Forthcoming in Vanzo, A and Anstey, P (eds.), *Experiment, Speculation and Religion in Early Modern Philosophy*, Routledge.

Newton's Scaffolding: the instrumental roles of his optical hypotheses

Kirsten Walsh

Abstract

Early modern experimental philosophers often appear to commit to, and utilise, corpuscular and mechanical hypotheses. This is somewhat mysterious: such hypotheses frequently appear to be simply assumed, odd for a research program which emphasises the careful experimental accumulation of facts. Isaac Newton was one such experimental philosopher, and his optical work is considered a clear example of the experimental method. Focusing on his optical investigations, I identify three roles for hypotheses. Firstly, Newton introduces a hypothesis to explicate his abstract theory. The purpose here is primarily to improve understanding or uptake of the theory. Secondly, he uses a hypothesis as a platform from which to generate some crucial experiments to decide between competing accounts. The purpose here is to suggest experiments in order to bring a dispute to empirical resolution. Thirdly, he uses a hypothesis to suggest an underlying physical cause, which he then operationalises and represents abstractly in his formal theory. The second and third roles are related in that they are both cases of *scaffolding*: hypotheses provide a temporary platform from which further experimental work and/or theorising can be carried out. In short, the entities and processes included in Newton's optical hypothesis are not simply *assumed* hypothetical posits. Rather, they play instrumental roles in Newton's experimental philosophy.

1 Introduction

Isaac Newton was often explicitly *anti*-hypotheses. He expressed this attitude in various methodological statements such as this one from Query 31 of the *Opticks*:

> This Analysis consists in making Experiments and Observations, and in drawing general Conclusions from them by Induction, and admitting of no Objections against the Conclusions, but such as are taken from Experiments, or other certain Truths. For Hypotheses are not to be regarded in experimental Philosophy (Newton, 1952: 404).

And this one from the General Scholium to the *Principia*:

> I have not as yet been able to deduce from phenomena the reason for these properties of gravity, and I do not feign hypotheses. For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, or based on occult qualities, or mechanical, have no place in experimental philosophy (Newton, 1999: 943).

Prima facie, Newton's speculations concerning the nature of light belie these anti-hypothetical statements. In his 1675 paper 'An Hypothesis explaining the Properties of Light discoursed of in my severall Papers', for instance, Newton described light as a collection of tiny particles, or corpuscles, that are emitted from shining, or 'luminiferous', bodies. A similar hypothesis is described in the *Opticks* in Books 2 and 3. It might seem surprising, considering his railing against hypotheses, that a corpuscular hypothesis is introduced so prominently in Newton's optical work. One might even wonder if, against his own methodological decree, Newton is feigning the corpuscular hypothesis.

In fact, Newton's position on hypotheses is much more interesting and complicated than the above passages suggest. While hypotheses are certainly not the goal of investigation—they are not an end in themselves—they nonetheless play vital supporting roles in Newton's experimental philosophy. In his early optical papers, Newton describes two permissible roles for hypotheses: (1) to explicate abstract theories with concrete metaphysics, thus providing a 'possibility proof' for the theory; and (2) to suggest experiments, thus offering new avenues for empirical support.

Examining the ways in which Newton employs hypotheses in his optical investigations, I discuss Newton's two permissible roles for hypotheses and identify a third. Firstly, Newton introduces his hypothesis on the nature of light to illustrate or explicate his abstract account of the composition of white light. The purpose here is primarily to improve uptake or understanding of the abstract theory. This fits with Newton's (1) above. Secondly, Newton uses Hooke's hypotheses on light as a platform from which to generate some crucial experiments to decide between his account and Hooke's. The purpose here is to suggest experiments in order to bring the dispute to an empirical resolution. This fits with Newton's (2) above. Thirdly, Newton uses his hypothesis on the nature of light in his investigations of interference phenomena. Here, the hypothesis suggests an underlying physical cause that Newton operationalises and thus represents abstractly in his formal theory of fits. This third use of a hypothesis does not fit with either of the roles Newton explicitly identifies, and yet it fits his overarching methodology. Moreover, the second and third roles are related in that they are both cases of *scaffolding*. In both cases, hypotheses provide a temporary platform from which further experimental work and/or theorising can be carried out.

The term 'scaffolding' here is an architectural metaphor. In architecture, scaffolding provides either temporary support for a building during construction or maintenance, or a temporary platform for workers and/or materials during the construction or maintenance of a building. Scaffolding is not part of the building; it is supposed to be removed after it has served its function. The analogue in Newton's methodology is his insistence that hypotheses be extracted from the final formal theory. Characterising Newton's method of hypotheses as scaffolding allows us to explain how Newton can, on the one hand, insist that he is not 'feigning' hypotheses, but on the other put them to work. Newton might make use of hypotheses in developing his theory, but the hypothesis is nonetheless separate from that theory—and not an essential part of it.[1] Obviously, in the building context, things can go wrong. Sometimes a building is never completed, and so the scaffolding becomes a permanent fixture (consider, for example, Gaudi's unfinished cathedral, *Sagrada Família*). Sometimes the scaffolding cannot be removed and becomes part of the design (consider, for example, the 13th-century scaffolding of the spire of Salisbury Cathedral that is now a tourist attraction). Such failures, too, have analogues in Newton's work. For example, we might regard the *Opticks* Book 3 as an uncompleted investigation: the queries represent hypotheses that are supposed to scaffold Newton's theorising. (We shall discuss such cases in section 3.2.)

Philosophers of science use the concept of scaffolding in a number of ways. For example, Adrian Currie applies the notion to the generation of scientific knowledge (e.g. Currie, 2015, 2018).[2] Currie argues that scaffolding occurs when a general or coarse-grained hypothesis that is relatively well-supported provides a platform from which to distinguish empirically between two or more finer-grained hypotheses. This account has much in common with the way Newton utilised Robert Hooke's hypothesis to suggest

---

[1] Indeed, the construction of King's College Chapel in Cambridge required an enormous amount of scaffolding that was not part of the finished product—as evidenced by the presence of numerous 'putlog holes' which show us where the scaffolding had been (Fitchen, 1981: 248).

[2] Also, a recent volume applies the notion to human cognition and evolution (Caporael*, et al.*, 2014).

experiments. (We shall discuss this point in section 2.2.) However, the kind of scaffolding we find in Newton's investigation of interference phenomena looks very different to this—as evidenced by the fact that Alan Shapiro has characterised this investigation as "very much as in the hypothetico-deductive method" (Shapiro, 1993: 200). It is misleading to characterise Newton's methodology in this way—there is little in his explicit methodological statements to support it (Walsh, 2017). But it is worth considering how my interpretation and Shapiro's differ. Shapiro regards the trajectory from hypothesis to formal theory in Newton's work as a process of deducing empirical consequences from the hypothesis and using experimental results to make adjustments to the hypothesis. Over the course of the investigation, the hypothesis is refined until it fits with all the observations. In contrast, I regard the process as one of abstraction. In scaffolding-language, Newton's hypothesis provides a temporary platform to enable him to get empirical traction on a vague hypothetical concept. Once that traction is obtained, Newton sets about removing the scaffolding. Shapiro's account suggests a higher level of commitment to hypothetical posits and processes than I think is warranted.

The paper will proceed as follows. In section 2, I offer an account of Newton's explicit method of hypotheses: first, I outline Newton's distinction between theories and hypotheses, then I discuss the two roles for hypotheses identified in Newton's methodological statements. In section 3, I discuss Newton's investigation of interference phenomena—the appearance of coloured rings on thin films. I outline the process by which Newton moved from the initial observations to the final theory of fits, focusing on the transition from 'æthereal pulses' to 'intervals of fits'. I then characterise this process as scaffolding. In section 4, I conclude by considering two upshots of scaffolding. The first concerns how we should understand Newton's metaphysics. I argue that we should understand Newton's metaphysical posits functionally: to be a corpuscle, on Newton's account, is to play a certain kind of role. The second upshot concerns what the case teaches us about the relationship between corpuscularism and early modern experimental philosophy. Early modern experimental philosophers often appear to commit to, and utilise, corpuscular and mechanical hypotheses. In this respect, Newton's attitude to corpuscles looks idiosyncratic—he neither assumed nor argued for them. Rather, corpuscles were *hypotheses* and thus played an instrumental role in his experimental philosophy.

2 Newton's method of hypotheses

Before we consider Newton's optical work in detail, it will be helpful to understand Newton's methodological statements concerning hypotheses such as the ones we saw in the introduction. So in this section, I outline Newton's distinction between theories and hypotheses and sketch the roles played by hypotheses in Newton's experimental philosophy.

2.1 The theory–hypothesis distinction

A well-known feature of Newton's methodology is his distinction between certainty and uncertainty.[3] Newton contrasted the certainty of his own natural philosophical claims with the mere hypotheses and speculations which other philosophers found appealing. Consider, for example, the following methodological statement from Newton's letter to the Royal Society, detailing his new optical theory:[4]

> A naturalist would scearce expect to see the science of [colours] become mathematicall, & yet I dare affirm that there is as much certainty in it as in any other part of Opticks. For what I shall tell concerning them is not an hypothesis but most rigid consequence, not conjectured by barely inferring 'tis thus because not otherwise or because it satisfies all Phænomena (the Philosophers universall Topick,) but evinced by the mediation of experiments concluding directly & without any suspicion of doubt (6 February 1672, Newton, 1959-1977: 96-97).

Here, Newton exhibits a striking lack of epistemic modesty. At a time when the Royal Society valued epistemic humility, never claiming certainty when the evidence only supported high probability,[5] Newton asserted certainty—and apparently without any special warrant!

