CHAPTER 2

Singular Compositional Explanations

If there were such a thing as a complete theory of scientific abduction – a complete theory of all the types of abductive inferences scientists use – it would include a complete theory of all the types of explanations used in scientific abductive inferences. This book develops a fragment of such a hypothetically complete theory. It is a theory of some, but likely not all, scientific abductions. This chapter, therefore, introduces a theory of some, but likely not all, scientific explanations.

There is, of course, a large philosophical literature dedicated to scientific explanation. A theory of scientific compositional explanation alone could constitute a book. However, since this book is on scientific compositional abduction, space must be left for the inference theory. Moreover, space must be left to show that the theory of compositional abduction is, in fact, a descriptively accurate account of at least some actual scientific reasoning. And many philosophers will want to know how the view of compositional abduction developed here relates to a wide range of potentially divergent views. So, there must be attention to that. To accommodate all this, the account of explanation given here will be relatively brief – just two chapters. It will leave aside many qualifications, justifications, and references to the philosophical literature. Because of space limitations, my goal in this chapter is primarily to orient the reader to my view, rather than to persuade the reader of my view. Many of the ideas in this chapter will be relatively familiar – even if objectionable – to those working on the philosophy of scientific explanation. In contrast, the principal ideas in Chapter 3 will be new. They are ideas that are necessary in an account of scientific compositional abduction that is of passably broad scope. They are ideas that arise from the interaction between philosophical theorizing and the examination of historical cases.

The theory developed here begins, in Section 2.1, with a realist conception of explanation, according to which an explanation is a representation of an ontological dependence relation. To flesh out this conception, one

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

needs to specify the entities standing in the ontological dependence relation(s), the ontological dependence relation(s), and the representation of these. Section 2.2 presents the ontological part of this story, whereas Section 2.3 reviews the representational. The entities standing in the ontological dependence relation(s) are spatiotemporal particulars that fall into three ontological categories, namely, individuals, activity instances, and property instances. There are three ontological dependence relations: constitution, implementation, and realization. These entities and their relations need not be represented by arguments, but may rely upon a wide range of representational formats, such as images, sentences, or tables. On this account, there is a genus of explanation, singular compositional explanation, of which there are three species corresponding to the three ontological categories. This constitutes a positive account of a plurality of distinct singular compositional explanations. Section 2.4 argues that singular compositional explanations are members of a genus of explanation.

2.1 A Realist Conception of Explanation

To introduce the realist conception of explanation that I take scientists to embrace, I begin with an empiricist foil, more specifically, an empiricist version of the Deductive Nomological (DN) model of explanation.[1] I add the qualification "an empiricist version" as my expository purposes will be served even if other versions of the DN model do not have the features I note.[2] Further, my expository purposes will be served even if the version does not do justice to the nuances of any particular philosopher's views.[3] To put the matter another way, at this point, I do not intend to do serious history of philosophy. Instead, I am doing theory exposition.

On the empiricist DN model, as I envision it, the explanation of a singular fact or event is a deductive proof of a statement expressing the thing to be explained – an "explanandum statement" – from statements expressing one or more laws and one or more particular facts – the

[1] The phrase "conception of explanation" is borrowed from Salmon (1984b). Bokulich (2018) uses the term in the same way. By contrast, the compositional explanations that I describe in this chapter are what Bokulich would call "accounts of explanation."

[2] Other philosophers have hinted at, or defended, realist versions of the DN-model. For example, Jaegwon Kim comments that "appropriate D-N arguments are particularly perspicuous as a vehicle for conveying causal information" (Kim, 1994, p. 55). Strevens (2008, 2012) offers a theory of explanation in which deductive (and other representative) relations are supposed to mirror causal relations.

[3] Salmon (1984a) sees Hempel as wavering on the "empiricist conception," whereas Kim (1994) sees Hempel as endorsing this version.

"explanans statements." This may be presented in a familiar schema for the model,

$$\begin{array}{l} C_1, C_2, \ldots, C_m \\ L_1, L_2, \ldots, L_n \\ \hline E, \end{array}$$

where $C_1, C_2, \ldots, C_m$ are the statements of the particular facts, $L_1, L_2, \ldots, L_n$, are law statements, and E is a statement of the fact to be explained. The deductive relation between the premises and the conclusion means that by accepting the truth of the premises and seeing the validity of the deduction, one has reason to accept the truth of the explanandum statement. In other words, the soundness of the argument makes the event to be explained "rationally expectable." One must incorporate further details into the model, but these suffice for present purposes.

This empiricist version of the DN model has two features that are "non-worldly." First, any ontological relation between the entities in the world that are mentioned in the explanans sentences, on the one hand, and in the explanandum sentence, on the other, are set aside in favor of a logical deductive relation between the explanans sentences and the explanandum sentence. In this model, what does the explanatory work, so to speak, is the logical deductive relation. The second "non-worldly" feature of the model is that it makes the event described by the explanandum sentence in some sense rationally expectable. If one accepts the truth of the explanans sentences and recognizes the entailment, then one has some reason to infer the truth of the explanandum sentence. As I understand this model, one of the principal strengths of the idea that explanations are a species of valid deductive arguments is that it enables empiricists to give an account of something that looks plausibly like explanation but avoids metaphysical commitments about ontological dependence relations among things in the world.

"Non-worldly" empiricism slights what I take to be most scientists' interest in what happens in the world. One might have the sentences, "All sodium salts burn orange in a Bunsen burner flame" and "X is a sodium salt" that entail "X burns orange in a Bunsen burner flame," but what scientists seek in at least some explanations is an accounting of how worldly features of X led to its burning orange when placed in the flame of a Bunsen burner. What is it about that sample of sodium salt – that spatiotemporally localizable individual in the world – that made it burn orange? More generally, what in the world "links" the entities mentioned in the explanans sentences to the entities mentioned in the explanandum sentence? Insofar as a version of the DN model denies that something about being a sodium salt makes it burn orange, that version is empiricist. Insofar as a version of the DN model renders an explanandum sentence rationally expectable, rather than specifying what in the world brought about the circumstance to be explained, the version is empiricist.

A realist conception of compositional explanation – in contrast to an empiricist conception – invokes something over and above the logico-linguistic.[4] Explanation is not merely representational, nor is it merely ontological. On a realist conception, a compositional explanation has both representational and ontological components. On a realist conception, a singular compositional explanation is a representation of a real compositional relation between things in the world that are to be explained and things in the world that are to do the explaining.

One of the attractive features of explanatory realism is that it offers a diagnosis of the problems underlying many of the famous counterexamples to the DN model of explanation. As is well-known, one might have a proof of a height-of-a-flagpole sentence that includes a length-of-the-shadow sentence, but this is not an explanation of the height of the flagpole. The realist diagnosis is that the logical relation is not explanatory. It does not do explanatory work. The length-of-the shadow "explanation" of the height of the flagpole does not work, since the length of the shadow does not ontologically determine the height of the flagpole. Further, pressing the point, it is not the logical relation between the height-of-the-flagpole sentence and the length-of-the-shadow sentence that does explanatory work. Instead, the work is done by the ontological dependence of the length of the shadow on the height of the flagpole. Consider another familiar objection to the DN model. Scientists do not explain a man's not becoming pregnant in terms of that man's taking birth control pills. There may be logical relations between sentences, but what is missing is the ontological dependence between taking a man's taking birth control pills and his not becoming pregnant. Another example: the change in the barometer reading does not explain the storm, since the storm does not ontologically depend on the barometer reading.

