Evidence
Lecture 3 (18. May 2022)
Newton's Investigations on Light and Color, Part II

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(date of version: 25. May 2022)

Contents

This lecture covers:

1. Newton (1726a): Book III, "Rules of Reasoning in Philosophy"
2. Newton (1672a): pp. 53–59
3. Newton (1672b): the diagram on p. 101

1 Admin Crap

1. REMEMBER TO RECORD THE LECTURE!
2. Thursday or Friday (26.–27. May) for make-up lecture?
3. remind: invitation to short essay

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2 Lecture Overview

1. review design of *Experiment Crucis*, interpretation of its results and structure of their evidential nexus of claims
2. briefly discuss Newton's Third Rule of Reasoning in Natural Philosophy
3. review the contents and form of Newton's Doctrine on light and color and the structure of its evidential nexus of claims
4. discuss the role of theory and metaphysics in the construction and interpretation of the evidential nexuses

3 The *Experimentum Crucis*

> To make a beginning
> out of particulars
> To roll up the sum by defective means...
>
> Rigor of beauty is the quest
> But how will you find it when it is locked away in the mind
> beyond all remonstrance?
>
> William Carlos Williams
> *Paterson*

The term has its origins in the *Novum Organum* of Francis Bacon, where he uses '*instantia crucis*' to mean a determining circumstance—decisive evidence—that would show that one hypothesis or theory holds true while all rivals do not. I am told (but cannot find the reference) that the term '*experimentum crucis*' was then coined by Robert Hooke, to mean the deliberate construction of a controlled situation whose observed result would provide an *instantia crucis*. But I am also told the same of Robert Boyle, so go figure.

The arrangement of Newton's *experimentum crucis* is shown in this diagram, drawn by him for Newton (1672b, p. 101), his reply to the second letter by Ignatius Pardies (1672) criticizing Newton (1672a).

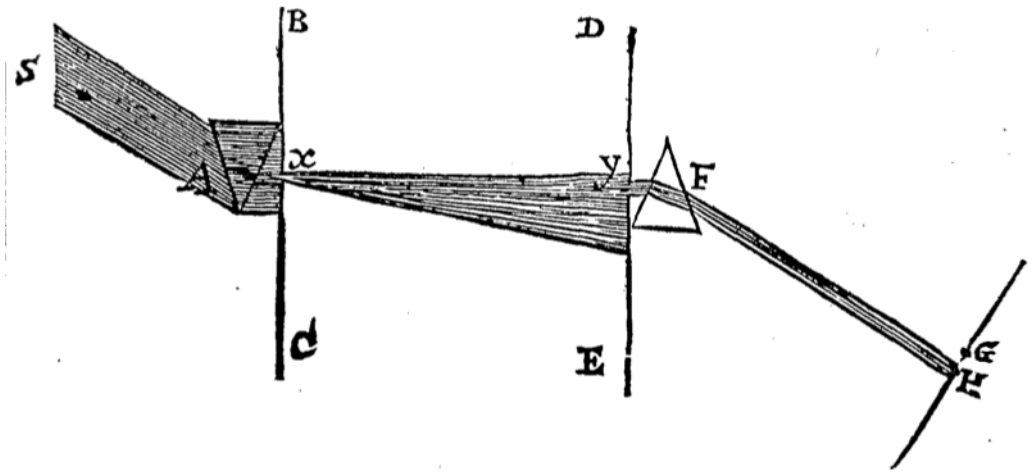

Figure 3.1: *Experimentum Crucis*

The labels in figure 3.1 denote as follows:

S the small, circular hole in the window cover allowing in only a narrow pencil of sunlight (or, perhaps, the pencil itself)

A the first prism through which the entering sunlight passes

B-C the wooden plank behind the first prism, perpendicular to the light's path, blocking almost all the light leaving the prism

X the small, circular hole in the wooden plank **B-C** allowing only a narrow, isolated ray of light leaving the prism to proceed

D-E the wooden plank in front of the second prism, perpendicular to the light's path, blocking almost all the light emanating from **X**

Y the small, circular hole in the wooden plank **D-E** allowing only a further narrowed, even more isolated ray of light to proceed through the plank to enter the second prism

F the second prism, through which the light passing through **Y** travels

G-H the small, circular image of the final ray of light leaving the second prism **F**, where it hits a smooth surface perpendicular to the direction of the ray's path

Newton (1672a, p. 51, his emphases) takes the *Experimentum Crucis* to show unequivocally that "[white] *Light* consists of *Rays differently refrangible*."

