Introduction

When we think about mechanisms there are two general issues we need to consider. The first is broadly epistemic and has to do with the understanding of nature that identifying and knowing mechanisms yields. The second is broadly metaphysical and has to do with the status of mechanisms as building blocks of nature (and in particular, as fundamental constituents of causation). These two issues can be brought together under a certain assumption, which has had a long historical pedigree, namely, that nature is fundamentally mechanical.

That's a thought that was introduced by René Descartes and was popularised by Pierre Gassendi and Robert Boyle. Indeed, Descartes referred to his own theory of nature as 'Mechanica' since it considers sizes, shapes and motions, adding that it's a true theory of the world (Letter to Fromondus, 3 October 1637). Boyle called 'mechanical philosophy' his own corpuscularian theory which was based on matter and motion, two principles more 'catholic and universal' than any others. Mechanical philosophy was both a metaphysics of nature and a scientific theory. The point of contact was in the assumption that all worldly phenomena were ultimately the product of the mechanical affections of tiny corpuscles. That's the content of the old mechanist view that nature is *mechanical*.

And yet this very assumption has had no concrete ahistorical conceptual content. Rather, its content has varied according to the dominant conception of nature that has characterised each epoch. Nor has it been the case that the very idea of mechanism has had a fixed and definite content. Even if in the seventeenth century and beyond, the idea of mechanism had something to do with matter in motion subject to mechanical laws, *current* conceptions of mechanism have only a very loose connection with this assumption.

What kinds of commitments does more recent talk of mechanisms imply? Until the 1980s, the dominant views about mechanisms in the philosophy of science had been metaphysical. Mechanism has been seen as

https://doi.org/10.1017/9781009019668.002 Published online by Cambridge University Press

a view about causation: mechanisms were taken to provide the missing link (David Hume's 'secret connexion') between the cause and the effect. 'Mechanism', on this approach, is the very causal connection, and has been described in various ways as mark transmission (Salmon 1984), persistence, transference or possession of a conserved quantity (Mackie 1974; Salmon 1997; Dowe 2000).

In the 1990s, the New Mechanical Philosophy emerged, which is a view about the causal structure of the world: the world we live in is a world of mechanisms. A mechanism, nowadays, is virtually *any* relatively stable arrangement of entities such that, by engaging in certain interactions, a function is performed or an effect is brought about. Take a very typical characterisation of mechanism by William Bechtel and Adele Abrahamsen (2005, 423):

> (M) A mechanism is a structure performing a function in virtue of its component parts, component operations, and their organisation. The orchestrated functioning of the mechanism is responsible for one or more phenomena.

On this conception, a mechanism is *any* structure that is identified as such (i.e., as possessing a certain causal unity) via the function it performs. Moreover, a mechanism is a *complex* entity whose behaviour (i.e., the function it performs) is determined by the properties, relations and interactions of its parts. This priority of the parts over the whole – and in particular, the view that the behaviour of the whole is determined by the behaviour of its parts – is the distinctive feature of this broad account of mechanism.

Behind this broad understanding of mechanism, there is a certain metaphysics of nature. New mechanists take 'mechanisms' to be complex *entities* in their own right which are characterised by a certain ontological signature. This is supposed to be a signature that all mechanisms share in common, something that unifies all mechanisms and grounds their role in causation and explanation. The dominant view is that mechanisms are *structured wholes of entities and activities*. The latter are supposed to be the 'ontic correlate' of verbs; they are meant to ground the productive relations among entities and the productivity of the mechanism as a whole.

This metaphysics of mechanisms, a.k.a. 'new mechanical ontology' of entities, activities, organisation of parts into wholes and so on, invites a number of questions: What, in general terms, are the constituents of mechanisms? And what are their relations with more traditional metaphysical categories, such as objects, properties, powers and processes? So,

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fundamental ontology is brought to bear on how best to understand mechanisms in science.

