intellectual pursuits to be worthy of being cultivated together, and to be able to give material aid to each other”, Ingleby continued to stress that he could not:

> but look upon any man as the enemy of intellectual progress, who delights in setting one class of investigators against the other, and endeavours to prolong the controversy which had raged between them since the “Principia” [Newton’s *Principia mathematica*] was promulgated.[5]

Ingleby’s Cambridge connection did not help him much. He was not part of the old boy network and for his mediating efforts he got nothing but contempt from Tait.

3. MATHEMATICAL APHASIA AND EMPTY FORMALISM

William Thomson had a similar disdainful attitude towards the understanding of metaphysics Ingleby endorsed and which was growing increasingly popular among British intellectuals. With an all-pervading practical sense of science intimately connecting theoretical research with its applications, Thomson saw a priori knowledge and idealism as impeding progress and consequently something to avoid in the discussion of natural philosophy.

For Thomson the only true metaphysics was mathematics. It could be misdirected as in pure formal analysis or mathematics for its own sake, still being true, but lacking utility and thus being a waste of mental powers. Thomson’s worries in that regard even concerned the friend and fellow Scotsman, James Clerk Maxwell’s electromagnetic theory of light. In his Baltimore lectures at Johns Hopkins University in 1884 Thomson was encouraging his listeners to “cure the mathematical disease of aphasia from which we suffered so long”.[6]

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[4] P. G. Tait, ibid.; Hutchinson is quoted from Silvanus P. Thompson, *The Life of William Thomson - Baron Kelvin of Largs*, London: Macmillan and Co. 1910, vol. II, p. 1122.; Thomson’s quote is from William Thomson, “The Tides” in *Popular Lectures and Addresses*, London: Macmillan & Co. 1891, vol. III, p. 154. The passage by Hegel that Thomson alluded to is found in G.W. F. Hegel, *Encyklopädie der philosophischen Wissenschaften in Grundrisse*, Hamburg: Verlag von Felix Meiner 1959, §269, pp. 223-24.

[5] C. M. Ingleby, ibid.

[6] William Thomson, *Kelvin’s Baltimore Lectures and Modern Theoretical Physics: Historical and Philosophical Perspectives*, R. Kargon and P. Achinstein (eds.), Cambridge, Mass.: The MIT Press 1987, p. 148.

Thomson was himself a skilful mathematician, but nonetheless reacted against the abstract formalism of the rationalistic tendencies as presented by the eminent French-Italian mathematician and astronomer Joseph-Louis Lagrange in his highly influential *Analytical Mechanics* from 1788. Lagrange had proudly announced that no figures would be found in his book:

> The methods I present require neither constructions nor geometrical or mechanical arguments, but solely algebraic operations subject to a regular and uniform procedure. Those who appreciate mathematical analysis will see with pleasure mechanics becoming a new branch of it and hence, will recognize that I have enlarged its domain.[7]

According to Thomson this view had actually, though positively perceived by many physicists, damaged the natural sciences by leading them astray into empty formalism. Formalism needed to be conceptualized in order to deal with the representational problems of science and to yield useful applications. “The old mathematicians”, Thomson argued, “used neither diagrams to help people understand their work, nor words to express their ideas. It was formulas and formulas alone.”[8]

The grand old man of British physics and chemistry in the last half of the nineteenth century, Michael Faraday, was seen as a great reformer in that respect with his language of “lines of force”. The Scottish engineer and physicist William John Macquorn Rankine too was considered by Thomson as an important contributor to this kind of reasoning by emphasizing the necessity of expressing physical concepts in words. In fact, Thomson went so far as to characterize Rankine’s genius, not as one being able to make secure foundations of his mathematics or explaining the substance or usefulness of his kind of matter, but through the enormous suggestiveness of the names in his physical hypotheses.

