Thermodynamics, Matter, Politics

Paper prepared for Hannah Knox and Tone Huse (eds.), Political Materials,

Forthcoming in *Distinktion: Scandinavian Journal of Social Theory*, 2015

Abstract

While there is a burgeoning literature on matter in social theory, there has been a surprising lack of interest amongst social theorists in the importance of the concept of energy in natural scientific accounts of matter. In this context, I examine how the work of Isabelle Stengers challenges social theorists to take thermodynamic accounts of energy, in particular, seriously. The paper develops three arguments: first, while social theorists have often wanted to add social relations to matter, in doing so they have ignored physical scientists' own analyses of relations, including thermodynamics; secondly, that thermodynamics offers a different way of theorising matter-energy than that suggested by vitalist approaches to political ecology; thirdly, that the thermodynamic concept of energy is necessarily linked to the practice and politics of measurement. At the same time, I argue that Stengers' account of thermodynamics both illuminates her understanding of politics, and points to its limitations.

Keywords:

Energy, Politics, Thermodynamics, Measurement, Cosmopolitics, Vitalism, Stengers, Whitehead

Funding

I have no financial interest or benefit that will arise from this research.

Thermodynamics, Matter, Politics

Introduction

This paper is prompted by a puzzle: it arises from a sense that while there is a burgeoning literature on energy across the social sciences, the concept of energy has been surprisingly underexamined by social theorists. Moreover, although there is renewed interest amongst anthropologists and geographers in the economy, culture and politics of energy, there has been little interest in the concept of energy as it is understood in physics, chemistry or engineering. Curiously, the lack of discussion of the concept of energy is mirrored in the growing social scientific literature on materiality. Recent accounts of materiality have had much to say about, for example, material culture (Miller 2005, Henare et al 2007, Hicks 2010), the politics of matter (Braun and Whatmore 2010), material agency (Hawkins 2009, Gregson and Crang 2010), affect and experience (Anderson and Wylie 2009, Navaro-Yashin 2012), and the multiplicity of material forms and entities (Mol 2002, Barry 2005, Harvey et al 2014). However, to the extent that the concept of energy is referred to in the literature on materiality, it tends to convey a vitalist understanding of 'energetic materiality' or what Deleuze and Guattari termed 'matter-energy' (Deleuze and Guattari 1987: 410, Massumi 2002, Bennett 2010). Although such vitalist accounts challenge the notion that matter should be understood as a merely passive or inert substratum to an otherwise lively social world, directing us to consider the energetic liveliness of materials, they leave the analysis of the concept of energy, as it is understood in the physical sciences, unaddressed.

Indeed there is a marked asymmetry between social scientific and natural scientific approaches to the study of energy more broadly. While the principles of thermodynamics are taken for granted by the physicist or chemist, thermodynamics is of marginal interest to social theorists concerned with the politics and economy of energy. Whereas the concept of energy is a fundamental in the natural sciences, relevant as much to an analysis of planetary orbits as the quantum chemistry of metals, in the social sciences the concept of energy tends to be associated either with a set of industries and resources (e.g. Bridge 2010, Huber 2013, Strauss et al 2013) or with domestic practices of energy consumption (e.g. Marres 2012, Shove and Walker 2014). In short, recent studies of energy have rightly sought to enrich and expand the study of energy production and consumption, but in doing so have not been centrally concerned with thermodynamics, or its political significance. [1]

Moreover, it is notable that the striking lack of attention paid to the natural scientific concept of energy, including thermodynamics, is in marked contrast with social theoretical interest in, for example, notions of life, culture, information, movement and earth. It is these latter concepts that have arguably been at the heart of efforts to bring the analyses of material powers and agencies into the social sciences (e.g. Callon 1986, Haraway 1991, Fraser et al 2005, Bennett 2005, Clark 2011). In the light of these observations the aim of this paper is modest. My argument is not that energy - rather than life, culture or information, for example - should provide a new basis for rethinking the concept of materiality in the social sciences. Rather my aim is to open up the question of the value of attending to the way in which physicists, chemists and engineers understand energy as an aspect of matter in general. As we shall see, this question leads onto a discussion of politics.

At the heart of this paper is a discussion of the work of Isabelle Stengers and, in particular, the significance of thermodynamics to her work. Unusually amongst social theorists and philosophers, Stengers draws inspiration *not* primarily from mathematics, nor from the human sciences, nor from theories of communication, culture or language, but from the apparently more mundane and unfashionable concerns of physical chemistry. Although Stengers' philosophy, including her formulation of the idea of cosmopolitics, has been influential in science and technology studies and geography (Latour 2004, Barry 2005, Greco 2005, Hinchliffe et al 2005, Hillier 2007, Farias 2011, Whatmore 2003, 2012), the critical importance of thermodynamics to Stengers' thought has not been widely discussed. In this paper, I argue both that a focus on thermodynamics illuminates Stengers' approach to politics and that her concern with thermodynamics indicates why an attention to energy as an aspect of matter in general should be of interest to social theory. The paper that follows is in three sections. In the first section I survey a number of reasons why social theorists could and should be interested in thermodynamic conceptions of energy. In the second section, I trace the importance of thermodynamics to Stengers' work and, in particular, to the argument she develops across the seven volumes of her study in the history and philosophy of science – *Cosmopolitics* (Stengers 2010a, 2011). In the final section of the paper, I return to consider the potential contribution, as well as the limitations, of Stengers' account of politics for those concerned with the relations between energy, matter and politics.

Energy and the 'Material Turn'

In the introduction to a collection of essays on *Material Powers* Tony Bennett and Patrick Joyce document what they call the 'material turn' in the social sciences, a movement in thought that, in their account, is indebted both to the philosophy of Deleuze and Guattari and 'particularly their contention that social life is to be understood in terms of the operation of assemblages' made up of material, semiotic and social flows (Bennett and Joyce 2010: 5) and, relatedly, to Latour's 'sociology of associations' (ibid.: 8). While giving voice to the importance of the material turn they also argue, taking a cue from Foucault's lectures on governmentality, that recent theorisations of materiality fail to give an adequate attention to the historically specific set of interacting forces 'mediating the relations between government and population' (ibid.: 7-8, Foucault 2008). For Bennett and Joyce, the sociology of associations directs us towards to the powers of materials in general, but fails to address the question of the historical transformation of the assemblages within which material powers matter. However, their emphasis on the need to attend to the historical variability of the arts and technologies of government contrasts with those who stress the need to attend to variations in the activity of materials. Michael Crang and Nicky Gregson, for example, in an introduction to a collection of papers on materiality and waste, also stage an encounter between theories of material agency and post-Foucaultian accounts of political power. However, while Bennett and Joyce prefer to fold an analysis of material powers into an account of the history of government, Crang and Gregson stress the need to attend to the materiality of matter, the affects that it generates, and the affordances that different materials proffer. While they recognise that it is important to acknowledge that waste is a political and cultural category, 'this begs the question of how different [waste] matters matter differently' (Crang and Gregson 2010: 1027). For Crang and Gregson, post-Foucaultian accounts of government fail to interrogate sufficiently the materiality of matter and its differential effects.