A main claim of this book is that those philosophical views that offer metaphysically 'inflated' accounts of mechanisms are not necessary in order to understand scientific practice. And not just that. We shall also claim that there is no argument from the practice of using mechanisms in science to any metaphysics of mechanisms. That's mainly because we take it that the concept of mechanism as it is used in science, and in biology in particular, is methodological. We call our view Methodological Mechanism (MM). The main tenet of MM is that commitment to mechanism in science is first and foremost a methodological stance. The core of MM is a deflationary account of mechanism that is ontologically non-committal. According to what we call *Causal Mechanism*,

(CM) A mechanism is a causal pathway that is described in theoretical language.

Moreover, we claim that commitment to mechanism in science means adopting a certain methodological postulate, that is, that one should always look for the causal pathways producing the phenomena of interest. As such, it does not make any general ontological assertions about the 'deep' nature of causal processes.

On our deflationary account, talk of mechanisms in (biological) practice is talk about how causes (described in the language of theories) operate to bring about a certain effect. To identify a mechanism, then, is to identify a specific causal pathway that connects an initial 'cause' (the causal agent) with a specific result. Wherever there is a cause for a specific effect, there exists a mechanism that accounts for how the cause operates. The scientific task, then, is to identify the *mode of operation* of the cause, that is, the causal pathway. Identification of the causal pathway is crucial in order to establish that a causal link exists between a putative causal agent and a result (e.g., a disease state). Moreover, knowing the causal pathway makes interventions possible (and in the case of pathology, treatment). Our examination and defence of CM will unravel some limitations inherent in any attempt to extract metaphysical conclusions from scientific practice.

Admittedly, CM is thin. But it does *not* follow from CM that mechanisms are not 'things in the world'. After all, they *are* causal pathways! In characterising CM as deflationary or metaphysically agnostic, the point is that there is no need to say something 'deeper' than this in order to have a useful concept of mechanism that elucidates practice: a mechanism simply *is* a sequence of causal steps (or a process) that leads from an initial 'cause' to an end result. In sum: mechanisms in science and, in particular, in

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biology are stable causal pathways, described in the language of theory, where to identify a *causal* pathway is to identify difference-making relations among its components. The best way to introduce the main thesis of the book is by a parable.

A Parable

Imagine you've been a lifelong metaphysician trying to understand the fundamental building blocks of reality. You've read (more or less) everything written on the subject, which after an accident of classification, came to be called 'metaphysics'. You started with Aristotle's treatises that deal with the fundamental ontological categories, and which because they were placed after his *φυσικά* (physica; physics), were collectively dubbed *μετά τά φυσικά* (metaphysica; metaphysics). And in the fullness of time, you acquired views about all important topics: universals versus particulars; categorical versus dispositional properties; necessitarian versus non-necessitarian laws of nature; Humean versus non-Humean accounts of causation; and so on. You've been particularly excited by the concept of mechanism. You read about the mechanical account of nature that emerged in the seventeenth century, you reflected on the alternative, non-mechanical, way of explanation. You came to believe that causation is intimately connected with the presence of mechanism. And of course you lived through the revival of the mechanistic account of nature in the end of the twentieth century.

Metaphysics being what it is, that is, quite remote from ordinary and scientific experience, you had various doubts about the theories you entertained but at no time did you doubt that there are well-founded answers to the questions you grappled with. Now (that's the beginning of the parable), you are standing at the Pearly Gates about to meet your maker. After the usual introductions (with lots of rhetorical questions on God's part, 'Did you enjoy what you did for a living?,' etc.) God asks you the question you've been waiting and longing for: 'My child, is there anything you'd like to ask me because you haven't been satisfied with the answers you've hit upon yourself?' You gather all the strength you have and say: 'Yes, my Lord, there are indeed quite a few things that gave me sleepless nights and I'd die to find out the answer.' God being very busy replies candidly that only three short questions are allowed. Here is your first: Are there universals? God replies. (Unfortunately, there is no record of his answer.) Here is your second: 'Are there mechanisms in nature?' God reflects for a minute and then replies: 'Certainly! Light reflection,

