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The Causal Argument Against Component Forces

Jessica Wilson†

1. *Introduction*

Do component forces exist in conjoined circumstances? Cartwright (1980) says no; Creary (1981) says yes. I'm on Cartwright's side in this matter, but find several problems with her argument (section 2). My primary aim here is to present a better, distinctly causal, argument against component forces: very roughly, I argue that the joint posit of component and resultant forces in conjoined circumstances gives rise to a threat of causal overdetermination, avoidance of which best proceeds via eliminativism about component forces (section 3). A secondary aim is to show that rejecting component forces does not require, *pace* Cartwright, rejecting certain attractive theses about what laws of nature express and the role such laws play in scientific explanations (section 4).

2. *Cartwright's argument against component forces*

Cartwright's (1980) argument against component forces is embedded in another argument, in which the denial of component forces as existing in conjoined circumstances is a premise.[1] As set-up for discussion of the former argument I will now sketch the latter.

2.1. *The problem of partial laws*

Cartwright's larger target is a package deal of two theses: first, a "facticity" view of laws of nature, according to which these express facts about what happens; second, a "covering law" account of scientific explanation, according to which giving a scientific explanation of some phenomenon consists in citing the scientific laws whose instancing is relevant to the occurrence and/or features of the phenomenon. Both accounts are natural and attractive, from a broadly realist point of view; and in one form or another are very commonly accepted.[2] As Cartwright

† Department of Philosophy, University of Toronto, 170 St. George St., Toronto, ON, M5R 2M8, Canada; Email: jessica.m.wilson@utoronto.ca

[1] Cartwright reproduces these arguments in her (1983), with the addition of a response to Creary (1981) that I will discuss down the line. Page citations of Cartwright's work are to her (1980) unless otherwise noted.

[2] Properly assessing Cartwright's argumentation against component forces requires attention to the package deal that is her official target, and given the package deal's attractiveness

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notes, the facticity account "is a pedestrian view that, I imagine, any scientific realist will hold" (p. 75), and notwithstanding that some versions of covering law accounts (as per, e.g., Hempel and Oppenheim 1948 and Hempel 1965) have fallen from favor, it remains that "most models of explanation offered recently in the philosophy of science are covering-law models" (1983, 44).[3] In any case, the facticity view seems right for many scientific laws. For example, Coulomb's law seems to express the fact that, in circumstances where a stationary charged particle q is a distance r from another stationary charged particle q', a force will occur with magnitude kqq'/r^2, along the direction from q to q'; and Newton's second law seems to express the fact that, in circumstances where a system of mass m experiences a net force $\mathbf{F}$, the system will accelerate in accord with $\mathbf{F} = m\mathbf{a}$. And for such laws, a covering law account provides an intuitively correct account of the role the laws play in scientific explanations. For example, an appropriate scientific explanation of a situation where an initially stationary charged particle accelerates away from another initially stationary charged particle would cite the instancing both of Coulomb's law and Newton's second law.

As Cartwright argues, however, the package deal faces a difficulty in the common cases where the phenomenon to be explained occurs in circumstances where there are multiple causal influences – involving forces, in particular.[4] Cartwright illustrates the problem with a case in which two particles, each of which is both massy and charged, accelerate away from each other.

In such conjoined circumstances, where both gravitational and electrostatic influences are at issue, it seems appropriate to appeal to Coulomb's law as part of the scientific explanation of the particles' acceleration; and similarly for Newton's law of gravitation. Such appeal to "partial" laws (sometimes called explanation "by composition of causes") tracks the serendipitous empirical fact that the determinative influences on behavior in conjoined circumstances may frequently be understood as broadly reductive (in the present cases, linear) combinations of the determinative influences in non-conjoined circumstances.[5] Explanation by composition of causes is standard in physics, and in the sciences generally, reflecting that nearly all scientific phenomena of interest involve multiple causal influences.

it is moreover worth observing (as per section 4) that it may be retained upon rejecting component forces. That said, the upcoming causal argument against component forces is broadly neutral on what accounts of laws and explanation are correct.

[3] Contemporary covering law accounts include, among others, Suppes's (1970) probabilistic model of causation and Salmon's (1971) statistical relevance model.

[4] Cartwright assumes, as I will here, that there are good reasons for admitting the reality of forces in classical (broadly Newtonian) contexts, distinct from either the bodies (e.g. electrons) or properties (e.g. charge) giving rise to forces, or the accelerations to which forces give rise; see Wilson 2007 for detailed arguments to this effect. What is at issue here is not whether forces exist in conjoined circumstances, but whether resultant and/or component forces exist in such circumstances.

[5] The terminology of "partial laws" and "conjoined circumstances" is my own.

But it is unclear how these explanatory appeals to partial laws conform to the package deal, for as Cartwright notes in discussing her case, neither Coulomb's law nor Newton's law of gravitation appear to "state the facts" about what goes on in conjoined circumstances.

Cartwright's case effectively involves a quintilemma, involving five claims which are individually plausible but mutually unsatisfiable:

1. Scientific laws express facts about what happens (the facticity account of laws).
2. Giving a scientific explanation of some phenomenon consists in citing the scientific laws whose instancing is relevant to the occurrence and/or features of the phenomenon (the covering law account of scientific explanation).
3. Explanations of phenomena in conjoined circumstances appropriately cite partial laws (explanation by composition of causes).
4. The relevant partial laws express the occurrence of forces which are (merely) component in conjoined circumstances (1, assumption).
5. Component forces do not exist in conjoined circumstances (assumption).

One or more of these has to go – but which?

Cartwright's treatment of what I'll call "the problem of partial laws" proceeds roughly by cases; a brief reconstruction, with some supportive filling-in, follows.

To start, one might deny (3) and rather maintain that only "super-laws", applying in the conjoined circumstances, should be cited in explanations of the associated phenomena. Cartwright rejects this strategy, however, on grounds that explanation by composition of causes is indispensible in the sciences; relatedly, one might be concerned that the strategy would give rise to a disunified and unsystematic proliferation of laws.

Next, one might deny (4) and rather maintain that the partial laws at issue express powers:

> We can preserve the truth of Coulomb's law and the law of gravitation by making them about something other than the facts – the laws can describe the causal powers that bodies have (p. 79).[6]

On such a view, partial laws can be true in conjoined circumstances even if the powers they attribute are not exercised. Cartwright's main concern is that such an approach is undeveloped and (perhaps) unworkable:

[6] To be sure, if powers are occurrent entities whose existence does not depend on their being manifested (as per Martin 1993), then the resulting partial laws would still express facts – not about the occurrence of forces, but about the presence of (potentially unmanifested) powers. Cartwright is thinking of 'facts' in narrower fashion, as involving happenings of some sort; as she describes the powers-based proposal, "the laws we use talk not about what bodies do, but about what powers they possess" (p. 79).

> If laws of nature are presumed to describe the facts, then there are familiar, detailed philosophic stories to be told about why a sample of facts is relevant to their confirmation, and how they help provide knowledge and understanding of what happens in nature. Any alternative account of what laws of nature do and what they say must serve at least as well; and no story I know of causal powers makes a very good start (p. 80).

Beyond Cartwright's observations, two concerns would remain, however the view is developed. First is that the partial laws at issue seem to express the occurrence of forces, not the (mere) having of powers. As such, the proposal results in a semantics for laws that is either counterintuitive (if laws express the having of powers in both conjoined and non-conjoined circumstances) or unsystematic (if laws express the occurrence of forces in non-conjoined circumstances, and the having of powers in conjoined circumstances). Second, as Creary (1981) notes, the approach fails to explain why appeals to partial laws are explanatory:

> [T]he view seems to me to be a non-starter. To say that the two particles in our example case have a power, *not successfully exercised in this case*, to produce a force of size Gmm/r^2, does not even begin to help explain the rate of mutual recession of the particles (p. 150; emphasis in original).

So go the arguments against rejecting premise (4) of the quintilemma.

Next, and most relevant to our discussion: one might deny (5) and rather maintain that component forces exist in conjoined circumstances; we'll explore Cartwright's arguments against this strategy shortly.

Given acceptance of (3), (4), and (5), we have no choice, Cartwright maintains, but to reject the facticity account of laws in (1): "The lesson to be learned is that the laws that explain by composition of causes fail to satisfy the facticity requirement" (p. 73). But if partial laws do not state the facts, then a covering law account of explanation does not, it seems, make sense of explanatory appeals to these laws; hence Cartwright takes rejecting the facticity account to also require rejecting the covering law account in (2).

2.2. Cartwright's argument(s) against component forces

I turn now to Cartwright's reasons for rejecting component forces as existing in conjoined circumstances.