At the heart of this debate, therefore, is the problem of how it is possible for social scientists to register the differential properties, agency and affordances of materials, without assuming that such powers derive simply from material objects in themselves (Bennett 2010, Braun and Whatmore 2010). In this context the thermodynamic concept of energy should have particular relevance. After all, in the natural sciences, the concept of energy is critical to the analysis of how the powers and capacities of materials differ in space and time. Consider, for example, the question of the potential energy of a massive object. This energy is not given by the identity of the object itself but by, for example, the distance of its mass from the ground onto which it might be dropped. In more general terms, the energy of an object is an effect of its relations with a shifting set of objects and forces, rather than an intrinsic property.[2] While social scientists have sought to interrogate differences between materials, they have surprisingly failed to attend to one of the key ways in which the variability of matter has been conceptualised and measured in the natural sciences.

A second reason for attending to energy is to acknowledge that materiality need not be equated with the existence of distinct physical objects at all. It is worth noting that some of the early expositions of actor-network theory almost invariably focused on readily identifiable physical entities or technological artefacts such as sleeping policemen (Latour 1999), scallops (Callon 1986) or ships (Law 1991). Later contributions to actor-network theory, such as Marianne de Laet and Annemarie Mol's influential analysis of the 'fluidity' of the Zimbabwe bush-pump (de Laet and Mol 2000), and John Law's explorations of the multiplicity of a military aircraft (Law 2002), also focused on what are recognisably distinct and bounded physical or biological artefacts. These case studies both challenged the notion that such artefacts had given properties and the idea, derived from Marx, that such properties were 'socially shaped' (cf Mackenzie and Wajcman 1985, Bijker et al 1987, Barry 2013: 139). However, the choice of such examples might also suggest that matter tends to exist as a series of clearly identifiable physical objects or artefacts in the first place. Contesting this assumption, Ben Anderson and John Wylie have highlighted the need to address the full range of forms (earth, fire, water), phases and states (gaseous, liquid, solid) in which materials exist, and not just focus on identifiable and distinct physical objects. In doing so, they contended that 'the question of materiality therefore far exceeds any invocation of ground or physicality' (Anderson and Wylie 2009: 319, cf Law and Mol 1994, Barry 1998). However, despite growing interest in the variety of forms of existence of matter, as Anderson and Wylie recommend, writers on materiality have had little to say about the ways in which the physical sciences measure the forms and flows of energy that are considered to lie at the heart of any analysis of transformations of phase or state.

Bennett and Joyce draw a distinction between analyses of the powers of materials and studies of the history of government. However, a third reason for addressing the existence of energy as an aspect of matter is precisely because of it political significance. One might note, for example, the importance of calculations of energy efficiency both to the design of machines, buildings and systems, and to the ways in which both the movement and activity of bodies and artefacts are regulated in everyday life (Marres 2012, Shove and Walker 2014). Equally there is a need to attend the critical importance of energy infrastructures to political life (Mitchell 2011, Barry 2013). And we need to attend to the ways energy flows are managed, measured and commodified. From the point of view of any analysis of government and politics the study of energy and its measurement has come to be of critical importance.

Physics, Chemistry and the Hierarchy of the Disciplines

From the point of view of those involved in the 'material turn' in social theory, Stengers' work is distinctive. After all, she approaches the question of materiality from the point of view of someone trained in the natural sciences who, following the example of Pierre Duhem and AN Whitehead, has subsequently become a philosopher. Indeed, it is striking that across the seven volumes of C*osmopolitics*, Stengers shows little interest in the distinction between the natural and the social sciences (cf Latour 1993). However, she shows a great deal of interest in the internal differentiation of the natural sciences and, in particular, the importance of an alternative tradition of research in physics and chemistry that offers a challenge to dominant accounts of the relations between these disciplines. Moreover, Stengers explicitly frames her proposal for what she terms an 'ecology of practices' in opposition to the hierarchical system associated with the dominance of theoretical physics: 'physics, today, is haunted by laws, and as long as this is so, as long as it presents itself as the science that discovered that nature obeys laws, it will stand as an obstacle to any ecology of practices...the physicist will continue to claim to have discovered laws whose objectivity is itself a denial of ecological thought....this wouldn't be such a problem if physics didn't serve as such a bad example' (Stengers 2010a: 87, 1996: 9). In a paper titled 'the cosmopolitical proposal', published some years after *Cosmopolitics*, she observes that those who accept her proposition for a cosmopolitics should 'learn to shrug their shoulders at the claims of the great generalizing theoreticians' (Stengers 2005: 994). The implication of her proposal is that it is a mistake to accept the prejudices of those who view chemistry merely as a set of illustrations of the general theoretical principles of physics (see also Barry 2010). While Stengers is not hostile to physics *per se*, she is opposed to the widely held view, articulated by Steven Weinberg and Max Planck, that physics provides the scientist with a set of theoretical principles on which all the other sciences are based (Stengers 2010a: 87). Thus Stengers' cosmopolitics is intended, in the first instance, to challenge the dominant position of theoretical physics within the hierarchical system of the scientific disciplines (Stengers and Bensaude-Vincent 2003, Stengers 2010a: 11, 66).[3]

If Stengers' ambulant ecology of practices is opposed to a vision of the authority of theoretical physics, it also asserts the autonomy of particular sciences from the orbit of this sovereign power. Indeed, in their *History of Chemistry*, published prior to *Cosmopolitics,* Stengers and her co-author Bernadette Bensaude-Vincent had already made it clear that thermodynamics establishes the irreducibility of chemical processes to physical laws and, in particular, the laws of mechanics: 'kinetic and thermodynamic [understandings of energy] both defined physical chemistry as an autonomous science in relation to mechanistic physics, which had neither reactional event[4] nor second principle' (Bensaude-Vincent and Stengers 1996).[5] In other words, the 'second principle' – i.e. the second law of thermodynamics – could not be deduced from the laws of Newtonian mechanics: it was a marker of the distinctiveness of chemistry. Towards the end of the third volume of *Cosmopolitics* Stengers herself makes a related point in a different way about the relation between physics and thermodynamics. With heavy irony, she notes that the trouble with 20th century physics is that it gives itself a fundamental task:

> 'Although to a large extent the problems are shared by many of the other sciences, chemistry in particular, physicists alone are in a position to present themselves as defenders, not of the generic cause of disinterested science, but of the particular one of an inspired physics, the only kind capable of unravelling the enigma of reality' (Stengers 2010a: 235).

