The Thermodynamic Moment in the History of Science and War

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ABSTRACT

For policy makers and for historians alike, there has never been a more urgent need to understand the relationship between science and war which has, so far, remained under-theorised. This paper examines the relationship in the context of the aftermath of the Napoleonic wars by considering the coincidental appearance of two foundational texts in the history of thermodynamics and in the history of war by Sadi Carnot and Carl von Clausewitz. On one hand, this 'thermodynamic moment' feeds the idea of escalation in war based on technological innovation, and it can reinforce material models of change. Yet the overlapping influences and similarities between the texts point instead, specifically, to a fundamental epistemological shift. War itself was being redefined in the sense that its creative capacity to build social order in the aftermath of the Revolution was being reimagined. Science, it seems, has a defining influence on war which, in order to fulfil its political purpose, is conceived as being aligned with, or part of, the natural world.

This paper was presented at the conference held at the IEA in June 2023, The Nature of War: Concepts and Challenges, a video recording of which is available in its entirety on the institute webpage. I would like to thank all those who took part and the fellows of the institute who provided much needed critical scrutiny of these ideas. For helping with my shaky understanding of thermodynamics, I am indebted to three engineers for their patience and stimulating conversation: Prof. Brian Fleck, Calum Hughes, and Robert James. More than I care to admit, this paper has its origins in a discussion over a bottle of wine or two with Alan Scorer.

War poses an existential, and increasingly unpredictable, threat to humanity. The ominous hum of drones that now fills the skies above active war zones is a reminder, if one were needed, that the nature of this threat is partly conditioned by the relationship of war with scientific and technological advances. Many other innovations, unimaginable only a few years ago, are now also commonplace, but it is the rapidity of change with such things as hypersonic missiles or nanotechnology that could transform war beyond recognition. Inevitably, our response to these changes will be affected by the assumptions we hold about this relationship. To identify these assumptions, then, and to interrogate their strength, we may consider the way that they are routinely projected back onto the long history of the emergence of modern war. To a surprising extent, it seems, this history continues to be written as a centuries-long process that unfolded in close step with innovations in our lethal capacity to fight. This is despite numerous studies that demonstrate that the history of war is simply too complex to be mapped with any precision against technological innovations or other material considerations alone.[1] Even our own experience of war today frequently challenges explanations of change based on scientific or military advances. Wars typically get bogged down into depressingly familiar contests of human will, endurance, and suffering. Of course, those working in the field of modern Science and Technology Studies (STS) have already long abandoned simple narratives of modernity built around technical progress. Their emphasis is on the politics and the social production of knowledge and uncovering the historical context of science. It is part of a varied cultural landscape, a reflection of the complexity of the many interacting influences that characterise an age. With respect to war, specifically, however, there is less discussion of the relationship with science which remains somewhat under-theorised, and this poses challenges for historians and policy makers alike.

This brief paper addresses this relationship within the context of the aftermath of the French Revolutionary and Napoleonic wars (1792-1815) which have long stood at the heart of debates about escalation, modernity, and the nature of war. It is a reflection on a simple observation of the coincidental and superficially unrelated appearance of two foundational texts in the history of science and in the history of war: Reflections on the Motive Power of Fire of 1824 by Sadi Carnot and On War of 1832 by Carl von Clausewitz. Both men witnessed extraordinary transformations. Carnot's work, which anticipated the field of thermodynamics, set out the principles behind the development of industrial steam power, just as Clausewitz sought to make sense of the sudden appearance of warfare on an altogether different scale. Befitting the Romantic period in which they wrote, both sought to understand the essence of their subject and the nature of what was occurring, and both emphasised powerful, latent, natural forces that could be harnessed with enormous potential. What is referred to here as this 'thermodynamic moment' in the history of war adds some weight to the argument that a fundamental

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change in war was occurring at this time. The earnestness with which steam and other industrial technology were later incorporated into war in the nineteenth century also suggests as much.