4. MAKING MECHANICAL MODELS

Although Thomson departed from the Lagrangian tradition communicated through the French mathematician and physicist Joseph Fourier’s work on the distribution of heat, he never stopped making mechanically understandable models of whatever he was working on. Fourier’s mathematical method had the great advantage that it was not connected with a specific physical model, but just provided the theory with a mechanical understandable explanation of the phenomena. According to Fourier the ‘primary causes’ which had often been the source of metaphysical speculations within the sciences were unknown. Other theories routinely implied assumptions about primary causes, but this question was irrelevant to Fourier’s theory. More specifically they were unnecessary hypotheses for his formal approach to the problems of the distribution of heat. His rational mechanics only considered the effects of the heat and not its

[7] J. L. Lagrange, *Analytical Mechanics*: Dordrecht: Kluwer Academic Publishers 1997, p.7.

[8] William Thomson, ibid.

causes. Hence, his theory was independent of the true nature of heat as its distribution could be represented by his differential equations alone.

This abstract formalism of Fourier's theoretical approach played an essential role for Thomson's practical development of analogies as a heuristic tool in science. In 1841 he had used Fourier's theory of heat as a successful analogy with electricity. He discovered that an electric charge corresponded to a heat source and could be treated mathematically in the same manner. The convincing results of this method were subsequently used on a variety of different fields covering optics, electricity, magnetism, heat and the aether. However, in Thomson's quest for a true physical theory he never failed the attempt to turn mathematical analogies into physical analogies, always cautious of not letting the theoretical work digress into pure formalism.

This was epitomized in the Baltimore lectures where he went against the formalistic tendencies in the electromagnetic theory of light. Although Thomson firmly believed in an electromagnetic theory of light, he did not want it to be founded upon mathematical formulas alone. Instead he wanted it to be made comprehensible through a dynamical theory:

> I never satisfy myself until I can make a mechanical model of a thing. If I can make a mechanical model I can understand it. As long as I cannot make a mechanical model all the way through I cannot understand; and this is why I cannot get the electro-magnetic theory.[9]

Because of its aprioristic characters Thomson interpreted the mathematical formalism of Maxwell's electromagnetic theory of light as a kind of metaphysics. It was not the same kind of philosophical metaphysics that Hegel espoused causing Thomson's anger. Lacking the proper mechanical foundation Maxwell's metaphysics was considered true, as it still belonged to mathematics. But Thomson thought it was misdirected and should be made useful to get back on the right scientific path again.

Like Tait had done in his rant against metaphysical philosophy, Thomson employed a distinction between good and bad metaphysics. Good formalistic scientific metaphysics could be misdirected, but was essentially true. Metaphysics in the bad sense were most likely false, Thomson argued. This was the case when wordy description was placed above rigid description. In such cases the problem was that not only was the language empty, but in the epistemological hierarchy it was also placed above the substance it needed as a foundation. Thomson's view on the false metaphysics was put forth on several occasions. It should be readily dismissed. True metaphysics should be worked upon. There was nothing above and beyond practical use. In a 1883 lecture on 'Electrical units of measurement', he summed it up: "the life and soul of science is its practical application".[10]

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[9] William Thomson, ibid., p. 206.

[10] William Thomson "Electrical units of measurement", in *Popular Lectures and Addresses*, London: Macmillan & Co. 1891, vol. I, pp. 75-6.

To give an example of what Thomson's emphasis on the necessity of practical application in the physical sciences meant, we can look at his scrupulous work on the tides. There was no question that it was impossible to avoid theorising and that a tidal theory had to be carried along with elaborated tidal observations. Clearly, to Thomson, it was not enough merely to lean upon definitions to avoid ambiguities and errors in the development of a tidal theory, as had been the case before Newton's gravitational theory. Galileo was applauded for noticing that the tidal theory coming from the German astronomer Johannes Kepler was "a lamentable piece of mysticism". But lacking a proper theory to work with Galileo was not able to do anything about it. The metaphysics of the early theories of the tides lacked a theoretical framework founded upon observation, conceptual coherence and mathematical innovation. The incitation though, both for the early and later theories of the tides as well as for Thomson, was a practical concern for securing harbours, helping ships to navigate and in the event make use of the tides. The work carried out by Thomson implied "the grand philosophical chain of the Newtonian theory" and the subtleties of physical astronomy, numerous observations and reports from around the world, the making of sensitive instruments, experiments, calculations, making of tables, and so on. All this combined into a unity revolving around the practical use of a theory of tides.[11]