In developing a challenge to the hierarchical order of the disciplines, Stengers claims to use a particular historical method. It is based on the idea of anamnesis, 'defined as the voluntary evocation of the past' (ibid.: 182). In Stengers' account, anamnesis is not a matter of reading texts that are now forgotten, nor is it a hermeneutic exercise in re-interpretation, nor does it focus on the work of specific 'scientific geniuses'. Rather, anamnesis implies the need to re-establish obligations whose rejection has become, in her reading, 'part of the identity of twentieth century physics' (ibid.:). In this way, the anamnesis of chemistry highlights the importance of some of the foundational texts of thermodynamics, directing us towards the obligations that they should still impose on the researcher. Thermodynamics still creates problems, Stengers contends, that the scientist is obliged to address. [6] If thermodynamics is arguably now taken for granted, a sense of its radical challenge must be restored:

> 'anamnesis will have done its job if it has succeeded in destabilizing what characterises the history of twentieth-century physics, the way in which it is presented to us, as well as the way in which it is present to itself: the enthusiastic disqualification of "common knowledge" in the name of the "revolutions" physics imposes on us all and the pathos

> associated with the great theme of the "vocation of the physicist", who aspires to a unified conception of the world beyond heterogeneous empirical phenomena' (Stengers 2010a: 261).

In this way, the method of anamnesis is an intervention in the history of science. It is opposed to the dominant narrative of twentieth-century science, which implies that physics establishes the theoretical principles that underpin 'applied' fields such as physical chemistry, geophysics and metallurgy (Barry 2005, 2010). But it is equally opposed to the arguments of historians who establish an ironic distance between the present and the past. Instead it is method that is intended to highlight the inventiveness of specific sciences and 'ecologies of practice' in the past, reanimating the conceptual importance and political value of texts that were once rightly considered significant, but are no longer read. In this way, the method of anamnesis challenges the received canon of the physical sciences, generating the potential for new forms of thinking in the present (Barry 2015).

Thermodynamics, Measurement, Energy

The subtitle of the third volume of *Cosmopolitics* announces that the development of thermodynamics represented a 'crisis for physical reality'. In making this declaration Stengers takes a cue from the work of AN Whitehead, whose philosophy she subsequently gave an extended treatment (Stengers 2002). In a series of lectures given at Harvard in 1925, Whitehead remarked that 'we have already got rid of the matter with its appearance of undifferentiated endurance' (Whitehead 1985 [1926]: 47); an observation that can be understood as an indication of his sense of the significance of the emergence of quantum theory at the time, which suggested to Whitehead that corpuscular bodies had 'no great stability of endurance' (ibid.: 167, 1920: 162). However, his remarks also recognised the historical importance of thermodynamic and electromagnetic theory that had, as he recognised, already begun to displace the idea of mass from the heart of physical theory. In particular, in his Harvard lectures, Whitehead noted that with the formulation of thermodynamics:

> 'the notion of *mass* was losing its unique pre-eminence as being the one final permanent quantity. Later on, we find the relations of mass and energy inverted; so that mass now becomes the quantity of energy considered in relation to some of its dynamical effects. This train of thought leads to the notion of energy being fundamental, thus displacing

> matter from that position. But energy is merely the name for the quantitative aspect of a structure of happenings' (Whitehead 1985 [1926]: 127-128, emphasis in original).

If Whitehead, writing in the early 20th century, takes the importance of thermodynamics as given, Stengers, writing towards the end of the century, wants to give thermodynamics a renewed significance. Moreover, whereas Whitehead notes that energy is merely 'the name for the quantitative aspect of a structure of happenings', Stengers takes the measurement of energy, the determination of the quantitative aspect of the 'structure of happenings', to lie at the heart of its significance for the sciences in general. In this way, the measurement of energy lies at the heart of her concerns.

Stengers introduces her anamesis of thermodynamics via an account of what she terms 'the Lagrangian event' in mathematical physics. In the late 18th century Joseph-Louis Lagrange developed an elegant mathematical account of a system of point masses, the spatio-temporal coordinates of which were governed by Newton's laws of motion. This 'amounts to representing a constrained system and the forces that determine its evolution as if it were a system of free points to which a set of fictional forces is applied' (Stengers 2010a: 121). In Stengers' analysis, the Lagrangian system was a rational fiction that appears to be fully transparent and free of 'metaphysical convictions' (ibid.: 121). It was a fictional device and a conceptual event that, according to Stengers, led later physical scientists in two directions. One she associates with the work of William Rowan Hamilton who, in the 1830s, developed Lagrange's strict formalism still further, detaching 'the identity of the dynamic system from the world in which humans prepare, control and measure' (ibid.: 155), and forging a new 'physical-mathematical fiction' (ibid.: 157). Stengers is happy to admire the elegance of this mathematical apparatus, but wants to draw her readers' attention to the specificity of its abstraction, rather than assume that the model developed by Hamilton can simply be applied in the analysis of physical systems in general. In arguing for the need to interrogate the construction of Hamilton's abstraction, she echoes Whitehead's injunction, cited by Gilles Deleuze, that the 'abstract does not explain, but must itself be explained' (Deleuze with Parnet 1987: vii). To the extent that Hamilton's formalist approach subsequently became hegemonic, Stengers wants to reveal its artifice while, at the same time, promote the claims of a rival heir to 'the Lagrangian event'.