Aside on the Duhem Thesis

Most philosophers, and perhaps many physicists, today would dismiss the possibility of a single experiment's decisively demonstrating the goodness of a theory (or theoretical account more generally), because of the Duhem Thesis: no experiment ever conclusively tests a single hypothesis or proposition in isolation, because to draw a conclusion from the hypothesis or proposition to

test, one must conjoin it with "auxiliary hypotheses" (*e.g.*, principles to interpret the operational description of the experimental outcome so to bring it into substantive semantic contact with the theoretical terms used to articulate the hypothesis, claims about the appropriate isolation of the experimental arrangement from possibly confounding environmental factors, *etc.*), and so the experiment tests only the conjunction of the hypothesis and the auxiliaries *en bloc*.[1] That is as may be, but, as philosophers never seem to realize, and as Duhem himself went on to point out after laying down the Duhem Thesis, while no *single* experiment can ever do the trick, a well designed *sequence* of experiments can, by isolating in turn the possible consequences of each of the auxiliaries and alternatives, so as to dismiss their potential explanatory relevance. And that is exactly what Newton did. The *Experimentum Crucis* is the culmination of just such a sequence, and that is why, in my opinion, it does decisively and indubitably show exactly what Newton claims it does.

4 Claims Receiving Evidential Support: Contents and Kinds

1. positive qualitative existential indicative claim about the present state of the world: "there is light that, properly circumstantiated, behaves in a particular way" (*viz.*, the "celebrated Phænomena of Colours")

2. negative qualitative modal claim about a theoretical proposition: "the properly described behavior of such circumstantiated light appears to contradict the received laws of optics"

3. negative qualitative existential modal claim about contingent features of the world: "no contingent feature of the observational circumstance (*e.g.*, irregularities in the glass of the prism) is the cause of the aberrancy"

4. negative modal claim about possible law-like quasi-quantitative regularities in the world: "this possible law-like regularity (*e.g.*, the effect of the varying thickness of the prism) is not the cause"

5. positive quantitative existential indicative claim about the present state of the world and its relation to a theoretical proposition: "the phenomenon truly is in conflict with the received laws"

6. negative quantitative universal modal claim about a theoretical proposition: "the received laws are not always true descriptions of all relevant phenomena"

7. positive qualitative modal claim about a theoretical proposition: "the received laws require modification"

8. positive quantitative existential indicative claim about the present state of the world and positive quantitative modal claim about a general phenomenon in the world: "there is a kind of light (*viz.*, white sunlight) that is truly described as having this specific composition (*viz.*, consisting of a mixture of rays differently refrangible)"

1. This is often called the Duhem-Quine Thesis, or even just the Quine Thesis, but I deprecate those names, because Quine got it so badly wrong. But that's another story.

5 An Interlude, *Andante e Contemplativo*, on Newton's Third Rule

Rule III of Reasoning in Natural Philosophy, along with the first paragraph of the attendant scholium on it (Newton 1726b, Bk. III, p. 398–399):

> *The qualities of bodies, which admit neither intensification nor remission of degree, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.*
>
> For since the qualities of bodies are only known to us by experiments, we are to hold as universal all such as universally agree with experiments; and such as are not liable to diminution can never be quite taken away. We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature, which is wont to be simple, and always consonant to itself.

6 Newton's Doctrine

I first give a distilled summary of the most important parts of the Doctine. I then briefly discuss some of the more detailed and, from today's perspective, less important of the Doctrine's propositions.