[4] My terminology borrows from Kim (1994), who developed his view, in part, through an examination of Wesley Salmon's three conceptions of explanation. See, for example, Salmon (1984a, 1984b). Kim's terminology has been adopted by various epistemologists, for example, Taylor (2018), Roski (2021), and McCain (2022), but has been all but ignored by New Mechanists.

I should emphasize here that, consistent with my metatheory described in Chapter 1, my goal is not, strictly speaking, to advance a realist theory of explanation *simplicter*. I do happen to hold this theory, but championing that theory is not my point in this book. Instead, consistent with the metatheory described in Chapter 1, my goal is to describe a realist theory of explanation that I think scientists have sometimes implicitly employed. What I am proposing, then, is that, in the case studies of Chapters 5 and 6, scientists are realists when it comes to explanation. The qualification regarding the case studies is not a mere hedging of bets. It is meant to recognize that some scientists have rejected the idea that science aims to offer explanations. Famously, Karl Pearson claimed that "Nobody believes that science explains anything; we all look upon it as a shorthand description, as an economy of thought" (Pearson, 1911, p. viii).[5] Here, I will take Pearson at his word that he, at least, did not aim to offer scientific explanations. Nevertheless, Hodgkin and Huxley, among others, did accept that scientists offer explanations.

To make this last point in another way, in my case studies, scientific work did not reflect the logical empiricist thinking about explanation that dominated mid-twentieth-century philosophy of science and that has continued to cast a long shadow over the philosophy of science up to the present. Similarly, as I will argue in Chapter 4, scientific work did not reflect logical empiricism's commitment to HD confirmation. Contemporary philosophical theories of how scientists explain and confirm need to move beyond empiricist interpretations of science.

2.2 The Ontology of Compositional Explanations

Once one attributes to a scientist a realist conception of compositional explanation – one that admits roles for both representation and ontology – something must be said about both the representational and ontological. I begin with the ontological in Section 2.2, so that it will be clearer what the representations represent in Section 2.3.

To address the ontological side of things, one may ask a deliberately broad question, "What in the world do scientists think is involved in a compositional explanation?" The answer has two parts. There are (1) the entities in the explanandum and the explanans and (2) the compositional relation or relations between the entities in the explanandum and the explanans. In other words, there are the relata of explanatory relations and

[5] Cited in Salmon (1984a). Also discussed by Oleksowicz (2023).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

the compositional relation(s) between them. Section 2.2.1 will describe the proposed relata; Section 2.2.2 will describe the proposed relations.

2.2.1 *The Relata of Compositional Relations*

My theory of compositional explanation focuses on singular compositional explanations. These are compositional explanations scientists sometimes give of spatially localizable, temporally datable particulars. Such explanations include explanandum and explanans entities that fall into at least three distinct ontological categories: individuals, property instances of individuals, and activity instances of individuals. Here, I provide illustrations of each of these ontological categories related to the case study to be presented in Chapter 5.

J. Z. Young is widely credited with the discovery of the squid giant axon, an axon many times larger than other axons known at the time.[6] In short order, this discovery became fundamental to enabling intracellular recordings of axonal activity.[7] Table 1 of Young (1936) reports the number of axons (individuals) counted in nerves (larger individuals) dissected from squid at the Marine Biological Station at Plymouth in the United Kingdom in 1935. Young indicated that various nerves in the dissected squid were made up of these axons. More technically, Young indicated that these axons would provide a singular analytical compositional explanation of what made up the squid nerves. In cases like this, the explanandum and the explanans entities were individuals.

Consider one of Hodgkin and Katz's experiments with intracellular recording. Hodgkin and Katz (1949a) report values for the resting potentials (property instances) of multiple individual squid axons measured at Plymouth, recorded sometime during the summer of 1947. Hodgkin and Katz, in time, concluded that the resting potential of a cell (a property instance of an individual) is explained in terms of the charges on intracellular and extracellular ions (instances of other properties of other individuals).

Hodgkin and Huxley (1952a) illustrate currents in squid axons no. 15 and no. 21 measured at Plymouth during the late summer of 1949. These are multiple activity instances of two individuals. Eventually, Hodgkin and Huxley concluded that these currents are explained by sodium and potassium ions moving across the axonal membrane.

[6] Young (1936). [7] Hodgkin and Huxley (1939), Curtis and Cole (1942).

The preceding examples of individuals, property instances, and activity instances from the work of Young, Hodgkin, Huxley, and Katz are just that, examples. What about some characterization of them? Here, I will offer less than a definition of these items, something less than a set of necessary and sufficient conditions for them. I will, however, draw attention to some of the characteristics of individuals, property instances, and activity instances and indicate some of the ways they are interrelated.

Scientists presuppose that individuals bear property instances. An individual human being may have an instance of normal color vision. An individual molecule of gamma-aminobutyric acid (GABA) will have instances of properties of size, shape, and charge. The property instances of an individual may be manifest or latent relative to some activity. An instance of normal color vision may manifest or reveal itself in human color perception when an individual human takes a color matching test, such as the Farnsworth Munsell 100 hue test or the Ishihara test. By contrast, an instance of normal color vision may be latent relative to seeing colors as when that person is asleep or trying to see in very low light. Instances of the size, shape, and charge of a GABA molecule may manifest themselves in the activity of the molecule's binding to a receptor, but some of the instances may remain latent relative to the activity of binding when the molecule is contained in a synaptic vesicle.

The qualifier "relative to some activity" is meant, in the first place, to capture the fact that property instances can manifest themselves in different ways. So, for example, the dipole moment of a single water molecule – a property instance – might manifest itself in an activity instance of forming a hydrogen bond that raises the boiling point of water. Alternatively, that instance of the dipole moment might manifest itself in an increase in the distance between two molecules of water as they align during the freezing and expanding of water. The qualifier is also meant to avoid a commitment to holding that a property instance is ever absolutely latent, that it does not manifest itself in any activity instance at all. The dipole moment of a water molecule might not manifest itself in an activity instance of freezing or boiling, but there might remain some other activity instance in which it is manifest. Maybe the dipole moment of a molecule always manifests itself in some activity or another.

I have just assumed that scientists presuppose that individuals have property instances and engage in activity instances. Scientists take property instances and activity instances, however, to differ in at least three respects. First, whereas property instances may be latent or manifest, activities are always manifest. Second, activity instances have rates, whereas property instances do not. Third, property instances enable activity instances.