In fact, Newton thought he was warranted in making such claims, because he had a reliable methodology. His approach was based on the idea that mathematics is a bearer of certainty—if one begins with certain axioms, one can reason deductively to certain

---

[3] This distinction has been discussed by (e.g. Guicciardini, 2011, Shapiro, 1993, Walsh, 2012b).

[4] This passage was omitted when the letter was published in the *Philosophical Transactions* (Newton, 1672).

[5] See, for example, Robert Hooke's 'Preface to the Royal Society' in his *Micrographia* (Hooke, 1966/1665).

theorems without epistemic loss. Newton thought it was possible to apply this method of reasoning to natural philosophy: one can reason deductively from laws and principles to propositions in natural philosophy. So, if one can establish *certain* natural philosophical principles, it is possible to reason mathematically to *certain* propositions. By reasoning in this way, Newton thought he could achieve a mathematical science. The challenge, then, was to identify principles that meet this requirement of certainty—via *deduction from phenomena*.[6]

Newton's distinction between certainty and uncertainty is best characterised as a distinction between 'theories' and 'hypotheses' (outlined in table 1 belowtable 1 below).[7] In Newton's methodology, theories and hypotheses deal with different subject matter, have different epistemic statuses and, as we shall see, perform different roles in the explanation of natural phenomena. Theories systematise the observable, measurable properties of things; hypotheses describe the (unobservable) nature of things. Theories are inferred from observation and experiment; hypotheses are speculative. For example, Newton regarded the heterogeneity of white light as a theory, since it was inferred from the observed phenomenon of the elongated prismatic spectrum (codified by the *experimentum crucis*), had empirically testable consequences and was used to systematise those observations. However, an explanation involving the *nature of light*—e.g. an emission or corpuscularian account—would be a hypothesis, since it concerned the unobservable nature of things, and was speculative, rather than inferred from experiment—and thus, any explanation of this sort would be, at best, only probable.

The distinction between theories and hypotheses is central to Newton's methodology. For Newton, theories were on epistemically surer footing than hypotheses because they were grounded on phenomena, whereas hypotheses were grounded in

[6] For Isaac Barrow's early influence on this methodology, see (Dear, 1995: chapter 8, Dunlop, 2012).

[7] Newton introduced his theory-hypothesis distinction in his response to Robert Hooke (11 June 1672). Here he explicitly used the labels 'theory' and 'hypothesis' to draw the epistemic distinction I have just outlined and which was implicit in his earlier writing (Newton, 1959-1977: 173-174). Newton rarely used the term 'theory' in his publications. What remains consistent is the epistemic distinction, rather than the labels themselves. My definition of 'theory' corresponds to his use of the labels 'proposition', 'theorem' and, in the context of his early optical work, to the term 'doctrine'. For a discussion of the distinction between theories and hypotheses in early modern philosophy more generally, see (Ducheyne, 2013).

speculations. And so, hypotheses could not undermine theories. When faced with a disagreement between a hypothesis and a theory (e.g. suppose that our theory states that white light is a compound, but the most plausible hypothesis about the nature of light states that white light is pure and homogeneous), we should modify the hypothesis to fit the theory, and not *vice versa*.

Theory	**Hypothesis**
A proposition is a 'theory' iff it meets the following conditions:	A proposition is a 'hypothesis' iff it meets one or more of the following conditions:
T1. It is certainly true, because it is reliably inferred;	H1. It is, at best, only highly probable; or
T2. It is experimental—deduced from empirical evidence; and	H2. It is a conjecture or speculation—something not based on empirical evidence; or
T3. It is concerned with the *observable, measurable properties* of an entity or process, rather than its nature.	H3. It is concerned with the nature of an entity or process, rather than its observable, measurable properties.

Table 1 Definitions of 'theory' and 'hypothesis'[8]

At this point, one might be tempted to conclude that Newton was advocating a wholesale rejection of hypotheses, especially considering his own rhetoric. However, we shall now see that, while Newton decried hypotheses—determined to preserve the certainty of his propositions and to avoid epistemic loss by keeping speculative conjectures apart—hypotheses played an important role in his negotiations between experimental results and certainly true conclusions. As Shapiro puts it:

> While it is true that Newton believed in a corpuscular theory, utilized it in developing many of his optical experiments and theories, and argued vigorously against the wave theory of light, he never believed that it was a demonstrated scientific truth (Shapiro, 2002: 227).

---

[8] Note, firstly, that the conditions doing most of the work are T1 and H1. These are strong epistemic requirements. T2 and T3 might be considered corollaries of T1, but I have stated them here as separate conditions, because I think it is useful for the discussion: on Newton's view, his new theory meets T2 and T3. Secondly, the definition of 'hypothesis' is disjunctive. Any one criterion on its own is a sufficient condition for calling something a hypothesis. This does not preclude the possibility of a hypothesis meeting more than one criterion—it is possible for a hypothesis to meet all three. Thirdly, a proposition meets the definition of 'hypothesis' if it fails to meet one criterion for 'theory'. So, in a very broad sense, propositions may be divided into theories and hypotheses.

2.2 The roles of hypotheses

So, Newton did not reject hypotheses wholesale—although he denied them an explicit evidential role. What, then, did they do? In this section, I identify two explicit roles for hypotheses in Newton's methodology—explicating theories and suggesting experiments.

Newton explained the role of hypotheses in a letter to Ignace-Gaston Pardies. It is worth quoting this passage *in extenso*:

> In answer to this it is to be observed that that Doctrine which I have explicated about Refraction and Colours consists only in certain *Properties of Light*, without regarding *Hypotheses* through which those Properties need to be explicated. For it seems that the best and safest method of philosophising is, first that we inquire carefully into the Properties of things and establish them through experiment; then more slowly that we seek Hypotheses for the explication of them. For *Hypotheses* ought to be brought forward only to explicate the properties of things, and not to be (unlawfully) assumed in determining them, unless insofar as they may provide experiments. And if anyone may conjecture, from the basis of the possibility of the Hypothesis, about the truth of things, I see not how anyone can determine certainty in any science; since numerous other Hypotheses always can be invented, which will seem to overcome new difficulties. And for this reason, I place aside improper arguments from the contemplation of *Hypotheses*, this avoidance having been thought necessary, and the force of the Objection to be abstracted, so that a fuller and more general answer may be received (10 June 1672, Newton, 1959-1977: Vol. 1, 164—my translation).

In this passage, Newton tells us what hypotheses can and can't do. Let's start with what they *can't* do. Hypotheses can neither constrain theorising nor influence our epistemic attitudes to theories. For example, explanations of optical phenomena should be drawn from the phenomena themselves, rather than from assumptions about, say, the purity or wave-like nature of white light. Nor should we take those assumptions into account when deciding whether or not to accept a theory. Instead, we must consider whether the theory is supported by empirical evidence.[9]

---

[9] Nowadays, we might think that hypotheses (in Newton's sense of the term) garner independent support from background theory, which enables them to have direct epistemic impact on theory. It is interesting to note that Newton doesn't seem to have an explicit notion of an empirically supported background theory. However, one might argue that something like this underwrites Newton's matter theory, expressed in propositions 1-10 of the *Opticks* Book 2. But this is beyond the scope of this paper.

Four decades later, Newton described a similar idea in a draft letter to Roger Cotes, again, quoting *in extenso*:

> One may suppose that bodies may by an unknown power be perpetually accelerated and so reject the first law of motion. One may suppose that God can create a penetrable body and so reject the impenetrability of matter. But to admit of such hypotheses in opposition to rational propositions founded upon phenomena by induction is to destroy all arguments taken from phenomena by induction and all principles founded upon such arguments. And therefore as I regard not hypotheses in explaining the phenomena of nature, so I regard them not in opposition to arguments founded upon phenomena by induction or to principles settled upon such arguments. In arguing for any principle or proposition from phenomena by induction, hypotheses are not to be considered. The argument holds good till some phenomenon can be produced against it (March 1713, Newton, 2014: 120).

Now consider what hypotheses *can* do. Hypotheses can be introduced to explicate a theory—that is, to make it more intelligible.[10] In this context, the hypothesis was to be introduced *after* the theory had been established, and judged as permissible by whether or not it agreed with the theory: that is, hypotheses are merely possible states of affairs, where 'possibility' is set by coherence with our theories. Indeed, Newton claimed that it is a trivial business ("*levissimi negtij est*" (Newton, 1959-1977: Vol. 1, 167)) to accommodate hypotheses to his doctrine ("*accommodare Hypotheses ad hanc Doctrinam*" (Newton, 1959-1977: Vol. 1, 167)). After all, he pointed out, Descartes' and Hooke's hypotheses of light might easily be altered to accommodate his theory.[11]

Newton publicised his 1675 paper, 'An Hypothesis explaining the Properties of Light discoursed of in my severall Papers', for this explicit purpose. He explained:

> I have observed the heads of some great virtuoso's to run much upon Hypotheses, as if my discourses wanted an Hypothesis to explain them by, & found that some when I could not make them take my meaning, when I spake of the nature of light & colours abstractedly, have readily

[10] For Newton, introducing hypotheses in this context was an 'optional extra'. But for others, it was a crucial step in providing an adequate explanation. Christiaan Huygens, for example, objected that Newton's optical theory was *incomplete* without a hypothesis. For, without a mechanical explanation of the nature of light and colours, Newton had not taught us about the nature and difference of colours, but only the accident of their different refrangibility (Newton, 1959-1977: Vol. 1, 256).

[11] For a discussion of Newton's demonstration of this claim, see (Shapiro, 2002).

