Introduction

Historians agree on the importance, both to natural philosophy and to the development of the modern sciences, of the emergence of a 'mechanical world picture': many have studied its history, defining features and governing motivations. One important reason for the development of this world picture in the early modern period seems to have been the reintroduction of a number of ancient Greek texts.[1] Rose and Drake suggest that it is no coincidence that the circulation of the Aristotelian *Mechanica* coincided with the formative period for modern science.[2]

Against this background, it might seem necessary to account for the absence of any comparable interest, amongst the ancient Greeks themselves, in the implications of their mechanics for natural philosophy. A number of classic explanations have been offered as to why ancient Greek thinkers might not have seen the applicability of ideas from mechanics to the understanding of the natural world. I suggest that these explanations are spurious, and moreover that there is evidence of a philosophical reception of ideas from mechanics, especially in late antiquity. The evidence is scattered and often only preserved in the criticisms of its detractors: the dominant figures in late antique philosophy rejected the 'mechanical hypothesis'. But its

[1] The Aristotelian *Mechanica*, works of Archimedes, Vitruvius and Hero of Alexandria all came into circulation in the sixteenth century, many of them acquiring considerable popularity.

[2] Rose and Drake (1971). The treatise gained currency after it was included in the Greek Aldine edition of 1495–8, the first printed edition of Aristotle's works. See the appendix for more on its history.

very existence is an interesting development that should not be overlooked.

Ancient Greek mechanics was a broad and diverse field, including a number of subfields concerned with different kinds of 'working artifacts' and the theory of their operation. Its branches include not only weightlifting technology, but also 'pneumatics', ballistics, sphere-making, and the making of automated theatrical displays. Its practitioners developed a number of theories and analytical techniques that were of interest to natural philosophers. The theory of weightlifting technology included analysis of circular motion as compound; the idea that causes of motion compounded mathematically; the use of weight as a way to measure effort or force; a distinction between weight and downward impetus; the notion that various parameters involved in the causes of motion co-vary, and that a given force can, ideally, be made to lift any given weight. The property of elasticity of matter was highlighted by third-century work on pneumatics and ballistics and seems to have been the inspiration for the idea of *eutonia* so important in Stoic physics. Pneumatics also discovered techniques for moving fluids intermittently, forcefully and uphill, providing the inspiration for a new approach to explanation in medical physiology and forcing philosophical reconsideration of the theory of void. The making of theatrical automata offered a new model of causal sequencing, showing how intended results could be preprogrammed to result by material means through a chain of events, and offering a new model for divine control of the natural world. The possibility that animals, the heavenly bodies, human beings – or even the whole cosmos – might work like mechanical devices merited consideration.

I suggest that there are a number of reasons why the reception of mechanics in Greek antiquity has not been taken more seriously. One is simply the practice of focusing on one branch of mechanics alone as definitive of the field: lever technology, because it played such a prominent role in the development of mathematical techniques for the new physics of the seventeenth century, is often treated by modern scholars as *constituting* the field of mechanics. This was not so in antiquity, nor, incidentally, in the eyes of figures such as Descartes and Boyle, who developed the idea of a 'mechanical

philosophy'. Pneumatic technology, for example, played a significant – if sometimes overlooked – role in seventeenth-century texts articulating the idea that nature might work 'like a machine'.

Another prominent reason why scholars have not thought that there was much to say about the reception of mechanics in antiquity is a belief that the ancient Greeks regarded mechanics as working 'against nature', as an art rather than part of natural philosophy, or as associated with trickery and deception. Claims of this sort about the ancient attitude to mechanics are found especially amongst historians of science and are partly based on some remarks by Galileo. Galileo's bid to regard mechanics as material for natural philosophy depends on rejecting some misconceptions of the status of mechanics. However, these conceptions gained currency in the Middle Ages, not Greek antiquity.[3]

Historians of technology offer somewhat different analyses of the supposed indifference to mechanics amongst Greek intellectuals in general. They postulate a disinterest in the menial or practical disciplines, often attributed to a disdain for manual labour common to a slave-holding society. While there are Greek texts that show this dismissal of the practical – Plutarch's famous presentation of Archimedes as only turning to practical mechanics under royal command, and the claim that Plato was angry about the association of mathematics with instruments, for example – there is little evidence that such disdain dominated the intellectual reception of ancient mechanics. The field was not perceived as purely practical: it was grounded in mathematical techniques and interacted with natural philosophical theory.

A further barrier to the recognition of the ancient reception of mechanics exists in twentieth-century histories of philosophy. This is the tendency to classify natural philosophical systems in terms of a dichotomy between teleological and so-called 'mechanistic' schools of thought. Because ancient atomism is taken as the prime example of the latter, yet developed before there was much evidence of mechanics, we are left to conclude that the school called 'mechanistic' arose

[3] I argue this in detail in the appendix to this volume.

without the inspiration of mechanics. At the least, this framing of the ancient debate in seventeenth-century terms has tended to minimize or mask the extent of the impact of Hellenistic mechanics on natural philosophy.