Recall that the partial laws in Cartwright's case appear to express the occurrence of certain forces – an electrostatic force in the case of Coulomb's law, a gravitational force in the case of Newton's law of gravitation. As such, one might think that the package deal doesn't really face a problem. For the forces that partial laws appear to express are assumed to add, by vector addition, to the resultant force that is input to Newton's second law. Why not take component forces to be present in conjoined circumstances, along with the resultant force that is their vector sum, compatible with both facticity and covering law accounts? As Cartwright asks:

> Doesn't vector addition provide a simple and obvious answer to my worries? When gravity and electricity are both at work, two forces are produced, one in accord with Coulomb's law, the other according to the law of universal gravitation. Each law is accurate. Both the gravitational and the electric force are produced as described; the two forces then add together, vectorially, to yield the total "resultant" force (p. 78).

Cartwright's initial response to the proposal is as follows:

> The vector addition story is, I admit, a nice one. But it is just a metaphor. *We* add forces (or the numbers that represent forces) when we do calculations. Nature does not "add" forces. For the "component" forces are not there, in any but a metaphorical sense, to be added [. . .]. [T]he force of size $\frac{Gmm'}{r^2}$ and the force of size $\frac{qq'}{r^2}$ are not real, occurrent forces. In interaction, a single force occurs – the force we call the "resultant" – and this force is neither the force due to gravity nor the electric force (p. 78).

In other words: a literal interpretation of the vector addition story as combining existing "summands" (that is, component forces) cannot be sustained, for only the resultant force exists in conjoined circumstances.

In support of this line of thought, Cartwright considers and rejects one specific way in which vector addition might be given a realistic metaphysical interpretation, as involving the part/whole relation. She first cites Mill as a proponent of the part/whole view:

> In [an] important class of cases of causation, one cause never, properly speaking, defeats or frustrates another; both have their full effect. If a body is propelled in two directions by two forces, one tending to drive it to the north, and the other to the east, it is caused to move in a given time exactly as far in *both* directions as the two forces would separately have carried it [. . .] (Mill 1843/1973, Book III, ch. VI).

Cartwright responds:

> Mill's claim is unlikely. [. . .] When a body has moved along a path due north-east, it has traveled neither due north nor due east. The first half of the motion can be a part of the total motion; but no pure north motion can be a part of the motion which always heads northeast. [. . .] The lesson is even clearer if the example is changed a little: a body is pulled equally in opposite directions. It doesn't budge an inch, but on Mill's picture it has been caused to move both several feet to the left and several feet to the right. [. . .] It is implausible to take the force due to gravity and the force due to electricity literally as parts of the actually occurring force (p. 79).

The above rejection of a literal interpretation of the vector addition story constitutes Cartwright's direct argument against component forces, and it contains three gaps. First, Cartwright assumes, but does not argue for, the existence of resultant forces (the "actually existing" forces) in conjoined circumstances. Not everyone accepts this assumption (e.g., Creary, 1981) and hence it needs to be argued for. Second, Cartwright's rejection of the vector addition story as literally interpretable rests on rejection of a single proposal. As Creary says, "Cartwright does not argue directly for her anti-realism concerning component forces. The closest she comes to this is an attempt to eliminate by refutation a single alternative view – the view that component forces are real because each is a part of the (real) resultant to which it contributes" (p. 152). Third, in fact Cartwright's argument does not refute even this view (that component forces are parts of resultant forces), for this is not the view she considers above. The 'Millian' case Cartwright considers and rejects is rather one where certain *behavioral effects* of component forces are supposed to be parts of the behavorial effects of resultant forces ("no pure north motion can be a part of the motion which always heads northeast"). But the failure of the part-whole relation to hold between the effects of component and resultant forces does not show that the forces themselves cannot stand in this relation, any more than the failure of two token visual experiences (yours and mine, for example) to stand in the part-whole relation shows that the cause(s) of those experiences (e.g., a given landscape) fail to do so.

Cartwright's discussion of the problem of partial laws might also be seen as constituting an indirect argument against component forces, as part of the best overall strategy for responding to this problem. There are two problems with this route to the rejection of component forces.[7]

The first problem is that Cartwright takes rejecting component forces to require rejecting a facticity account – as applying, at any rate, in conjoined circumstances. Her resolution thus faces the same difficulty as the powers-based semantics discussed earlier, of resulting in a semantics for laws that is either counterintuitive or unsystematic. More generally, rejecting a facticity account invokes significant costs – more significant, perhaps, than the costs associated with embracing super-laws or, indeed, component forces. A better indirect argument for rejecting component forces as required by resolving the problem of partial laws would explicitly treat the costs of rejecting the facticity view – or better yet, avoid these costs altogether (and similarly for Cartwright's rejection of a covering-law account of explanation).

The second, more serious problem is that Cartwright ignores what Creary (1981) suggests is a fairly "simple and obvious" response to the problem, which seems to avoid these costs; namely, to maintain that component forces exist in conjoined circumstances, and deny that resultant forces do so. Creary (p. 152) offers a general schema for understanding the interplay between partial laws, component forces, laws of action, and effects, which involves two steps. First, "Separate laws of influence [e.g., Coulomb's law and Newton's law of gravitation]

[7] A third problem is that there is a better version of a powers-based approach than that which Cartwright (and Creary) considers, which I'll discuss in section 4.2. To the extent that this better version is also plausibly motivated by the rejection of component forces, no real damage to the indirect argument against component forces ensues from its neglect. As we'll see, however, the availability of this alternative does undermine Cartwright's arguments against the package deal.

connect the various causes composed in a given situation [e.g., massy or charged bodies] with real intermediate entities such as natural component forces". Second, a law of action – e.g., Newton's second law, "interpreted as saying that the set of all natural forces acting on a body will produce an acceleration in the direction of the mathematical resultant of the forces which is directly proportional to the magnitude of the resultant, and inversely proportional to the mass of the body" – "is then required to complete the explanatory link to the effect of the composed causes". As indicated by his talk of "mathematical" resultants, Creary denies that resultant forces, understood as real entities, exist in conjoined circumstances; rather, only component forces do so. Partial laws, on Creary's view, uniformly express the occurrence of certain forces, whether these laws are instanced in isolated or in conjoined circumstances; explanatory appeal to such laws in conjoined circumstances may thus be straightforwardly accommodated, in line with the package deal.

Cartwright effectively grants the viability of this strategy, in responding to Creary in her (1983). She starts by noting that in her original case, she was assuming the existence of the resultant force:

> Consider our original example. Creary changes it somewhat from the way I originally set it up. I had presumed that the aim was to explain the size and direction of a resultant force. Creary supposes that it is not a resultant force but a consequent motion which is to be explained. This allows him to deny the reality of the resultant force. We are both agreed that there cannot be three forces present – two components and a resultant. But I had assumed the resultant, whereas Creary urges the existence of the components (p. 66).

She goes on to say that Creary's strategy in the case at issue is "plausible"; and indeed, that "Creary may well be right about resultant and component forces" (1983, 66). To be sure, Cartwright doesn't think that Creary's strategy works "as a general strategy" for accommodating explanation by composition of causes, for reasons I won't enter into here. But for our purposes the crucial point is that Cartwright concedes that the problem of partial laws can be resolved for the cases involving forces that are our concern, compatible with granting that component forces exist in conjoined circumstances, and compatible with the package deal. For reasons that will become clear down the line, Cartwright need not and should not have conceded this. As it stands, however, Cartwright's discussion of the problem of partial laws does not provide either direct or indirect motivation for rejecting component forces.

3. *The causal argument against component forces*

I now want to provide a better argument against component forces, which bears some relation to Cartwright's (in ways I will flag as we go) but differs in focusing on a distinctly causal concern attaching to the posit of component forces.

In what follows, we should keep in mind certain central metaphysical facts about forces. Forces, traditionally understood, are generalized pushes or pulls, characterized by magnitude and direction, that are the direct (or fairly direct) causes of motions (where 'motions' may include stasis). This understanding leaves open various ontological options as regards how forces stand to the usual causal relata (that is, to substantial particulars, properties, and events, . . .), between which we need not decide here.[8] In any case it is, I take it, uncontroversial that forces (of whatever varieties may exist) are individuated by (at least) magnitude and direction: forces with different magnitudes are different forces, and forces with different directions are different forces.

3.1. The existence of resultant forces in conjoined circumstances

As above, Cartwright assumes that resultant forces exist in conjoined circumstances; so will I in giving the upcoming causal argument against component forces. The assumption is plausible, but why so? As I'll now argue, there are good *prima facie* theoretical and experiential motivations for the assumption, indicating that we should accept resultant forces unless presented with reasons for rejecting them that are at least as good as the reasons for accepting them. Neither motivation presupposes or (in itself) establishes that component forces do not exist in conjoined circumstances – that result is consequent upon presentation and consideration of the causal argument to come.