The other heir to the Lagrangian event, according to Stengers, was Sadi Carnot, who published a diagram of the heat cycle of an efficient steam engine in 1824. Carnot's diagram did not represent a real steam engine. After all, his engine enabled all the heat it released to be transformed into work, and all the work that was done on the system to be transformed into heat. It was a design that was based on the widely accepted idea that heat was the manifestation of a substance called caloric, which was conserved: 'regardless of the path taken......whether the system [the Carnot engine] is compressed at constant temperature and then cooled or cooled at constant volume and then compressed, the conservation of caloric ensured that, from the moment the cycle becomes closed, all the heat absorbed has been restored' (Stengers 2010a: 198). As the caloric theory of heat was displaced by the theory of energy conservation over the course of the following decades[7], Carnot's diagram raised the question of the difference between the operation of an ideal cycle and a real cycle, which would necessarily entail the dissipation of energy beyond the confines of the cycle. Stengers notes in passing that although the steam engine had been developed in England, it was only in France that it became 'worthy of an event' and of the French tradition. While English engineers merely calculated the monetary value of the steam engine, enabling it to be compared to the costs of using other sources of power, Carnot's steam engine ultimately made it possible to render calculable the efficiency of energy conversion in its own terms. Unlike the utilitarian English engineers, Carnot did not simply provide a technical solution to an economic problem; he gave the concept of energy a critical conceptual place in the physical sciences.[8]

In Stengers' account, the importance of Carnot's invention was only finally recognised by the German physicist Rudolf Clausius. Whereas Carnot had imagined that the heat engine would be powered by one source of heat (a furnace), Clausius saw the need to view 'the cycle as carrying out two simultaneous operations: *conversion* of part of the heat taken from the hot source to mechanical motion, and *transmission* of the remaining heat to the cold source. Carnot's ideal output established the maximum ratio between conversion and transmission. For a given quantity of mechanical motion produced, any nonideal cycle transmits to the cold source a *greater* quantity of heat than is ideally possible' (Stengers 2010a: 203, emphases in original)

In effect, Carnot's system, as it was reinvented by Clausius, made it possible to measure the energy lost by a real system for, as Stengers notes, 'only Carnot's cycle can assign a 'measurable' character to the loss or 'degradation' (Stengers 2010a: 206, Prigogine and Stengers 1982: 154-155; Prigogine and Stengers 1985: 114). There is no doubt that Carnot's work, developed further by Clausius, was 'entirely focused on the manipulation, control and production of measurement' (ibid. 210), but although Carnot and Clausius were concerned with measurement and manipulation, it would be a mistake to see their work as merely instrumental or applied. Clausius' reading of Carnot was not intended to make Carnot more realistic by rendering it closer to the behaviour of a real steam engine; rather it was to use the Carnot cycle as the basis on which it was possible to recognise irreversible deviations from it. This was his critical contribution to the formulation of the second law of thermodynamics, which stated that the entropy of any system could only increase over time. The increase in entropy of the system is a marker of the deviation of any system from the reversible system constructed by Carnot.

The introduction of the concept of energy reduced the 'pre-eminence' of mass in the physical sciences, as Whitehead reminds us. But Clausius' critical contribution to thermodynamics also points to the intrinsic relation between energy and measurement. Energy is not a physical object with given dimensions, such as mass and length. Rather, energy has to be understood in terms of its conversion, or the potential for its conversion in the future between different forms, such as heat and work. Moreover, the conversion of energy between specific forms may be more or less efficient, and more or less spontaneous, according to conditions.[9] The measurability of energy, and the measurement of its conversion, is quite different in this respect from the measurability of the position and velocity of a mass. While the position of a mass can be determined in isolation from the position of other masses, the measurement of energy cannot. As Stengers contends, 'in the case of energy transformations.... ..measurability is in no way a "given", it must be created, fabricated from the whole cloth; in this case the definition of ability to measure something is not arbitrary, it *creates the object it measures'* (Stengers 2010a: 210, emphasis added). In order to measure the conversion of energy, the physicist or chemist has to imagine an ideal system within which the efficiency of energy conversion is maximised. The physicist creates the fictional device that makes measurement possible. In this way, according to Stengers, he should recognises himself as a constructivist or manipulator: 'this is the new factor differentiating mechanics from thermodynamics – it obligated the physicist to be conscious that he was a manipulator, an active participant in the definition of the world' (ibid.: 211).[10]

Unfortunately, physicists tended to either forget or blunt the radical challenge of thermodynamics. They claimed to be able to reduce thermodynamics to the laws of Newtonian mechanics. In the classical formulation of thermodynamics, as formulated by Clausius, the physicist creates a fictional reversible system and thus becomes an 'active participant in the definition of the world'. By contrast, in the so-called statistical or probabilistic interpretation of thermodynamics, associated with the work of Boltzmann, it was possible to understand the second law of the thermodynamics as the statistical effect of the random collisions between a large number of moving particles. For the proponents of statistical thermodynamics, a system tended to increase irreversibly towards an equilibrium simply because this was the most probable course for the system to follow.[11] Stengers is in no doubt about the historical importance of this problematic argument, which gave rise, in her words, to the physicist of the 20th century, who tended to explain away the problem of irreversibility that the introduction of the second law had introduced. Given that physicists have preferred to forget the challenge of classical thermodynamics to mechanics 'we must again ask, [why] weren't the variety of kinetic events, even which, with the exception of elastic collision[12] [between masses], all seem to point to a difference between past and future, used to resist the power of dynamics?' (Stengers 2010: 255). Indeed, it is the question of the difference between the past and the future, introduced by thermodynamics, which remains central to Stengers' concerns in the later volumes of *Cosmopolitics*. It is here that she engages extensively with Ilya Prigogine's work on far-from-equilibrium processes, dissipative structures and emergence, while remaining highly critical of the all too rapid appropriation of Prigogine's ideas into physical and social theory.[13] In this essay, rather than review Stengers' discussion of the importance of Prigogine's work, and its theoretical aftermath, I want to remain with her interest in the classical thermodynamics of the 19th century, and the radical challenge she claims it continues to present. In pursuing this claim, her argument contrasts with Deleuze's over hasty dismissal of classical thermodynamicists' preoccupation with the tendency of systems to move towards equilibrium as merely bourgeois 'good sense' (Deleuze 1994: 223, Colebrook 2008).

Cosmopolitics

Despite Stengers' preoccupation with the history of thermodynamics, a striking feature of *Cosmopolitics* is the lack of any explicit discussion of the politics and government of energy. Although Stengers turns to discuss the politics of scientific practice in general in the seventh volume of *Cosmopolitics*, she shows little interest in the politics of energy technologies, or the economic or cultural history of 19th century physics (Smith 1998) or, for that matter, with the relations between energy and political economy (cf Mitchell 2011). This absence is particularly notable given that Stengers herself co-authored an afterword with Ilya Prigogine to the English translation of a series of short extracts from Michel Serres' *Hermès* (Prigogine and Stengers 1982). Yet Stengers' argument in *Cosmopolitics* contrasts strikingly with Michel Serres' observation in the fourth volume of *Hermès* that it is the earth that provides the energy input into Carnot's system, thereby acting, in an apparent allusion to Marx, as a source of 'primitive accumulation' (Serres 1977: 59). Her analysis also stands in marked contrast to the stories told by recent historians of science who stress the need to attend to the intimate relations between energy physics, industry and empire in the 19th century (Harman 1982, Norton Wise 1995, Smith 1998). In her account of the work of Carnot and Clausius, Stengers draws our attention to the importance of the distinction between two trajectories that emerge from the Lagrangian event in mathematical physics, and she directs us to revisit the question of the probabilistic interpretation of thermodynamics and its limitations. However, in adopting this internalist approach to the history of science, she brackets the question of the importance of energy, and measurements of energy, to political and economic life, or to what she later termed the 'mode of existence' of capitalism (Pignarre and Stengers 2011).