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chemical bonding, mitosis but also economic crises and demonstrations are mechanisms. Where there is causation, there is mechanism!' Time for the third question, God says. You are puzzled. You collect all of your philosophical might and ask: 'Well, that's a list! Isn't there anything all these, and plenty of others like those in the list, share in common in virtue of which they are *mechanisms*? Isn't there something metaphysically deep that constitutes a mechanism?' God is somewhat upset since as he pointedly remarks these are *two* questions, but, knowing that his interlocutor is a philosopher he let it pass. 'So', you say with genuine aporia in your eyes. 'Well', he says, 'they are all causal pathways described in some theoretical language. That's what they have in common.' And before he parts company he winks and adds: 'I'm afraid you were barking up the wrong tree. "Mechanism" is everywhere as a piece in methodology but not in ontology.'

The Aim and Scope of Our Argument

The very aim of the book at hand is to explain the foregoing reply in detail and to show its plausibility. Lest we are misunderstood, that's not God's reply (who knows what this might be). But it's a possible reply to be assessed as any other philosophical theory.

We should be clear from the outset about the scope of our argument. Let us again distinguish between two questions one may ask about causation, one metaphysical, the other methodological. The metaphysical one concerns how exactly causation bottoms out: Does it bottom out in irreducible productive activities, in the manifestation of powers, in Humean regularities or (perhaps) in primitive difference-making relations? The methodological question is this: If we focus on how scientists discover mechanisms and how experiments are being done, are difference-making relations enough in order to understand scientific practice, or do we need also to say something about the ultimate nature of the truth-makers, if there are any, of these difference-making relations?

Concerning the question about methodology, we claim that if we focus on methodology and the epistemology of practice, difference-making relations should be enough (the case of the cause of scurvy, discussed in Chapter 4, will drive this point home). We do not have to say anything more about the truth-makers of causal claims. So, if one just focuses on the methodological question, one can remain agnostic about the metaphysics. It is in this sense that we described CM as a metaphysically agnostic position.

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Concerning the question of metaphysics, one can, surely, give reasons to prefer some particular metaphysical picture over others. Our point is that whatever else these reasons are, they are not related to scientific practice. That is, what we emphatically reject is a particular kind of strategy of offering arguments in favour of a specific metaphysics of causation: that in order to understand the concept of mechanism *as it is used in the sciences* we need to be committed to a layer of thick metaphysical facts, for example, about activities or powers, as the truth-makers of causal claims.

In fact, in the subsequent chapters we will offer reasons to favour a particular metaphysical picture, namely, a Humean view that grounds difference-making relations in laws of nature understood as regularities, and to reject activities-based views that several mechanists accept. What is important to note however is that the argument against activities and in favour of Humean regularities will not be based on scientific practice. Rather, it will be based on an examination of the philosophical merits of the various specific metaphysical views. This means that if one is not inclined to pose the metaphysical question about causation and wishes to confine oneself to what is licensed by scientific practice, one can adopt CM for the concept-in-use and remain a metaphysical agnostic.

Given our complete view that combines a practiced-based CM with a particular approach to metaphysics, two opposite reactions are possible if one wants to reject our position. One can either opt for a stronger account about the metaphysics of causation, or an even more minimal metaphysical view. Let us be clear about each of them (although a fuller answer will be given in subsequent chapters).

When it comes to the search for stronger accounts that ground difference-making relations to something metaphysically robust, we take the central issue to be whether these accounts can tell illuminating stories about how mechanisms are used in science – we think that they do not. The point can be made as follows: when it comes to the practice of discovering difference-making relations, it does not matter whether we live in a Humean or a non-Humean world containing perhaps irreducible activities; in all cases, scientific practice would be the same and the search for mechanisms equally prevalent. This means, again, that such stronger accounts of causation do not help us understand scientific practice – of course, as noted already, one may have other kinds of reasons to favour a Humean metaphysics, for example, on grounds of conceptual economy.

Accounts of causation that may assume difference-making relations while not requiring an explicit stance on laws rely typically on a notion of variation among the values of relevant variables or invariance under

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interventions, which is less robust than regularity. Our differences with such accounts are less important than the similarities. Hence, they dismiss calls for metaphysically thicker views of causation and focus on how causal statements are established empirically. The key problem with such accounts is to avoid collapsing causation to correlations.