> apprehended it when I illustrated my Discourse by an Hypothesis […] (Newton, 1959-1977: Vol. 1, 363)

He puts a pedagogical spin on all of this: the purpose of writing up his hypothesis is to help others to understand his new theory. But presumably he thought *understanding* might lead to *acceptance*.[12] And so the hypothesis seems to offer a 'possibility proof' for Newton's theory. Nevertheless, Newton takes an explicitly instrumental attitude to the hypothesis:

> […] not concerning my self whether it shall be thought probable or improbable so it do but render the papers I send you, and others sent formerly, more intelligible (Newton, 1959-1977: Vol. 1, 361).

Given the purpose for which the hypothesis is introduced, its truth or otherwise is irrelevant. A false hypothesis could perform the task just as well. Indeed, for Newton, when a hypothesis agrees with the theory and fits the facts, it is by no means confirmed. Hypotheses should fit the known facts, but their ability to accommodate the empirical evidence does not give them any credence—they tend to be underdetermined by the evidence. In contrast, propositions explaining observable, measurable properties can be certain, and therefore labelled theories, if they are obtained in the correct manner.

Hypotheses can also play a role in the process of investigation: they may suggest experiments ("*experimenta subministrare possint*" (Newton, 1959-1977: Vol. 1, 164)). Here one draws empirical consequences from the hypothesis—a process that Newton calls 'abstraction' ("*abstrahendam*" (Newton, 1959-1977: Vol. 1, 164))—and uses these to make predictions which can be tested. Newton used hypotheses in this way in his response to Robert Hooke. He presented these empirical consequences in the form of queries:

> I shall now in the last place proceed to abstract the difficulties involved in Mr Hooks discourse, & without having regard to any Hypothesis consider them in general termes. And they may be reduced to these three *Queries*. Whether the unequal refractions made without respect to any inequality of incidence, be caused by the different refrangibility of several rays, or by the splitting breaking or dissipating the same ray into diverging parts; Whether there be more then two sorts of

[12] Indeed, Newton's notion of certainty might be interpreted as 'compelled assent': Newton appeared to think that the evidence compelled him undeniably to his conclusion; no rational person, having carried out the experiment, could deny the conclusion (Walsh, 2017). And so, on Newton's view, the only thing standing in the way of universal acceptance of this theory was lack of understanding.

colours; & whether whitenesse be a mixture of all colours (11 June 1672, Newton, 1959-1977: Vol. 1, 177-178).

Cunningly, Newton used Hooke's hypothesis to identify key points of empirical disagreement and then, in effect, to generate a series of crucial tests to decide between his account and Hooke's.[13] That is, Newton employed Hooke's hypothesis to provide a kind of temporary platform: it served to make explicit empirical tests which could adjudicate between various ways in which the world might be. Let's consider just the first of these three queries.

The first query concerns the source of the phenomenon of elongation that Newton identified in his 1672 'New Theory'. According to Newton, his account and Hooke's gave different reasons for this elongation: on his account, the incident light was composed of a mixture of rays of different refrangibility;[14] on Hooke's, the homogenous incident light was split into multiple parts. How can we choose between these two possibilities? Newton argued that they make different predictions about what will happen when the elongated image is projected through a second prism. On Newton's refrangibility account, the rays only separate once—when they pass through the first prism (leaving the now homogenous, non-white rays). And so, the image remains the same size after it is projected through the second prism. In contrast, on Hooke's splitting account, the ray should split every time it passes through a prism, and so the image should become more spread out with each subsequent prism. In a series of experiments, Newton demonstrated that there is no change to the size and shape of the image. In other words, *his* account generated the correct prediction; Hooke's didn't. And so Newton used Hooke's hypothesis to identify a point of empirical disagreement between the two accounts, and then constructed an experiment that decided in his favour. Indeed, this experiment didn't just rule out Hooke's account, but all accounts

[13] On Hooke's account, light is a 'pulse or motion' through a uniform medium. White light is produced by 'pure' and 'undisturbed' pulses; colour is produced by the disturbance of white light. Only two colours are produced by the disturbance of white light; all the other colours are produced by mixing various amounts of those two colours with white light (summarised by Hooke in Newton, 1959-1977: Vol. 1, 112).

[14] *Refrangibility* is the degree to which light can refract when passing from one medium into another, or a "predisposition, which every particular Ray hath to suffer a particular degree of Refraction" (Newton, 1959-1977: Vol. 1, 96).

that explained the elongation effect by appeal to breaking or splitting of incident light. Thus, ruling out most traditional accounts.

And so Newton identified two permissible roles for hypotheses with respect to theories: (1) explicating the theory; and (2) suggesting experiments. An important feature of these supporting roles is that the epistemic status of the hypothesis is moot. This is not to say that there are no epistemic constraints on hypotheses. As we have seen, on Newton's account, the admissibility of a hypothesis depends upon its coherence with a theory. But, for Newton, coherence is a very low bar: we should not be impressed just because a hypothesis 'saves the phenomena'. Thus, Newton considered hypotheses to have little value in their own right. They were valuable only insofar as they could facilitate understanding, development and justification of theories.

Moreover, hypotheses were only to be introduced in such a way that they would not directly influence the epistemic status of a theory. To put a modern spin on this point, hypotheses did not play any direct role in influencing our credence *vis-à-vis* a theory. Rather, a hypothesis could only support a theory in two ways: firstly, it could indirectly increase the conceivability or intelligibility of the theory, by demonstrating how it may be filled out metaphysically; and secondly, it could help to deliver an empirical result that could decide between two competing descriptions of the way the world is. It is important to note that, in the example we considered, Newton didn't take the experimental results to provide additional support for his theory. That is, these results were old evidence: he'd already taken them into account in the development of the theory, and so they couldn't provide further confirmation.[15] Rather, the experimental result served to demonstrate that Hooke's explanations did not 'save the phenomena'. This process looks similar to the kind of scaffolding described by Currie (e.g. Currie, 2015, 2018). Currie describes cases where a coarse-grained hypothesis provides a platform from which to distinguish empirically between two finer-grained hypotheses.[16] In the above case, Hooke's hypothesis provides a platform from which to distinguish

[15] Indeed, this 'no double-counting' requirement is a very common intuition: if evidence x has been used to construct a theory T(x), then x should not be used again in support of T(x) (for discussion, see e.g. Glymour, 1980).

[16] More generally, Currie argues that positing hypotheses can tell us what kinds of things will count as evidence, and hence, they can help us see the empirical ways forward (particularly in Currie, 2018).

between his and Newton's accounts of light. Hooke claims that his hypothesis agrees with the observed facts—indeed, his account can explain the phenomenon of elongation. Newton uses Hooke's hypothesis to demonstrate that the two accounts are not empirically equivalent. In other words, he demonstrates that his account and Hooke's have different empirical consequences, and constructs an experiment to decide between them.

In the next section, we'll consider how Newton's hypothesis also provided a different kind of scaffolding.

3 Investigating coloured rings

In this section, I examine Newton's use of hypotheses in his investigation of interference phenomena, now known as 'Newton's rings'. And, in doing so, I identify a third role for hypotheses in Newton's methodology: scaffolding for the purpose of theory-building. Newton's hypothesis on the nature of light postulated a physical cause for the observed pattern of coloured rings: an æthereal 'pulse'. Operationalising the concept of a pulse—i.e. defining the concept through the operations by which it was measured—gave Newton a unit of measurement and, eventually, a way of formalising and abstracting the explanation. Drawing on the architectural analogy, Newton's hypothesis supported his investigation in a way that enabled him to build a theory. Once completed, the hypothesis was removed or 'abstracted'.

Before we continue, it's worth outlining the key points of Newton's hypothesis of the nature of light. The hypothesis, as he described it in his 1675 'Hypothesis' paper, has three aspects. Firstly, there is an *æthereal medium*. This is a medium, like air, but rarer and more elastic. It fills empty spaces, including the pores of solid substances, and vibrates, carrying sounds, scents and light. The æthereal vibrations differ in size, causing different sensations. Secondly, there is *light*. Light is neither the æther, nor the vibrations in the æther, but a substance that is emitted from 'lucid' bodies and travels through the æther in the form of rays. Rays of light are physically heterogeneous, differing in size, shape and velocity, which accounts for their ability to cause different kinds of vibrations in the æther. Thirdly, light and æther *interact*. Light warms the æther and the æther presses on the light. This interaction is the cause of most optical phenomena. Newton made use of his hypothetical æthereal vibrations in order to establish the length of a 'pulse'—the distance between æthereal contractions.

That this hypothesis played an important role in Newton's establishing the phenomenon of periodicity and his formulation of the theory of fits is old news.[17] Here, we are less interested in the details of the case itself than in what the case can teach us about Newton's method of hypotheses. In fact, in this case, Newton's hypothesis performs something of a 'stealth function'—the role itself is not made explicit in Newton's methodology, and moreover, the formal presentation of the theory in the *Opticks* belies the fact that hypotheses played such an important role.[18] I shall argue that this role is consistent with Newton's overarching method. His use of the hypothesis enabled him to make the calculations which, in turn, led him to formulate the theory of fits. Once formulated, Newton abstracted his formal account of periodicity of all hypothetical assumptions about the physical cause—the scaffold was removed. Despite the fact that Newton's didn't make this role explicit, this case offers a nice example of the role of hypotheses in Newton's natural philosophy.

3.1 Pulses and intervals

Here's an interesting feature of Newton's hypothesising. Where conceiving of light as corpuscular clearly played an important heuristic function in Newton's conception of light as heterogeneous,[19] it was the concept of æthereal vibrations that was most useful for Newton's work on interference phenomena—establishing the periodicity of light and the theory of fits. In this section, we see that Newton made use of his hypothetical æthereal vibrations in order to establish the length of a 'pulse'—the distance between æthereal expansions and contractions. However, in the final version of the theory, presented in the *Opticks* Book 2, 'pulses' were replaced with 'intervals'—a unit of measurement.