The theoretical motivation for resultant forces appeals to the role these arguably play in Newtonian mechanics. Newton's laws of motion, so usefully confirmed in their domain, directly cite forces, and that the distinctive characteristics of forces are alone sufficient to determine and explain the motions of non-force entities across a wide range of diverse circumstances, provides good theoretical reason for thinking that forces, as traditionally understood, exist (see Wilson 2007). So if we are looking for reasons to think that *resultant* forces exist, Newtonian mechanics is the first place to look. Now, forces appear in Newtonian mechanics in two ways: in force laws (e.g., Coulomb's law) and in Newton's laws of motion. It is the forces that enter into Newton's laws of motion, however – and in particular, into Newton's second law – that are most immediately implicated in the generation of motion by forces. And there is a strong case to be made that this law refers to resultant forces, as part of the law's standard, and only plausible and systematic, interpretation.

Newton's second law, translated from the *Principia*, is as follows:

> The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed (1687/1999).

[8] See Ellis 1976, Bigelow and Pargetter 1988, Wilson 2007, and Massin 2009 for discussion and assessment of various ontological options.

The contemporary formulation (reflecting Newton's understanding of "motive" force as directed against the mass of a body) is along the following lines: "The acceleration of an object is proportional to the force applied, and inversely proportional to the mass of the object" – that is, $\mathbf{F} = m\mathbf{a}$. Both formulations presuppose that a *single* force ("*th*e motive force impressed", "*th*e force applied") is at issue in the second law, regardless of whether the circumstances of application of the law are conjoined or not. Independent of whether the multiple influences at issue in conjoined circumstances correspond to multiple component forces existing in such circumstances, then, it would appear that Newton's second law takes these influences to eventuate in a single force.

Moreover, as per usual, this single force is specifically a *resultant* force, understood as the force (in a given set of circumstances) whose magnitude and direction are given by a vector sum, where the magnitude and direction of each summand are (to speak neutrally concerning whether component forces exist in conjoined circumstances) those of the force that would be present if the circumstances were such that only the associated influence were operative. In cases where only one influence is at issue, there is only one summand, the sum is trivial, and the resultant force just is the single force present in the (non-conjoined) circumstances. Correspondingly, the LHS of the second law may be plausibly and systematically interpreted as referring to a single resultant force in both conjoined and non-conjoined circumstances.

An interpretation of Newton's second law on which it involves reference to a single resultant force is standard, plausible, and systematic. But might there be a neglected interpretation that is also plausible and systematic, which denies that resultant forces are so input in conjoined circumstances? It seems not.

One alternative interpretation might suggest that, in conjoined circumstances, the single force referred to in Newton's second law is one of multiple component forces present in the circumstances, which single component force is then associated with a 'bit' of acceleration.[9] On this view, Newton's law would be applied piecemeal in conjoined circumstances, with one application per influence (component force). Such a suggestion is implausible, in obviously departing from the usual non-piecemeal applications of Newton's law. Moreover, the suggestion is unsystematic. Piecemeal applications of Newton's law in conjoined circumstances cannot be given a realist interpretation: an object cannot move (as a whole) in more than one direction at a time; hence an object cannot have more than one velocity at a time; hence an object cannot have more than one acceleration at a time; hence

[9] Johansson (2004, 163–164) comes close to endorsing such a view. He first distinguishes the "realized acceleration" at issue, associated with the usual interpretation of $\mathbf{F} = m\mathbf{a}$ from the "partial accelerations" associated with $\mathbf{F}_p = m\mathbf{a}_p$; then says "it is a mistake to say that the partial accelerations [. . .] are not realized". See note 10, however, for an alternative understanding of Johansson's view.

'acceleration' as it appears on the RHS of Newton's second law cannot refer to real (bits of) acceleration, when this law is instanced in conjoined circumstances.[10] On the other hand, 'acceleration' as it appears in non-piecemeal applications of Newton's second law can and should be given a realist interpretation; hence an interpretation of this law as taking single component forces as input is unsystematic. (This alternative interpretation also spells trouble, unlike the standard interpretation and the next, for a facticity account of laws.)

A second alternative interpretation, favored by those denying the existence of resultant forces, rejects the usual understanding of Newton's second law as taking a *single* force as input. Hence after noting that, in his view, "it is the *component* forces (gravitational and electrostatic) that are real, while the resultant force is merely a mathematical fiction", Creary (1981) says:

> Newton's second law of motion is interpreted as saying that the set of all natural forces acting on a body will produce an acceleration in the direction of the mathematical resultant of the forces that is directly proportional to the magnitude of the resultant, and inversely proportional to the mass of the body. Thus, the law implies that multiple natural forces acting together will have the same net effect as would a single natural force having the magnitude and direction of their vector sum (p. 152).

Presumably it is not fictitious resultant forces, but rather real component forces "acting together", that are causally responsible for the productions of accelerations in conjoined circumstances; in such circumstances the joint action of the component forces is such that they causally act "as if" there were a single force present with magnitude and direction given by their vector sum. I don't see any in-principle metaphysical problem with this story about how forces directly cause accelerations in conjoined circumstances. Nonetheless, the associated interpretation of Newton's law incurs two costs. First, it is implausible. If the interpretation were correct, we would expect either that (a) standard formulations of the law would indicate that the law takes multiple forces, not a single force, as input (e.g., as $\Sigma \mathbf{F}_i = m\mathbf{a}$ rather than $\mathbf{F} = m\mathbf{a}$), or that (b) standard presentations of the law as usually formulated would indicate that the seemingly single force $\mathbf{F}$ at issue is a merely technical innovation introduced to simplify treatment of multiple component forces (along lines, e.g., of the standard disclaimer in presentations of laws appealing to the center of mass of a system, which may be located where nothing is). Since standard formulations and presentations of the second

[10] As Johansson (2004, 163) acknowledges, "it turns out to be equally mistaken to say that [the partial accelerations] are realized, since one then imagines that the body in question will accelerate with just that accelerations each of the partial forces prescribes". Reflecting his stated aim (p. 164) to develop the view in Bhaskar 1975, Johansson might be better seen as endorsing a version of a powers-based view along lines discussed in section 4.2, according to which component influences are "realized" or manifested in conjoined circumstances, though not as component forces.

law (starting with Newton, and continuing to the present day) typically do not conform to either (a) or (b), Creary's interpretation is correspondingly implausible. Second, although Creary's interpretation is systematic in giving a uniform semantics for partial laws both in conjoined and non-conjoined circumstances, it is unsystematic in another semantic respect – namely, in giving a fictionalist interpretation to what seems to be literal reference to a single resultant force in $\mathbf{F} = m\mathbf{a}$. Relatedly, given that component forces causally interact so as to behave "as if" a single resultant force is present, why not take this behavior at face value as indicating that a resultant force having the associated magnitude and direction really exists? To resist this natural interpretation, especially given the background realism about forces as characterized by magnitude and direction, is, I submit, semantically unsystematic. Of course, as per usual, philosophical or other pressures might lead us to endorse a non-standard or unsystematic interpretation of a given notion; and Creary thinks that we face such compensating pressures here (which I will address down the line). My point at present, again, is just to point out that an interpretation of Newton's second law as not involving reference to resultant forces in conjoined circumstances incurs costs that the standard interpretation does not incur.

This exhausts the available interpretive options for Newton's second law (at least those on which the law is understood as involving force(s), as per the background realist assumption), and in any case exhausts the options advanced by those denying resultant forces. An interpretation on which this law involves reference to resultant forces is plausible and systematic, while the alternative interpretations are implausible and unsystematic. These considerations provide good theoretical reason to suppose, following the standard, systematic interpretation, that resultant forces exist in conjoined circumstances. This is compatible, of course, with there being other theoretical reasons (in particular: explanation by composition of causes) for thinking that component forces also exist in such circumstances; and I will later consider what theoretical motivation(s) for component forces there might be.

The second reason for positing resultant forces as existing in conjoined circumstances is broadly experiential. We experience forces in interacting with the world, which are directly associated with our accelerations; and these forces are frequently associated with multiple influences. In the latter cases, we always seem to experience resultant forces (whether or not we also experience component forces): forces associated with a single magnitude and direction, that directly result in our accelerations. So, for example, when one is slowly losing a tug of war, one experiences oneself being pulled with the magnitude and direction of the resultant force. Moreover, in at least some cases where multiple influences are at issue, we seem to experience resultant forces *without* experiencing the associated component forces. For example, when one rides in a tilt-a-whirl, one feels only a single force pinning one to the wall, not two distinct forces, one gravitational and one centrifugal; when a magnet in one's hand is drawn up to another magnet, one experiences only a single resultant force, not individual magnetic and gravitational forces. Experience thus provides us with good reason to posit resultant forces as existing in conjoined circumstances. This result is compatible with our also experiencing component forces in at least some cases of conjoined circumstances; and I will later consider whether there is a case to be made to this effect.