Stengers' notable lack of interest in the political economy of energy, or the relations between thermodynamics, industry and empire, nonetheless does make some sense in the context of the broader argument of *Cosmopolitics*. For her preoccupation, in these volumes, is with the need to develop a positive account of a form of situated scientific practice in opposition to the hierarchical relations both between the different natural sciences and between the sciences and a range of what are commonly understood to be 'non-scientific' knowledge practices. At the same time, her account of the hierarchical relations between physics and the other natural sciences reinforces her sense that the relations between the social sciences and other non-expert forms of knowledge are also hierarchical, which in turn informs her account of politics. In her cosmopolitical vision, politics is not something about which the social sciences could or should claim any specific expertise (Stengers 1997).

In this light, one can understand why Stengers should be hostile to those sociologists of scientific knowledge who purported to give a sociological explanation of scientific change by imposing their concepts, such as 'motivation', 'interest', 'suggestion' and 'symbol' on their subjects, including scientists (Stengers 2011a: 382, cf. Barnes 1974, see also Stengers 2010b). It is in relation to her opposition to the arguments of sociologists of scientific knowledge, and what she perceives to be their failure to grasp the obligations of scientific practice, that we can understand why she both emphasises the importance of Carnot's fictionalised steam engine but does not want to consider its relation to the development of industry and the economy (cf Marx 1976: 497). In this way, her approach resonates with the work of Michel Callon and Bruno Latour, who also took issue, a few years prior to the publication of *Cosmopolitics*, with the efforts of sociologists of scientific knowledge to account for scientific change in sociological terms, without first interrogating the distinction between nature and society which underpinned their arguments (Callon and Latour 1992). However, whereas Latour had adopted the position of an untutored outsider who sought to follow scientists 'in action' (Latour 1987), Stengers is confident about her own capacity to inform scientific practice in a manner that has some parallels with, for example, the philosophy of Karl Popper. Stengers, like Popper, exhorts scientists to take the risk of allowing their objects to offer resistance to their analyses and their analytic approaches. However, by contrast to Popper, she favours those scientific and non-scientific practices that are attuned to the specificity of the situations and systems, rather than those that lead to the formulation of the most generalised and therefore, according to Popper, 'falsifiable' laws or theories. Moreover, whereas Popper sought to establish the philosophical basis for scientific methods in general, Stengers emphasises that each practice 'has its own recalcitrant, diverging manner of defining what matters' (Stengers 2010b: 25). It is because each practice can, in principle, 'define what matters' that the practice of chemists is irreducible to politics as it is conventionally conceived.

We may, however, note a second striking contrast between the earliest formulations of actor-network theory and Stengers' approach in *Cosmopolitics*. In its first incarnation, actor-network theory was intended to alert the researcher to how the strength and identities of actors shifted in a fluctuating and contested field of relations with other human and nonhuman actors. In doing so, actor-network theory translated a semiotics of the relationality of the sign, drawing on the work of Greimas, into a general approach to the study of the relationality of human and nonhuman actants (Callon and Latour 1981). By contrast to this semiotic account, Stengers' account of relationality, although less explicitly articulated than actor-network theory, begins from thermodynamics rather than semiotics. As a student of thermodynamics, Stengers knows that objects do not have properties and powers in themselves. Viewed from the perspective of thermodynamics it would obviously be a mistake ever to treat objects in isolation from the fields of relations or the systems in which they are situated. Social scientists have often wanted to *add* social relations or meanings or politics to objects that might otherwise thought of as clearly defined by their intrinsic natural properties.[14] However, Stengers' work reminds us that thermodynamics had already established that objects had relational powers and identities, long before anthropologists and sociologists began to be interested in the social life of things. If energy is taken to be an aspect of matter in general then objects are always have the potential for change, in ways that are not necessarily predictable or governable. According to thermodynamics, matter should not be thought of as inert, nor as necessarily lively, as the vital materialists would argue, but as an aspect of an open system of relations. Stengers' *Cosmopolitics* can be read, in part, as a philosophical articulation of the thermodynamicists' view of the relationality of matter.

As we have seen, Stengers' account of thermodynamics stresses the importance of the relation between the thermodynamic energy and the metrological and conceptual work of the physicist or chemist. The physical scientist is conceived of as a 'manipulator' or constructivist who neither represents nor 'shapes' material reality (Bernal 1969, Marx 1976), but transforms reality in order to render energy into a calculable and comparable form. In the *History of Chemistry*, Bernaude-Vincent and Stengers introduce a concept that might help make sense of this transformative practice. Chemistry, they argued, does not just develop new materials by rearranging or synthesising the finite set of elements given in the periodic table. Rather, the chemist is interested in generating new substances or 'informed materials' the properties of which, in specific conditions, could be measurable and knowable. In this way, chemists could give chemicals new and multiple forms of informational material existence (Barry 2005, 2010, 2013, Lloyd Thomas 2010, Rosengarten 2010). An informed material is a transformed material. In this way, molecules come to have different properties and powers as they move between different experimental apparatuses in the laboratory and between different forms of existence, whether in the laboratory, the factory, the hospital, and the field. The task of the chemists is both to multiply these forms, to translate between them, and to give them stability.[15] Likewise, thermodynamics enables the scientist to give a quantitative measure of energy transformations within what Whitehead termed the 'structure of happenings'. Measurements of energy both make such transformations visible to the scientist, but also add to their existence.

From Cosmopolitics to Politics

In *Cosmopolitics*, Stengers brackets off the question of the relation between energy, on the one hand, and government and the state, on the other. In this way, she has surprisingly little to say about politics as it is conventionally understood and, at times, she appears sceptical that social scientists could offer anything to those interested in the conduct of politics. Although Stengers' *Cosmopolitics* is centrally concerned with both the study of energy and politics, readers of her work will struggle to find any explicit account of politics in her work on thermodynamics. Indeed, part of the importance of Stengers' account of thermodynamics is to caution us from thinking that thermodynamics can and should just be understood only in conventionally political or economic terms. Whereas readers versed in critical and poststructuralist theory might imagine that all forms of knowledge are political, Stengers recognises the need to hold onto an account of the specificity of different ecologies of practice and, thus, to attend to the heterogeneity of both scientific and political practices in their diverse forms.