Newton demonstrated unequivocally:

1. that sunlight consists of an innumerable number of simple light rays differing from each other in their refrangibility relative to a given medium of propagation [positive quantitative existential indicative claim about the present state of the world and positive quantitative modal claim about a general phenomenon in the world];

2. that the refrangibility associated with a particular simple ray for a given medium of propagation is a primitive property of that ray in the sense that no manipulation of the ray Newton could contrive would change it [positive quantitative existential indicative claim about the present state of the world and positive quantitative modal claim about a general phenomenon in the world];

3. that when a simple ray exhibits a particular refrangibility, it also always exhibits a particular correlated colorific character, *viz.*, the appearance to a normal observer under normal conditions of a particular color when the simple ray falls on a white surface, always the same color for a given refrangibility [positive qualitative existential indicative claim about the present state of the world and positive qualitative modal claim about a general phenomenon in the world];

4. that light from all sources he could find to experiment on has the property of being composed of simple rays of fixed refrangibility, if it is not itself in the first place such a simple ray [positive qualitative existential indicative claim about the present state of the world];

5. that simple, homogeneal rays manifest a local quasi-additive structure in their colorific properties: the composition of two rays close in color (as determined by relative position in the spectrum) tends to produce a complex ray whose color is intermediate between the two [positive quasi-quantitative existential indicative claim about the present state of the world and positive qualitative modal claim about a general phenomenon in the world]

In modern terminology, Newton discovered that:

1. an adequate mathematical representation of any light ray, relative to the experimental technique available to him, has (crudely speaking) a canonically privileged, unique Fourier decomposition;

2. the refrangibility of individual components of the Fourier composition—a ray of light of a single pure frequency—depends on the frequency of the light;

3. (visible) light of a single frequency tends to produce only one color, always the same, to a normal observer under normal conditions;

4. the frequency of a pure, single frequency light ray cannot be changed (at least, again, not by any experimental methods or any physical processes known at the time to Newton);

5. the Maxwell-Helmholtz-Young color manifold has a locally additive structure.[2]

6. the apparent color of material bodies is determined by a combination of the composition of the ambient light falling on it and of the bodies' disposition to absorb and transmit different types of simple rays of light; limitations of time do not allow further discussion of this claim, but I cannot emphasize enough how extraordinary a moment it marked in the evolution of our understanding of the nature of ordinary matter, especially in light of the use Newton put it to in his further, later researches on light and its interaction with matter

Every single part of Newton's doctrine is still thought today to be true to an extraordinarily high degree of approximation in our deepest theory of light, quantum electrodynamics.

1. sunlight is a manifestation of an incoherent state of the quantum electromagnetic field (itself a manifestation of a broken symmetry in the electroweak field), composed of an innumerable mixture of simple modes of a Fourier decomposition of that field, each mode possessing a distinct, single frequency and associated intensity in the field's power spectrum, sometimes usefully thought of as photons (the analogue to the composition of sunlight as a mixture of simple rays)

2. the phase velocity of a field consisting of only a single of these modes changes in fixed, determinate ways across the boundary of two different states of matter of given types, always the same type of change in occupied energetic states corresponding to the same mode and states of matter (part 1 of the analogue to a fixed refrangibility)

2. More accurately, and for the *cognoscenti*, the extension of Newton's conclusions to non-spectral colors, when saturation and brightness are accounted for (which Newton laid the groundwork for), is naturally represented by a three-dimensional, compact Fréchet manifold.

3. to these characteristic changes in phase velocity of each simple mode correspond characteristic patterns of photonic absorption and scattering by different fundamental particles, such as electrons, protons, positrons, π-mesons, *etc.*, determining a characteristic path through which photons—the particulate representation of a simple mode—will scatter, always the same pattern *in specie* across the boundary of two different states of matter of given types (part 2 of the analogue to a fixed refrangibility)

4. a simple mode "freely propagating trhough vacua and ordinary matter" will not change its energetic state (analogue to the fixed correlation of a colorificity and a refrangibility of a simple ray)

5. the power spectrum of an incoherent mixture of these modes can be computed based on the knowledge of the intensities of the individual modes, and this power spectrum is, roughly speaking, additive in those intensities (the analogue to the fact that the colorificity of a mixture of simple rays can be computed based on the quasi-additive composition of the simple rays composing the mixture)

The careful reader may have noticed a lacuna in this account: nothing is said about the generic immutability of the frequency associated with a given mode. In fact, we know that the frequency of light, at this level of representation, is not a fixed, immutable, invariant property. This mutability, however, manifests itself only in experimental circumstances far exceeding the technological capacity of Newton's time to have realized, such as those in which one can observe Compton scattering, or the red-shift of light traversing a gravitational field with a great enough total gradient.