---

[17] For the full gory details of the development of Newton's theory of fits, see (Shapiro, 1993).

[18] Given Newton's method of hypotheses, and the requirement that the final product be cleansed of all hypotheses, it should come as no surprise that we don't find them playing an obvious role in his published work. Fortunately, Newton's use of hypotheses in this case is well documented in unpublished draft material.

[19] We shall discuss this in section 4.1.

Newton began investigating interference phenomena in the mid-1660s—around the time he was investigating the elongation effect.[20] In the *Opticks*, he would describe these investigations as "*Observations concerning the Reflexions, Refractions, and Colours of thin transparent Bodies*" (Newton, 1952: 193) (the 'thin transparent body', also described as a 'thin film' or 'thin plate', refers to the film of air in the gap between the two glass surfaces).[21] Newton had noticed that, when two glass prisms are pressed together, a transparent spot appears where the two surfaces touch, with concentric rings of light appearing around that spot. Newton supposed that the effect was generated by the alternate reflection and transmission of light incident upon the top prism. Where the two surfaces touched, the light seemed to be completely transmitted; where there was a gap, the light seemed to be sometimes reflected and sometimes transmitted.

Newton wondered if this was a function of the thickness of the gap between the two glass surfaces. To establish this effect, he pressed a convex lens of a known curvature onto a flat glass plate—this produced a regular pattern of concentric circles and enabled him to (1) measure the size and colour of each ring and (2) calculate the thickness of the gap between the two surfaces (see figure 1 below). Newton noticed that the rings formed repeating patterns of colours, and established a numerical relationship between ring colour and thickness of the film. He was struck by the arithmetical regularity of the patterns of colours—the alternation was periodic, not random.

---

[20] At this time, Newton was also developing a theory of vision which utilised the vibrating æther as the primary means by which colour sensations travel from the retina up the optic nerve to the brain (e.g. Hamou, 2014).

[21] Hooke had described this phenomenon first, in his *Micrographia* (1665), but the phenomenon is now known as 'Newton's rings'.

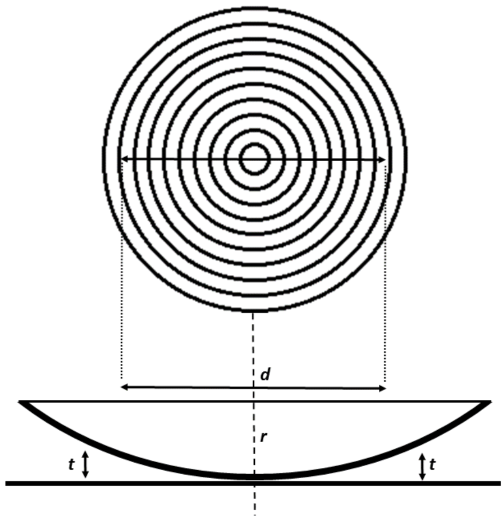

Figure 1 Investigating the colours of thin films: Newton's basic experimental set-up.[22]

Newton wanted to explain this phenomenon by drawing on his theory of light and colour: colour is an original and immutable property of individual rays of light and bodies have colour because they reflect coloured rays of light. But in order to see how this explanation might work, he turned to his hypothesis. He imagined light corpuscles alternately passing through and bouncing off the two surfaces. When light is transmitted through a prism, the rays separate into their colour groups. Similarly, when light is incident upon a thin film, the rays seem to separate according to their colours—each colour group forming its own set of rings. And yet, unlike the prism case, the colour pattern repeats itself indefinitely.

So what caused this pattern? Newton quickly recognised that it couldn't simply be attributed to unequal refrangibility. He started to think about the phenomenon as a property of the vibrations being stirred up by the light corpuscles—light, being physically heterogeneous, could stir up vibrations of different sizes. And so he postulated a 'pulse'. A pulse is not an action or property of the light itself, but a feature of the æthereal vibrations. Æther is excited by the light striking it, and begins to vibrate, and hence, to expand and contract periodically. If a ray of light approaches a surface when the æther is contracted, it is reflected; but if the æther is expanded, then the ray is transmitted. 'Pulse' refers to the period or distance between expansion and contraction. And so, if light approached a surface after one pulse, it was reflected; if it approached the surface after

[22] Where the thickness of the film (*t*) is a function of the radius of the sphere (*r*) and the diameter of the ring (*d*): $t=d^2/8r$.

two pulses, it was transmitted; if it approached a surface after three pulses, it was reflected; and so on… Each colour excited pulses of a different length.

A pulse was not something that Newton could directly observe or measure—it being a property of an invisible and hypothetical medium. However, Newton took its existence to be indicated by the regularity of the phenomenon. And *this* was something Newton could measure. Knowing the curvature of the lens and the diameter of the rings, Newton could calculate the thickness of the film (i.e. the air) at any point (represented in figure 1 above). He knew that, when the two surfaces are touching, light is transmitted.[23] So he took the smallest ring to represent the smallest gap required for light to be reflected. Establishing the thickness of the air at the innermost ring, he identified the length of 'one pulse'. A pulse thus became a unit of measurement: light was reflected when the distance between the two glass surfaces was equal to 1, 3, 5, 7, etc. pulses, and transmitted at 2, 4, 6, 8, etc. pulses. And so Newton took a vague hypothetical concept—neither observable or measurable directly—and, attaching it to an empirical effect, clearly defined it. Æthereal pulses became measurable and understandable in terms of empirical observations.

Early on, Newton made this concept explicit, describing the details in an early manuscript, 'Of Colors'[24] (c. 1665-6). He had already established the diameters of the rings and had noticed that the squares of the diameters of successive rings increased integrally. For the first six circles, he established that the thickness of the air increased in integral multiples of the thickness of the air at the first circle. He then calculated:[25]

---

[23] According to Newton's matter theory, if there is no gap between two mediums of the same density, the surfaces of the two mediums effectively disappear—the two mediums become one. See, for example, Newton's discussion of proposition 1 in his *Opticks* Book 2 (Newton, 1952: 246-248).

[24] MS. Add. 3975, pp. 1-22.

[25] Shapiro has pointed out that these calculations (even the adjusted ones) were widely off the mark. However, they were enough to provide a measure for the periodicity. The method for determining the thickness of the film would later allow him to develop a mathematical theory of the periodicity (Shapiro, 2002).

[…] the thicknesse of the aire <for one> circle[26] was 1/64000 inch or 0,000015625. [which is the space of the pulse of the vibrating medium.] <by measuring it since more exactly I find 1/83000 = to the said thicknesse>. (MS. Add. 3975, p. 10)

Notice the bracketed remark. Newton wasn't simply reporting on an observed regularity (the thickness of the film for a given ring). He was treating his notion of a hypothetical pulse as the physical cause of the regularity, and using his calculations of thickness to operationally define the notion.

In his manuscript 'Of the coloured circles twixt two contiguous glasses'[27] (c. 1670), Newton went even further, establishing the 'ratio of pulses' for purple at one end of the spectrum to red at the other end:

Prop 6 That if the glasse bee illuminated by coloured light, that which is most refrangible makes the least circles. & the thicknes of a pulse for the[28] extreame red, to that for the extreame <purple>[29] is <greater than 3 to 2>[30] & scarce greater than 5 to 3. Viz about 9 to 14 or 13 to 20 (MS. Add. 3970, f. 350r).

This ratio provided an empirical foundation for Newton's quantitative treatment of colours of solid bodies.

Newton's 1675 'Hypothesis' offered a more extensive discussion of the mechanism by which the phenomenon of coloured rings is produced:

If the plate be of such a thicknesse, that the condensed part of the first wave overtake the ray at the second Superficies, it must be reflected there; if double that thicknesse that the following rarefied part of the wave, that is, the space between that and the next wave, overtake it, there it must be transmitted; if triple the thicknesse that the condensed part of the second wave overtake it, there it must be reflected, & so where the Plate is 5. 7. or 9 times that thickness it must be reflected by reason of the third fourth or fift wave overtakeing it at the second Superficies; but when it is 4. 6. or 8. times that thicknesse, so that the ray may be overtaken there by the dilated interval of those

[26] Following "{illeg.}" deleted.

[27] MS. Add. 3970, ff. 350r-353v.

[28] Following "{illeg.}" deleted.

[29] Following "blew" deleted.

[30] Following "twixt 4½ 3 to 5 to 3 or above" deleted.

waves, it shall be transmitted, & so on; the second Superficies being made able or unable to reflect accordingly as it is condensed or expanded by the waves (Newton, 1959-1977: Vol. 1, 378).

Interestingly, in this passage, Newton was no longer using the term 'pulse'—talking instead about 'dilated intervals'. The underlying mechanism looked the same: light of a given colour will be reflected when the length of the vibration, or some multiple of the length of the vibration, matches the thickness of the film, and transmitted otherwise. But the terminology was in flux. The trouble was, of course, that the concept of a pulse was unacceptably hypothesis-laden—at least, for Newton's methodology. The challenge was to retain the important insights it yielded without the problematic metaphysical commitment.

Vibrations were still crucial to Newton's account when he started preparing the manuscript for the *Opticks* (early 1690s):

> Prop 9 The motion excited in[31] <pellucid> bodies by[32] <the impulses[33] of> the incident rays of light is a vibrating one & the vibrations are propagated every way in concentric circles from[34] the points of the incidence[35] through[36] the bodies (Add. MS. 3970, f337r).

And:

> Prop. 7[37]. The[38] vibrations excited by the more refrangible rays are shorter then those excited by the less refrangible ones: <& upon this difference depends the different reflexibility & different inflexibility of light.> (MS. Add. 3970, f373r).