The similarities, significance, and timing of these texts, however, all point specifically to an epistemological shift. This escalation in the methods of war was linked directly to the unprecedented political effect that war was being called upon to have in the complete re-invention of the French state after its collapse in the Revolution. War itself, therefore, was being redefined in the sense that its transformative potential was re-imagined. Clausewitz famously described violence as the essence of war, but, of course, that violence has a political, culturally conditioned purpose. In one way or another, that purpose is always to restore or to create social order.[2] This creative function of war depends upon more than violence against an enemy and the imposition of political terms. It depends upon a timeless principle about the relationship between science and war which is that war needs to be justified in order to create a consensus, and for this it must be conceived as being aligned with, or part of, the natural world.

The French Revolution and the enormous changes in the conduct of war in its wake naturally raised questions among contemporaries about the very nature of war and of escalatory change. For historians, these changes have traditionally been credited either to politics and the ideological nature of the conflict between republican France and its sworn enemies, to the politicisation of the population and élan of the enormous citizen armies, or to the military organisation of the revolutionary government and its military leadership, particularly that of Napoleon. These have led to longstanding debates about whether these were merely serious, though ultimately incremental, changes or if they represent a fundamental, defining change in war. In these debates, technology has never played a leading explanatory role. No doubt, this is because it is generally recognised that the weapons and communications systems employed were essentially the same as they had been in the eighteenth century. Ironically, however, keeping science and technology out of these debates and out of any related epistemological questions about war leaves the most instrumental, material models of change unspoken and unchallenged.

Without a perspective offered by science, it is difficult to recognise the significance of the changes to the way that war itself was conceived. Clearly, something extraordinary was happening. As Alan Forrest concedes,

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France ... now thought on an altogether more ambitious scale ... aspiring to create a new Carolingian empire under Napoleon. ... They did not hesitate to open up several fronts at once or to take on powerful coalitions of states. Indeed, ... there seemed no limit either to French territorial ambitions or to her military capability. France, it appeared, had created a new kind of warfare, and many contemporary observers were convinced that 1789 ushered in a military as well as a political revolution across Europe.[3]

Forrest, however, immediately then questions the judgement of these contemporary observers by asking if any such revolution really did occur. Consistent with a lot of work on eighteenth and early nineteenth-century military history, he points out many essential continuities, even challenging the originality and impact of the celebrated morale and ideological fervour of the revolutionary armies. Instead, he isolates as the only significant modernising change the scale of recruitment (although promotion on merit which the lack of experienced officers forced upon the revolutionary government is also acknowledged as an important development). This reluctance to concede that there was fundamental change fits Roger Chickering's description of a broader academic consensus that much of what occurred in the Napoleonic wars had eighteenth-century precedents and that the only real difference after 1789 was the sudden increase in the size of French armies and the ramifications specifically of this. Because of these many continuities, he says, the French Revolution does not mark a new departure in the development of modern war and can, instead, 'be situated in the same master narrative as the military revolution of the early modern era'.[4]

In this way, however, the sheer numbers available to France become just one in a long series of material developments going back to the sixteenth century in what armies could physically achieve and how they set about it. Indeed, the Military Revolution thesis is built upon the assumption that increased capacity in the form of innovations in technology and tactics in the sixteenth and seventeenth centuries led inevitably to escalation and from there to the wider social and political changes that define early modernity. This idea has come under critical attack for many decades now. It is not just the timing and location of significant change in the past that has been called into question but the very conceptual logic of the thesis itself.[5] That it remains a subject of live debate after so much time seems, therefore, to be due more to the failure of historians to develop any alternative to replace it than to any theoretical strengths. Yet the challenge with respect to science and its relationship with war can no longer be simply to try to establish its place in the novelty or the evolving effectiveness of the

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means of fighting but also its place in the very definition of war and in the nature of change.