First, whereas property instances may be either manifest or latent, activity instances are always manifest. By "manifest," I do not mean that activity instances are always measured or detected by scientists. Instead, I mean merely that activity instances are active. They are doings. Visually discriminating a numeral in one of the Ishihara plates is an instance of an activity. A capacity for visually discriminating a numeral in one of the Ishihara plates, a property instance, is not the same thing as the activity of discriminating a numeral. Binding to a receptor is an instance of an activity. A capacity for binding is not the same thing as an activity instance of binding.

Property instances differ from activity instances in a second regard. Since an activity instance is a doing, it is something that takes time. Visually discriminating a numeral in an Ishihara plate or binding to a receptor takes time. Activity instances can, therefore, have associated rates. There are rates at which numerals in Ishihara plates can be visually discriminated and rates at which GABA molecules can bind to receptors. Thus, activity instances have rates, whereas property instances do not.

Property instances differ from activity instances in a third respect: property instances enable activity instances.[8] A property instance of S during some temporal interval t_0-t_1 may enable an activity instance of S during t_0-t_1. A human's having an instance of normal color vision enables that individual to discriminate numerals in an Ishihara plate. Instances of the size, shape, and charge of a GABA molecule enable that molecule to bind to receptors.

There are three key features of enabling: (1) it is an intra-individual relation, so it is not a compositional relation, (2) its relata are contemporaneous, so it is not a causal relation and (3) it is an ontological dependence relation. Consider these features in order. If there is a property instance of S, it may enable an activity instance of S. Enabling is an intra-individual relation. Thus, "enabling," as I use it, is not a term for a compositional relation. It is not a relation between an individual, property instance, or activity instance at one level and an individual, property instance, or activity instance at another level. If a property instance enables an activity instance during t_0-t_1, then the property instance and the activity instance occur during the same window of time. The property instance and the activity instance are contemporaneous. This feature indicates that the

[8] See, for example, Craver and Darden (2013, pp. 16f, 78f). Craver and Darden do not provide an account of what they mean by "enabling."

enabling relation is not a causal relation, since causes are taken to temporally precede their effects. Nevertheless, enabling is an ontological dependence relation. Were S not to have property instance F during t_0-t_1, then it would not engage in activity instance Ψ during t_0-t_1. If a water molecule were not polar during t_0-t_1, then it would not engage in forming hydrogen bonds during t_0-t_1. What all this suggests is that there are noncausal, noncompositional "enabling explanations" which are representations of ontological dependence relations. As important and undertheorized as are these explanations, their further investigation goes beyond the focus of this book.

To be clear, as I use the term, "enable" is not supposed to be a term of ordinary language. Instead, it is another technical philosophical term used to describe the relation between some property instances and some activity instances. So, one might say in ordinary English that the extinction of the dinosaurs enabled the rise of mammals, but that is not the sense of "enable" I have in mind. In offering this account of enabling, I do not mean to stipulate how I will use a term. Instead, I am offering a theory of a putative relation between property instances and activity instances. Philosophers of science should feel free to offer reasons to believe that this account is mistaken.

These three features are far short of a complete characterization of how scientists understand the differences between property instances and activity instances. Nevertheless, the features do provide a *prima facie* basis for them. Further, having the distinction between property instances and activity instances provides a tool for a more detailed, accurate description of scientific work.

Contrast this ontological framework of individuals, activity instances, and property instances with the New Mechanist framework. New Mechanists often propose a "dualist" ontology of what they sometimes call "entities" (close to what I mean by "individuals") and "activities."[9] For one thing, my framework is explicitly formulated in terms of spatiotemporal particulars. The choice of "activity instances" and "property instances" over "activities" and "properties" is meant to make this clear. For another, where I recognize three ontological categories, New Mechanists propose two. To preserve their dualism, some New Mechanists may propose to use the term "activity" to cover both activities

[9] Cf., for example, Machamer et al. (2000), Craver (2007), Illari and Williamson (2012), Craver and Darden (2013), Kaiser (2017), and Krickel (2018a). For variants of this dualism, see Bechtel and Abrahamsen (2005) and Bechtel and Richardson (2010).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

and properties. This terminological proposal saves the New Mechanist dualism from a simple counterexample. Nevertheless, the goal here is to develop a philosophy of science that provides a descriptively adequate account of scientific compositional abductive reasoning regarding experimental results. To this end, there needs to be some distinction between activities and properties. The New Mechanist who would use "activities" to cover both activities and properties would still need a distinction between two subtypes of "activities." One subtype would correspond to the "activity activities" and the other to the "property activities." The issue for the New Mechanist dualism is not that it falls prey to a counterexample; it is that it needs more theoretical detail. A descriptively adequate philosophy of science needs at least three ontological categories.

Before moving on, let me add a methodological clarification. Sometimes metaphysicians propose "analyses" of these ontological categories. Machamer et al. (2000) mentions philosophical attempts to analyze, define, reduce, or understand the activities of individuals in terms of properties at instants.[10] It also mentions proposals by process metaphysicians to reduce individuals to activities.[11]

Such philosophical analyses are orthogonal to my purposes. Most importantly, as noted in Chapter 1, I am not engaged in metaphysics. I am not developing a theory of the (fundamental) structure of reality. I am developing a theory of what scientists believe exists and how they reason. Further, even within the scope of my efforts to understand scientific compositional abduction, it suffices to say that scientists typically treat these ontological categories as basic. Maybe in some journal article somewhere, some neuroscientist or psychologist offers an analysis, definition, or whatever, of individuals in terms of processes, or whatever. In my case studies, however, physiologists and psychologists treat the ontological categories of individuals, property instances, and activity instances as basic. For my part, I will abide by this.

2.2.2 *Compositional Relations*

Turn now from the relata in scientific compositional explanations to the scientific compositional relations. My argument for thinking that scientists believe in these relations is that this makes sense of the scientific idea that putative lower level entities generate or produce higher level entities. These relations flesh out what realists think is really in the world underlying

[10] Machamer et al. (2000, p. 4). [11] Machamer et al. (2000, p. 5).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

Table 2.1 *Scientific compositional relations*

Type of entity	Compositional relation
Individuals	Lower level individuals together *constitute* a higher level individual.
Activity instance	Lower level activity instances together *implement* a higher level activity instance.
Property instance	Lower level property instances together *realize* a higher level property instance.

explanations, but what empiricists deny is really in the world. I will offer only some brief comments indicating some of the features scientists take these relations to have and how these differ from other noncausal relations. Defenders of some of the alternative accounts will find my treatment superficial, but again my goal here is mainly expository rather than polemical.

As broached in the Introduction, I propose that scientists are committed to at least three compositional relations – constitution, implementation, and realization – that obtain between individuals, activity instances, and property instances, respectively. Table 2.1 summarizes these relations. Scientists implicitly assume these relations have seven features: (1) they are many-one relations, (2) they are asymmetric, (3) they are transitive, (4) they are relations of natural dependence, (5) they do not involve the transfer of mass-energy, (6) their relata are contemporaneous, and (7) their relata are not wholly distinct.[12]

As mentioned in Chapter 1, compositional relations are many-one relations. Many sodium ions moving across an axonal membrane implement an axon's inward current. Three instances of the electronegativity of atoms of hydrogen and oxygen realize the polarity of a water molecule. Many photoreceptor cells constitute a retina.