With respect to science there was nothing at the side or above practical application. But that was not only a question of metaphysics being methodologically unnecessary, it was also morally wrong. The aspect of practicality combined with Thomson's Victorian capitalist vision produced a unity of personal profit and public welfare, which would bring profits to investors, strength to the Empire, and material benefits to mankind. On the other hand metaphysical speculations and the like would bring uncertainty, divisiveness, and ruin.[12] For Thomson, the combination of physical and practical knowledge simply ruled out the necessity for metaphysics. Trying to force it upon scientific enterprises would only damage the sciences and their ability to yield useful solutions for practical needs.

5. THE END OF THE WORLD

The openly declared condemnation of metaphysics made neither Tait nor Thomson to refrain from elaborated speculations about the nature of things. The most explicit example from Tait is *The Unseen Universe* (1875) and the sequel *Paradoxical Philosophy* (1878) written in collaboration with Balfour Stewart. *The Unseen Universe* had the subtitle *Physical Speculations on a Future State* and was an attempt to provide Victorian physics with a consistent ontological foundation including energy conservation, the aether, the second law of thermodynamics, and the vortex atom, immune to destruction or dissipation. But also Thomson was grappling with big issues.

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[11] Cf. William Thomson, "The Tides", pp. 152-55 and pp. 168-71.

[12] Cf. C. Smith and N. Wise, *Energy and Empire: a biographical study of Lord Kelvin,* Cambridge: Cambridge University Press 1989, pp. 454-5.

One of the major problems arising as a consequence of the second law of thermodynamics was that even though energy was conserved, it was irreversibly and progressively dissipated. At the annual British Association meeting in 1854 Thomson argued that if the thermodynamic actions were traced forward in time, “we find that the end of this world as a habitation for man, or for any living creature or plant at present existing in it, is *mechanically inevitable*”.[13]

Along with Thomson the German physicist Rudolph Clausius had been instrumental in the development of thermodynamic theory in the 1850s. However, he did not comment on Thomson’s prediction of the end of the world until 1865. Finally recognizing the significance of Thomson’s dissipation principle, Clausius introduced the concept of entropy as a convenient way of stating the directional character of cosmic processes. Thus, Clausius was able to conclude his paper with the “two fundamental theorems of the mechanical theory of heat”: 1) The energy of the universe is constant, and 2) The entropy of the universe tends to a maximum.[14]

In a lecture three years later Clausius explicitly commented on the consequences of the entropy tending to its maximum. The occasions for further changes would diminish and supposing the conditions of the highest possible entropy would be obtained, the universe, Clausius concluded, would be in a state of unchanging death.[15] This was to be known and feared in Victorian society as “the heat death”: molecular uniformity in the entire universe preventing any forms of life as we know it.

6. CONTINUITY AND DISCONTINUITY IN NATURE

Although some attempts were made in order to avoid this conclusion, it was a widespread belief that the consequences of the second law of thermodynamics were inevitable. This line was also taken up by Stewart and Tait, but they were led to quite a different interpretation from most of their colleagues. One of the aims of *The Unseen Universe* was to refute the materialism, which they thought dominated Victorian science. Stewart and Tait wanted to demonstrate that immortality was strictly in accordance to the fundamental principle of continuity in physics. They agreed with John Tyndall, who became Michael Faraday’s successor at the Royal Institution in London, in the emphasis on continuity in nature, giving science the ability to deal with all aspects of the natural world. Tyndall had boldly expressed this strong belief in a justification of continuity in his *Fragments of Science*:

> Believing, as I do, in the continuity of nature, I cannot stop abruptly where our microscopes cease to be of use [..]. By a necessity engendered and justified by science I cross the boundary of the experimental evidence, and discern in that Matter which we, in our ignorance of its latent powers,

[13] William Thomson, *Report of the British Association of the Advancement of Science* **24**, (II), 59, (1854).