This need to integrate science more meaningfully in the epistemology of war is laid bare in the debate sparked by David A. Bell. Bell is the latest historian to make the case for fundamental change. Building on various earlier studies, he argues that war took on a redemptive, cleansing role and that the mobilisation of society by French Revolutionary governments and the scale of the fighting, therefore, represents the first 'total' war in modern history.[6] Bell has received strident and compelling criticism about his use of this concept. The scale of Napoleonic warfare, many people say, does not permit any such implicit comparison to the truly industrial and large-scale demographic mobilisation of the wars of the twentieth century. Plus, there is simply too much continuity with the eighteenth century to ignore.[7] Bell sidesteps his critics, however, by directing attention away from the means available or employed and toward 'prevailing political and cultural assumptions' in war. Total war, he says, is not war that involves the total mobilisation of society, that 'exceeds a certain threshold of intensity', or that necessarily succeeds in annihilating the enemy. It is a 'process' of radicalisation sparked by a perceived threat to survival by which one can begin to imagine such annihilation. There is an ever-greater commitment to increasingly intense fighting 'until one or the other [side] collapses under the strain'.[8] The break, in other words, is in the perceived function or effect of war, not its scale, methods or even its intensity. Whether this is adequately captured by the concept of 'total war' or not, it is clear that, in the long, fluctuating history of change in war, concepts and ideas matter.

To see the influence of science from this perspective, we must look beyond the obvious immediate effect of technical and material developments on the conduct of war and take a cue from those historians of science and technology. Scientific advances need not be treated as the drivers of wider change. They can also be cultural artefacts, the cause but also the effect of wider developments in society. It is such an approach that is behind Antoine Bousquet's important, ambitious study of science and war since the eighteenth century. He very usefully adopts science as an interpretative framework and as an actor in its own right. In the nineteenth century more widely, he reminds us, science was conspicuously influential. At the level of international politics, this is most obvious with the idea of the Social Darwinism of competing states. Yet natural laws were applied to everything from the human personality by Freud, for example, to the structure of society by Marx. Even biology was affected by the main influence, thermodynamics. The human body, as Bousquet says, came to be seen as an engine of

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sorts 'burning calories', using heat for energy. In a similar way, thermodynamics, he claims, also had a defining influence on the way that war was perceived.[9]

Bousquet's overall argument is that, in different eras, changing scientific worldviews provide a 'metaphor' by which war is understood, and it is easy to see why thermodynamics was so important in this respect. Sadi Carnot described heat as the essential force in nature. It was, he said, behind the 'vast disturbances we see occurring everywhere on earth', in the weather, rivers, volcanoes and elsewhere.[10] It was also behind the utter transformation of nineteenth-century society that he was witnessing due to the increasing use of steam power. His challenge, therefore, was to understand the principles and the potential of the many combustibles that nature provides to convert into mechanical work. Clausewitz, too, captured this scientific spirit of the age in his attempt to understand escalating war. As is well-known, he reacted against strict geometric, logical, or 'scientific' analyses of war. Nevertheless, with his emphasis on the unknowability of war and the essential role of the genius of the general and the play of probability and chance, along with the natural, escalating reciprocal forces leading to the 'spontaneous discharge of violence' in the theoretically unlimited 'absolute war', Bousquet tells us that he anticipated the future development of thermodynamics.[11]

The effect of this concern with harnessing the dynamic, volatile energy of the universe, which included an appreciation of the notions of randomness and unpredictability, was that the power of entire populations was exploited in the pursuit of victory. Battles and battlefields became unthinkably deadly, marked by chaos, spontaneous eruptions of violence, movement, autonomy of units, and so forth. The armies of the French Revolution famously embodied the mobilisation, concentration, and discharging of energy --material and human---as political ideals 'galvanised society into armed struggle with metaphysical significance'.[12] War became something of a force of nature. Others, such as the philosopher Manuel de Landa have also seen this altered view of war instrumentalised by the armies of Napoleon which he likened to a machine running on an endless reservoir of manpower.[13] Thus followed a century of industrialisation, described by Bousquet, in which steam and other technologies were increasingly employed to introduce unprecedented lethality in a system of militarised states with large, conscript armies exploiting all available resources. The culmination of this period of 'thermodynamic war' was the atomic bomb of 1945 which was the ultimate eruption of nature's lethal energy.