---

[31] Following "by" deleted.

[32] Following "light is" deleted.

[33] Following "the incident" deleted.

[34] Following "through the bodies" deleted.

[35] Following "impu" deleted.

[36] Following {illeg.} deleted.

[37] Following "8" deleted.

[38] Following "Vision is made" deleted.

But in the published version of the *Opticks* (1704), Newton presented his theory of fits: austere and pristine, it was cleansed of all mention of æthereal pulses. Let's now turn to this account.

In Book 2 Part I of the *Opticks*, Newton explained the effect as follows:

> And from thence the origin of these Rings is manifest; namely, that the Air between the Glasses, according to its various thickness, is disposed in some places to reflect, and in others to transmit the Light of any one Colour […] and in the same place to reflect that of one Colour where it transmits that of another (Newton, 1952: 213-214).

In other words, the pattern of coloured rings is produced by the alternating reflection and transmission of light of different colours. More experiments revealed that this alternating was periodic, increasing in an arithmetical progression, and moreover that this pattern continues "without end or limitation" (Newton, 1952: 279), and depends on both surfaces of the thin plate.

In Part III of the book, Newton introduced a proposition to explain the phenomenon:

> *Every Ray of Light in its passage through any refracting Surface is put into a certain transient Constitution or State, which in the progress of the Ray returns at equal Intervals, and disposes the Ray at every return to be easily transmitted through the next refracting Surface, and between the returns to be easily reflected by it* (Newton, 1952: 278).

Abstracted of all mention of pulses, vibrations and æther, it is difficult to make sense of this proposition. Roughly, Newton was arguing that the observed periodicity of the light is a product of the interaction between rays of light and the two refractive surfaces. Just as light is differently refrangible, it also has some sort of disposition towards periodic reflection and refraction, under certain circumstances.

Newton quickly set about making the proposition intelligible—indeed, on its own, the passage was nearly incomprehensible! His approach here is very familiar to us: it's the same approach taken in the 1675 'Hypothesis' paper. Newton began with a disclaimer: it was not his purpose to inquire into the *nature* of the action or disposition (i.e. "Whether it consists in a circulating or a vibrating motion of the Ray, or of the Medium, or something else" (Newton, 1952: 280)). But, for the benefit of those who needed to be assured that *some* hypothesis could explain this disposition, he could offer one. In other words, he was offering a possibility proof. Newton started with an analogy: he directed his readers to consider how, when a stone falls into a pool of water, it creates ripples. He then suggested that rays of light might cause the medium or substance of a refracting surface to vibrate in a similar way. This vibration, in turn, agitates the solid parts of the reflecting or refracting body, causing the body to grow warm or hot. The vibrations are propagated through the medium (like sound through air), and move faster than the rays, thus overtaking them. The vibrations have a pulse-like motion—causing the medium to alternately expand and contract. When the ray of light approaches a refracting surface as the medium is expanding, it will easily pass through the surface, and thus be transmitted through to the adjacent medium. However, if the ray approaches the surface as the medium is contracting, the ray cannot pass through. And so, instead of being transmitted, it is reflected. In short, Newton's hypothesis was still roughly the same; it was simply no longer part of the formal explanation.

True to his method of hypotheses, Newton was careful to maintain epistemic distance from this explanation. He wrote:

> But whether this Hypothesis be true or false I do not here consider. I content my self with the bare Discovery, that the Rays of Light are by some cause or other alternately disposed to be reflected or refracted for many vicissitudes (Newton, 1952: 280-281).

In other words, this hypothesis was here merely to help with uptake and intelligibility—its truth or otherwise was beside the point. Moreover, to emphasise this, and to abstract the theory from the hypothesis once more, Newton introduced a new definition:

> *The returns of the disposition of any Ray to be reflected I will call its* Fits of easy Reflexion*, and those of its disposition to be transmitted its* Fits of easy Transmission*, and the space it passes between every return and the next return, the* Interval of its Fits (Newton, 1952: 281).

By introducing this definition, Newton was clearly trying to avoid hypothesis-loaded language to explain (what he saw as) a hypothesis-free physical concept.

3.2 Scaffolding the theory of fits

Æthereal vibrations played two roles with respect to Newton's theory of fits. Firstly, as we have just seen, in the *Opticks* Newton introduced the hypothesis to explicate the formal theory—to offer a possibility proof. That is, the hypothesis was there to satisfy "[t]hose that are averse from assenting to any new Discoveries, but such as they can explain by an Hypothesis" (Newton, 1952: 280). Moreover, his attitude to æthereal vibrations was explicitly instrumental: "whether this Hypothesis be true or false I do not here consider" (Newton, 1952: 280-281). Secondly, from Newton's unpublished manuscripts, we saw that he used the hypothesis to posit a physical cause for the observed pattern of coloured rings: an æthereal 'pulse'. He operationalised the concept, which provided him with a unit of measurement and, eventually, a way of formalising and abstracting the explanation. The latter usage was not explicitly identified by Newton as a permissible role for hypotheses in any of his methodological statements. And so we have identified a third role for hypotheses in Newton's methodology: scaffolding for the purpose of theory-building.

The two explicit roles for hypotheses in Newton's methodology—explicating theories and suggesting experiments—look very different to this third role. For one thing, there is a sense in which, in the former roles, hypotheses function as heuristics: hypotheses enable individuals to discover or learn something for themselves. As Newton described them, hypotheses invite an individual to think about a problem, phenomenon or theory in a way that guides them towards a solution. But hypotheses are not perfect guides to truth. When they are employed to explicate a theory, the truth is already available—the hypothesis merely helps with understanding or uptake of the truth. When they are employed to suggest experiments, the truth is revealed experimentally—the hypothesis merely points the experimenter towards a certain set of experiments. In both cases, the truth lies somewhere other than with the hypothesis. In the case we've just examined, Newton's hypothesis did not merely serve as a heuristic; rather it provided crucial, albeit temporary, support for the investigation.

While this use of a hypothesis doesn't fit with Newton's explicit method of hypotheses, this role should be considered permissible on Newton's account. In this role, the epistemic status of the hypothesis is not at issue, and so the role is consistent with Newton's methodology. Recall that an important feature of the first two supporting roles is that the truth or otherwise of the hypothesis is irrelevant. Hypotheses were not introduced to be supported or believed; they were there to facilitate understanding, development and justification of theories. Furthermore, recall that hypotheses were only to be introduced in such a way that they would not directly influence the epistemic status of a theory. A hypothesis might support a theory indirectly by increasing the conceivability or intelligibility of the theory or by helping to deliver an empirical result that could decide between two competing accounts of the world.

In the third role, the hypothesis guides the way Newton thinks about interference phenomena. It provides him with a concept that he can operationalise, which enables him to gather more experimental results and eventually construct a theory. In other words, the hypothesis helps him to identify features of the phenomenon that he can measure and theorise about. But then he extracts the hypothesis, leaving the theory supported by experimental results.[39] That is, the theory is ultimately supported empirically. Here it's useful to distinguish between 'discovery' and 'justification'. Newton's hypothesis was involved in the discovery of his theory of fits, but not in its justification: its truth was irrelevant to the justification of the theory.

When investigating interference phenomena, Newton's use of æthereal vibrations enabled him to make the calculations which, in turn, led him to formulate the theory of fits. Once formulated, Newton abstracted his formal account of periodicity of all hypothetical assumptions about the physical cause. And so, in Newton's methodology hypotheses can provide scaffolds for theorising: hypotheses were to be separated from the final presentation of the theory, but were a necessary means for building the theory. Hypotheses, then, had a purely instrumental role in Newton's methodology: he could use hypotheses, without feigning them.

One final point, before we turn to consider lessons from this case. The notion of scaffolding looks like a promising way to think of Newton's use of hypotheses in other contexts. For example, scaffolding occurs when Newton began to investigate the phenomenon of coloured fringes—what's now referred to as 'diffraction'. Again, Newton did not get very far with the investigation before he turned to his hypothesis. This time, the process wasn't completed and the scaffolding wasn't removed. Instead, Newton used the scaffold to structure the investigation and develop a rough idea of how formal theory might look. This resembles this early stages of Newton's investigation of interference phenomena, and so I take it that this fits with what I have identified as Newton's third way of using hypotheses. Newton presented this work in the form of queries.[40]

---

[39] Shapiro has argued that Newton's theory of fits was actually well-supported by his experiments on *thick* plates (Shapiro, 1993: 201). In the *Opticks*, these were introduced *after* his theory of fits.

[40] We might also understand the hypotheses in the *Principia* as providing scaffolding. But this is beyond the scope of the present discussion.

4 Lessons from the case

In this paper, I've examined Newton's use of hypotheses in his investigations of interference phenomena and provided a three-pronged analysis of the roles of hypotheses in Newton's work—the first two follow his own methodological statements, but I have identified a third role: scaffolding for the purpose of theory-building. It is now time to draw some lessons from this case. I'll discuss, first, how we should understand Newton's metaphysics, and second, early modern experimental philosophy more generally.