Finally, it is worth noting that the experiential motivation for resultant forces fits well with the theoretical motivation. Given that the forces entering into Newton's second law are most immediately implicated in the generation of motion by forces, we would expect that whatever forces are at issue in the second law – that is, as per the interpretive argument above, resultant forces – would coincide with those we directly experience when we or entities with which we interact undergo accelerations. The theoretical and experiential motivations for resultant forces are thus both weighty and mutually supporting.

3.2. The threat of force-based causal overdetermination

There are good theoretical and experiential reasons for thinking that resultant forces exist in conjoined circumstances. Why not allow that component forces also exist in such circumstances – as motivated, in particular, by theoretical appeals to explanation by composition of causes? As above, Cartwright claims that this doesn't make sense, on grounds that there is no way of making literal sense of vector addition so as to allow the joint existing of component forces (as summands) with their associated resultant force (as sum); and as motivation for this claim she rejects an interpretation of vector addition as involving the part/whole relation. Putting aside the aforementioned difficulties with Cartwright's argumentation here, why think that there is even a *prima facie* problem with component forces existing alongside resultant forces, in one way or another?

Given that forces are first and foremost causes of motions (again, including stasis), the *prima facie* problem is not far to find. It is the threat that, should both component and resultant forces exist in conjoined circumstances, this would lead to an unacceptable overdetermination of effects. Cartwright does not discuss this threat, though Creary (1981) charitably claims that a "between the lines" motivation for her rejection of component forces (which also enters into Creary's rejection of resultant forces) is a desire to avoid an unsatisfactory redundancy of forces:

> [I]f one rejected the "part-whole" thesis [. . .], and took for granted the reality of overall resultant forces, then one would naturally be led to conclude that component forces are unreal, since one would otherwise have to regard them, most implausibly, as physically redundant real forces that "shared" their effects with their (presumably real) resultants (p. 152).

In any case, a good first step in arriving at a compelling argument against component forces is to recognize and develop this concern, since its appropriate resolution places certain constraints on the available options concerning whether, and if so how, component as well as resultant forces may jointly exist in conjoined circumstances.

In developing the concern, it is useful to first attend to another context in which there is a threat of causal overdetermination – namely, that where concurrent mental and physical states of a subject each appear capable of producing the same physical effect (as when a mental state of feeling thirsty, and the brain state that concurrently necessitates the mental state, each appear capable of bringing about a reaching for a glass of water).[11] In particular, it's worth recalling the main broad strategies of response to this problem (commonly called "the problem of mental causation"), both to get a feel for the underlying concern and as set-up for considering how to respond to the parallel problem involving forces.

Eliminativism. Overdetermination is avoided by denying that either the mental or the physical state exists. This is a tough row to hoe, for we have good theoretical reasons for thinking that the physical state exists, and good introspective reasons for thinking that the mental state exists.

Reductionism. The mental and physical states each exist; overdetermination is avoided by identifying the states. This approach is typically associated with reductive physicalism.

Non-reductionism. The mental and physical states each exist, and though they are not identical, they are sufficiently intimately related – e.g., by the parthood (Shoemaker 2001) or the determinable/determinate relation (Yablo 1992) – so as to plausibly avoid overdetermination. This approach is typically associated with non-reductive physicalism.

Schematically, both reductive and non-reductive physicalist approaches to the problem of mental causation proceed by imposing a condition on the token causal powers (henceforth: just "powers") of the mental state; namely, that every power of this state be numerically identical with a power of the physical state that necessitates it on a given occasion.[12] Satisfaction of this condition avoids

[11] Two terminological points are relevant to this description of the threat. First, I am using 'physical' broadly, as referring to entities that are either physical in whatever core sense might be at issue in the physicalist thesis (e.g., as adverting to the entities treated, approximately accurately, by present or future physics; and which are not fundamentally mental) as well as any entities (e.g., brain states) which are uncontroversially "nothing over and above" the core physical entities. Second, use of the term 'necessitation' is intended as broadly neutral on the details of the relation between mental and physical states; as we'll see, responses to the problem of mental overdetermination differ on these details.

[12] See Wilson 1999. Talk of "powers" here may be understood in entirely metaphysically neutral terms, as talk (just) of the actual and potential causal contributions a feature or state may make, relative to a given set of laws of nature, when occurring in certain circumstances. This

overdetermination: on any given causation, there is only one causing, not two. The dispute between reductive and non-reductive physicalists is over what metaphysical means are available for purposes of satisfying this condition. Reductive physicalists suppose that identity is required, whereas non-reductive physicalists maintain that mental and physical states may stand in other intimate relations (e.g., the determinable/determinate or proper part/whole relations) that satisfy the condition on powers, compatible with non-identity of mental and physical states.[13]

Emergentism. The mental and physical states each exist and are non-identical. Overdetermination is avoided by denying that the physical state causes the effect in question, or (more weakly, and plausibly) by denying that the physical state causes the effect in the same (direct) way as the mental state. In terms of powers: "robust" or "strong" emergentists, contra all physicalists, maintain that mental states typically have powers to produce effects that are not numerically identical with any powers of their associated physical states. Again, there are various ways to implement the strategy. One naturalistically acceptable approach takes the physical state to be a lawfully necessary precondition for the coming into play of a new fundamental force or interaction, which then enters into constituting the mental state (and its powers), and in virtue of which the mental state enters into new causal laws implicated in the production of the effect in question (see Wilson 2002). Hence even if there is a sense in which the physical state also causes the effect, it does so only derivatively, in virtue of bringing about the mental state; hence the powers of the states to produce the effect are not numerically identical.

Now let's return to the threat of causal overdetermination as it attaches to component and resultant forces.

As above, theoretical and experiential considerations provide good reason for taking resultant forces to exist in conjoined circumstances; and let's suppose that component forces (motivated, for a start, by explanation by composition of causes) also exist in these circumstances. Given how forces are individuated, a resultant force in such circumstances is different from any individual component force in those circumstances.[14] In Cartwright's paradigm case, for example, the posit of component forces in addition to the resultant force entails that there are three

weak sense of "power" does not presuppose any controversial theses about features or states (e.g., that they are or are not essentially or exhaustively individuated by powers) or causation (e.g., that powers are or are not prior to regularities). See Wilson in progress for further discussion.

[13] See Wilson (1999 and in progress) for discussion of the schematic condition on powers (again, metaphysically neutrally understood) and arguments that the diversity of physicalist accounts are unified in imposing this condition, in opposition to robust emergentist accounts, of the sort to be next discussed.

[14] A resultant force can have the same magnitude and direction as a component force, if the other component forces cancel each other out, but in general resultant forces will have both magnitudes and directions different from any of the associated components. Here and elsewhere I will assume that a general failure of identification indicates a failure of identification, *simpliciter*.

forces on the scene: two component forces, and one resultant force. Moreover, a single resultant force is not identical with multiple component forces, understood as merely jointly existing (though for the moment it remains open that a resultant force may be identical with some relational state constituted by multiple component forces).

As Creary notes, the presence of component as well as resultant forces in conjoined circumstances invokes an "implausible redundancy", if forces are real entities with their traditional characteristics (as we are here supposing). Initial support for Creary's claim stems from the fact that forces are directed pushes or pulls: surely it is not as if, in conjoined circumstances, there are the directed pushes or pulls associated with the component forces, and, in addition, the directed push or pull associated with the resultant force. The deeper concern about redundancy, however, stems from the fact that forces are supposed to be the immediate causes of motions. The resultant force is, in itself, sufficient to bring about the resulting motion: this is what both Newton's second law and our experience tells us. But the distinct component forces, each acting during the time in question, also appear sufficient to bring about the effect: this is what the superposition principle (grounding the appropriateness of calculating the resultant force via vector addition, and relatedly, of explanation by composition of causes) tells us.

We now face a difficulty. For if the jointly existing component forces and the single resultant force are each sufficient to bring about the effect in the conjoined circumstances, and if the resultant force is different from the (jointly existing) component forces, then the effect appears to be causally overdetermined. The problem of causal overdetermination, as applied to component and resultant forces, can be expressed as follows:

1. Resultant forces exist in conjoined circumstances (theoretical and experiential considerations)
2. Component forces exist in conjoined circumstances (explanation by composition of causes)
3. In conjoined circumstances, the resultant force is distinct from the component forces, either individually or as jointly existing (individuation conditions of forces)
4. In conjoined circumstances, the resultant force is sufficient to produce the effect (Newton's second law)
5. In conjoined circumstances, the jointly existing component forces are sufficient to produce the effect (the superposition principle)

∴The effects produced in conjoined circumstances are generally causally overdetermined.