Nonetheless, if Stengers' account of the politics of energy in her writings on thermodynamics is deliberately limited, she does offer a positive account of the ecology of political practice in other texts. In doing so, she focuses attention on the importance of what she terms 'interstices', and the need to cultivate and maintain the existence of interstitial forms, that are generative of emergent effects.[16] In so doing, she distances herself from those anti-political thinkers who try to turn democracy into a form of professional practice by managing the process of consultation or 'stakeholder engagement' (Barry 2013: 95-115, Whatmore 2013, cf Rancière 1998). But she equally distances herself from those on the left who search, as she and Phillippe Pignarre put it, for 'those who will take the place of the working class' (Pignarre and Stengers 2011: 115). In this way, Stengers' argument resonates with Deleuze and Guattari's observation that the 'molecular politics' of minorities is often 'imperceptible from the view of macropolitics' (Deleuze and Guattari 1987: 216, Thoburn 2001). Indeed, those who inhabit what Stengers and Pignarre term interstices may need to resist attempts to co-opt or interpret their politics in macropolitical terms. As I have argued, the actions of political activists may be politically generative precisely in so far as they are not seen to be reducible to a given politics (Barry 2001: 196). Positively, Pignarre and Stengers advocate the formation of 'concrete situations' within which learning can take place, and through which the 'political creation of the possible' can displace 'the anti-politics of the probable' (Pignarre and Stengers 2011: 114, Stengers 2005). This is an argument that has been developed, in particular, by Sarah Whatmore (Whatmore 2013). In this respect, Pignarre and Stengers' approach resonates with that taken by forms of political activism that are particularly attuned to the specificity of concrete problems, and the questions that such specific problems pose. In this way, there are evident parallels between their analysis of the ecology of political practice and the ecology of scientific practice that Stengers finds in the development of classical and non-equilibrium thermodynamics (see also Barry 2013: 152). For Stengers, classical thermodynamics was certainly 'focused on the manipulation, control and production of measurement [but], at the same time, it also demonstrates the invention, the free and entirely counterintuitive production of meaning implied by the creation of certain types of measurements (Stengers 2010a: 210). Likewise the practitioner of an interstitial politics is an inventive and active participant in the definition of the world. For Stengers, this inventiveness should both be acknowledged and fostered, rather than viewed merely as an expression of something else.

Although Stengers does not explicitly address the ecology of political practices in *Cosmopolitics*, her investigations of thermodynamics nonetheless raise the question of the relation between thermodynamics and the politics of energy as it is conventionally understood. In this way, Stengers' work directs our attention to the critical importance of measurements of energy production and consumption in political and economic life (e.g. Mitchell 2011, Boyer 2011, Huber 2013, Lohmann and Hildyard 2013, von Schnitzler 2013). In this paper, there is not the space to address the question in any detail and, indeed, the politics of the measurement of energy remains a matter for further empirical research. In the 19th century, the question of how to calculate the energy efficiency of the steam engine informed the development of classical thermodynamics (see also Bernal 1954). Today, the thermodynamic efficiency of a vast range of devices, from light bulbs to internal combustion engines, is increasingly regulated, while individuals and organisations are expected to monitor and manage their expenditure or consumption of energy (Marres 2012, von Schnitzler 2013), in the face of growing concerns about energy security, resource scarcity, and climate change (Urry 2014). In these evolving conditions, the empirical and political challenge, following Stengers, is to interrogate how the measurement of energy efficiency has become both an object of government and a focus for politics in 'concrete situations' (Barry 2002).

Conclusions

At the heart of recent social theoretical interest in materials is, as I have suggested, a puzzle: namely, that while there has been growing concern with the importance of both matter and energy in social and political life, natural scientific accounts of energy have been largely ignored. In this respect, Isabelle Stengers' focus on the conceptual significance of thermodynamics deserves wider attention, despite its apparently narrow focus on the history of the physical sciences. In *Cosmopolitics* she articulates the thermodynamicist's sense of the importance of the concept of energy to natural scientific accounts of matter and, in doing so, challenges the received view of the hierarchy of the physical sciences (Barry 2015). This is a core contribution of her argument. Yet despite her focus on the history of the physical sciences, Stengers' work has a number of further implications, I suggest, and should not only be of interest to those concerned with the politics of energy, but also to those concerned with the study of material politics more broadly. She reminds us first that physical scientists have long recognised that matter does not take the form of bounded massive objects, with given powers or capacities. While social theorists have long sought to add social relations to matter, in doing so they have bypassed physical scientists' own analyses of relationality, which include the account provided by thermodynamics. As she argues, thermodynamic accounts of energy are critical to the way that physical chemists both understand the relational properties of matter, and attempt to both trace and manage what A.N. Whitehead once termed the 'structure of happenings' (Whitehead 1985 [1926]: 128). Secondly, thermodynamics suggests a different way of theorising the matter-energy relation than that offered by vitalist approaches to political ecology. In effect, thermodynamics offers us an account of the limits to which energetic systems can be governed or managed, an account that does not rely on the idea of the incalculability of vital force (cf Bennett 2005). Finally, as Stengers suggests, the thermodynamic concept of energy is necessarily related to the practice of measurement. In this way, the thermodynamicist is a constructivist, who recognises that measurement 'creates the object that it measures' (Stengers 2010a: 210). Today, in the context of growing concerns with climate change and energy efficiency, the challenge is to show how the diverse ways in which the conversion of energy is measured have become an explicitly governmental and political matter.

References

Anderson B., Wylie J. (2009), 'On geography and materiality', *Environment and Planning A,* 41, 318 – 335.

Atkins, P. (2001) *The Elements of Physical Chemistry*, Oxford: Oxford University Press, 3rd edition.

Barnes, B. (1974) *Scientific Knowledge and Sociological Theory*, London: Routledge and Kegan Paul.

Barry, A. (2001) *Political Machines: Governing a Technological Society*, London: Athlone

Barry, A. (2002) 'The Anti-Political Economy', *Economy and Society*, 31, 268-284.

Barry, A. (2005) 'Pharmaceutical Matters: the Invention of Informed Materials', *Theory, Culture, and Society*, 22, 51-69.