Conceptual Geography

In the book, we draw a number of distinctions and offer a number of characterisations of mechanism. To avoid confusion, we shall try here to offer a map of the conceptual landscape of mechanism.

The central distinction we draw is between the Old Mechanism and the New Mechanism, which is based on two pillars. The first is historical, while the second is conceptual. Old Mechanism emerged as a reaction to Aristotelian natural philosophy; it was foremost a theory of the natural world backed up by a metaphysics of nature. It was an attempt to leave behind the physics and the metaphysics of later scholasticism and to replace it with a new physics. The relation of the new physics with metaphysics was a matter of dispute. The clearest relation was in Descartes's metaphysical physics, to use Dan Garber's apt expression. By contrast, New Mechanism is, by and large, a philosophical re-interpretation of scientific practice and not a new science. As such, it is mostly a new metaphysics of nature. The second pillar of the distinction concerns the key features of the new metaphysics of science. The key feature of the metaphysics of Old Mechanism was that everything material was explainable by reference to shape, size and motion. A mechanism was any configuration of matter in motion subject to laws. By contrast to this 'flat' ontology, New Mechanism takes *any* kind of thing to be a mechanism provided it has a certain structure of entities engaging in activities, the entities and the activities being a lot more 'colourful' than the 'dull' entities (corpuscles) and the 'activities' (forces acting by contact) of Old Mechanism. A bit provocatively put, a mechanism of the new mechanical metaphysics is a matter of structure whereas Old Mechanism is a matter of content.

Occasionally we refer to 'Old Mechanism (narrowly understood)' aiming to draw a distinction *within* Old Mechanism between a narrow (Cartesian) understanding of mechanism as involving contact-action and a more liberal (post-Newtonian) account of mechanism which takes it that a mechanism is any system subject to Newton's laws, namely, the laws of *mechanics*. As Robert Schofield (1970, 15) has argued, post-Newtonian

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mechanists took it that 'causation for all the phenomena of nature was ultimately to be sought in the primary particles of an undifferentiable matter, the various sizes and shapes of possible combinations of these particles, their motions, and the forces of attraction and repulsion between them which determine these motions'. By the time of Henri Poincaré, this more liberal account of Old Mechanism was the dominant one.

This more liberal version of Old Mechanism we call 'mechanical mechanism' and we contrast it with what we call following A. C. Ewing 'quasi-mechanical' mechanism. That's a distinction that can, arguably, be traced to Immanuel Kant's *Third Critique* and is meant to introduce a conception of mechanism such that the properties of the whole are determined by the properties of its parts, but with no particular reference to mechanical properties and laws. Rom Harré has called these mechanisms *generative mechanisms*. They are taken to underpin causal connections: in virtue of them causes are supposed to produce their effects. As Harré aptly put it: 'not all mechanisms are mechanical' (1972, 118). This idea of quasi-mechanism or generative mechanism is a precursor of New Mechanism.

Finally, we draw a distinction between mechanism-of and mechanism-for, which relates to the role of mechanisms in causation. The dominant conception among new mechanists is that a mechanism is *for* a behaviour or function. The function/behaviour of a mechanism determines the boundaries of the mechanism and the identification of its components and operations. For us, however, the notion of a mechanism-for captures the functional notion of mechanism. A mechanism-of is any causal process, irrespective of whether or not a function is performed. We will argue that every mechanism-for is a mechanism-of, but not conversely. The mechanism-for/-of distinction serves to illustrate the fact that some causal pathways have a function and a functional role to play (they are mechanisms-for) while other causal pathways do not (they are mechanisms-of). The distinction then is important for driving home the point that there are mechanisms everywhere (where there are causal pathways) even if there is no function they perform.

The Road Map

Having drawn the conceptual map of mechanism, it's time to move to an orderly summary of the chapters of the book.

In Part I we look at some main aspects of the historical development of the concept of mechanism. This broader narrative is motivated by the

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explicit intention of the new mechanists to link the current mechanical philosophy with its older counterpart in the seventeenth century.