Scientists treat constitution, implementation, and realization as asymmetric relations. This reflects the asymmetry of many scientific compositional explanations. Scientists explain what a molecule is made of by citing its atoms, but not vice versa. Scientists explain the action potential in terms of ion fluxes, but not vice versa. Scientists explain the dipole moment of a

[12] For a longer, slightly different list, see Gillett (2016). Note that, strictly speaking, in the literature, these seven ideas typically take the form of metaphysical claims about composition and causation, rather than, as here, the form of descriptive claims about what scientists take composition and causation to be like.

hydrogen fluoride molecule by appealing to the electronegativity of its constituent atoms, but not vice versa.

Although the asymmetry assumption is widely accepted, it is not universally accepted. Craver has proposed that "Constitutive relevance is symmetrical in a way that etiological (that is, causal) relevance typically is not. . . . all constitutive dependency relationships are bidirectional" (Craver, 2007, p. 153).[13] The symmetry assumption plays an important role in Craver's motivation for his "mutual manipulability" account of the testing for constitutive relevance: "This is the core reason why constitutive relevance should be understood in terms of mutual manipulability rather than in terms of the unidirectional variety" (Craver, 2007, p. 153). Thus, abandoning the symmetry assumption would undercut "the core reason" for *mutual* manipulability. This is a point to which I will return in Chapter 10.

Scientists treat constitution, implementation, and realization as transitive relations. Scientists maintain that protons, electrons, and neutrons constitute atoms and that atoms constitute molecules, so that protons, electrons, and neutrons constitute molecules. Scientists propose that ion fluxes implement an action potential of a cell and that action potentials of cells implement an activity instance of a small neuronal circuit, so that ion fluxes implement an activity instance of a small neuronal circuit. Scientists take the electronegativities of hydrogen and oxygen atoms and the bond angles in an H_2O molecule to realize the polarity of that molecule and they take the polarity of water molecules to realize the buoyancy of an ice cube in water, so that they take the electronegativities of hydrogen and oxygen and the bond angles in an H_2O molecule to realize the buoyancy of an ice cube in water.

A fourth feature of the scientific concepts of constitution, implementation, and realization is that they are natural dependence relations. By this I mean that scientists presuppose that these relations obtain only under certain background conditions, the most familiar of which are temperature and pressure. Squid giant axons only constitute nerves under certain temperatures and pressures. Extreme highs or lows destroy the axons and nerves. As Hodgkin, Huxley, and Katz sometimes noted in passing, resting and action potentials are sensitive to temperature. Again, extreme highs and lows destroy the axon, hence their resting and action potentials. Natural dependence relations, such as constitution, implementation, and realization, differ from "non-natural" dependence relations in this regard.

[13] See Schindler (2013) for a critique of Craver's view. See Krickel (2024, p. 14) for a more recent endorsement of this view.

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

Logical and semantic entailment, for example, do not hold under background conditions.

A fifth feature of compositional relations, as scientists conceive them, is that they are "mass-energy neutral." Consider again the water molecule. The two hydrogen atoms and the oxygen atom have some mass-energy. When covalently bonded, these atoms form a not wholly distinct entity, a water molecule. This molecule, however, does not have mass-energy over and above the mass-energy of the constituent atoms. (This is not to deny that the bonding of separate atoms releases energy.) Contrast the compositional case with a case of adding an atom. Three hydrogen atoms and an oxygen atom have greater mass-energy than the two hydrogen atoms and the oxygen atom. In this case, the addition of a distinct entity does increase mass-energy.

The compositional relations to which scientists are committed are distinct from the causal relations to which they are committed based on the assumption that causes must precede their effects, whereas composing entities are contemporaneous with the composed entity. This marks a sixth feature of compositional relations. An individual water molecule is contemporaneous with its individual constituent atoms of hydrogen and oxygen being covalently bonded. An individual red cone opsin Red (Ser^{180}) – the human red cone opsin having a serine in position 180 – is contemporaneous with the chain of individual amino acids that constitute it. A property instance of buoyancy in an individual cork is contemporaneous with the property instances of impermeability of the cork's individual constituent cells. A property instance of the dipole moment of an individual water molecule is contemporaneous with the property instances of the electronegativities of the molecule's constituent atoms. An activity instance of an initial inward ionic current of an individual squid giant axon is contemporaneous with the activity instances of individual sodium ions moving into the cell. An activity instance of an individual ion channel opening is contemporaneous with the activity instances of the movement of the channel's individual constituent monomers. Notice that when many instances of x_i ϕ_i-ing implement S Φ-ing from t_0 to t_1, the assumption is not that each of the x_i ϕ_i-ing is engaged in its activity instance throughout t_0-t_1. Instead, it is that from t_0 to t_1 there is some x_i ϕ_i-ing. The influx of sodium ions is a clear illustration. For the duration of the initial inward current from t_0 to t_1, there are sodium ions entering the axon. There is, however, no single sodium ion that spends the entire interval t_0-t_1 crossing the axonal membrane.

To forestall a possible confusion, recall that, back in Section 2.2.1, I proposed that one feature of the enabling relation is that its relata are

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

contemporaneous. During t_0-t_1, a property instance enables some activity instance. In this section, I have proposed that the relata of the compositional relations constitution, implementation, and realization are contemporaneous. This is an empirical hypothesis about how scientists treat these relations. There is nothing mysterious about enabling, constitution, implementation, and realization all involving contemporaneously existing relata. This is no more mysterious than various relations, such as being older than, being heavier than, or being larger than all being transitive relations.

In drawing the preceding distinction between how scientists implicitly understand causation and composition, I assume that I am describing what other philosophers have described in terms of diachronic versus synchronic relations.[14] The idea that causes temporally precede their effects is sometimes described by saying that the causal relation is diachronic. The idea that the composed is contemporaneous with the composing is sometimes described by saying that compositional relations are synchronic.

Some philosophers (critical of the causation/ composition distinction), however, interpret the diachronic/synchronic terminology differently.[15] They assume that the idea is that the diachronicity of causal relations means that this relation exists over time, whereas the synchronicity of compositional relations means that these relations hold only at an instant. They then point out that such a synchronic compositional relation does not correctly describe scientific cases, so that a new conception of compositional relations is needed. While I take such critics of the diachronic/synchronic distinction to be uncharitable in their reading, I will agree with them that their version of the diachronic/synchronic distinction does not capture the scientific compositional cases. My term "contemporaneous" is meant to capture the fact that compositional relations hold over an interval of time and that the composed and composing stand in this relation.