Barry, A. (2010) 'Materialist Politics: Metallurgy', in Braun, B. and Whatmore, S. *Political Matter*, Minneapolis: Minnesota University Press, 89-118.

Barry, A. (2013) *Material Politics: Disputes along the Pipeline*, Chichester: Wiley-Blackwell.

Barry, A. (2015) 'Geography and other disciplines: genealogy, anamnesis, and the canon', ms submitted to the *Journal of Historical Geography*.

Bell, V. (2007) *Culture and Performance: the Challenge of Ethics, Politics and Feminist Theory*, Oxford: Berg.

Bennett, J. (2005) *Vibrant Matter: a Political Ecology of Things*, Durham, NC: Duke University Press.

Bennett, T and P Joyce (eds.) (2010) *Material Powers: Cultural Studies, History and the Material Turn*, London: Routledge.

Bensaude-Vincent, B. and I. Stengers (1996) *A History of Chemistry*, Cambridge, MA: Harvard University Press.

Boyer, D. (2011) 'Energopolitics and the anthropology of energy', *Anthropology News*, 52, 5-7.

Braun, B. and Whatmore, S. (eds.) (2010) *Political Matter*, Minneapolis: Minnesota University Press.

Callon, M. and Latour, B. (1992) 'Don't throw the baby out with the Bath School! A reply to Collins and Yearley', in Pickering, A. (ed.) *Science as Practice and Culture*, Chicago: Chicago University Press, 343-368.

Clark, N. (2011) *Inhuman Nature: Sociable Life in a Dynamic Planet*, London: Sage.

Colebrook, C (2008) 'Bourgeois Thermodynamics' in I. Buchanan and N. Thoburn (eds.) *Deleuze and the Political*, Edinburgh: Edinburgh University Press.

de Laet, M. and A. Mol (2000) 'The Zimbabwe bush pump: mechanics of a fluid technology', *Social Studies of Sciences*, 30, 2, 225-263.

Debaise, D. (2013) 'A philosophy of interstices: thinking subjects and societies from Whitehead's philosophy', *Subjectivity*, 6, 101-111.

Deleuze, G. with Parnet, C. (1987) *Dialogues*, London: Athlone.

Deleuze, G (1993) *Difference and Repitition*, London: Athlone.

Duhem, P. (1903) *Thermodynamics and Chemistry*, New York: John Wiley.

Duhem, P. (1954 [1914]) *The Aim and Structure of Physical Theory*, Princeton: Princeton University Press.

Foucault, M. (2008) *The Birth of Biopolitics: Lectures at the Collège de France 1978-79,* Basingstoke: Palgrave Macmillan.

Gregson, N. and Crang, M. (2010) 'Materiality and waste : inorganic vitality in a networked world.', *Environment and planning A.*, 42 (5): 1026-1032.

Halewood, M. (2011) *AN Whitehead and Social Theory: Tracing a Culture of Thought*, Anthem.

Harman, P.M. (1982) *Energy, Force, and Matter: the Conceptual Development of Nineteenth Century Physics*, Cambridge: Cambridge University Press.

Haraway, D. (1991) 'The Cyborg Manifesto, in *Simians, Cyborgs, and Women*, London: FaB.

Harvey, P. et al (eds.) (2014) *Objects and Materials*, London: Routledge.

Harvey, P and H. Knox (2015) *Roads: an anthropology of infrastructure and expertise*, Ithaca, NY: Cornell University Press.

Henare, A, Holbraad, M. and S. Westell (2007) *Thinking Through Things: Theorising artefacts ethnographically*, London and New York: Routledge

Hinchliffe, S., Kearnes, M. and Whatmore, S. (2005) 'Urban Wild Things: a Cosmopolitical Experiment', *Environment and Planning D: Society and Space*, 23, 643 – 658.

Huber, M. (2013) *Lifeblood: Oil, Freedom and the Forces of Capital*, Minneapolis: Minnesota University Press

Kuhn, T.S. (1977) 'Energy Conservation as an example of simultaneous discovery', in *The Essential Tension*, Chicago: Chicago University Press.

Latour, B. (1993) *We Have Never Been Modern*, Hemel Hempstead: Harvester Wheatsheaf

Latour, B. (1999) *Pandora's Hope: Essays on the Reality of Science Studies*, Cambridge, MA: Harvard University Press

Lloyd Thomas, K. (2010) *Building Materials: Conceptualising Materials via the Architectural Specification* unpublished PhD thesis.

Lohmann, L. and Hildyard, N. (2013) 'Energy Alternatives – Surveying the Territory', The Cornerhouse, http://www.thecornerhouse.org.uk/sites/thecornerhouse.org.uk/files/ENERGY%20ALTERNATIVES%20--%20SURVEYING%20THE%20TERRITORY.pdf (accessed March 2015)

Marres, N. (2012) *Material Participation*, Basingstoke: Palgrave Macmillan

Marx, K (1976) *Capital, vol 1*, Harmondsworth: Penguin

Massumi, B. (2002) *Parables for the Virtual: Movement, Affect, Sensation*, Durham, NC: Duke University Press.

Miller, D. (ed) (2005) *Materiality*, Durham: Duke University Press.

Mitchell, T (2011) *Carbon Democracy: Political Power in the Age of Oil*, London: Verso.

Navaro-Yashin, Y (2012) *The Make-Believe Space: Affective Geography in a Postwar Polity*, Durham, NC: Duke University Press.

Norton Wise, M. (1995) 'Precision : Agent of Unity and Product of Agreement Part II – the age of Steam and Telegraphy', in Norton Wise (ed.) *The Values of Precision*, Princeton: Princeton University Press

Pignarre, P. and I. Stengers (2011) *Capitalist Sorcery*, Basingstoke : Palgrave Macmillan

Prigogine, I. and I. Stengers (1982) 'Postface : Dynamics from Leibniz to Lucretius', in Serres, M., *Hermes: Literature, Science, Philosophy*, Baltimore: Johns Hopkins University Press, 135-159.

Prigogine, I. and I. Stengers (1985) *Order Out of Chaos : Man's Dialogue with Nature*, London : Flamingo.

Rancière, J. (1998) *Disagreement: Politics and Philosophy*, Minneapolis: Minnesota University Press.

Schnitzler, A. von (2013) 'Travelling Technologies: Infrastructure, Ethical Regimes, and the Materiality of Politics in South Africa', *Cultural Anthropology*, 28 (4), 670-693.

Serres, M (1977) *Hermès IV : La Distribution*, Paris : Les Éditions de Minuit.