The conclusion is unsatisfactory: surely the effect in a given case of conjoined circumstances is not caused twice over – once by the component forces assumed to be present, and again by the (dffierent) resultant force assumed to be present. These causal considerations fill in and confirm Creary's observation that "[I]f one [. . .] took for granted the reality of overall resultant forces, then one would naturally be led to conclude that component forces are unreal, since one would otherwise have to regard them, most implausibly, as physically redundant real forces that 'shared' their effects with their (presumably real) resultants". I turn now to the question of how the threat of force-based overdetermination may be avoided.

3.3. Candidate solutions to the force-based threat of causal overdetermination

In considering how to avoid force-based overdetermination, it is useful to consider strategies parallel to those offered in response to the threat of mental overdetermination. (In what follows, I'll assume that talk of forces, boolean combinations of forces, and so on, may be translated into talk of states constituted by such entities, if so desired.) My initial goal will be to establish that none of the non-eliminativist strategies are appropriately implemented, so that the correct response to the threat of force-based overdetermination must involve eliminativism about either resultant or component forces. I'll then argue that we do better to eliminate component forces as existing in conjoined circumstances.

Non-eliminativist strategies all maintain that both resultant and component forces exist in conjoined circumstances. The question here is then: what relations might hold between resultant and component forces, that would plausibly block the threat of overdetermination?

Reductionism. Above, I noted that reductive physicalists typically identify mental with physical states. More specifically, mental states are typically identified with relational physical states, constituted by physical entities standing in physical relation (e.g., the microphysical correlate of a brain state), or (if the mental state is of a type that is multiply realized) with disjunctions of such relational physical states. These strategies reflect that mental states are not plausibly identified with states constituted (just) by individual physical entities (e.g., by individual fundamental physical particles) or by conjunctive states constituted by multiple physical entities understood as jointly existing (e.g., by unstructured collections of fundamental physical particles). Similarly, in considering whether resultant forces may be reductively identified with component forces, the candidate entities involving component forces need to be relational entities, constituted by the component forces standing in certain relations, since as previously noted, resultant forces are not plausibly identical either to individual component forces or to (conjunctive states constituted by) multiple component forces understood as jointly existing. The problem, as I will now argue, is that there is no relational state with which the resultant force is plausibly reductively identified.

Let's start by noting two constraints on the desired relational state. First, the state must be such as to be associated with only a single magnitude and direction, having the values of the magnitude and direction of the resultant force which is to be identified with the relational state. Second, the state must have component forces as constituents (and not just as causes or lawfully necessary preconditions) – otherwise identification of the resultant force with the state would not implement the reductionist's distinctive strategy for avoiding overdetermination. So far as I can tell, the only sort of state with any promise of satisfying both desiderata is a relational state in which the component forces are related to the resultant force as existing summands are related to a sum; in other words, the (resultant) whole is identical with the sum of its existing (component) parts. Note that such a sum is not to be confused with a conjunction. In abstract terms, a set is not a sum; more specifically, a sum of component forces, but not a (mere) conjunction of such forces, is guaranteed to be associated with a single magnitude and direction with the desired values (corresponding to those associated with the resultant force).

It is this sort of suggestion that Cartwright (broadly) considers, in rejecting that the effects of component forces might be considered parts of the effects of resultant forces. It is no more plausible to see component forces as parts of resultant forces, on any ordinary understanding of the part/whole relation, or any reasonable extrapolation therefrom. On the ordinary understanding of parthood, as applied to broadly scientific entities, these may have spatial, and perhaps also temporal, parts. But since resultant forces may be instantaneously exerted at a single point, component forces cannot be spatial or temporal parts of resultant forces. Nor can we make sense of the suggestion by extrapolating from the ordinary understanding of parthood, taking the parthood of component forces to be a matter of parthood, broadly construed, as holding between the the magnitudes and directions of component and resultant forces. The most plausible such extrapolation would take force $\mathbf{F}_1$ to be part of force $\mathbf{F}_2$ just in case the magnitude of $\mathbf{F}_1$ is less than or equal to $\mathbf{F}_2$, and both forces are exerted along the same direction; but component forces may point in directions different from their resultant, and may have magnitudes greater than those of their resultant. The claim that resultant forces are wholes identical with the sum of their (component force) parts thus seems incorrect. Here I concur with Russell's (1903, 477) claim that "[vector] composition is not truly addition, for the components are not *part*s of the resultant. The resultant is a new term, as simple as its components, and not by any means their sum".

But (recalling Creary's observation that Cartwright only considers "a single proposal" for understanding vector addition in metaphysical terms) might there be some other way of understanding the sums at issue, in terms other than the part-whole relation? Spurrett (2001) presumably has such a strategy in mind when, in considering a solution to the problem of partial laws admitting both component and resultant forces, he approvingly cites Nagel's (1963) objection that Russell is operating with a needlessly restrictive notion of "sum":

> From Nagel's point of view the "sum" of more than one thing of some kind will not necessarily have the constituents as literal parts, as is the case with length, but will more generally be determined by some function (p. 262).

Not just any function of the "constituents" will do, for purposes of showing how component and resultant forces can mutually exist – for example, if summation of component forces involves their "fusing" (*a la* Humphreys 1997), going out of existence in the process. Nor will a conception on which component forces cause resultant forces without going out of existence provide a basis for a reductive identification of resultant forces with (sums of) component forces (though we will consider this strategy under the 'Emergentist' head, below).

The deeper problem, however, with taking resultant forces to be a new kind of "sum" of component forces reflects that the threat of causal overdetermination is at the core of the problem of partial laws, and associated concern about whether component forces can exist in conjoined circumstances. From this perspective, the point of appealing to the part/whole relation is to show how the threat may be avoided in non-eliminativist fashion: if the whole (the resultant force) is the sum of its parts (the component forces), then – by analogy to ordinary cases where wholes are reductive sums of parts, as in the case of lengths or masses – we can see how component and resultant forces can jointly exist without inducing overdetermination. But if the intuitive understanding of parthood does not make clear sense as applied to resultant and component forces, then appeal to this relation loses its dialectical force, being little better than a dogmatic insistence that no problematic overdetermination is at issue. Hence, at least so far as reductive identification is concerned, the single part-whole proposal that Cartwright considers is (when applied to forces rather than their effects) the only metaphysical game in town so far as vector summation is concerned.

Summing up (no pun intended): resultant forces, if they are to be identified with a relational state constituted by component forces, must be identified with a sum of component forces; such an identification would entail that resultant forces have component forces as existing parts; but component forces are not appropriately seen as existing parts of resultant forces; hence the reductionist strategy for avoiding mental causal overdetermination cannot be applied so as to avoid force-based causal overdetermination.

Non-reductionism. As above, non-reductionist strategies for avoiding mental overdetermination aim to establish that mental states stand to physical states in a relation intimate enough to avoid overdetermination (by satisfying the general physicalist condition on the numerical identity of powers discussed earlier) but which is not identity. In the mental-physical case two relations have been seen as promising along these lines: the proper part/whole and determinable/determinate (a.k.a. "determination") relations. Neither relation appears to make sense, though, as holding between resultant and component forces.

First, for reasons parallel to those canvassed earlier, there is no ordinary understanding of parthood or reasonable extrapolation therefrom according to which resultant forces are parts (much less proper parts) of any (or all) individual component forces. The closest one can get to this suggestion is to take resultant forces to be improper parts of (that is, identical with) relational states wherein the component forces are related to each other as existing summands are related to a sum, which is at odds both with non-reductionism and with the fact that component forces are not appropriately seen as parts of resultant forces.

Second, resultant forces don't appear to be determinables of more determinate component forces or associated states. To start, determination is a relation of increased specificity (e.g., to be scarlet is to be red, in a specific way);[15] but forces (of whatever variety) are equally specific, so far as their characteristic magnitudes and directions are concerned. One might wonder if we can make sense of resultant forces being determinables of relational states, where the latter are again supposed to be sums having component forces as existing summands. This suggestion would make abstract room for an increased specificity relation as holding between resultant forces and specific sums of component forces, with the idea being that resultant forces are less specific than (sums of) component forces in that different collections of component forces can add up to the same resultant force.

One problem with the suggestion reflects that, while an increase in specificity is necessary for determination, it is not sufficient (an effect may be caused in many specific ways, but causation is not determination). It is, moreover, characteristic of determinables that they are always determined (nothing can be red without being a specific shade of red). This indicates that resultant forces are not appropriately seen as determinables of sums of component forces, since resultant forces may occur (in non-conjoined circumstances, in particular) without any more specific component forces occurring.