[14] Rudolf Clausius, *Annalen der Physik* [2] **125**, 353, (1895).

[15] Cf. Rudolf Clausius, *Philosophical Magazine* [4] **35**, 405, (1868).

> and notwithstanding our professed reverence for its Creator, have hitherto covered with opprobrium, the promise and potency of terrestrial life.[16]

The materialistic philosophy implied by Tyndall's arguments, on the other hand, was not followed by Stewart and Tait. One way of dealing with the problems involved when science bounced against the boundaries of the indefinite was a clear-cut separation of what belonged to science and what did not, as in Thomson's rejection of metaphysical speculation. But at the same time these discussions had produced a kind of familiarity with a divine providence in theoretical discussions about the nature and limits of science.

Thus, for the English polymath and Cambridge don William Whewell, discontinuities—as he perceived the introduction of, for example, new species, and changes of the earths surface, and so forth—was seen as direct evidence for a divine intervention. The domain of science did not embrace these issues. The same was the case for the creation of the world. It was indeed possible to register the events in the sciences, but one should refrain from explaining them. Whewell put this argument forth in *Philosophy of the Inductive Sciences, founded upon their history* from 1840: "science can teach us nothing positive respecting the beginning of things [..]. [T]he providential history of the world has its own beginning and its own evidence".[17]

7. THE VISIBLE AND BEYOND

To the practical man of mid-Victorian physics, William Thomson, there was no conflict between science and the idea of an "intelligent and benevolent design in nature".[18] James Clerk Maxwell, too, agreed on this, but he warned that science had indeed limits. In a lecture on molecules delivered at the British Association in Bradford in 1872 he reasoned:

> we have been led, along a strictly scientific path, very near to the point at which Science must stop. Not that Science is debarred from studying the internal mechanism of a molecule which she cannot take to pieces, any more than from investigating an organism which she cannot put together. But in tracing back the history of matter Science is arrested when she assures herself, on the one hand, that the molecule has been made, and on the other, that it has not been made by any of the processes we call natural. Science is incompetent to reason upon the creation of matter itself out of noting. We have reached the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created.[19]

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[16] John Tyndall, *Fragments of Science: A Series of Detached Essays, Addresses and Reviews*, London: 1879, II. p. 193; quoted from P. M. Heinmann, "The *Unseen Universe*: Physics and the Philosophy of Nature in Victorian Britain", *BJHS*, 6 (1972), 73-79, p. 73.

[17] William Whewell, *Philosophy of the Inductive Sciences, founded upon their History,* London: 1840, II, p. 143; quoted from Heinmann, ibid., p. 74.

[18] William Thomson, *Popular Lectures and Addresses*, ii, p. 203 (quoted from Heinmann, ibid. p. 75.)

[19] James Clerk Maxwell, "Molecules", *The Scientific Papers of James Clerk Maxwell*, New York: Dover Publications, 1965, II. p. 376.

Stewart and Tait dismissed Maxwell's demarcation of science and metaphysical speculations, while defending the latter on the grounds of scientific objectivity. The premise of their arguments was that the second law of thermodynamics predicted the end of the known universe while the principle of uniformity of nature denied such consequence. The latter was the case because the concept of uniformity did not only affirm the constancy of natural laws but also postulated a continuity of action within the natural order.

It was a fact that the known universe had been created and it was now known through the infallible laws of physics that it would come to an end. "The visible universe", Stewart and Tait maintained, "must, *certainly in transformable energy, and probably in matter* come to an end. We cannot escape from this conclusion," and continued, that due to "the principle of Continuity upon which all such arguments are based still demanding a continuance of the universe, we are forced to believe that there is something beyond that which is visible".[20]

The visible and that which was beyond, the invisible universe, were connected by means of the transference of energy from one universe to the other. This allowed the dissipation of energy to be considered as a gradual transference into an invisible order of things while energy travelled outward through space. The all-pervasive aether filling space, according to the Victorian theories of physics, was thought to be more than just a bridge between different portions of the visible universe; it was supposedly a bridge between one order of things and another, so that when energy was carried from matter to the aether, it was carried from the visible to the invisible universe. Due to the fundamental law of the conservation of energy, which applied to the total operations of nature, the system comprising the visible and the invisible was seen as a self-contained system manifesting its own activity.