Consider yet another clarification. Scientists treat many of the relata of compositional relations as dynamic. The relata in a single relation change over time. To take an unproblematic feature, water molecules and proteins oscillate. However, one should not infer, simply on that basis, that scientists think that the compositional relation must also be dynamic. The dynamic character of the *relata* is insufficient basis for thinking that the *relation* is dynamic. This is no more remarkable than the idea that two individuals may remain siblings even as they age.

[14] See, for example, Craver and Bechtel (2007), Gillett (2016), and Bennett (2017).
[15] For example, Kirchhoff (2013).

There is an important, but underappreciated, implication of the idea that compositional relations are between contemporaneous particulars. In many instances, scientists propose to explain, say, an instance of a rat's behavior by reference to activity instances of parts of the rat's brain, as in the computations in a hippocampal cognitive map. If we take an instance of the rat's behavior to be S Ψ-ing and an instance of the hippocampus's activity as x_i ϕ_i-ing, then strictly speaking the x_i ϕ_i-ing will not be contemporaneous with S Ψ-ing. The behavior instance of S Ψ-ing can begin before the activity instances x_i ϕ_i-ing begin. Maybe the behavior begins with a movement of the rat's head or eyes. Further, the S Ψ-ing can continue after the activity instances x_i ϕ_i-ing cease. Maybe the behavior instance includes contractions in the rat's leg muscles. In notation, for successive times t_o, t_1, t_2, t_3, S Ψ-ing can occur during the interval t_o-t_3, whereas the x_i ϕ_i-ing occurs during the interval t_1-t_2. More succinctly, the explanans x_i ϕ_i-ing will not be contemporaneous with the explanandum S Ψ-ing. *A fortiori* the x_i ϕ_i-ing will not stand in the implementation relation to the S Ψ-ing. How is the scientific practice to be reconciled with the philosophical theory of compositional relations?

Sticking with the case of activity instances, the reconciliation I propose is that scientists accept the x_i ϕ_i-ing as an explanation of the S Ψ-ing if they believe the x_i ϕ_i-ing implement a "contributing" activity instance S Ψ_C-ing for S Ψ-ing. In general, the contributing activity instance S Ψ_C-ing is not named or specified, but it is assumed to be an activity of S and is assumed to be contemporaneous with the x_i ϕ_i-ing. This is a loose description of a contributing activity instance. Probably inadequate as a characterization. Still, the idea is that a hippocampal activity instance explains rat navigation on the assumption that the hippocampal activity compositionally explains a contributing activity instance of the navigation. If one were to add some terminology, one might say that scientists accept a "derivative compositional explanation" of S Ψ-ing in terms of x_i ϕ_i-ing, if there is a compositional explanation of S Ψ_C-ing in terms of x_i ϕ_i-ing.

Consider another example of the importance of contributing activity instances. In Chapter 6 we shall see that scientists often look to activity instances of retinal ganglion cells (RGCs) as offering an explanation of instances of the Hermann grid illusion. RGCs do not compositionally explain the *experience* of the illusion. Assuming that the experience is implemented in the cortex, RGCs do not explain the experience, since they are found in the retina. Instead, what scientists have in mind is that RGCs offer a derivative explanation of the *perception* of the illusion, where an activity instance of perception is implemented by activity instances in the retina, the optic tract, and various regions of the cortex. The RGC activities offer a derivative compositional explanation of an instance of the perception of the Hermann grid illusion because they provide a compositional explanation of an activity instance S Ψ_C-ing that contributes to the perception of the illusion. In this regard, the RGC example differs from another example to be discussed in Chapter 10. In Chapter 10, I will review an example wherein certain cortical cells are thought to implement an experience of a sensation of flutter. Many examples of compositional explanation in cognitive science are plausibly interpreted as "derivative compositional explanations."

The Hodgkin–Huxley theory of the currents associated with the action potential provides a valuable contrast with the foregoing cases. One of Hodgkin and Huxley's many achievements was to recognize the total ionic current as the sum of a capacity current, a sodium current, a potassium current, and a leak current. Hodgkin and Huxley developed a compositional explanation of the capacity current in terms of the movements of charge up to the axonal membrane. Further, they developed compositional explanations of each of the ionic currents in terms of movements of ions across the axonal membrane. Each current, however, is a contributing activity instance of an instance of a total current. In other words, part of what the equation $I_{tot} = I_C + I_{Na} + I_K + I_{leak}$ tells us is that an instance of a capacity current, I_C, an instance of a sodium current, I_{Na}, an instance of a potassium current, I_K, and an instance of a leak current, I_{leak}, are contributors to a total current instance, I_{tot}. So, one might say, informally, that sodium influx explains part of the action potential. More formally, one might say that sodium influx compositionally explains the sodium current, the potassium efflux compositionally explains the potassium current, . . ., which explains the action potential.

Finally, the seventh feature of the scientific conception of compositional relations is that their relata are not wholly distinct. In a causal relation, the individual associated with the cause is wholly distinct from the individuals associated with the effect.[16] In the New Mechanist literature, Craver and Bechtel defer to David Lewis:

> C and E must be distinct events – and distinct not only in the sense of nonidentity but also in the sense of nonoverlap and nonimplication. It won't do to say that my speaking this sentence causes my speaking this sentence or that my speaking the whole of it causes my speaking the first

[16] Cf., for example, Lewis (2004) and Craver and Bechtel (2007).

half of it; or that my speaking causes my speaking it loudly, or vice versa. (Lewis, 2004, p. 78; cited in Craver & Bechtel, 2007, p. 552)

Compositional relations allow the violation of the nonoverlap condition. An individual water molecule "overlaps" with its hydrogen and water atoms. An individual cork having a property instance of being buoyant overlaps with its individual constituent cells having property instances of impermeability to water. An individual ion channel engaged in an activity instance of opening overlaps with its individual constituent protein monomers engaged in their activity instances of moving.

Before moving on I should note one feature that does not make the list: spatial containment.[17] It is sometimes said that, in a compositional explanation of an activity instance of an individual, the explanans individuals are spatially contained in the explanandum individual. Accordingly, the compositional relation should have the individuals cited in the relata of the explanans be spatially contained in the individual cited in the relatum of the explanandum. Although the spatial containment condition is often satisfied, it is clearly violated in the case of the axonal currents during the voltage clamp. The initial inward sodium current is ontologically determined by the influx of sodium ions into the axon and is obviously a case of individuals not spatially contained in the axon entering the axon. The late outward current is ontologically determined by the efflux of potassium ions and is obviously a case of individuals spatially contained in the axon leaving the axon. The same story might be told in terms of the action potential, rather than axonal currents. Moreover, there are large classes of cases where the spatial containment relation is not respected. When an individual melts, the components of that individual cease to be spatially contained in the individual. When a liquid freezes to form an individual crystal, individuals that are not spatially contained in the crystal come to be spatially contained in the crystal. There is a parallel story to be told in terms of sublimation and desublimation. It is because of violations of the spatial containment condition that I sometimes refer to "associated" parts, where I use "associated" as a black box term that is meant to encompass the cases of nonspatially contained parts.