4.1 Vibrations and corpuscles

Newton's hypothesis on the nature of light is usually described as a 'corpuscular hypothesis'. However, we've seen that, at least in Newton's investigation of more complex optical phenomena, æthereal vibrations did a lot of the work. This tells us something about how we should understand Newton's hypothetical entities, posits, and processes. We should understand his corpuscular hypothesis functionally. As we shall see, this function varies according to context. In some contexts, a corpuscle is a thing that sustains qualities; in other contexts, a corpuscle is something that can excite vibrations in a medium. In short, in Newton's hypothesis, to be a corpuscle is to play a certain kind of role.[41]

Let's consider how Newton argued for the corpuscular nature of light. In the final pages of his 'New Theory' (1672), Newton suggests that light is a substance, as opposed to a wave or a pressure. That is, light is a substantial body, rather than a quality of a body:

> For, since Colours are the *qualities* of Light, having its Rays for their intire and immediate subject, how can we think those Rays *qualities* also, unless one quality may be the subject of and sustain

[41] I take it that my account complements Katherine Brading's 'law-constitutive approach' (e.g. Brading, 2011, 2012). Brading argues that, in Newton's mechanics and celestial dynamics, physical bodies are functionally defined—a necessary condition for the individuation and identity of physical bodies is that they satisfy the laws of motion. On her view, Newton's avoidance of claims concerning the nature of bodies reflects not the estrangement of physics from metaphysics, but the entanglement of the two: Newton's matter theory must be developed in consort with his mechanics, not prior to it. My account of Newton's corpuscular hypothesis, I think, offers some support for Brading's general picture, and yet complicates it in ways I have not yet fully explored.

> another; which in effect is to call it *substance*. We should not know Bodies for substances, were it not for their sensible qualities, and the Principal of those being now found due to something else, we have as good reason to believe that to be a Substance also (Newton, 1959-1977: Vol. 1, 100).

Newton's reasoning in this passage is revelatory. He offers two arguments for thinking of light as substantial or corpuscular. Firstly, he argues that, since colour is a quality or property of light, we should consider light to be a substance. But notice that this isn't for any special empirical or metaphysical reason. It's simply that we think of substance as the thing that sustains or supports properties—substance ties a group of properties together, it's the thing that makes them *properties of* something. Since light has properties (specifically colour and refrangibility—and maybe others), and hence, is a thing that supports properties, it *functions as a substance*. Secondly, he points out that, since we don't have direct epistemic access to substance, we recognise substance by its sensible qualities—such as colour. An important upshot of his theory of colour is that bodies have colour by virtue of reflected light. Thus, colour is not a property of bodies but a property of light. And so, Newton argues, since we recognise bodies as substance by virtue of properties such as their colour, now that we know that colour is not a property of bodies but of light, we should recognise light as a substance too. So again Newton hasn't offered any special empirical or metaphysical reason to consider light a substance. It's simply that it performs the substance-role with respect to colour properties. Which is to say, light is a 'substance' in that it supports colour.

Another place where Newton argues for the corpuscular hypothesis is in his 1675 'Hypothesis' paper. Here he argues for the corpuscularity of light (again, loosely defined) by virtue of its role in explaining optical phenomena. Having described the properties of æther and its vibrations, he writes:

> I suppose Light is neither this Æther nor its vibrating motion, but something of a different kind propagated from lucid bodies. They that will may suppose it an aggregate of various peripatetic qualities. Others may suppose it multitudes of unimaginable small & swift Corpuscles of various sizes, springing from shining bodies at great distances one after another, but yet without any sensible interval of time […]. But they that like not this, may suppose Light any other corporeal emanation or an Impulse or motion of any other Medium or æthereall Spirit diffused through the main body of Æther, or what else they can imagine for this purpose. […] Onely whatever Light be, I would suppose it consists of Successive rayes differing from one another in contingent circumstances, as bignes, forme or vigour, like as the Sands on the Shore, the waves of the Sea, the faces of men, & all other naturall things of the same kind differ, it being almost impossible for any sort of things to be found without some contingent variety (Newton, 1959-1977: Vol. 1, 370).

Again, this is revelatory. Newton is explaining the nature of light in terms of its function, and leaving the rest open to the imagination. Light might be corpuscular, an æthereal spirit, some other kind of force or process, or even a cluster of properties. But there are some constraints. Firstly, it needs to be physically heterogeneous, since Newton has established that white light is composed of a heterogenous mixture of rays. And so, if light is corpuscular, then the corpuscles need to come in a variety of shapes or sizes. Or if it's some sort of wave or vibration, the waves need to come in a variety of sizes or speeds. Secondly, it must be something different to the æther and æthereal vibrations. Let's look more closely at his reasons for this:

> I would suppose it divers from the vibrations of the æther, because (besides, that were it those vibrations, it ought alwayes to verge copiously in crooked lines into the dark or quiescent Medium, destroying all Shadowes, and to comply readily with any crooked pores or passages, as Sounds do,) I see not how any superfices, (as the side of a Glass Prism on which the rayes within are incident at an angle of above 40 degrees) can be totally opake. For the vibrations beating against the refracting confine of the rarer & denser æther must needs make that pliant Superficies undulate, & those undulations will Stir up & propagate vibrations on the other side (Newton, 1959-1977: Vol. 1, 370).

Again, he offers two reasons. Firstly, he reasons from an analogy with sound. He takes sound to be generated by waves or vibrations in air. For example, earlier in the paper, he had said:

> And, as in Air the Vibrations are some larger then others, but yet equally Swift (for in a ring of Bells the Sound of every tone is heard at two or three miles distance, in the Same Order that the bells are Stroke;) So I suppose the æthereall Vibrations differ in bigness but not in Swiftnesse (Newton, 1959-1977: Vol. 1, 366).

Comparing light to sound, he argues that sound travels in non-linear paths in a way that light cannot—indeed, there was no direct acoustic-equivalent of the shadow. And so, Newton argues that light can't be a vibration. In other words, vibrations do not save the phenomena. Secondly, and perhaps more importantly, if light is an æthereal vibration, then it ought always to be able to pass through bodies, because vibrations propagate across surfaces. But light is sometimes reflected; not just transmitted—we know this is the case because reflection is the cause of opacity. And so, again, Newton's reasons for preferring one account of light over another are functional.

We noted in section 2.1 that Newton's hypotheses were constrained by the empirical evidence. The above offers a clear example of this process. Newton conducted experiments to establish the (observable and measurable) properties of light, and then considered—often by analogy—what kinds of entities and processes might sustain those properties. He excluded some kinds of entities and processes on the grounds that they could not do the required work. So, for instance, light—the substance bearing colour properties—cannot be æthereal vibrations, because these cannot support the property of reflexibility. The basic idea, then, is that experimentally established properties allow us to *rule out* some possible entities and processes on the grounds that they would be unable to support—fulfil the function of supporting—those properties. It should be noted, however, that this process doesn't allow us conclusively to *rule in* a particular entity or process. Hence, Newton's vagueness *vis-à-vis* the precise nature of light.

It's worth considering why Newton settled on æthereal vibrations, and not corpuscles, to do the heavy lifting in the explanation of interference phenomena. The answer seems to be: because it made the problem tractable—it was a more successful way of thinking about the problem. From vibrations, Newton was able to establish the periodic nature of colours of the rings and to calculate a unit of measurement that enabled him to make predictions about interference phenomena. But he also considered whether corpuscles could do the job. For example, in his manuscript 'Of the coloured circles' (c. 1670), Newton was trying to understand rings in terms of corpuscles:

> Prop 2 That they[42] swell by the obliquity of the eye. <soe> that[43] the diameter of the same circle is as[44] the secants of the rays obliquity; that is, reciprocally as that <part of the> motion of the ray in that said[45] filme of aire which is perpendicular to it, or reciprocally as the force it strikes the refracting surface with all.
>
> Prop 3. And hence the spaces which the rays passe through twixt the circles in one position to the said spaces in another position are as the squares of the said secants or reciprocally as the quares of the sines, motion, or percussion (MS. Add. 3970, f. 350r).

And so, using corpuscles, he tried to establish a relationship between the sizes of the rings and the obliquity of the incident light. However, he did not make much headway

---

[42] i.e. the circles.

[43] Following "{illeg.}" deleted.

[44] Following "{illeg.}" deleted.

[45] Following "{illeg.}" deleted.

with this idea, for, as we saw in section 3.1, by the end of the manuscript, Newton had settled on vibrations and pulses as the crucial explanatory concepts.

But he didn't stop there. In his 1675 'Hypothesis', Newton suggested that corpuscles might operate under the laws later described in his *Principia*:[46]

> Others may suppose it multitudes of unimaginable small & swift Corpuscles of various sizes, springing from shining bodies at great distances one after another, but yet without any sensible interval of time, & continually urged forward by a Principle of motion, which in the beginning accelerates them till the resistance of the Æthereall Medium equal the force of that principle, much after the manner that bodies let fall in water are accelerated till the resistance of the water equalls the force of gravity (Newton, 1959-1977: Vol. 1, 370).

And in at least one early draft of the *Opticks*, Newton toyed with the idea that the periodicity was a property of the velocity of corpuscles. For example:

> Prop. If the rays of light be bodies the <various bignesse> of the waves excited by them in refractions & reflexions arises from the various sizes & velocities of those bodies (MS. Add. 3970, f. 342v).

These speculations led Newton to wonder if some colours move more quickly than others. He hoped to integrate optics with mechanics and explain refraction using short-range forces. On the account he offered in the *Principia* Book 1 section 14, different refrangibility was most easily explained by the differing velocity of rays of different colours (Newton, 1999: 622). Newton realised he could test this by observing the colours of the eclipses of Jupiter's moons: when a moon disappears behind Jupiter, as it disappears, the slowest colour should be seen last; and as it reappears, the fastest colour should be seen first. Newton wrote to ask John Flamsteed, Astronomer Royal, if he had ever observed such a thing:

> When you observe the eclipses of Jupiter's satellits I should be glad to know if in long Telescopes the light of the Satellit immediately before it disappeares incline either to red or blew, or become more ruddy or more pale then before (10 August 1691, Newton, 1959-1977: Vol. 3, 164).