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There are two dangers with seeing science as metaphor for war, however. As with all metaphors, it can lead to over-simplification. More significantly in this case, it can inadvertently reinforce the presumed instrumental role of science. Thus, whereas the steam engine provided the lens by which war was understood in the nineteenth century, Bousquet says the mechanical clock represented the peak of technological and scientific achievement in the eighteenth. From this and building on the earlier work of Otto Mayr and others, Bousquet paints quite a traditional, almost caricaturised, picture of eighteenth-century war. In that age of 'rationality', war was limited, that is to say methodical, purposeful, and focused. The universe itself was seen by some to resemble an elaborate mechanism like a clock created by God but allowed to run its set course.[14] Accordingly, war was fought in a similarly set fashion. It could be perfectly understood and mastered, and it could be conducted through careful manoeuvre and bloodless demonstrations of strength. Of course, Bousquet concedes that his periodisation is necessarily approximate. There is, inevitably, a lot of overlap and lingering influences between the different, scientifically-defined stages in the emergence of modern war that he identifies. Yet this concession will not inoculate his model against familiar criticisms based on the many continuities in war. Military historians will forever find contradictions and exceptions which, far from proving the rule, will deny it. Historians of eighteenth-century warfare, for example, are not generally struck by the lack of passion, innovation, violence, or ambition that they find. The mechanical clock very quickly falls away as a useful parallel, obscuring more than it helps to explain. Likewise, historians of Napoleonic warfare will find a metaphor of a steam engine suggestive at most but more likely misleading. Napoleonic armies were not actually directed as if they were thermodynamic machines.

The problem, however, goes beyond how the boundaries of periods are defined and drawn. It lies in the way that the conceptual role of science is extended and reassumes its determining role. One on hand, Bousquet argues that science had quite an indirect influence, framing how war was conceived. War, he says, came to be seen as consistent with a general 'aesthetic of thermodynamics' in much the same way that Michel Serres described the conceptual break with the past introduced by steam. In particular, the paintings of J.M.W. Turner, for example, also reflected this new modernity of uncertainty and potential with the incorporation of steam and fog and blurred boundaries that evoke violent, natural forces beyond full human control.[15] On the other, however, Bousquet presents scientific world views as just one more exploitable means to pursue war more effectively and on an ever-grander scale, whether that was inspired by the

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clock, the steam engine or later by the computer in an information age, or ultimately in today's age of 'chaoplexity' in war. This relative emphasis on how science affected how people set about trying to 'win' wars over how they 'understood' them is a reflection of a problematic, but fairly common, strategic assumption. It suggests a belief that, throughout human history, changes in war have been driven by a consistent and universal pursuit of relative power. In Bousquet's formulation, there is a timeless and natural human struggle to 'impose order on chaos' and thereby become better, more efficient fighters.

Arguably, it was the thermodynamic moment in war that did most to consolidate this persistent strategic assumption and the mutually reinforcing role of science behind it. The uncertainty of war was recognised. However, the belief was confirmed that, by maximising power, war could still be managed and even understood. A self-fulfilling view thus emerged in the nineteenth century of war as an escalatory process. This saw its fullest flowering in World War Two and in the continuous investment in the Cold War in ever more sophisticated and lethal weapons and systems. Notably, the influential concept of a Revolution in Military Affairs (RMA) from the 1980s was based on the belief that, historically, war changed fundamentally with the introduction of technologies and systems and that rapid technological change then could do so again. Although experience has since proven that there are no such simple answers to the problem of war, there nevertheless remains what can only be called a 'faith' in our ability to direct war by mastering the physical laws of nature as well as in the very idea that war is governed by laws, or theories, in the first place. The obvious and determining role in the conduct of nineteenth-century war that steam technology and industrialisation played goes a long way in sustaining this faith. Not to be overlooked is the fact, too, that thermodynamic principles seem no less relevant today. Thermodynamics, after all, is about the calculation of measurable outcomes from the countless, unfathomable interactions that occur at the molecular level. Here, we can see a parallel in the current rise of the manipulation of big data which raises the prospect of identifying patterns and making predictions based upon the countless human and physical interactions that are involved in war, and this can incorporate complexity and chaos. In a similar way, the social sciences were developed in the twentieth century out of a confidence that scientific principles could be applied to understanding human behaviour more generally, often employing concepts directly inherited from thermodynamics such as entropy to do so.