One might, of course, try to save the spatial containment requirement. One might postulate that, in cases of the action potential, melting, freezing, sublimating, desublimating, and so forth, the explanandum individual is a system and the explanans individuals are spatially contained

[17] See, for example, Krickel (2020, 2024).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

parts of this system. While that would technically work, it would be *ad hoc*. What is the evidence that, say, Hodgkin and Huxley drew a distinction between the axon and a larger "axonal system"? Are there instances where scientists postulate ice cubes along with "ice cube systems?"

At various points in my discussion I have referred, and will refer, to a notion of "levels." The topic of levels is the subject of its own vigorous philosophical debate, most of which I will avoid as tangential to my concerns.[18] Pre-theoretically, I assume that an organism's brain is at a lower level than the organism, that an organism's cells are at a lower level than the organism, and that ions are at a lower level than a cell. These assumptions will cover what is needed for the cases studies in Chapters 5 and 6. Further, these are assessments that, *prima facie*, a theory of levels should capture. Although I will not defend a theory of these levels here, if pressed, I would turn to a version of Gillett's "Integrative Account of Levels."[19]

To this point in the chapter, I have been developing a realist conception of explanation that I take to be implicit in scientific work. According to this conception, an explanation is a representation of a compositional ontological dependence relation between entities in at least three distinct ontological categories. Something like this conception can be found in diverse subdisciplines of philosophy, albeit with distinct commitments regarding the ontological dependence relation. By and large, my commitments regarding the ontological dependence relations stems from my focus on the scientific use of singular compositional explanations and the distinctive features of those explanations. If historians and philosophers of science are to have a descriptively adequate account of how scientists compositionally abductively reason, they will need a descriptively adequate account of the compositional relations that scientists presuppose.

My relatively narrow interest in scientific compositional explanations differs from the relatively broad interest of epistemologists who have adopted explanatory realism. John Greco, for example, believes that to understand that p is to have an explanation of p, but to have an explanation of p is to locate p in a system of appropriate dependence relations.[20] Greco's list of dependence relations includes "logical relations, mathematical relations, and various kinds of supervenience relation" (Greco, 2014, p. 286). Maybe one can read Greco's "various kinds of supervenience relation" as covering the compositional relations of constitution, implementation, and realization, but I suppose that logical and mathematical relations are not the dependence relations scientists invoke in singular compositional

[18] See, for example, Brooks et al. (2021). [19] See Gillett (2021). [20] Greco (2014).

explanations.[21] They are not what I described above as natural dependence relations, that is, relations that hold subject to background conditions. My point is that Greco's interest in explanation is broader than my own.

My relatively narrow interest in scientific compositional relations also differs from the broad interest of analytic metaphysicians thinking about ontological dependence and Ground. The introduction to Thompson (2022) provides a helpful orientation:

> The notion that ontological dependence is intended to capture is that of a distinctively metaphysical dependence relation. Common examples of ontological dependence proposed in the literature include the following: a nonempty set ontologically depends on its members; the holes in a piece of cheese ontologically depend on the cheese itself; normative facts ontologically depend on nonnormative facts; and mental phenomena ontologically depend on physical phenomena. Ontological dependence is usually thought to help provide for a distinctive kind of metaphysical explanation. (Thompson, 2022, p. 1)

Clearly, the analytic metaphysicians' project casts a broad net. The case of mental phenomena ontologically depending on physical phenomena probably covers the singular compositional explanation of mental phenomena in terms of physical phenomena, although possibly a lot more. Maybe it would cover the explanation of putative psychological laws in terms of physical or neurophysiological laws. My account of singular compositional explanation is not meant to address relations between laws. Thompson's other examples, however, are completely outside the scope of what I take to be singular compositional explanations.

Thompson's outline captures the spirit of earlier discussions of Ground. Fabrice Correia and Benjamin Schnieder provide a longer list of examples of putative instances of Grounding:

1. Mental facts obtain because of neurophysiological facts.
2. Legal facts are grounded in non-legal, e.g. social, facts.
3. Normative facts are based on natural facts.
4. Meaning is due to non-semantic facts.
5. Dispositional properties are possessed in virtue of categorical properties.
6. What accounts for the existence of a whole is the existence and arrangement of its parts.

[21] See also Grimm (2014), who traces the idea to Kim (1994).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

7. A set of things is less fundamental than its members.
8. What makes something beautiful are certain facts about the reception of its beholders.
9. A substance is prior to its tropes or modes.
10. That snow is white is true because snow is white. (Correia & Schnieder, 2012, p. 1)

As with the Thompson list, Correia and Schnieder's item 1 probably includes more than singular compositional explanations. Item 6 is very close to the idea of providing what I call an "analytic compositional explanation" of an individual. Nevertheless, many, if not all, of the other cases plausibly fall outside the scope of a theory of singular compositional explanation.

One more illustration. Michael Clark and David Liggins provide their own list of the putative instances of Grounding:

(A) The brittleness of the cup results from the way its constituent atoms are arranged.
(B) The truth-value of a proposition is determined by how the world is.
(C) Actions have their moral properties in virtue of their non-moral properties.
(D) Non-empty sets depend for their existence on their members.
(E) A mental state is grounded in the brain state which realizes it. (Clark & Liggins, 2012, p. 812)

In this list, it is only (A) and (E) that plausibly include instances of a singular compositional relation to be invoked in a singular compositional explanation. The analytic metaphysicians, however, are implicitly interested in cases such as the single set {Socrates} ontologically depending on the individual human Socrates. See Thompson's first example, Correia and Schnieder's 7, and Clark and Liggins' (D). My account of compositional relations does not aspire to characterize this case.

The examples of work in analytic metaphysics serve three important functions. First, it provides an opportunity for me to reiterate the point from Chapter 1 that this book, unlike the work of the analytic metaphysicians, is not a work of metaphysics. This book is not concerned with the fundamental structure of the world. It is not even concerned with the structure of the world. Instead, it focuses on how scientists *think* the world is structured. It is, for the space of this book, an open question whether the world is, in fact, structured the way scientists think it is structured.

Second, the scope of the aspirations of the analytic metaphysicians is greater than the scope of my aspirations.[22] As I repeatedly noted above, I am focused on singular compositional explanations. I now want to add a bit to that to reiterate another metatheoretical point from Chapter 1, namely, that I do not take singular compositional explanations to be universal. Some of the features of these explanations have emerged in scientific research only in the course of the twentieth century and may well not reflect scientific thinking in earlier eras.[23] So, for one thing, I have proposed that compositional relations reflect mass-energy neutrality. Such a scientific presupposition, however, could only come after a scientific embrace of mass-energy. Such a presupposition could only implausibly be attributed to scientists such as Galileo, Descartes, or Newton. For another thing, I have proposed that singular compositional explanations are used in scientific compositional abductive reasoning, which I take to be used in the scientific experimental literature. However, the nature and organization of the scientific experimental literature is the product of multiple social forces coming to the fore in the twentieth century. It is an understatement to say that this scientific literature is, in certain respects, different than the scientific literature produced by Galileo, Descartes, Newton, and Darwin.