---

[46] In the *Principia*, Newton developed this idea in the final section of Book 1, which concerned "*The motion of minimally small bodies that are acted on by centripetal forces tending toward each of the individual parts of some great body*" (Newton, 1999: 622).

Flamsteed replied that he hadn't: "I cannot say that I ever saw any change to a blewish colour or red by duskish when I used a glass of 27 foot" (24 February 1692, Newton, 1959-1977: Vol. 3, 202). And so Newton realised that this wasn't a viable way of thinking about light.

The differing velocity of rays couldn't save the phenomena. Nevertheless, the contemplation of this hypothesis looks fruitful. From the hypothesis, Newton extracted some empirical consequences which he was then able to investigate. Flamsteed's observations of the moons of Jupiter effectively provided a crucial test of the hypothesis. This process looks very similar to Newton's use of queries to reject Hooke's hypothesis (discussed in section 2.2). And so, this case looks like an example of our first kind of scaffolding: using hypotheses to suggest experiments. (Unfortunately for Newton, however, in this case the crucial observations didn't decide in his favour.)

Newton repeatedly said that he was unwilling to speculate on the nature of light beyond what could be inferred from its experimentally-established properties. We've seen that this prevented him from explicitly and unequivocally declaring his corpuscularism. However, his corpuscularian assumptions seemed to influence his theoretical claims. For example, he argued that original colours remain separate and unaltered when they are mixed to form white light.[47] He was thinking of rays as one might think of grains of sand or powder—or, more likely, chemicals: the particles mix together, but each retains its separate identity.[48] This influence was carried through to his study of interference phenomena and the theory of fits. As Shapiro puts it:

> [H]is theory of fits was still permeated by the emission theory of light in a latent form. The location of the physical activity of the fits at the second surface, the variation of the interval with direction of propagation, and the consideration of rays rather than wave fronts are features indelibly wedded to the emission theory (Shapiro, 1993: 201).

And so, despite his claims to the contrary, Newton's corpuscular hypothesis *does* constrain his theorising: it prevents him from considering other possibilities. For example, on Newton's account, the relevant refractive surfaces were the innermost

---

[47] Sabra has pointed out that this was barely intelligible to wave theorists (Sabra, 1967: 280-282).

[48] William Newman has recently demonstrated that Newton's thinking about light in this way most likely originates with his alchemical investigations (Newman, 2016). We shall discuss the relevance of this in the final section.

ones—those immediately adjacent to the film of air—and the reflective and refractive activity occurs as rays approach those surfaces. On the present-day view, in contrast, some of the activity occurs at the outer surfaces. This is a possibility that Newton couldn't even consider with his hypothesis involving corpuscles and vibrations. Again, this situation seems to have a scaffolding analogue: the size and shape of a building is, to some extent, constrained by the form of the scaffolding; similarly, Newton's theory of light was constrained, to some extent, by metaphysical possibility.[49] And so, although Newton wasn't committed *epistemically* to the corpuscular hypothesis, he did seem to be committed to reasoning with it—and this may have prevented him from identifying the correct location of the optical activity.

So, there is a lesson here for philosophers and historians who want to understand Newton's metaphysical theses. They are not, perhaps, as concrete as they first appear. Rather, Newton's hypotheses about the natures of things were based upon the capacity of certain kinds of entities and processes to support properties he had experimentally established. Unless the hypothesis was being used as a possibility proof, or a scaffold, he was not interested in developing it further.

4.2 Corpuscular, Mechanical and Experimental Philosophy

It's now time to consider the broader picture: what does this case teach us about the relationship between corpuscularism, mechanism and early modern experimental philosophy? Well, as this volume attests, the three philosophies are related in complicated ways. Yet historical scholars often tend towards (over-)simplification by focussing on one philosophy to the exclusion of the others,[50] or running them together. For example, Alan Shapiro argues that, for the Royal Society, the terms 'experimental philosophy' and 'mechanical philosophy' were largely synonymous (Shapiro, 2004) and Daniel Garber seems to conflate mechanism with corpuscularism when he talks of the

---

[49] One might speculate here that Newton was too quick to rule out a wave hypothesis—perhaps betraying a lack of imagination of how light waves might move.

[50] There is, in principle, nothing wrong with such selective focus: historical scholarship necessarily involves foregrounding some things and backgrounding others (for discussion, see Currie & Walsh, Manuscript). However, scholars have tended to foreground in such a way that the dominant narrative is one in which the mechanical philosophy is the main, or even the only, driving force of early modern philosophy (see, e.g. Anstey, 2015).

"mechanical (or corpuscular) philosophy" (Garber, 2013: 3). Indeed, the early modern actors themselves often seem to speak of these philosophies interchangeably. For example, in his *Excellency of Theology*, Robert Boyle talks of "the corpuscularian or mechanical philosophy" (Boyle, 1772: Vol. IV, 19), and in the preface to his *Micrographia*, Robert Hooke expounds the virtues of "the real, the mechanical, the experimental Philosophy" (Hooke, 1966/1665: Preface).[51] Nevertheless, it's worth attempting to draw the positions apart.

Mechanical philosophy roughly states that natural phenomena should be explained by mechanical principles—i.e. matter and motion. Whereas corpuscular philosophy states that matter is composed of minute particles—i.e. corpuscles. Thus, the former is a theory of explanation; the latter, a theory of matter. For example, Anstey argues that, in the case of Boyle, the two titles bring out different aspects of his philosophy:

> […] the 'corpuscular philosophy' connotes the role of particulate matter in the explanations of natural phenomena, whereas the 'mechanical philosophy' connotes the role of the twin principles of matter and motion (Anstey, 2000: 2).

And so, as Boyle's usage makes clear, there is a significant amount of overlap between the mechanical and corpuscular philosophies, for example the focus on shape, size, motion and texture; but they are not logically interchangeable. Indeed, it wasn't the case that everyone who held a corpuscularian theory of matter was a mechanical philosopher.[52] In contrast with the other two, experimental philosophy holds that our knowledge of natural phenomena is limited by the fact that we only have epistemic access to the natural world via the evidence of our senses. Thus, experimental philosophy is a theory of method, which can be viewed as placing epistemic constraints on philosophical endeavours—as opposed to the explanatory constraints of the

---

[51] For reasons discussed below, Anstey has argued that 'corpuscular philosophy' and 'mechanical philosophy' are only 'virtual synonyms' for Boyle—since there is a nuanced difference between them (Anstey, 2000: 2). I have made a similar point with respect to Hooke (Walsh, 2012a).

[52] Alchemists, for example.

mechanical philosophy, or the ontological constraints of the corpuscularian philosophy.[53] So, at least notionally, these are three distinct philosophical positions.

Many self-identified experimental philosophers cleaved to the corpuscularian philosophy and/or the mechanical philosophy. But often for very different reasons. For example, Boyle pleaded for the 'excellency of the mechanical hypothesis' on the grounds that the natural world is composed of corpuscles which operate according to mechanical principles (e.g. Boyle, 1991/1674: 139). Robert Hooke expounded the virtues of the mechanical and experimental philosophies, not for reasons of ontological commitment but because an understanding of mathematics and mechanics "will most assist the Mind in making, examining, and ratiocinating from Experiments" (Hooke, 1705: 19). This is not a perfect method: Hooke recognised that many natural processes are "hid from our discerning, or discovering of them" (Hooke, 1705: 20). And yet, when it follows a good natural history, reasoning mechanically is the best method we have. Finally, John Locke expressed ambivalence about corpuscularism. While he considered the corpuscular hypothesis "as that which is thought to go farthest in an intelligible Explication of the Qualities of Bodies" (Locke, 1979: IV.iii.16), he didn't think we had direct epistemic access to corporeal substances. Rather, our knowledge of substance comes from investigating their 'qualities' and 'powers'. However, the corpuscular hypothesis can guide us in our investigations of those qualities and powers. And so, given the 'weakness of human understanding', this is the best we can do.

Newton was also an experimental philosopher. This is more explicit in his later work. For instance, in the General Scholium to the *Principia* (1713), he described his work as 'experimental philosophy'. But his early optical work looks relevantly experimentalist. For example, in a letter to Henry Oldenburg (1672), Newton explained that "the proper Method for inquiring after the properties of things is to deduce them from Experiments" (Newton, 1959-1977: Vol. 1, 209). Moreover, we have good reason to suppose that Newton was familiar with, and sympathetic to, the Baconian method of natural history—the experimental method favoured by the early Royal Society—by the time he wrote his 'New Theory' paper (1672) (e.g. Anstey, 2004, Jalobeanu, 2014). And

[53] This is not to suggest that the methodological views of experimental philosophers were uniform: experimental philosophers indeed found much to agree on at a coarse grain, and yet there was still a lot of room for disagreement on the finer details.

so we might be tempted to treat Newton's corpuscularism as a by-product of his experimentalism, influenced, as it was, by his interest in the early Royal Society. However, as we've seen, Newton's corpuscular hypothesis doesn't look at all like a standard corpuscular philosophy (to the extent that there is such a thing as a standard position). For one thing, he was talking about light, not all matter. And for another thing, as we've seen, his commitment to the corpuscular nature of light was weak. He was neither strongly metaphysically committed to corpuscles, nor do they play an indispensable role in his explanations—as we saw, it was the vibrating medium which did most of the heavy lifting. And so, it doesn't look as though Newton adopted corpuscular philosophy as part and parcel of his experimental philosophy.