Shove, E. and G. Walker (2014) 'What is Energy For ? Social Practice and Energy Demand' *Theory, Culture and Society*, 31 (5), 41-58.

Smith, C. (1998) *The Science of Energy : a Cultural History of Energy Physics in Victorian Britain*, Chicago : Chicago University Press

Stengers, I. (1996) *L'Invention de la mécanique : pouvoir et raison*, Paris : Les Empêcheurs de Penser en Rond.

Stengers, I. (1997a) *Thermodynamique: la Réalité Physique en Crise* : Paris : Les Empêcheurs de Penser en Rond.

Stengers, I. (1997b) *Power and Invention: Situating Science*, Minneapolis, MN: Minnesota University Press.

Stengers, I. (2000) *The Invention of Modern Science*, Minneapolis, MN: Minnesota University Press.

Stengers, I. (2002) *Penser avec Whitehead: un libre et sauvage creation de concepts*, Paris: Seuil.

Stengers, I (2005) 'The Cosmopolitical Proposal', in B. Latour and P. Weibel (eds) *Making Things Public: Atmospheres of Democracy*, Cambridge, MA: MIT Press, 994-1003.

Stengers, I (2010a) *Cosmopolitics I*, Minneapolis: Minnesota University Press.

Stengers, I (2010b) 'Including nonhumans in political theory', in Braun and Whatmore, 3-31.

Stengers, I (2011a) *Cosmopolitics II*, Minneapolis: Minnesota University Press.

Stengers, I. And B. Bensaude-Vincent (2003) *100 mot pour commencer à penser les sciences*, Paris : Les Empêcheurs de Penser en Rond.

Strauss, S., S. Rupp and T. Lowe (eds.) (2013) *Cultures of Energy : Power, Practices, Technologies*, Walnut Creek, CA : Left Coast.

Thoburn, N. (2001) *Deleuze, Marx, and Politics*, London : Routledge

Urry, J. (2014) 'The Problem of Energy', *Theory, Culture and Society*, 31, 3-20.

Whatmore, S.J. (2013) 'Where Natural and Social Science Meet ? Reflections on an experiment in geographical practice', in A. Barry and G. Born (eds.) *Interdisciplinarity : Reconfigurations of the Social and Natural Sciences*, London : Routledge, 161-177.

Whitehead, A.N. (1920) *The Concept of Nature*, Cambridge: Cambridge University Press.

Whitehead, A.N. (1978) *Process and Reality*, New York: Free Press.

Whitehead, A.N. (1985) *Science and the Modern World*, London: Free Association Books.

Wrigley, E. A. (2010) *Energy and the English Industrial Revolution*, Cambridge: Cambridge University Press.

Notes

---

[1] Shove and Walker argue, for example, 'Despite defining energy as the 'ability to do work', natural scientists rarely comment on the kind of work that is thereby enabled or on how this changes' (2014: 41).

[2] The recognition that potential energy has to be understood as a product of a system is one aspect of what Stengers terms 'the Lagrangian event': 'the Lagrangian system creates an "egalitarian" figure in the sense that, unlike weight for Galileo, no term in the description escapes being permanently redefined as a function of all the others. That force can be derived from potential means that what we call a force depends on the system as what we call a state' (Stengers 2010a: 125).

[3] In the second book of *Cosmopolitics*, Stengers remarks that in the late 18th and early 19th century, 'the practice of engineering, as an applied science was not entitled to present new problems that might have questioned the authority of rational mechanics [i.e. physics]' (Stengers 2010a: 135).

[4] In other words, physics provided no account of the dynamics of chemical reactions.

[5] The second law of thermodynamics, which is a key principle of physical chemistry, was not reducible to the laws of mechanics, the basis for Newtonian physics.

[6] The notion of obligation plays an important in the conceptual architecture of *Cosmopolitics*, together with the concept of requirement. The idea that a specific practice imposes obligations enables Stengers to attend to the way that all practices operate under 'constraints'. In effect, the obligations of specific practices impose themselves on the scientist. This enables her both to agree with sociologists of scientific knowledge that scientific theories are constructed, while also arguing that this does not lead to relativism. 'It was the error of contemporary relativists to deny, under the pretext that they were unable to supply [phenomena] with a stable identity, that experimental research was singularised by requirements and obligations irreducible to just another argumentative strategy' (Stengers 2010a: 51-52).

[7] On the history of the emergence of the idea of 'the conservation of energy' see Kuhn 1977.

[8]In drawing our attention to the existence of national cultural differences scientific practice, Stengers' work echoes the analysis of Pierre Duhem, who was scathing in his denunciation of the German scientific tradition [check] Stengers account of the history of thermodynamics draws inspiration from the work of the French physical chemist and philosopher of science, Pierre Duhem, the author of the *The Aim and Structure of Physical Theory* (Duhem 1954 [1914]). Duhem himself was particularly interested in national traditions of scientific analysis arguing that the English preoccupation with models failed to capture...and nationalist tradition.

[9] According to the second law of thermodynamics. For further explanation see Atkins 2001.

[10] Prigogine and Stengers make a similar observation can be made about quantum mechanics: 'The real discovery of quantum mechanics, as it is expressed by the inseparable character of reversible evolution and irreversible reduction, is not that the process of measurement disturbs, but rather that it participates in the definition of the measured parameter, so that this parameter cannot be attributed to the quantum system "in itself" and one cannot speak of "hidden variables"' (Prigogine and Stengers 1982: 147). The notion that scientific research intervenes in

the make of the world is an idea that informs Bruno Latour reformulation of the notion of constructivism in *Pandora's Hope* (1999). In effect, Latour comes to recognise that the earlier formulation of actor-network theory relied too heavily on a semiotic conception of the actor.

[11] 'while the collision between two particles can be represented as a dynamic event, collisions between a population of particles can explain the irreversible process towards equilibrium' [ie. the maximisation of entropy within any given system] (Stengers 2010: 247, see also 2011: 124).

[12] In an elastic collision between particles no kinetic energy is dissipated, so in principle the collision is reversible.

[13] '…at worst, and considerable commotion, new paradigms (with short life spans) were announced, turning dissipative structures or order through fluctuation into one of those all-purpose concepts that seem to proliferate whenever the will of science take the place of practice' (Stengers 2011a: 249).

[14] There are resonances here between Stengers' approach and Donna Haraway's analysis of the situatedness of knowledge production (Haraway 1991).

[15] On the constitution of relations between different forms of existence of matter see Mol 2002, Barry 2005.

[16] The term interstice is taken from Whitehead (1978: 105). For an extended development of the concept see Debaise (2013).