Chapter 1 examines the relationship between Old and New Mechanism and uses it to illuminate the relations between metaphysical and methodological conceptions of mechanism. This historical examination will directly motivate our new deflationary account of mechanism developed in the subsequent chapters. We start by focusing on the role of mechanistic explanation in seventeenth-century scientific practice, by discussing the views of Descartes, Christiaan Huygens, Gottfried Wilhelm Leibniz and Boyle, and the attempted mechanical explanations of gravity by Descartes and Huygens. We thereby illustrate how the metaphysics of Old Mechanism constrained scientific explanation. We then turn our attention to Isaac Newton's critique of mechanism. The key point is that Newton introduces a new methodology that frees scientific explanation from the metaphysical constraints of the older mechanical philosophy. Last, we draw analogies between Newton's critique of Old Mechanism and our critique of New Mechanism. The main point is that causal explanation in the sciences is legitimate even if we bracket the issue of what mechanisms or causes are as things in the world.

In Chapter 2, we continue our historical discussion of mechanistic explanation. The chief purpose of this chapter is to disentangle what we call *mechanical* and *quasi-mechanical* mechanism and point to the key problems they face. We begin by offering an outline of the mechanical conception of mechanism, as this was developed after the seventeenth century. We then present Poincaré's critique of mechanical mechanism in relation to the principle of conservation of energy. The gist of this critique is that mechanical mechanisms are too easy to be informative, provided that energy is conserved. We then advance the quasi-mechanical conception of mechanism and reconstruct G. W. F. Hegel's critique of the idea of quasi-mechanism, as this was developed in his *Science of Logic*. Hegel's problem, in essence, was that the unity that mechanisms possess is external to them and that the very idea that *all* explanation is mechanical is devoid of content. Finally, we bring together Poincaré's problem and Hegel's problem and argue that though mechanisms are not the building blocks of nature, the search for mechanism is epistemologically and methodologically welcome.

Part II develops our own science-first difference-making account of Causal Mechanism.

In Chapter 3 we present the first main part of our case for CM, by discussing in detail apoptosis, a central biological mechanism. We examine

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how Kerr and his co-workers first introduced apoptosis in 1972. We then present the most important stages in scientific research regarding apoptosis during the last decades that led to its identification as a central biological mechanism, explaining the shift from morphological descriptions to biochemical descriptions of the mechanism. We generalise the molecular definition of a pathway to arrive at a more general notion of a causal pathway. We also show that several distinctions used by biologists in order to differentiate between causal pathways and identify the genuine biological mechanisms (active vs passive, programmed vs non-programmed, physiological vs accidental) do not correspond to internal features of causal pathways, but concern an external feature, that is, the role those processes play within the organism.

In Chapter 4 we build on this discussion in order to argue that understanding mechanisms in the CM sense is all that is needed in order to understand biological practice. We clarify the main commitments of our view by presenting three theses that together constitute CM. (1) Mechanisms are to be identified with causal pathways; (2) causal relations among the components of a pathway are to be viewed in terms of difference-making; and (3) CM is metaphysically agnostic. A key point is that, in contrast to mechanistic theories of causation, for CM causation as difference-making is conceptually prior to the notion of a mechanism. We examine in some detail the discovery of the mechanism of scurvy in order to argue that difference-making is what matters in practice. We then turn to the main inflationary accounts of mechanism and contrast them with our deflationary view and its metaphysical agnosticism. We argue that CM offers a general characterisation of mechanism as a concept-in-use in the life sciences that is deflationary and thin, but still methodologically important.

In Chapter 5, we examine the relation between mechanisms and laws/counterfactuals by revisiting the main notions of mechanism found in the literature. We distinguish between two different conceptions of 'mechanism': *mechanisms-of* and *mechanisms-for*. We argue that for both mechanisms-of and mechanisms-for, counterfactuals and laws are central for understanding within-mechanism interactions. Concerning mechanisms-for, we claim that the existence of irregular mechanisms is compatible with the view that mechanisms operate according to laws. The discussion in this chapter, then, points to an asymmetrical dependence between mechanisms and laws/counterfactuals: while some laws and counterfactuals must be taken as primitive (non-mechanistic) facts of the world, all mechanisms depend on laws/counterfactuals.