Manifestations of divine providence such as the creation of the visible universe and life was not explained as discontinuities or occurrence of unforeseen events, but instead by transfer of energy from the invisible to the visible universe. Such events, seemingly inexplicable without divine intervention or violation of the continuity-concept, should, Stewart and Tait claimed, "no longer be regarded as absolute breaks of continuity [..], but only as the result of a peculiar action of the invisible upon the visible universe".[21]

In this way Stewart and Tait themselves thought to have reconciled the insurmountable dilemmas of physics and theology without violating any known laws of nature. The interference of a "Divine Govenor", an intelligent agency resident in the invisible universe acting through energy-transfer upon the visible, was to be viewed a 'being' "not in defiance of law, but in fulfilment of it".[22]

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[20] Balfour Stewart and Peter Guthrie Tait, *The Unseen Universe, or Speculations on a Future State*, London: 1875, p. 90ff.; quoted from Heinmann, ibid., p. 77.

[21] Stewart and Tait, ibid., p. 189; cf. Heinmann, ibid. p. 78.

[22] Stewart and Tait, ibid, .pp. 60ff.; cf. Heinmann, ibid.

8. DEMARCATIONISM

Stewart and Tait were not happy about the demarcationist reaction in science advocated by Maxwell and the Oxford mathematician and Anglican priest Baden Powell, among others. Powell had argued against a mixture of the miraculous and the study of the natural order, by clearly separating their domains:

> It is the province of science to investigate nature—it can contemplate nothing but in connection with the order of nature—it cannot point to anything out of nature [..]. It is evident that the *supernatural* can never be a matter of *science* or *knowledge*; for the moment it is brought within the cognisance of reason it ceases to be supernatural.[23]

Reviewing the sequel to *The Unseen Universe* in *Nature* Maxwell was unyielding in his demarcation of what could belong to a scientific discourse and what could not:

> *Nature* is a journal of science, and one of the severest tests of a scientific mind is to discern the limits of the legitimate application of scientific methods. We shall therefore endeavour to keep within the bounds of science in speaking of the subject-matter of this book, remembering that there are many things in heaven and earth which by the selection required for the application of our scientific methods, have been excluded from our philosophy.[24]

Stewart and Tait could not be accused of entrapping the readers into some peculiar form of theological belief, Maxwell argued, recognising the effort to communicate the results of modern science to layman. "No book" [i.e. *The Unseen Universe*], he wrote, "containing so much thoroughly scientific matter would have passed through seven editions in so short time without the allurement of some human interest".[25]

Although Maxwell went seriously into the discussion about life after death, the question of the human soul, and so on, admitting the merits of general human interest, by the end of the day there was no question at all that this was not and could not be a scientific discussion. As soon as such questions were raised we got beyond the limits of science, Maxwell argued and concluded that:

> The progress of science, therefore, so far as we have been able to follow it, has added nothing of importance to what has already been known about the physical consequences of death, but 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.[26]

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[23] Baden Powell, *The Order of Nature Considered in Reference to the Claims of Revelations*, London: 1859, p. 110; cf. Heinmann, ibid., p. 74.

[24] James Clerk Maxwell, "Paradoxical Philosophy", *The Scientific Papers of James Clerk Maxwell*, II, p. 760.

[25] James Clerk Maxwell, ibid., p. 757.

[26] James Clerk Maxwell, ibid., p. 762.

Stewart and Tait went too far and in the process left the sciences. Maxwell would not and could not accept that. But he understood, in a way none of the mathematicians from the old boy Cambridge network understood or accepted speculative metaphysics. To them there was a difference.