It is often thought that – despite some 'eclectics' in the Hellenistic period – the dichotomous division into teleological and mechanistic schools aptly characterized the viable alternatives available throughout the remainder of the ancient Greek world. The idea that the emergence of modern science involved the rejection of teleological thinking in favour of mechanism too easily plays into a caricature in which the scientific advances of the mechanistic atomists were impeded by the teleological Aristotelians. A simplistic understanding of the dichotomy would suggest that only ancient atomism is worthy of serious philosophical consideration as a precursor to modern ideas on causal explanation, and much ancient natural philosophy would too readily be dismissed as naive, *ad hoc*, superseded, or philosophically uninteresting.

There are, of course, many problems with this caricature.[4] Aristotle's school, after all, produced the earliest surviving treatise on mechanics. It was Aristotle, rather than Democritus, who even considered the idea that animal functions could be understood by comparison to mechanical devices. It has long been noticed that some of those most interested in mechanical comparisons in explaining the functioning of organisms are also committed teleologists; labelling hard-to-classify views as 'eclectic' is unilluminating.[5]

The dangers inherent in the twentieth-century classifications of the 'mechanistic' are best illustrated by two important works from the early 1960s. Dijksterhuis' classic work, *The Mechanization of the World Picture*, traces the history of the emergence of a concept by looking for antecedents of a modern notion of the 'mechanistic' in antiquity. His work illustrates the ways in which focus on the different senses of the term 'mechanical' affects the questions that are considered. Taking as a given that atomism is a 'mechanistic'

[4] A point well made by De Groot (2008).
[5] For difficulties with the classification 'eclectic', see Donini (1988).

theory, Dijksterhuis traces the prehistory, in antiquity, of ideas contributing to what came to be called a 'mechanical' world-view – the development of mathematical physics and corpuscular materialism – and scarcely considers the contributions made by the discipline of mechanics.[6] Tellingly, he downplays the contribution of the machine analogy to the history he is writing, *because* of its incompatibility with atomism.[7]

This shows how the identification of atomism with mechanical can mislead, since it risks omitting a significant facet of the history of the reception of mechanics, and missing the opportunity to illuminate the process by which a particular *kind* of materialism – not that of the Stoics, for example – acquired an unparalleled authority in early modern science. The appeal to mechanics as a reference point played a role in the emergence of a consensus as to the properties that *should* be ascribed to matter, a consensus that did not exist in antiquity. Moreover, a history of the development of mathematical techniques for analysing motion and its causes would be lacking if it did not consider the contributions of mechanical theory.

Even an author as aware as Sambursky of the importance of mechanics to the natural philosophy of late antiquity is hampered by the use of the term 'mechanistic' to describe the atomists. Sambursky's *The Physical World of Late Antiquity* offers a rich and searching survey of the reception of mechanics in ancient natural philosophy. Avoiding some of the assumptions of Dijksterhuis' approach, he notes the importance of Hellenistic machinery in producing a 'mechanistic attitude'.[8] The debt the present work owes to Sambursky's synthetic knowledge of late antiquity will be apparent. Yet the association of the 'mechanical' with atomism prevents the importance of the ancient discipline of mechanics from coming through more clearly in his study.

Although the core of this work is a historical account of the emergence of mechanics and its impact on natural philosophy, I believe

[6] Dijksterhuis (1961), pp. 72–5, is dismissive of the ancient understanding of mechanics.
[7] Dijksterhuis (1961), p. 12. [8] Sambursky (1962), p. xi.

that to fail to address the existing terminological confusions would inevitably lead to misunderstandings. Despite all the careful attention paid to the exact meaning of the term 'teleological', the term 'mechanical' is freely used in current scholarship in sometimes anachronistic or ill-defined – and certainly various – ways, as though it were a self-evident concept available to all. This obscures the historical development of ideas about mechanics, and the critical historical role played by the discipline of mechanics in *formulating* our notions of 'the mechanical' and of the natural world.

Contemporary notions of the 'mechanistic' are in fact quite various, despite a belief in its simplicity and perspicuity. Attention to the history of the term, and to the different ways 'the mechanical' can be used – to describe the genesis of a view, or our own perception of its systematic features – helps us disentangle its complex meanings and, with it, the origin of the belief in the perspicuity of the term.[9] This 'perspicuity thesis' is itself a historical artifact, important in understanding the contribution of mechanics to the history of natural philosophy.

Attention to the impact of ancient Greek mechanics on natural philosophy is merited. While ancient natural philosophy is typically understood as dividing into two contesting approaches, I argue that a third, independent approach emerged, principally in the post-Aristotelian period. Unlike atomism, this third approach is inspired by mechanics. I shall understand 'natural philosophy' broadly, not limiting its scope only to the systematic theories of the natural world formulated by schools of philosophy, but including the views of the natural world held by others of its students, including medical theorists, astronomers and the mechanics themselves. While philosophers proper tended to reject this approach, traces of a 'mechanical hypothesis' can be found in late antique discussions of the natural world. The evidence is vestigial, but it is there.