In fact, Newton's corpuscularism *vis-à-vis* light appears to be a consequence of his thinking about optics in terms of analysis and synthesis—i.e. white light can be analysed or separated into its component colours, which can then be synthesised or reintegrated to re-form white light. William Newman argues that this way of thinking about optics most likely emerged from Newton's alchemical investigations—and, in particular, his reading of Boyle's chymical writings (e.g. Newman, 2010, 2016). In the early 1660s, Boyle demonstrated that naturally occurring compounds could be analysed (or separated) into their parts and then synthesised (or reassembled) to form the original compound. From such demonstrations, Boyle argued for the corpuscularian basis of mechanical philosophy. Newman argues that Newton's use of analysis and synthesis in his optics appears to be a direct appropriation from chymistry.

This case offers an example of, what I call, Newton's 'rhetorical style'. Newton took familiar terms and stretched them to fit his methodology. He did this with physical concepts such as 'force' and 'mass', and methodological concepts such as 'query', 'hypothesis' and 'principle'. Newman's work reveals that Newton also borrowed concepts from chymistry and adapted them to his optical work—massaging them to fit his own needs. And so, we shouldn't be surprised that Newton's optical corpuscularism looks different to, say, Boyle's more general corpuscular philosophy. For Boyle, the corpuscularian hypothesis was taken as *true*—and it formed the basis for the mechanical philosophy which constrained theorising. For Newton, corpuscles were *hypotheses* and thus, as we have seen, played an instrumental role in theorising. More generally, this case should alert us to the limitations of interpreting early modern philosophers in terms of their adherence to general philosophical positions. Often, understanding such idiosyncratic thinkers as Newton by assuming terminological, methodological and conceptual continuity with his contemporaries is misleading. This is not to say that focusing on general philosophical positions, such as the experimental, corpuscular and mechanical philosophies, can't be fruitful. Rather, this suggests that we should be mindful of the fact that the corpuscular philosophy, for example, looks different depending on who is expounding it.

I'll conclude by abstracting a little. I've argued that Newton's hypotheses perform three roles in his experimental philosophy. Firstly, hypotheses illustrate or explicate abstract theories with the purpose of improving uptake or understanding of the theory. Secondly, hypotheses provide platforms from which to suggest experiments, thus empirically deciding between competing accounts. Thirdly, hypotheses suggest underlying physical causes that Newton operationalises and thus represents abstractly in his formal theories. We saw that the second and third roles are related in that they are both cases of scaffolding. In both cases, hypotheses provide a temporary platform from which further experimental work and/or theorising can be carried out. This explains how Newton could use hypotheses without feigning them—just as an architect might use scaffolds, but not have them as part of the completed building. I've identified two related upshots. Firstly, Newton's metaphysical claims—his hypotheses—are *functional*, they are importantly 'thin'. Secondly, Newton was an idiosyncratic thinker who didn't quite follow the semantics and norms of his contemporaries. These two upshots are important for the historiographical understanding of Newton and the context within which he worked.

Bibliography

Anstey, P. R. (2000), *The Philosophy of Robert Boyle*, London, Routledge.

Anstey, P. R. (2004), 'The methodological origins of Newton's queries', *Studies In History and Philosophy of Science Part A*, *35*, 247-269.

Anstey, P. R. (2015), 'Revisiting Matter, Form and Mechanism in the Seventeenth Century', *British Journal for the History of Philosophy*, *23*, 569-579.

Boyle, R. (1772), *Works of the Honourable Robert Boyle, 2nd edition, 6 vols*, London, Printed for J. and F. Rivington, etc.

Boyle, R. (1991/1674), 'About the Excellency and Grounds of the Mechanical Hypothesis'. In R. Boyle and M. A. Stewart (eds), *Selected Philosophical Papers of Robert Boyle*, Indianapolis, Hackett Publishing, 138-154.

Brading, K. (2011), 'On Composite Systems: Descartes, Newton, and the Law-Constitutive Approach'. In D. Jalobeanu and P. R. Anstey (eds), *Vanishing Matter and the Laws of Motion: Descartes and Beyond*, New York, Routledge, 130-152.

Brading, K. (2012), 'Newton's law-constitutive approach to bodies: a response to Descartes'. In A. Janiak and E. Schliesser (eds), *Interpreting Newton*, New York, Cambridge University Press, 13-32.

Caporael, L. R., Griesemer, J. R. and Wimsatt, W. C. (eds) (2014), *Developing Scaffolds in Evolution, Culture, and Cognition,* Cambridge, MA, The MIT Press.

Currie, A. M. (2015), 'Marsupial lions and methodological omnivory: function, success and reconstruction in paleobiology', *Biology and Philosophy*, *30*, 187-209.

Currie, A. M. (2018), *Rock, Bone & Ruin: an optimist's guide to the historical sciences*, MIT Press.

Currie, A. M. and Walsh, K. (Manuscript), *Frameworks for Historians*,

Dear, P. (1995), *Discipline & Experience: The Mathematical Way in the Scientific Revolution*, Chicago, University of Chicago Press.

Ducheyne, S. (2013), 'The Status of Theory and Hypotheses'. In P. Anstey (ed), *The Oxford Handbook of British Philosophy in the Seventeenth Century*, Oxford University Press, 169-191.

Dunlop, K. (2012), 'What Geometry Postulates: Newton and Barrow on the relationship of mathematics to nature'. In A. Janiak and E. Schliesser (eds), *Interpreting Newton*, Cambridge, Cambridge University Press, 69-101.

Fitchen, J. (1981), *The Construction of Gothic Cathedrals: A study of medieval vault erection*, Chicago, University of Chicago Press.

Garber, D. (2013), 'Remarks on the Pre-history of the Mechanical Philosophy'. In D. Garber and S. Roux (eds), *The Mechanization of Natural Philosophy*, Springer, 3-26.

Glymour, C. (1980), *Theory and Evidence*, Princeton, Princeton University Press.

Guicciardini, N. (2011), *Isaac Newton on Mathematical Certainty and Method*, Cambridge, Massachusetts, The MIT Press.

Hamou, P. (2014), 'Vision, Color, and Method in Newton's *Opticks*'. In Z. Biener and E. Schliesser (eds), *Newton and Empiricism*, Oxford, Oxford University Press, 66-93.

Hooke, R. (1705), 'A General Scheme, or Idea Of the Present State of Natural Philosophy'. In S. Smith (ed), *The Posthumous Works of Robert Hooke, ... Containing His Cutlerian Lectures, and Other Discourses, Read at the Meetings of the Illustrious Royal Society. ... Illustrated with Sculptures. To These Discourses is Prefixt the Author's Life, ... Publish'd by Richard Waller*, 1-70.

Hooke, R. (1966/1665), *Micrographia: Or, some physiological descriptions of minute bodies made by magnifying glasses, with observations and inquiries thereupon*, New York N.Y., Dover.

Jalobeanu, D. (2014), 'Constructing natural historical facts: Baconian natural history in Newton's first paper on light and colours'. In Z. Biener and E. Schliesser (eds), *Newton and Empiricism*, Oxford, Oxford University Press, 39-65.

Locke, J. (1979/1690), *An Essay Concerning Human Understanding*. Edited by P. H. Nidditch, Oxford, Oxford University Press.

Newman, W. (2010), 'Newton's Early Optical Theory and its Debt to Chymistry'. In D. Jacquart and M. Hochmann (eds), *Lumière et vision dans les sciences et dans les arts. De l'Antiquité au XVIIe siècle*, Geneva, Droz, 283-307.

Newman, W. (2016), 'A preliminary reassessment of Newton's alchemy'. In R. Iliffe and G. E. Smith (eds), *The Cambridge Companion to Newton, 2nd Edition*, Cambridge, Cambridge University Press, 454-484.

Newton, I. (1672), 'A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; Containing His New Theory about Light and Colors: Sent by the Author to the Publisher from Cambridge, Febr. 6. 1671/72; In Order to be Communicated to the R. Society ', *Philosophical Transactions*, *6*, 3075-3087.

Newton, I. (1952), *Opticks: Or a Treatise of the Reflections, Refractions, Inflections & Colours of Light*, Dover Publications, Inc.

Newton, I. (1959-1977), *The Correspondence of Isaac Newton, 7 Volumes*. H. W. Turnbull, J. F. Scott, A. R. Hall and L. Tilling (ed). Cambridge, Published for the Royal Society at the University Press.

Newton, I. (1999/1726), *The Principia: Mathematical Principles of Natural Philosophy*. Translated by I. B. Cohen and A. M. Whitman. Berkeley, University of California Press.

Newton, I. (2014/*Isaac Newton: Philosophical Writings*. Edited by A. Janiak, Cambridge, Cambridge University Press.

Sabra, A. I. (1967), *Theories of Light From Descartes to Newton*, London, Oldbourne Book Co Ltd.

Shapiro, A. E. (1993), *Fits, Passions and Paroxysms: Physics, Method and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection*, Cambridge, Cambridge University Press.

Shapiro, A. E. (2002), 'Newton's optics and atomism'. In I. B. Cohen and G. E. Smith (eds), *The Cambridge Companion to Newton*, Cambridge, Cambridge University Press, 227-255.

Shapiro, A. E. (2004), 'Newton's 'Experimental Philosophy'', *Early Science and Medicine*, *9*, 185-217.

Walsh, K. (2012a), 'Conflating the Experimental and Mechanical Philosophies'. In *Early Modern Experimental Philosophy:* https://blogs.otago.ac.nz/emxphi/2012/04/conflating-the-experimental-and-mechanical-philosophies/, archived at https://archive.fo/8hDEA. Accessed: 9 June 2013.

Walsh, K. (2012b), 'Did Newton Adopt Hypothetico-Deductivism?'. In *Early Modern Experimental Philosophy:* https://blogs.otago.ac.nz/emxphi/2012/12/did-newton-adopt-hypothetico-deductivism/. Accessed: 2 December 2014.

Walsh, K. (2017), 'Newton: from certainty to probability?', *Philosophy of Science*, *84*, 866-878.