9. STATISTICS AND DEMONS

The demarcationist reaction became imperative in the discussions of the molecular foundation of thermodynamics. In the mid-1860s Clausius was working with a quantity he called 'disgregation' which depended on molecular arrangements. It was never clearly related to actual positions and velocities of molecules, but nonetheless demonstrated Clausius' attempt to make his macroscopic mechanical theory of heat intelligible based upon microscopical unobservable molecular assumptions.

However, Clausius was very careful in emphasizing the distinction between his formulation of the general laws of thermodynamics and his more specific assumptions of the constituting matter, stressing that his attempt to provide a mechanical explanation for thermodynamic processes was only supplementary to his prior attempt to establish the laws of thermodynamics as axioms independent of material assumptions.[27] Thus, Clausius expressed a general tendency of prudence in nineteenth-century physics, basing theoretical formalism on observation while trying to formulate general principles not critically depending upon assumptions of the constitution of matter. The physical theory itself should be constructed in such a way that it would not have to be abandoned if the conception changed of how the material world was connected and of what.

Maxwell never felt at ease with Clausius' introduction of the disgregation-concept as an expression for the molecular configuration. For Maxwell there was nothing clarifying in this reference to a mechanical model of molecules, rather it confused the conceptual structure of thermodynamics. Maxwell himself defined this as the investigation of the dynamical and thermal properties of bodies deduced entirely from the two laws of thermodynamics, without any hypotheses about the molecular constitution of bodies. In contrast to Clausius, Maxwell argued that the second law of thermodynamics was a statistical law dealing with a very large number of molecules and should be understood as such, not explained by the movements of single molecules.

To illustrate his point, Maxwell suggested the thought-experiment of a 'finite being'–later by Thomson called a demon–neat-fingered, very intelligent and able to sort slow moving molecules from fast moving by opening and closing a hole between two chambers without any use of additional energy. This 'being' would contradict one of the basic assumptions of the second law of thermodynamics, namely the transport of heat from a cold body to a warmer

[27] Cf. Peter Harman, *Energy, Force, and Matter: The Conceptual Development of Nineteenth-Century Physics*, Cambridge: Cambridge University Press 1995, pp. 64-6.

without the performance of external work on the system. Maxwell did not want to speculate about the possibility of such a situation, but merely point to the possibility of similar spontaneous fluctuations on the molecular level where heat was transported from colder bodies to warmer by the random motions of the molecules. This happened all the time, Maxwell argued, but without violating the second law of thermodynamics.

The point was that the second law was not a mechanical law, but a law only dealing with statistical certainty. There would be nothing contradictory for mechanics and the conservation of energy by the assumption of a regulating 'being'. Furthermore, it would not violate the second law since it was not a dynamical law concerned with single molecules, but a statistical description working on a macroscopic level. Therefore Maxwell dismissed Clausius' attempt to describe the second law in terms of individual molecular motions, even though Clausius himself emphasized the difference between the theoretical level of the second law and the mechanical illustration. Although Maxwell and Clausius fully agreed on the status of the theoretical description, Maxwell did not accept this distinction since it had the possibility of confusing the lack of connection between the two working descriptive levels of thermodynamics, namely the statistical and the deterministic.

For the Austrian physicist Ludwig Boltzmann, who in the 1860s tried and failed to make a secure mechanical foundation of the second law by attempting to construct a theorem of mechanics that corresponded to it, the importance of demonstrating the statistical interpretation of the second law was also used to show the necessity of a theoretical independency with respect to physical assumptions. Although Boltzmann firmly believed in an atomistic foundation of the material world, he continuously stressed that this was just one among many possible physical interpretations; it was probable, he thought, but it could never be certain. Therefore, physical theories should be kept at a general level, not letting them depend critically on physical assumptions. Boltzmann also dismissed the dynamical interpretation of the second law in favour of Maxwell's statistical interpretation. As part of the work from the 1870s on while trying to formulate a statistical proof for the second law, Boltzmann derived a formula expressing the increase of the entropy in an isolated system whenever irreversible processes occurred. This was later to be known as the 'H-theorem'.