The deeper problem, though, again concerns the role that sums of component forces play in this attempt to implement the non-reductionist's strategy for avoiding causal overdetermination. For purposes of this strategy, it doesn't much matter whether the relation between resultant forces and sums of component forces is appropriately called 'determination' or not. What does matter is that this relation, whatever it is, guarantee satisfaction of the condition that every power of the resultant be numerically identical with a power of the component forces when these are (just) jointly present. But to suppose that resultant forces are determinables (or whatever) of sums of component forces does not guarantee satisfaction of the condition, since the status of the summation relation remains crucially unclear, insofar as component forces are not appropriately taken to be existing parts of

[15] That determination involves increased specificity is what Yablo (1992) calls the "core idea" of determination, and what Funkhouser (2006) calls the "most central" aspect or "key idea" of determination.

resultant forces. (Hence it turns out that arguments against a 'part/whole' understanding of vector summation indicate that non-reductive as well as reductive physicalist strategies for avoiding overdetermination don't work for the case of forces.) Indeed, given that component forces cannot be seen as existing parts of resultant forces, one might be led to interpret the summation at issue as involving causation, as per the emergentist strategy that we will now consider, which strategy presupposes that the condition on powers is not satisfied.

Emergentism. Recall that the emergentist maintains that the causally competing states both exist, but avoids overdetermination by maintaining either that one of the states does not in fact cause the effect, or (more plausibly) that one of the states causes the effect in a less direct way than the other. As above, the emergentist can motivate the claim that the states differently produce the effect at issue by taking one of the states to be a lawfully necessary precondition for the operation of some new law or interaction, which is to some extent constitutive of the other state, and in virtue of which the other state has a new causal power. One might try to implement a similar strategy in the present case, by appeal to the laws of composition operative when component forces are combined in conjoined circumstances (see Broad 1925 and McLaughlin 1992). Effectively, the suggestion would be that component forces, together with composition laws, cause resultant forces, which then are the direct causes of the effects in question.

Though there is no incoherence in taking component forces to cause resultant forces, the emergentist strategy is ineffective in avoiding the force-based threat of causal overdetermination. For the emergentist strategy to dismantle the threat, it must be at least arguable that component forces are not themselves sufficient for directly causing the effect in question (as it is at least arguable that physical states only indirectly cause the effects in question, in virtue of bringing about the mental states which, with the help of new fundamental interactions or emergent laws, directly cause these effects). But since component forces *are* directly sufficient for the effect in question when in non-conjoined circumstances (when first one acts, and then the other), it is reasonable to assume that they are also directly sufficient for the effect in question – in particular, without the mediation of the resultant force – when jointly present in conjoined circumstances. Ultimately, then, a causal account of the relation between component and resultant forces in conjoined circumstances equally invokes a problem of overdetermination, with both the component and resultant forces each being independently capable of directly producing the effect in question.

Eliminativism. We have now exhausted the usual non-eliminativist strategies, so far as avoiding causal overdetermination is concerned. I turn now to assessing the merits of the eliminativist options that remain.

Eliminativism about resultant forces. As above, Creary (1981) thinks that a fairly "simple and obvious" way of resolving the problem of partial laws is to maintain that component, but not resultant, forces exist in conjoined circumstances, and one might wonder whether this strategy equally provides a straightforward response to the problem of force-based overdetermination. Recall that on Creary's view, partial laws (e.g., Coulomb's law and Newton's law of gravitation) connect massy or charged bodies with component forces, which forces are then connected by a law of action (e.g., Newton's second law, understood as encoding the relevant composition laws) to accelerations. To a certain extent, then, Creary's suggestion is along lines of the emergentist view just considered, with the crucial difference that component forces, in combination with composition laws, cause behavioral effects rather than resultant forces. Having gotten rid of resultant forces, no problem of overdetermination remains; or so Creary might claim.

Solving the problem of force-based overdetermination (or the problem of partial laws) is not this easy, however, and Creary himself indicates why when he cites the need to avoid an implausible redundancy of forces, as a motivation for his as well as for Cartwright's views. As earlier discussed, the threat of causal overdetermination underlying the problem of partial laws gets started on the plausible assumption that we have good theoretical and experiential reasons for believing that resultant forces exist in conjoined circumstances. For Creary's suggestion to provide a satisfactory solution to this threat, it isn't enough just to point to the advantages that accrue if one rejects resultant forces. In addition it is required that one address – and presumably, explain away – the aforementioned theoretical motivations (pertaining to the standard, plausible, systematic interpretation of Newton's second law) and experiential motivations (pertaining to our seeming experience of resultant forces in conjoined circumstances) for thinking that resultant forces exist. Creary doesn't discuss these motivations, however, much less explain them away.

In considering the prospects for Creary's discharging this burden, it is illuminating to compare the case of eliminativism about mental states. As noted, this is a hard row to hoe, but to the extent that eliminativists get traction here, it is in virtue of there being a distinction in the grounds for the posits in question, with the suggestion being that the introspective and folk-psychological motivations for taking mental states to exist are not in as good standing as the theoretical motivation for thinking that physical states exist (see, e.g., Churchland 1981 and 1984). Creary's row may be harder still, for his primary motivation for thinking that component forces exist – namely, that these play a crucial role in theoretical explanations of phenomena in conjoined circumstances – is also a motivation for thinking that resultant forces exist. After all, we may also explain why an object has a certain acceleration in conjoined circumstances by citing the resultant force operating on it; and there are clear contexts where the features specifically of the resultant force are relevant to the explanandum – e.g., where what is at issue is the similar behavior of entities subject to different component influences. Considerations of theoretical explanation thus motivate accepting resultant forces as much as they do component forces. Moreover, even granting that we seem to experience component forces (a claim I'll assess in more detail shortly) it remains that we also seem to experience resultant forces. On the face of it, then, motivations for accepting component forces are equally motivations for accepting resultant forces.

The reverse is not true, however. As above, considerations of the proper interpretation of Newton's second law motivate accepting resultant, not component forces. I would also maintain that there is an asymmetry in experiential motivation, for while we sometimes seem to experience resultant forces without seeming to experience component forces (as when on a tilt-a-whirl), we do not (or so I introspect) ever seem to experience component forces without also seeming to experience resultant forces (assuming, as I do, that we can experience nil forces; see note 17).

All this is just to say that Creary and other eliminativists about resultant forces need to attend to the motivations for and costs of rejecting resultant forces, before such eliminativism can be seen as providing a solution to the problem of force-based overdetermination – or, for similar reasons, to the problem of partial laws. Merely highlighting the independent reasons we have to accept component forces as existing in conjoined circumstances only exacerbates these problems.

Eliminativism about component forces. As with the rejection of resultant forces, the threat of overdetermination is straightforwardly avoided if eliminativism about component forces is embraced. However, as I'll argue here and in the next section, the rejection of component forces as existing in conjoined circumstances is, at least for all anyone has established so far, cost-free, from either an experiential or a theoretical point of view.

Let's start by considering whether the rejection of component forces is compatible with experience. As above, our experience of forces in conjoined circumstances seems always to involve experience of a single resultant force, and moreover sometimes (as on a tilt-a-whirl) seems not to involve experience of distinct component forces. Still, might our experience of forces in conjoined circumstances sometimes involve component forces, in addition to resultant forces?

Here it is useful to comparatively consider cases where the resultant forces are the same, but one's experience is different.[16] For example, consider two arm wrestlers whose hands are in poised contact prior to the contest, with the resultant force on each hand being zero. The contest starts, but since the wrestlers are evenly matched, no motion occurs, and the resultant force on each hand is again zero. Nevertheless, the experience of each wrestler is different from before: each will

[16] Such cases are discussed in Spurrett 2001 and Massin 2009, though in service of motivating component forces on theoretical rather than experiential grounds.

experience a feeling of pressure on (and in) their hand. More generally, it's clear that we frequently experience compressions – say, when standing, or when one's elbows rest on a table – even when not experiencing any accelerations. Insofar as the resultant forces in these cases are all the same (namely, of zero magnitude and direction), the differences in experience can't be explained as involving differences in resultant forces. By way of contrast, were component forces to exist, they would be different in the different cases; hence one might suggest that in order to explain our experience we should accept component forces as existing in conjoined circumstances.

The suggestion is natural enough, but considerations of causal overdetermination give us good reason to look for an alternative explanation of this experience, that does not require the posit of component forces. Indeed, there are several sources of difference in the cases at issue, including differences in spatiotemporal relations between one's parts, differences in sensory quality associated with the different positioning of these parts (if one's parts get too close, one may feel pain), and differences in (scalar) potential energies associated with the different positioning of these parts. Moreover, each of these differences appear to be differences we can experience. As such, there appear to be resources available to explain the differences in experience in the above cases even supposing we reject component forces.