The understanding of mechanics, perhaps unsurprisingly, changed considerably between the time of Homer and late antiquity. There is little credible evidence before Aristotle's time that might

[9] I thank Max Weiss for noting a meaning–use distinction here.

count as the use of working artifacts in understanding the functioning of nature: stories in early literature are not, as some think, evidence of mechanical conceptions of organisms. Evidence from the fourth century is mixed. Some ideas important to mechanics can be found in Plato and Aristotle, used only in piecemeal fashion. It seems to be in the Hellenistic period that mechanics consolidated as a discipline. Unfortunately, some of the key texts are lost or survive only in part, and there are many gaps in our understanding. But this can be said: with the development of mechanical technology and mechanical theory in Hellenistic times, some ancient Greek thinkers made use of mechanical theories and drew analogies to mechanical devices as a guide to investigating the natural world.

In tracing the origins of mechanics and its development in the Hellenistic period, no attempt is made to provide a complete account of the field, nor to offer a technical history of ancient mechanics.[10] The intent is to do something rather different: to sketch a *philosophical* history of the discipline, that is, to consider the relationship of ancient Greek mechanics to the categories and concepts of ancient Greek natural philosophy. It is not the intent of this work to detail every piece of technology or to assess the technical significance of the devices or theories presented. Much remains to be said, nonetheless, about the impact of mechanics on theories of matter and void; of motion and its causes; of natural order and its transmission.

To write a thorough history of the impact of ancient Greek mechanics on the history of philosophy would require knowledge of ancient technology, archaeology, art history, literature, military history and medicine, as well as philosophy, mathematics, astronomy and practical engineering, Arabic, medieval and Renaissance mechanics, and seventeenth-century natural philosophy and science. Needless to say, I am not such an expert. Some will doubtless find this work inadequate in its attention to the social and economic context in which technology existed, in its lack of engagement with the technical proficiencies of the theories, or in its lack of detail on the

[10] The decision to use modern drawings, for example, is made for the convenience of the reader and not for the specialist.

devices themselves. While I am conscious of the many limitations of this work, I nonetheless hope to open a question. If we reject the implications behind our current, troublesome terminology and ask instead what effect ancient mechanics had on the history of ancient Greek philosophy, would there be a story to be told?

CHAPTER 1

Mechanics and the mechanical: some problems of terminology

David Furley begins his work *The Greek Cosmologists* with a concise presentation of the differences between two main approaches to natural philosophy in antiquity. One of these, the teleological tradition, best represented by Aristotle, understands form to be explanatorily irreducible and holds that teleological explanations cannot be omitted from a complete account of the natural world. Philosophers in this tradition consider matter to be continuous and to have no imperceptible microstructure; they regard qualitative change as fundamental and not reducible to rearrangement of smallest parts; and they think of the material cosmos as structured and finite in extent. The atomists, by contrast, take all change to be fully explained by the spatial rearrangement of these smallest parts, without reference to any purposes these changes might be thought to serve. They take matter to be composed of indivisible smallest parts moving in a void, treat macroscopic structures as explanatorily reducible to the properties of the smallest parts and regard the universe as infinite and unstructured.[1]

It is important to notice that the contrast between two competing approaches is not presented as a logically exhaustive dichotomy: neither in the ancient nor the modern world are these the only possible explanatory options. Furley's point is not simply to segregate philosophical positions according to an exhaustive and exclusive dichotomy, but to note an interesting tendency of philosophical positions to cluster around certain key assumptions. Part of the

[1] Furley (1987), pp. 1–15.

fascination of Furley's account is that it raises a question why there should be an association between distinct ideas: why a certain view of matter should tend to align with a given view of the nature of explanation or of the form of the cosmos. Furley takes these two main explanatory alternatives to characterize ancient natural philosophy, even while he allows that some later figures forged so-called 'eclectic' or 'compromise' positions.[2]

I take his account to capture elegantly a consensus of contemporary scholarship as to the classification of ancient theories of the natural world, and to correctly identify two main trends in ancient natural philosophy in Aristotle's time, at the least.[3] It is an established usage in twentieth-century scholarship on ancient natural philosophy to describe this dichotomy as an opposition between teleological and 'mechanistic' views. Nonetheless, there is a legitimate question – as Furley himself recognizes – whether the term 'mechanistic' adequately and illuminatingly describes the non-teleological side of this divide. I suggest that some confusion might easily be avoided if we were to describe the opposition here as between teleological and materialist approaches, and I reserve the term 'mechanistic' for a third approach that later emerges, inspired by the mechanics of the Hellenistic period. At the very least, different senses of the term 'mechanistic' need to be clearly distinguished.

Despite the vast amount of attention in twentieth-century scholarship on ancient philosophy to the notion of teleology, there has been much less analysis and discussion of the notion of 'the mechanistic' or 'the mechanical'. As twentieth-century scholars apply this term to ancient philosophy, it is defined in a surprising number of different ways. Some of the attempts in the literature to define the 'mechanistic' are really definitions of a materialist or efficient-causal system and could better be relabelled to avoid potentially misleading associations that surround the complex term 'mechanistic'. Others

[2] Furley (1987), p. 8. The tradition of regarding deviations from this binary classification as compromises dates back to Diels (1893).

[3] See Hirsch (1990), Menn (in preparation), for discussion of the reasons why this dichotomy is not easy to formulate in Presocratic thought.