My third point draws together some consequences of the last two. One can now see how it is possible to abandon (would-be) empiricist conceptions of scientific compositional explanation without adopting what many philosophers of science would dismissively describe as analytic metaphysics. I am not doing (analytic) metaphysics since I am not describing the (fundamental) structure of the world. Nor am I engaged in the (analytic) metaphysician's ambitious project of a sweeping account of ontological dependence. My project has a much finer, granular focus on singular compositional explanations that scientists have given at specific times and places. Developing a descriptively adequate account of singular compositional explanations in the recent scientific literature involves granular attention to the arguments scientists give in that literature. This project is, thus, what many would take to be mainstream history and philosophy of science. It may be a project of no interest to epistemologists or analytic metaphysicians.

[22] In a well-known critique of Grounding, Wilson (2014) makes the case that there is no work to be done by a general "big G" notion of Grounding. Instead, the work of Grounding might be done in different contexts by multiple "small g" conceptions of grounding. In this context, one might view the compositional relations described in this book as "small g" grounding relations, although not necessarily small g grounding relations that Wilson would embrace.

[23] Recall, again, the proposal in Pearson (1911) that science is not engaged in explanation.

2.3 Representation and Compositional Relations

The empiricist version of the DN model described in Section 2.1 proposed that explanations are merely representations. More specifically, they are representations of a particular form, namely, formally valid deductive arguments. Although this version of the DN model has been widely rejected by philosophers over the last forty years or so, the idea that causal explanations and causal relations are aptly represented by DN arguments has been more enduring. For example, Jaegwon Kim commented that "appropriate D-N arguments are particularly perspicuous as a vehicle for conveying causal information" (Kim, 1994, p. 55). Kim does not explain what he means by saying that DN arguments are a "particularly perspicuous" way to convey causal information. Nor does he give any reason to believe that they are. Nevertheless, it is safe to say that scientists rarely use instances of the DN schema to convey causal information. Moreover, it is undoubtedly an understatement to say that in recent years both philosophers and scientists have more commonly used directed acyclic graphs rather than instances of the DN schema to convey causal information.[24] As I look at actual scientific compositional explanations in the special sciences, there is no assumption that these explanations are represented as arguments even superficially looking like the DN schema.

Indeed, once one sets aside empiricist preconceptions stemming from the DN model, one finds that scientists use a wide range of representational devices to communicate both the explanantia and explananda of compositional explanations. These representational devices probably also play a role in the scientific development of compositional explanations, but I set that aside as orthogonal to their role in arguments that are published in the scientific literature. One could probably develop a complicated, multidimensional matrix in which to place different examples. One dimension might be along the develop/communicate distinction, another might be along the explanans/explanandum distinction, and yet another might be along the individual/property instance/activity instance distinction. I will assume that such a complicated system is unnecessary. I will instead review some examples.

In truth, I foreshadowed some of this representational diversity in the examples in Section 2.1. I noted that Young (1936) used a table of cell counts to articulate the explanans of an analytical compositional explanation of what certain squid nerves are made of. I also noted that Hodgkin

[24] See, for example, Spirtes et al. (2000) and Pearl (2009).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

and Katz (1949a) used a table to represent values for resting potentials. This table communicated results to be explained. Finally, I noted that Hodgkin and Huxley (1952a) used images of total currents to represent explananda.

It should be unsurprising that different phenomena are represented differently. Scientists use different words, tables, and images to represent different things. Nor should it be surprising to find multiple representations of the same explanandum. Different sentences in the same or different natural languages might refer to the same ontological configuration in an explanation. Here is a more "scientific" gloss of the same point. Conventional differences among representations make for the simplest cases. Physiologists and neuroscientists have used the Nernst equation as a representation of part of an explanans for the resting potential of the axon. Hodgkin et al. (1952, p. 132) and Hodgkin and Huxley (1952a, p. 454) used a version of the Nernst equation expressed as a ratio of an internal ion concentration over the external ion concentration. By contrast, contemporary conventions, as illustrated in Shepherd (1988, p. 91), Hodgkin (1994, p. 273), and Hammond (2014, p. 34), use a ratio of external ion concentration over the internal ion concentration. These mere conventional differences between representations constitute clear (but, in some sense, trivial?) differences among representations of the same ontological thing. Perhaps surprising to philosophers, in recent years neuroscientists have been concerned with helping students and their fellow scientists appreciate the work of Hodgkin, Huxley, and Katz by drawing attention to the (trivial?) differences between mid-twentieth-century representational conventions and twenty-first-century representational conventions.[25]

2.4 Singular Compositional Explanations as a Genus

Singular compositional explanations are a genus of explanation that represents compositional relations among entities. Each species of this genus corresponds to a distinct compositional relation among the entities in a distinct ontological category. I have now added further details to this sketch. I have added some discussion of the representations, the compositional relations, and the entities and their ontological categories. While this is undoubtedly not a complete account, it is at least a preliminary exposition of the principal features of the account.

[25] For further discussion of this and other examples, see Brown (2019, 2020), Hopper et al. (2022), and Raman and Ferster (2022).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

This account complements the work of Aizawa and Gillett (2019). That paper proposed that scientists offer three species of compositional explanations: analytic compositional explanations, dynamic compositional explanations, and standing compositional explanations (see Table 0.1). Further, I proposed that each of these species of explanations is backed by a distinct compositional relation, namely, constitution, implementation, and realization, respectively. The present account now articulates what it is for those *prima facie* scientific explanations to be scientific explanations, not in the sense of being "real" scientific explanations but in the sense of being what scientists, in the relevant cases, understand by being an explanation. I have an account of what scientists think they are doing in giving singular compositional explanations.

For those familiar with New Mechanism, what I am calling a singular dynamic compositional explanation is at least similar to what some of the New Mechanists have called "mechanistic constitutive explanation." It may be as similar to existing New Mechanist accounts as those accounts are to each other.[26] However, for those who have not read (Aizawa & Gillett, 2019), the idea of singular standing compositional explanation and singular analytic compositional explanation is likely unfamiliar. So, here I want to articulate, for a New Mechanist audience, some reasons to accept these unfamiliar compositional explanations.[27]

One can make the case for singular standing compositional explanations and singular analytic compositional explanations by providing examples. This is done in Aizawa and Gillett (2019). Take analytic compositional explanations. Aizawa and Gillett (2019) proposed that, during the Scientific Revolution, Robert Hooke explained what corks were made of, namely, cells. Moreover, he explained the composition of the drone fly eye: it is a compound eye made of smaller units that have come to be called "ommatidia." In the nineteenth century, Michael Faraday used distillation to isolate a liquid, benzene, he proposed was made up of molecules of C_6H_6. In the twentieth century, organic chemists learned to use mass spectrometry to identify what makes up various compounds, such as

[26] For some of the variants on the New Mechanist accounts, see Bechtel and Abrahamsen (2005) and Craver (2007).