The Methodology behind the Doctrine

As an example of the methodology, what Newton considers evidence and how he builds it up and applies it, let us consider the immutability of the refrangibility of simple rays. Consider the full statement of the evinced claim, the general evidential warrant and Newton's subsequent litany of particular concrete, specific evidential claims supporting the general warrant (pp. 53–54. item 3):

> 3. The species of colour, and degree of Refrangibility proper to any particular sort of Rays, is not mutable by Refraction, nor by Reflection from natural bodies, nor by any other cause, that I could yet observe. When any one sort of Rays hath been well parted from those of other kinds, it hath afterwards obstinately retained its colour, notwithstanding my utmost endeavours to change it. I have refracted it with Prismes, and reflected it with Bodies, which in Day-light were of other colours; I have intercepted it with the coloured film of Air interceding two compressed plates of glass; transmitted it through coloured Mediums, and through Mediums irradiated with other sorts of Rays, and diversly terminated it; and yet could never produce any new colour out of it. It would by contracting or dilating become more brisk, or faint, and by the loss of many Rays, in some cases vary obscure and dark; but I could never see it changed *in specie*.

Analysis:

1. The evinced claim receiving evidential warrant: "The species of colour, and degree of Refrangibility proper to any particular sort of Rays, is not mutable by ... any ... cause, that

I could yet observe."

2. The general evidential claim supporting it: "When any one sort of Rays hath been well parted from those of other kinds, it hath afterwards obstinately retained its colour, notwithstanding my utmost endeavours to change it."

3. the particular concrete, specific evidential claims supporting the general evidential claim: he fucked with it in every way he could think of, and nothing he did had any effect on it

4. BUT the evinced claim itself is then immediately used as evidence for a more remarkable, abstract, schematic, one might say metaphysical and ontological, claim (which we will call "the second evinced claim", and the former "the first"): it was the immutability of the refrangibility and colorificity that led Newton to think of these rays as the 'simple' components of the more 'complicated' ray of sunlight, and his denomination of the properties of refrangibility and colorificity of a ray "of a particular sort" as "original and connate" properties of those rays—though strictly speaking he explicitly denominates only colorificity so, but the intended extension to refrangibility is, I think, clear, as mandated by his Third Rule of Reasoning in Natural Philosophy

5. it is important to note that the first evinced claim can be used as warrant for the second *only* in conjunction with the (implicit) claim that refrangibility and colorificity are the only two physical properties of light that can be used to differentiate it into species. (Strictly speaking there is also reflectivity, but that is trivial and so we, and Newton, ignore it.)

6. What is the nature of this second evinced claim? Interpretive? Architectonic? Ontological? Metaphysical? Epistemic? Methodological?

7. In any event, given that it must be presupposed in order even to formulate Newton's Doctrine, and *a fortiori* apply it in research to produce new possible knowledge claims, can one assign it a different evidential weight from that of the framework as a whole?

7 The Role of Theory and Metaphysics in the Design of the *Experiment Crucis*, *et al.*, and Interpretation of Their Results as Evidence

1. he could not even have formulated the idea for, designed and interpreted the results of the *Experiment Crucis*, and *a fortiori* used it as evidence for the theoretical claims of his framework, without already using the metaphysical and theoretical machinery of the framework as applied to the formulation of the idea for, the design and the results of earlier experimental outcomes

2. does this make the evidence "theory-laden" in any demeritorious sense?

8 Invitation to a Short Essay

I invite you to write me a short discussion (no more than 2 pages, *i.e.*, no more than 1000 words) on any issue discussed in this lecture or any of this week's readings, required or suggested. You

can raise further questions, propose answers or interpretations, or whatever seems of most interest to you. If you get it to me by the start of next lecture (25. May), then I will return it to you with my comments the following week.

References

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Newton, Isaac. 1672a. "Letter of February 6, 1671/72, to Henry Oldenburg, Secretary of the Royal Society, Outlining Newton's Researches on Light and Color". In Cohen 1958, 47–59.

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