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In Chapter 6, we defend the *difference-making* thesis of CM, that is, the view that mechanisms are underpinned by networks of difference-making relations, by showing that difference-making is more fundamental than production in understanding mechanistic causation. Our argument is two-fold. First, we criticise Stuart Glennan's claim that mechanisms can be viewed as the truth-makers of counterfactuals and argue that counterfactuals should be viewed as metaphysically more fundamental. Second, we argue against the view that the productivity of mechanisms requires thinking of them as involving activities, qua a different ontic category. We criticise two different routes to activities: Glennan's top-down approach and Phyllis Illari and Jon Williamson's bottom-up approach. Given these difficulties with activities and mechanistic production, it seems more promising to start with difference-making and give an account of mechanisms in terms of it.

Given the centrality of counterfactual difference-making relations to the argument of the book, in Chapter 7 we say a few more things about the contrary-to-fact conditionals. We offer a primer on the logic and the semantics of counterfactuals, focusing on the two main schools of thought: the metalinguistic and the possible-worlds approach. We also present and examine James Woodward's interventionist counterfactuals and the Rubin-Holland model. We argue that the counterfactual approach is more basic than the mechanistic, but information about mechanisms can help sort out some of the methodological problems faced by the counterfactual account.

In Part III we show how our account of Causal Mechanism goes beyond New Mechanism and defend our own Methodological Mechanism.

In Chapter 8 we examine Carl Craver's well-known account of constitutive mechanisms, which takes the organised entities and activities that are the components of the mechanism to constitute the phenomenon to be explained. The main aim of the chapter is to criticise the adequacy of this view for illuminating mechanism as a concept-in-use in biological practice. We identify two main problems for the constitutive view: the problem of external components and the fact that some mechanisms can exist outside the entity the behaviour of which they underlie; we argue that both problems undermine the usefulness and appropriateness of viewing typical and paradigmatic cases of biological mechanisms in constitutive terms. The main claim of the chapter is that in order to understand the notion of mechanism as a concept-in-use, there is no need to posit a non-causal relation of constitution.

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In Chapter 9 we present and defend a causal account of multilevel mechanistic explanation by examining various case studies from biology. We argue that two key consequences of Causal Mechanism are: (1) that levels and mechanisms are distinct notions and (2) that levels of multilevel explanations are levels of composition. This view is in stark contrast to Craver's account according to which levels in multilevel explanations are levels of mechanisms and multilevel explanations are instances of constitutive explanations. A key claim of the chapter is that whatever contributes to the phenomenon is part of the same pathway; but causal pathways can contain entities from multiple levels of composition. In order to motivate and illustrate our view, we use various examples from biology and medicine. We criticise some common views associated with the picture of a hierarchy of mechanistic levels and argue that our view allows for causation at higher levels.

In Chapter 10 we pick up the various threads and defend the main thesis of the book (Methodological Mechanism), namely, the claim that to be committed to mechanism is to adopt a certain methodological postulate, that is, to look for causal pathways for the phenomena of interest. We compare our view of Methodological Mechanism with an important discussion by Joseph Henry Woodger (1929) concerning the meaning of mechanism, which has been ignored in current discussions, as well as with the views of Robert Brandon. We then formulate a dilemma that new mechanists face; the dilemma arises from the unstable combination of two main tenets of New Mechanism, an ontological and a methodological one, both of which depend on the general characterisation of mechanism but that pull in opposite directions. We argue that CM is able to resolve the dilemma, by providing the best defence of the methodological tenet of New Mechanism, while at the same time preventing the adoption of a robust version of the ontological tenet.

In the last chapter, the Finale, we examine to what extent CM can be seen as a descendant of the original notion of mechanism developed in seventeenth century, by examining possible extensions of the seventeenth-century notion of mechanism and discussing whether they can be used to characterise mechanism as a concept-in-use.

In sum: Methodological Mechanism is mechanism enough.

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