For similar reasons, I do not see the above sorts of cases as providing much theoretical motivation for component forces. Spurrett (2001, 261) takes component forces to be needed to explain "the fact that nothing happens", but this much seems explicable by Newton's law, along with the fact that the resultant force has zero direction and magnitude.[17] Massin (2009) suggests that component forces are needed to explain changes of dispositions in such cases. So, for example, the wrestlers' hands have different dispositions before and after the contest begins: if one pulls away their hand, the other's hand will quickly accelerate to the table. Even granting that different component forces in conjoined circumstances would provide a ground for such a difference in dispositions, however, so might other available differences. For example, differences in (scalar) potential energy appear well suited to be the ground of different dispositions, for the circumstances in which such a disposition becomes manifest – say, involving the pulling away of one hand – appear to be the very circumstances in which potential energy is converted into kinetic energy, due to the operation of what is now a resultant force on the other hand.

Beyond these brief remarks, I won't attempt to develop alternative strategies for accommodating the experiential or theoretical differences in the above cases,

[17] Spurrett supposes that in such cases, no resultant force exists, but this is incorrect: following Balashov (1999) we should distinguish between having zero (value of) a given feature P, and P-less-ness, and understand forces with zero magnitude and direction in the former terms.

both because such development would take us further afield (e.g., into the natures of dispositions and potential energies), and because such development isn't needed, dialectically speaking. The above motivations for component forces proceed by assuming (what I am here granting) that certain differences in experience or dispositions could be explained by differences in component forces, were such forces to exist. It suffices to respond to such arguments to point out that they are enthymematic, in that the comparative cases at issue also involve differences in non-force entities (notably, potential energies; or, perhaps, non-force manifestations of dispositions along lines of the account proposed in section 4.2) which, it seems, could also explain the experiential and dispositional differences in question. The burden of proof here is thus on the proponent of component forces, to argue that we *mus*t explain the differences at issue in terms of component forces rather than non-force grounds. Meanwhile, the opponent of component forces can maintain that such cases do not show that any cost attends to their view.

A. Wilson (2009) cites another broadly theoretical motivation for taking component forces to exist in conjoined circumstances, as follows. Assume a case of conjoined circumstances, in which an object accelerates as per a resultant force determined by two component influences. Do the component influences correspond to component forces? Wilson argues yes, on grounds that in a non-inertial reference frame accelerating as per one of the component influences, the object will appear to accelerate subject to a resultant force with the same magnitude and direction as the other component force. He interprets this sort of possibility as indicating that the status of a force as component or resultant is frame-dependent: what is a component force in an inertial reference frame appears as a resultant force in a non-inertial frame. And given that we have good reason to accept resultant forces, we will have corresponding good reason to accept component forces.

Unlike Creary, Massin, and Spurrett, Wilson appears to accept resultant as well as component forces as existing in conjoined circumstances, and to this extent his discussion serves mainly to exacerbate the problem of force-based causation. But in any case the motivation for positing component forces here is weak. After all, depending on what non-inertial reference is chosen, the object at issue might appear to move with an acceleration associated with any force whatsoever, including the nil force. Clearly, the vast majority of these seeming forces are not even *prima facie* candidates for existing in the conjoined circumstances at issue. Hence from the fact that an object may appear to be subject to a given force from within a non-inertial reference frame no motivation yet accrues for thinking that the force exists as a component force in whatever inertial frame(s) are associated with the conjoined circumstances.

So far, so good, then, for purposes of implementing eliminativism about component forces. There remains, however, the primary theoretical motivation for component forces, associated with the fact that partial laws, most plausibly taken to express the occurrence of forces, are cited in explanations of phenomena in conjoined circumstances. Can such explanatory appeals be accommodated, compatible with the rejection of component forces?

4. Return to the problem of partial laws

I see two different ways of accommodating explanatory appeals to partial laws, that are compatible not just with rejecting component forces, but with preserving the package deal. Either strategy thus may enter into a better indirect argument for rejecting component forces, as part of the best resolution of both the problem of partial laws and the associated problem of force-based overdetermination.

4.1. Extending the standard covering-law account

The first strategy presupposes that the partial laws at issue express the occurrence of certain forces in circumstances where other determinants of motion are negligible (call these "relatively isolated" circumstances); on such a *ceteris paribus* understanding, partial laws are instantiable, and true, only in such circumstances. Such relatively isolated circumstances are not in place in conjoined circumstances; hence here there isn't any question of partial laws' being instanced in conjoined circumstances – the relatively isolated conditions of their instantiation are simply not in place.

Two points are worth noting as regards this observation. First, there's nothing unusual about laws being instantiable only in certain circumstances; indeed, effectively all causal laws make tacit reference to such circumstances (or "background conditions"); the match's striking when lit requires the presence of oxygen, the absence of dampness and the abrupt end of the world, and so on. Given that the background conditions relevant to the instantiation of, e.g., Coulomb's law (pertaining to relatively isolated circumstances) are not present in conjoined circumstances, the fact that component forces do not exist in such circumstances does not in itself pose any problem for the facticity account; on the contrary, it's just what one would expect from this account (given the understanding of partial laws at issue).

Of course, to observe that there isn't any question of, e.g., Coulomb's law being instanced in conjoined circumstances (compatible with this law's expressing, in line with a facticity account, the occurrence of forces in relatively isolated circumstances), isn't yet to make sense of explanatory appeals to partial laws in such circumstances. But (and this is the second point) it does suggest that the pressure such appeals place on the package deal falls more immediately on the standard covering law account of explanation (requiring that explanations appeal to actually instanced laws) than on the facticity account of laws. For only if appeals to partial laws must conform to a covering law account is there any reason to think that partial laws, if explanatory, must be instanced in conjoined circumstances. But since *ceteris paribus* partial laws are not instanced in conjoined circumstances, a standard covering law account of explanatory appeals to such laws would appear to be a clear non-starter from the perspective of a facticity account, independent of considerations about whether or not component forces exist in conjoined circumstances.

On the other hand, it appears straightforward to extend the standard covering law account in order to accommodate explanatory appeals to partial laws (understood as above), in a way clearly in the spirit of such an account. To start, it is worth noting another way in which aspects of scientific explanation appear to go beyond a standard covering law account; namely, in counterfactual deliberations wherein competing law-candidates are ruled out on grounds that, were they to be instanced, they would entail the truth of some actually false state of affairs, or vice versa. In this broad sense, appeals to counterfactually instanced laws may enter into scientific explanations. The spirit of a covering-law account is plausibly in line with such explanatory appeals to counterfactually instanced laws, and the account can and should be extended accordingly. Similarly, attention to appeals to partial laws in conjoined circumstances may be seen as providing reason to extend the standard covering law account so as to allow appeal to counterfactual as well as actual instancings of laws in scientific explanations.

It is, after all, no real mystery why appeals to counterfactually instanced laws can be explanatory: in particular, as it conveniently happens, goings-on (and associated laws) in relatively isolated circumstances typically serve as a reductively determinative basis for goings-on (and associated laws) in conjoined circumstances.[18] Whether this convenient connection is a matter of contingent or necessary fact need not detain us. For purposes of explanation, what is crucial is that partial laws are, as a matter of actual fact, typically jointly determinant, in the usual compositional fashion, of goings-on in conjoined circumstances.

More broadly, then, it is plausible that appeals to partial laws that are only counterfactually instanced in conjoined circumstances may nonetheless be explanatory of phenomena occurring in those circumstances, when the partial laws serve as a determinative basis for the goings-on (and associated laws) that are actually instanced in the circumstances. And here again, extending the standard covering law account to accommodate appeals to counterfactually instanced laws in reductive explanations appears to be in the spirit of a covering law account.

If we do amend a covering law account as just suggested, what then of the facticity account of laws? So far as I can tell, it may remain intact – first, because

[18] I say "typically" as a hedge against the presently live possibility of emergentism about some complex (e.g., qualitative mental) phenomena.

partial laws are not instanced in conjoined circumstances (compatible with the advisable rejection of component forces as existing in such circumstances) and second, because there is no barrier to so-called "super-laws" being instanced in such circumstances. Recall that super-laws were rejected as entering into a solution to the problem of partial laws on grounds that explanations by composition of causes are indispensible in the sciences, and relatedly, that super-laws would lead to a profligate and unsystematic proliferation of laws. But seeing how a covering law account can be extended to accommodate explanations involving conjoined circumstances shows that these concerns are misguided: explanation by composition of causes is grounded in partial laws that are reductively determinative of goings-on, and associated super-laws, in conjoined circumstances; and such reductive strategies are paradigmatic of systematic and parsimonious approaches to metaphysical and scientific theorizing.