Another result from this work was the probabilistic interpretation of the increase of entropy. Since the second law was a statistical law, it could not state anything with absolute necessity, but it could say that it would be exceedingly improbable that the entropy in a given system would decrease. Having introduced probability in thermodynamics, the increase of entropy could be described as the tendency of a thermodynamic system to reach the most probable molecular distribution. Hence, a consequence of the second law of thermodynamics was that the irreversibility of natural processes followed from the tendency of the system to reach the most probable thermodynamic state, namely that of thermal equilibrium. Consequently, the irreversible increase of entropy in thermodynamic systems was characterized as an irreducible statistical law.

10. ABSOLUTE CERTAINTY, MIGRAINES AND METAPHYSICS

The German physicist Max Planck challenged Maxwell and Boltzmann's statistical interpretation and in the 1890s advanced the view that the second law of thermodynamics possessed absolute certainty. Accordingly, Planck tried to connect the ontological assumptions of a mechanical worldview with a purely thermodynamic theory without any statistical explanations. However, as a result of his study of the irreversibility of radiation processes which lead to the introduction of the quantum theory in 1900, Planck eventually accepted Boltzmann's probabilistic interpretation of entropy and the statistical view on the second law of thermodynamics.

Maxwell and Boltzmann's statistical interpretation of thermodynamics was kept on the level of *description*, not making a molecular *explanation* submitting itself to ontological commitments. Their theories refrained from expanding the domain of validity to count for the mechanical structure at the molecular level and thereby maintained the demarcationist attitude held by a number of physicists in the late nineteenth century. One of them was the German Heinrich Hertz, who in his axiomatic attempt to free mechanics from contradictions, claimed that even though his system of mechanics was sufficient for representing the motion of inanimate matter it appeared, he argued, "too simple and narrow to account for even the lowest processes of life".[28]

In a lecture at the Vienna Philosophical Society in 1905 on the German atheistic pessimist Arthur Schopenhauer's incompetence as a philosopher, Boltzmann followed Hertz' line of thought and spoke for prudence in theorizing combined with a unification of our laws of thought and corresponding experience. This "would ensure", Boltzmann argued, "cessation of the disquit and the embarrasing feeling that it is a riddle that we are here, that the world is at all and it is as it is, that it is incomprehensible what is the cause of this regular connection between cause and effect, and so on". By stopping asking such questions, he concluded, "Men would be freed from the spiritual migraine that is called metaphysics".[29]

By the early twentieth century the anti-metaphysical campaign advanced by the Victorian old boy network of Cantabrigian Wranglers from Peterhouse and Trinity College in Cambridge was easily digested and appropriated by continental German speaking physicists. Metaphysical philosophy was readily dismissed as utter nonsense unworthy of any serious thought. On the other hand, it was perfectly acceptable to speculate wildly within a scientific framework as long as one belonged to the club. Tait had dismissed philosophers for wild metaphysical speculation. Ingleby, himself a Cambridge mathematics graduate, was trying to mediate. But not belonging to the inner circles of elite physicists and influential Wranglers he failed. Later, when Maxwell did not agree with Stewart and Tait in their holistic interpretation of thermodynamics and

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[28] Heinrich Hertz, *The Principles of Mechanics*, London: Macmillan and Co. 1899, p. 8.

[29] Ludwig Boltzmann, "On a Thesis of Schopenhauer's", *Theoretical Physics and Philosophical Problems*, Dordrecht: D. Reidel Publishing Company 1974, p. 198.

dismissed their books for going beyond the bounds of science, he still accepted them as peers. It would have been an entirely different matter had they been philosophers.

As physicists disagreed where to draw the line they stood united in not letting philosophers into their domain. They also disagreed about the ontological status of the physical reality their theories were describing. But again, this was acceptable as long as the discussion was among fellow physicists. There was plenty of space to disagree within science. If, however, philosophers tried to intervene, the migraine mounted. To prevent that, the self-proclaimed sentinels of science kept their guard.