[27] As far as I can tell, there are few discussions of compositional explanation in the abduction/IBE literature. Certainly, the idea does not appear in some of the more prominent recent works in the area. See, for example, Magnani (2009, 2017), McCain and Poston (2017a), Niiniluoto (2018), and Douven (2022). Lipton (2003, pp. 16, 66–68) mentions "vertical" inferences in passing. "Micro-part abduction" in Schurz (2008) is unlike compositional abduction as understood here, since "micro-part" abduction postulates the same thing, only smaller, whereas in compositional abduction, as understood here, the parts are qualitatively distinct from the wholes.

pheromones. There are also explanations of the composition of anatomical structures, such as the composition of a eukaryotic cell.

Consider some of the standing compositional explanations from Aizawa and Gillett (2019). Hooke explained the buoyancy of a cork in terms of the impermeability of its cells and a drone fly eye's being circumspect in terms of the positions and orientations of the ommatidia. Contemporary biochemists explain the properties of individual proteins in terms of their constituent amino acids, their property instances, and their bonding relation instances. Biologists explain the shape of individual micelles in terms of the property instances of their constituent phospholipid molecules.

In addition to the argument by example from Aizawa and Gillett (2019), I now have a theory that articulates what unifies compositional explanations as compositional explanations. Each of these explanations is a representation of an ontological dependence relation among entities, where each of the ontological dependence relations – constitution, implementation, and realization – shares a family of features. As described in Section 2.2.2, these relations have seven features: (1) they are many-one, (2) they are asymmetric, (3) they are transitive, (4) they are relations of natural dependence, (5) they do not involve the transfer of mass-energy, (6) the relata are contemporaneous, and (7) the relata are not wholly distinct. This is an argument from theoretical unity.

Consider, now, a third somewhat different argument for the same conclusion. To begin, I suppose that scientists in the special sciences postulate individuals, activity instances, and property instances. In the special sciences, scientists postulate individuals, such as atoms, molecules, cells, tissues, and organs. In the special sciences, scientists also postulate instances of activities of these individuals, such as bonding, attracting, adhering, synthesizing, metabolizing, and secreting. Most New Mechanists accept these claims, which one might independently document by a review of the scientific literature. Finally, scientists also postulate property instances, such as charge, polarity, shape, and spectral absorption.

If the scientific literature shows that scientists postulate individuals, property instances, and activity instances in the special sciences, then where do scientists think these entities come from? In principle, scientists might think that they are basic features of the world that have their own independent existence. That, however, is not the New Mechanist take on the science when it comes to activity instances. The New Mechanist's answer for activity instances is that activity instances of parts explain activity instances of wholes. But what of individuals and their property instances? The answer offered here is that there are parallel accounts. Just

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

as there are compositional explanations of activity instances of wholes, there are compositional explanations of individuals and their property instances.

So, there are three reasons to think that there is a genus of compositional explanation containing three distinct species. But what reason is there to resist this conclusion? How might one the resist compositional explanation of individuals? How might one resist the compositional explanation of property instances? Consider two answers.

One path of resistance to compositional explanations of whole individuals is to argue that the sample narratives regarding cells, etc., are not really explanations. Here, the most likely source of resistance is to claim that cells are related to organelles by definition and that organs are related to tissues by definition. One might take as a model the idea that water is defined as H_2O. One might think that it is a conceptual impossibility that water is not H_2O.

To challenge this view, one might first begin with the observation that, even if some philosophers define water as H_2O or find it to be conceptually impossible for water to be other than H_2O, that does not show that scientists have that definition or concept of H_2O.[28] Next, one might look to the philosophy of chemistry literature, where there is some debate about what water is.[29] Part of the concern is that even a sample of "pure" water is not merely a collection of H_2O molecules. H_2O molecules in relatively close proximity to each other will dynamically interact. For one thing, two nearby molecules of H_2O may dissociate to form a hydronium ion (H_3O^+) and a hydroxide ion (OH^-). For another, given the polarity of H_2O molecules, they are prone to forming short chains of differing lengths with the positive side of one molecule hydrogen-bonded to the negative side of the next molecule. Water molecules may not polymerize, but they do oligomerize. The account advanced here has it that scientists think that congeries of individual H_2O molecules, hydronium ions, hydroxide ions, and various H_2O oligomers constitute samples of water. This is why aggregates of H_2O molecules, hydronium ions, hydroxide ions, and various H_2O oligomers explain what water is made of. Similarly, it is why one can explain that organs are made of tissues, that tissues are made of cells, and that cells are made of organelles.

How might one resist the compositional explanation of property instances? One might claim that scientists are not committed to property

[28] See Hendry (2006, 2023) for a similar view of the chemical elements. See Needham (2008) for a defense of the definitional view.

[29] Cf., for example, Needham (2000) and Hendry (2006).

https://doi.org/10.1017/9781009435710.003 Published online by Cambridge University Press

instances. But why think scientists are not so committed? It would be beside the point to argue for the metaphysical conclusion that there are no property instances. Scientists might be committed to property instances, even if metaphysicians were to prove that property instances do not exist. That would be a case where metaphysicians prove the scientists are mistaken about ontology. It would also be beside the point to note that philosophers have not been able to develop any widely accepted theory of what properties are, whether universals, tropes, powers, or what have you. Surely, there are any number of concepts in scientific use that have yet to receive widely accepted characterizations by philosophers. Simplicity, natural kinds, causation, natural law, and explanation are obvious examples.

One might dismiss properties and property instances on the grounds that they are covered by the term "activities." Properties are just a type of activity. I mentioned this idea above in Section 2.1. Unfortunately, this is a mere terminological proposal that papers over the ontological distinction scientists draw between property instances and activity instances. One could call both property instances and activity instances "activities" or "activity instances," but there remain at least three noteworthy differences between the way scientists treat properties and the way they treat activities. First, scientists allow that properties are sometimes latent relative to a given activity. Second, scientists allow that properties may manifest themselves in different activities at different times. Third, scientists propose that properties do not have rates, whereas activities do.

On balance, there are reasons to think that scientists recognize individuals, property instances, and activity instances. Moreover, there are reasons to think that scientists give compositional explanations of some of them. Simply look at scientific practice. Perhaps there are reasons to resist this picture, but as this picture has not been examined in the philosophical literature it is unclear what this resistance might be. The reasons to resist a pluralism of compositional explanations scouted above are not compelling.

2.5 Summary

In this chapter, I have developed an account of singular compositional explanation as a genus of explanation with three species: singular analytic compositional explanation, singular dynamic compositional explanation, and singular standing compositional explanation. Such explanations are representations of a compositional ontological dependence relation among entities in three distinct ontological categories. The representations in these explanations may be quite diverse, relying upon images, tables, and texts, hence displaying a broad range of representation resources. Beneath the representational diversity, however, there is a relatively simple unity to be seen in the common features of the ontological relations. The relatively simple theoretical unity of these examples will not carry over to other scientific compositional explanations to be discussed in Chapter 3.