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The idea of an influential thermodynamic moment with overlapping influences between science and the escalation of war even seems to be confirmed by the very circumstance of Sadi Carnot's life and the network of personal influences around him. He was, of course, the son of Lazare Carnot, himself a mathematician and physicist and author of papers which had a clear influence on Sadi's scientific thinking.[16] Lazare Carnot was also a military engineer and a politician, famous as the 'organiser of victory', responsible for the levée en masse and the strategic shift by the Revolutionary government toward the pursuit of total victory with vast citizen armies. He was also instrumental in the career of Clausewitz's inspiration, Napoleon, whom he appointed in 1795 as general of the army of Italy. He provided essential, early political support before himself later being named by Napoleon as a minister of war. Sadi Carnot did not have a distinguished military career himself, and his paper on heat is strictly scientific and theoretical regarding the efficiency of engines. Nevertheless, it reveals an unmistakeable element of geopolitical competition. He opens by describing Britain's dependence on the steam engine which was behind the revival of its mining industry. 'If England were to-day to lose its steam engines', he says, 'this loss would dry up all its sources of wealth .... It would annihilate this great power.' Steam, he even suggests, is more important to Britain than its celebrated navy.[17] What follows is a detailed study of changes in volume and temperature. His work is essentially a reflection on the nature of power generated by heat and the theory behind it with an extended thought experiment of an idealised thermodynamic engine which in some ways evokes Clausewitz's On War.

The similarities between the works are certainly suggestive. According to Carnot, the source of all motive power is the flow of heat, or what is referred to as 'caloric', which always moves in one direction, from hot to cold, and never in reverse. As he saw it, just as the flow of water can drive a paddle of a millwheel, this movement of caloric via the medium of steam or other substances can generate motive force. He imagined a reversible system in which caloric flows back, but he concludes no additional work would be generated by this oscillation between two systems (and, indeed, some would always, inevitably, be lost). There is a theoretical limit, therefore, to the work that can be produced by heat. In some ways, the 'Carnot cycle', with its alternating flows, is not dissimilar conceptually to Clausewitz's famous duel between two wrestlers as an illustration of the quintessence of war, or to the series of reciprocal actions he describes from them that lead to escalation. Both men imagine an ideal (the perfect engine or 'absolute war'), and both recognise that they are unattainable in the real world for

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practical and for theoretical reasons. They are unattainable, and they are unknowable. Carnot, for example, admits to not knowing how 'caloric' is carried by steam, and Clausewitz, of course, refers to the 'remarkable' trinity of influences that characterise war which he describes but does not pretend to explain.

Perhaps more than any other period in history, therefore, the thermodynamic moment appears to confirm the symbiotic influence of science and war. There are important differences between these two works, however, which should call into question our 'faith' that science can provide an insight into the universal nature of war. Whilst Clausewitz considered war to be consistent with what was being discovered about the natural world, it was not beholden to its laws. He was not applying thermodynamic principles to war nor anticipating the later science of thermodynamics. Clausewitz was obviously conversant with and influenced by current scientific thinking and specifically by advances in theories of probabilities. The two men inhabited a common intellectual environment and shared some vocabulary and conceptual approaches. Yet whilst there are natural limits to the efficiency of an engine, in theory, at least, there is no limit to war. War tends to escalate toward a spontaneous discharge of violence. The key difference is that, for all their recognition of the unfathomable forces of nature, Carnot, and thermodynamics generally, are interested in a heuristic understanding of phenomena on a colossal scale which is measurable, precise, predictable. In other words, it is all about calculating knowable outcomes. Thus, when Carnot recognised that energy inevitably escapes from a system, this could later become formalised as 'entropy' and become a foundational idea specifically in what would become the Second Law of Thermodynamics. However, entropy is a mathematical invention designed simply to put the unknown to one side (what is happening at the molecular level), and to allow for reliable calculation, whereas, for Clausewitz, war is the collective effect of individual actors. From a thermodynamic perspective, then, war occurs at the level of the unknowable or unpredictable. One implication of this is that the 'friction' that Clausewitz described must not be confused with 'entropy'. Friction is one part of what keeps war from being knowable, or measurable, and makes the play of probability and chance so important, making war a gamble, like a 'card game', and, it must be said, very unlike a steam engine.