Finally, the proposed strategy can address the concern, analogous to Creary's concern about how appeal to powers can be explanatory of goings-on in circumstances where the powers are unmanifested, that it is unclear how appeal to laws that are only counterfactually instanced in some circumstances can be explanatory of phenomena in those circumstances. The key lies in noting that the fact that appropriately determinative relations are in place between laws in relatively isolated and in conjoined circumstances is itself a matter of law. In particular, these relations may be seen as grounded in composition laws, which like conservation laws are not implausibly seen as expressing higher-order facts: like conservation laws, composition laws appear to express constraints on complex goings-on – that is, facts about facts. Actually instantiated composition laws serve, then, as the ultimate reason why appeals to partial laws that are only counterfactually instanced can be explanatory of goings-on in conjoined circumstances.[19]

4.2. A disposition-based account of partial laws

The second strategy for accommodating explanatory appeals to partial laws takes them to be potentially true in conjoined as well as non-conjoined circumstances, again compatible with the rejection of component forces and in line with the package deal. The strategy appeals to a better version of a powers-based account of the semantics of the partial laws at issue (better, that is, than the powers-based account Cartwright and Creary consider, on which partial laws express the having of potentially unmanifested powers).

On my preferred schematic way of thinking about a powers-based approach, partial laws rather express the manifestations of stable dispositions, where the

[19] Here I assume that, as per the understanding of composition laws as expressing constraints, instantiation of a composition law only requires that the component entities be hypothetically instanced.

same disposition may have different (though typically related) manifestations in different circumstances. It may be that Bhaskar (1975) has such an approach in mind, in claiming that laws express attributions of "tendencies", which are "roughly powers which may be exercised unfulfilled" (p. 98), as well as fulfilled. Talk of tendencies that may be "exercised unfulfilled" is obscure, but if interpreted along lines of my preferred disposition-based account would make some sense (the idea being, I take it, that only certain paradigm manifestations of a disposition count towards its being 'fulfilled').[20]

Let's run through the relevant advantages of a disposition-based account of laws (or more circumspectly: of the partial laws at issue). First, such an account conforms to a facticity account of laws, since manifestations of dispositions are occurrent "happenings", suited to enter into even a relatively strict notion of what counts as a fact. Second, such an account of the semantics of partial laws is systematic: Coulomb's law, for example, expresses the same thing – namely, the occurrence of a manifestation of a single stable disposition – whether instanced in conjoined or in non-conjoined circumstances. Third, insofar as the manifestations of a single stable disposition can differ in different circumstances, the account has the resources to make sense of intuitions that Coulomb's law expresses the occurrence of a force in non-conjoined circumstances, but expresses the occurrence of some other (non-force) manifestation in conjoined circumstances – compatible with the denial of component forces as existing in such experiences. Fourth, the account can appeal to empirically determined composition laws as providing a basis for the determinative relations between different manifestations of a single stable disposition. Fifth, by appeal to the first and fourth features, the account can accommodate explanatory appeal to partial laws, compatible with a standard covering law account.

5. *Concluding remarks*

At the heart of the problem of partial laws is a problem of causal overdetermination – in particular, the threat that, if partial laws express the occurrence of component forces in conjoined circumstances, such forces will causally overdetermine the effects of the resultant forces that we have good experiential and theoretical reason to believe exist in such circumstances. I have argued that, unlike the similar threat attaching to mental and physical states, there are no available non-eliminatist strategies for avoiding the threat of force-based overdetermination: either resultant or component forces must go. And I have argued that, while the

[20] It may also be that Cartwright's own recent account of laws as expressing capacities (developed in her 1989 and 1999) can be seen as a version of my preferred disposition-based account; however, that she sees her view as competing with a facticity account counts against such an interpretation.

rejection of resultant forces definitely incurs theoretical costs and is likely to incur experiential costs, the rejection of component forces is, at least for all that has been shown thus far, cost-free. In particular – to return to the problem of partial laws – we have at least two ways of accommodating appeal to partial laws in conjoined circumstances, compatible both with the rejection of component forces and acceptance of the package deal: one extending a covering-law account of explanation to allow appeal to partial laws only counterfactually instanced in conjoined circumstances, and one which takes partial laws to uniformly express (possibly different) manifestations of stable dispositions. I conclude that the best resolution of the problem of overdetermination and associated problem of partial laws is, after all, one which rejects component forces.*

References

Balashov, Y. 1999, 'Zero-Value Physical Quantities', *Synthese* **119**, pp. 253–286.

Bhaskar, R. 1975, *A Realist Theory of Science*, York: Alma Book Company.

Broad, C. D. 1925, *Mind and Its Place in Nature*, Cambridge: Kegan Paul. (From the 1923 Tanner Lectures at Cambridge).

Cartwright, N. 1980, 'Do the Laws of Physics State the Facts?', *Pacific Philosophical Quarterly* **61**, pp. 75–84.

Cartwright, N. 1983, *How the Laws of Physics Lie*. Oxford: Oxford University Press.

Cartwright, N. 1989, *Nature's Capacities and their Measurement*, Oxford: Clarendon Press.

Cartwright, N. 1999, *The Dappled World: A Study of the Boundaries of Science*, Cambridge: Cambridge University Press.

Churchland, P. 1981, 'Eliminative Materialism and the Propositional Attitudes', *Journal of Philosophy* **78**, pp. 67–90.

Churchland, P. 1984, *Matter and Consciousness*, Cambridge MA: MIT Press.

Creary, L. 1981, 'Causal Explanation and the Reality of Natural Component Forces', *Pacific Philosophical Quarterly* **62**, pp. 148–157.

Ellis, B. 1976, 'The Existence of Forces', *Studies in the History and Philosophy of Science* **7**, pp. 171–185.

Funkhouser, E. 2006, 'The Determinable-Determinate Relation', *Nous* **40**, pp. 548–569.

Gillett, C. and Loewer, B. (eds) 2001, *Physicalism and Its Discontents*, Cambridge: Cambridge University Press.

Hempel, C. 1965, *Aspects of Scientific Explanation and Other Essays in the Philosophy of Science*, New York: The Free Press.

Hempel, C. and Oppenheim, P. 1948, 'Studies in the Logic of Explanation', *Philosophy of Science* **15**, pp. 135–175.

Humphreys, P. 1997, 'How Properties Emerge', *Philosophy of Science* **64**, pp. 1–17.

Johansson, I. 2004, *Ontological Investigations: An Inquiry Into the Categories of Nature, Man and Society*, Frankfurt: Ontos Verlag.

Bigelow, J., Ellis, B. and Pargetter, R. 1988, 'Forces', *Philosophy of Science* **55**, pp. 614–630.

Martin, C. B. 1993, 'Power for Realists', in: J. Bacon, K. Cambell and L. Reinhardt, eds, *Ontology, Causality, and Mind: Essays on the Philosophy of D. M. Armstrong*, update. Cambridge: Cambridge University Press.

Massin, O. 2009, 'The Metaphysics of Forces', *dialectica* **63**, pp. 555–589.

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McLaughlin, B. 1992, 'The Rise and Fall of British Emergentism', in: H. Flohr, A. Beckerman and J. Kim, eds, *Emergence or Reduction? Essays on the Prospects of Non-reductive Physicalism*, Berlin: De Gruyter, pp. 49–93.

Mill, J.S. 1843/1973, *A System of Logic,* vols II and III of *The Collected Works of John Stuart Mill*, Toronto: University of Toronto Press.

Nagel, E. 1963, 'Wholes, Sums and Organic Unities', in: D. Lerner, ed., *Parts and Wholes*, New York: The Free Press.

Newton, I. 1687/1999, *The Principia: Mathematical Principles of Natural Philosophy*, trans. by I. Bernard Cohen and a. Whitman, Berkeley: University of California Press.

Russell, B. 1903, *The Principles of Mathematics*, London: Routledge.

Salmon, W. 1971, *Statistical Explanation and Statistical Relevance*, Pittsburgh: University of Pittsburgh Press.

Shoemaker, S. 2001, 'Realization and Mental Causation', in: G. Gillett and B. Loewer, eds, *Physicalism and its Discontents*, pp. 74–98. Cambridge: Cambridge University Press.

Spurrett, D. 2001, 'Cartwright on Laws and Composition', *International Studies in the Philosophy of Science* **15**, pp. 253–268.

Suppes, P. 1970, *A Probabilistic Theory of Causality*, Amsterdam: North-Holland.

Wilson, A. 2009, 'Disposition-manifestations and Reference-frames', *dialectica* **63**, pp. 591–601.

Wilson, J. 1999, 'How Superduper Does a Physicalist Supervenience need to Be?', *The Philosophical Quarterly* **49**, pp. 33–52.

Wilson, J. 2002, 'Causal Powers, Forces, and Superdupervenience', *Grazer Philosophische-Studien* **63**, pp. 53–78.

Wilson, J. 2007, 'Newtonian Forces', *British Journal for the Philosophy of Science* **58**, pp. 173–205.

Wilson, J. in progress, 'Metaphysical Emergence: Weak and Strong'.

Yablo, S. 1992, 'Mental Causation', *The Philosophical Review* **101**, pp. 245–280.