Thermodynamics only make sense within a closed system with a limited number of inanimate, simple molecules that interact in identical fashion. War is the very opposite of a closed system. The parameters, even the definition of war, are not fixed. Moreover, it is the effect of a range of human reactions and, as Beatrice Heuser argued

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in a recent talk, of many other 'interdependent variables' that influence each other in a dynamic fashion. In this respect, it is a concern that Carnot shared with Clausewitz with the decisive role of individual, human intervention which is most striking. Carnot closes his study by claiming that in the real world an engine cannot be built that would be strong enough or precise enough even to approach producing the theoretical maximum of motive force available. Therefore, different priorities need to be considered and balanced for any engine that is to be designed and constructed (safety, size, function, etc.) Thus, 'to reach the best result by the easiest method -- such should be the power of the man who is called on to direct and to co-ordinate the labours of his fellow-men, and to make them concur in attaining a useful purpose'.[18] And in a very similar way, of course, Clausewitz highlights the calculations of generals and the 'subordinate character' of war as a political tool, belonging to the province of pure intelligence and the concern of the government.

That individual judgements are the key for both has been overshadowed somewhat by the course of events over the nineteenth century with the competitive pursuit of national power and industrial might. The impact of these changes is reflected in the language used. It is only in the English translation of 1890, for example, that Carnot refers to this necessary intervention in the design of an engine as a person's 'power'. In the original version of 1824, it is his 'principal talent'.[19] Thus, Carnot and Clausewitz might be credited with initiating great changes in society, but it must be remembered that they were witnesses, not prophets, and the fundamental change that Clausewitz witnessed was unprecedented political invention through war. The French Revolution represented the collapse of the state and indeed of political legitimacy, and so recovery required the creative impact of war more than ever. Accordingly, there was a fundamental change not simply in the scale and methods of war but in its function or perceived political potential, and this had serious implications. Deadly, far-reaching, and lasting changes in the conduct and strategic assumptions about war were duly established in the nineteenth century. Of course, these cannot all be credited to the impact of changes in military thought any more than they can to specific material innovations. It is clear, however, that war was conceived differently. Its capacity to effect political change expanded, and it is in this that science perhaps had its most significant role.

Because material and technological factors can have such a direct and obvious impact on the physical conduct of war, this more profound, defining influence of science is often overlooked. We tend, as a result, to be left with slightly artificial historical debates between the themes of continuity or change which are based upon competing,

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unspoken assumptions about the influence of science. As we have seen, many essentially material models of historical change have encouraged an emphasis among many historians of the Revolutionary and Napoleonic wars on continuity. Some others, however, adopt a political model of change and focus on the rapid escalation of the time which is credited to changes in aims and the increased stakes. A feature of Antoine Bousquet's important idea of science as metaphor is that it begins to address this tension. It permits, without privileging, a direct escalatory impact in history of practical innovations. Primarily, though, it credits wider scientific world views with affecting how war has been understood and how people have, therefore, hoped to best approach and to conduct it. However, the influence of science goes deeper than this. It is not limited to incremental improvements in military capacity over time. It affects those political aims and perceived stakes that can lead to escalation because it shapes perceptions of the very political capacity and function of war itself. This suggests something fundamental about the nature of war that was hinted at by Clausewitz and other romantic military thinkers, which is that war is socially constructed. It is ultimately a process of self-definition or political invention, and it is fought over, and by, culturally-shared ideas of the successful self. In other words, how success is defined in any given age is the key to understanding how and why we wage war, and thermodynamics provides some important insight here.

In the nineteenth century, the standards of successful political invention were altered by scientific thinking. Of course, it was the strictly 'political' effect of the Revolution that led to a massive increase in the perceived stakes in war that resulted in far greater aims and military escalation.[20] Yet, this was only possible with a corresponding expansion of war's creative function, facilitated, in part, by thermodynamics. Power took on greater value as a defining feature of success. In a self-reinforcing way, it grew as an indicator of national cultural success and thus as a source of political capital that was easily recognisable and accepted. It is worth noting, however, that to claim that science shapes the political imagination that animates war is not to indulge in any sort of modern conceptual exceptionalism. For over 45,000 years, the supernatural has been invoked in war. Occasionally, this was for direct intervention by gods on the battlefield; always, though, it was needed to secure political gains won. Some sort of ownership or affinity with the supernatural was essential for the domestic support and international stature that provided the legitimacy that was sought.[21] It, therefore, shaped the understanding of the function and purpose of war. As Jan Willem Honig argues, as an example, medieval monarchs performing public and private acts of piety made the very

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conduct of war itself a sort of ritualised process of political invention through divine endorsement as much as it was a mere act of violence for political ends.[22] From 1792, the scale of the political change needed was new, and thermodynamics was part of the necessary re-imagining of war and its generative impact. Then, as now, war was conceived as consistent or aligned with the natural order in order for it to be successful and have a meaningful political effect.

In one respect, therefore, approaching the thermodynamic moment in the history of war through Sadi Carnot and Carl von Clausewitz in this way, contributes to the de-throning of science and technology as determining factors in war. Certainly, it casts a sceptical light on the perennial question concerning the social sciences and whether they can adopt statistical, or otherwise scientific, means of studying human behaviour. This is not to suggest that there is no practical value in the study of discernible historical patterns. Big data, game theory, chaos, and complexity are, of course, all useful analytical tools that will, no doubt, help. Artificial intelligence and machine learning may well affect war in a number of surprising ways and may one day, perhaps soon, be able to make some accurate predictions that can inform policy. Yet, to presume that these patterns are subject to any laws or universal theories is still dangerous. It is an inheritance from the nineteenth century and the strategic assumptions of the time: that war is driven and won by power; that this gives us an insight into the very nature of war itself; and, that science and technology can, therefore, provide us with the answers that we need to address short, medium, and long-term security threats.

The thermodynamic moment bears a lot of responsibility for creating and sustaining this 'faith'. Yet looked at differently, we can identify a more fundamental, defining relationship of science with war. Views of the natural world help shape the cultural assumptions that inform strategic purpose. They influence the changing definition of war, or at least its perceived political function and potential. Taking this more comprehensive view is valuable in a number of respects. For one, it helps to reconcile historiographical tensions behind longstanding, intractable debates about modernity and change. Certainly, it accommodates what has been called a recent cultural turn in the history of war, and it contributes to the demolition of technological determinism.[23] Equally, because it privileges the contribution of scientific worldviews to the evolving standards of success that animate wars, it accommodates a Latourian co-creation of science and war. In other words, there is not necessarily a conceptual contradiction with a preferred focus on material changes in the past and their sometimes undeniably important repercussions. Influential, technical or material innovations might well often

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accompany escalation as an appropriate reflection of an increased threat to a sense of identity and of a greater need for political invention. In a similar way, the thermodynamic moment offers a vantage point from which to consider the range of motivations for war that are frequently identified. Territory, money, power, pride, honour, brutality, or even just the unintended effect of arms races, for example, can all be recognised and accommodated. They need not compete as the foundation of unspoken assumptions about some presumed universal nature of war.

The wider implications are not insignificant. This should cause us to reflect on the sheer extent to which war has built our current international order and will continue to shape our future. There can be no more pressing question for humanity, therefore, than whether or not war is currently going through a fundamental transformation, what this even means, or what it might look like. Yet we must be careful, because science (and its application) can provide no objective insights into its nature or any of the limitless transformational directions of travel war might follow. Thus, we cannot afford to consider the prospect simply in terms either of the new instruments or systems that might characterise the battlefields of the future nor of any other opportunities for greater efficiency, precision, or lethality. Nevertheless, scientific thinking may well offer clues about changing perceptions of the purpose of war and what it is capable of creating. War may be a social construction, but it has always had an elevated status as part of the natural world exerting an active force on society. Any such changes are necessarily consistent with our ideas of the natural, or supernatural, world. The 'thermodynamic moment', therefore, does more than affirm Clausewitz's conclusion that war is unpredictable. It is a reminder of the uncertainty of the future of war itself. Today, we are not simply entering another historical period of rapid technological innovation with far-reaching but potentially foreseeable effects on the conduct of war which might fit into existing historical patterns. It is a revolution in which our relationship with technology, information, and knowledge itself is being transformed. Unless we identify, confront, and try to affect the assumptions about war that might arise, the repercussions could be as deadly as they are currently unfathomable.

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Footnotes

1 : See the new book, Black, J. (forthcoming). Continuities: European Warfare, 540-1920. I would like to thank Prof. Black for allowing me to see a draft.↩

2 : See, for example, Honig, J. W. (2001). Warfare in the Middle Ages. In A. V. Hartmann & B. Heuser (Eds.), War, Peace and World Orders in European History (pp. 113-126). Routledge.↩

3 : Forrest, A. (2004). The French Revolutionary and Napoleonic Wars. In G. Mortimer (Ed.), Early Modern Military History, 1450-1815 (pp. 196-211). Palgrave.↩

4 : Chickering, R. (2010). Introduction. A Tale of Two Tales: Grand Narratives of War in the Age of Revolution. In R. Chickering & S. Förster (Eds.), War in an Age of Revolution, 1775-1815. Cambridge University Press.↩

5 : For an up to date and thorough critique, see the chapter on the Military Revolution in Black, J. (forthcoming). Continuities: European Warfare, 540-1920.↩

6 : Bell, D. A. (2007a). The First Total War: Napoleon's Europe and the Birth of Modern Warfare. Bloomsbury.↩

7 : See the debate at Bell, D. A. (2007b). H-France Forum: The First Total War: Napoleon's Europe and the Birth of Modern Warfare. http://www.h-france.net/forum/forumalphaauthor.html. And, see especially, Kiesling, E. C. (2011). 'Total War, Total Nonsense' or 'the Military Historian's Fetish'. In M. S. Neiberg (Ed.), Arms and the Man: Military History Essays in Honor of Dennis Showalter (pp. 215-242). Brill.↩

8 : Bell, D. A. (2023). The First Total War? The Place of the Napoleonic Wars in the History of Warfare. In B. Colson & A. Mikaberidze (Eds.), The Cambridge History of the Napoleonic Wars: Volume 2: Fighting the Napoleonic Wars (Vol. 2, pp. 665-681). Cambridge University Press. https://doi.org/DOI: 10.1017/9781108278096.033↩

9 : 'Chap. 3. Thermodynamic Warfare', in Bousquet, A. J. (2009). The scientific way of warfare : order and chaos on the battlefields of modernity. Columbia University Press.↩

10 : Carnot, S. (1890). Reflections on the Motive Power of Heat. In W. F. Magie (Ed.), The Second Law of Thermodynamics. Memoirs by Carnot, Clausius and Thomson (pp. 3-61). Harper and Brothers.↩

11 : Bousquet, A. J. (2009). The scientific way of warfare : order and chaos on the battlefields of modernity. Columbia University Press.↩

12 : Ibid.↩

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13 : De Landa, M. (1991). War in the age of intelligent machines. Zone Books.↩

14 : Mayr, O. (1986). Authority, liberty, & automatic machinery in early modern Europe. Johns Hopkins University Press.↩

15 : Serres, M. (1974). Hermès III, La Traduction. Éd. de Minuit.↩

16 : See the Introduction by Robert Fox in Carnot, S. (1986). Reflexions on the Motive Power of Fire. A Critical Edition of the Surviving Scientific Manuscripts (R. Fox, Ed. & Trans.). Manchester University Press. And see, Gillispie, C. C., & Pisano, R. (2014). Lazare and Sadi Carnot: A scientific and filial relationship. Springer.↩

17 : Carnot, S. (1890). Reflections on the Motive Power of Heat. In W. F. Magie (Ed.), The Second Law of Thermodynamics. Memoirs by Carnot, Clausius and Thomson (pp. 3-61). Harper and Brothers.↩

18 : Ibid.↩

19 : Carnot, S. (1986). Reflexions on the Motive Power of Fire. A Critical Edition of the Surviving Scientific Manuscripts (R. Fox, Ed. & Trans.). Manchester University Press.↩

20 : Stone, J. (2011). Military strategy : the politics and technique of war. Continuum.↩

21 : Polinskaya, I., James, A., & Papadogiannakis, I. (Eds.). (2024). Religion and War from Antiquity to Early Modernity. Bloomsbury Academic.↩

22 : See the essay by Honig in Ibid.↩

23 : See, for example, Edgerton, D. (2006). The shock of the old : technology and global history since 1900. Profile. This explores a common historical ‘reluctance’ to innovate in war and the influence of a reliance on the familiar and reliable.↩

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