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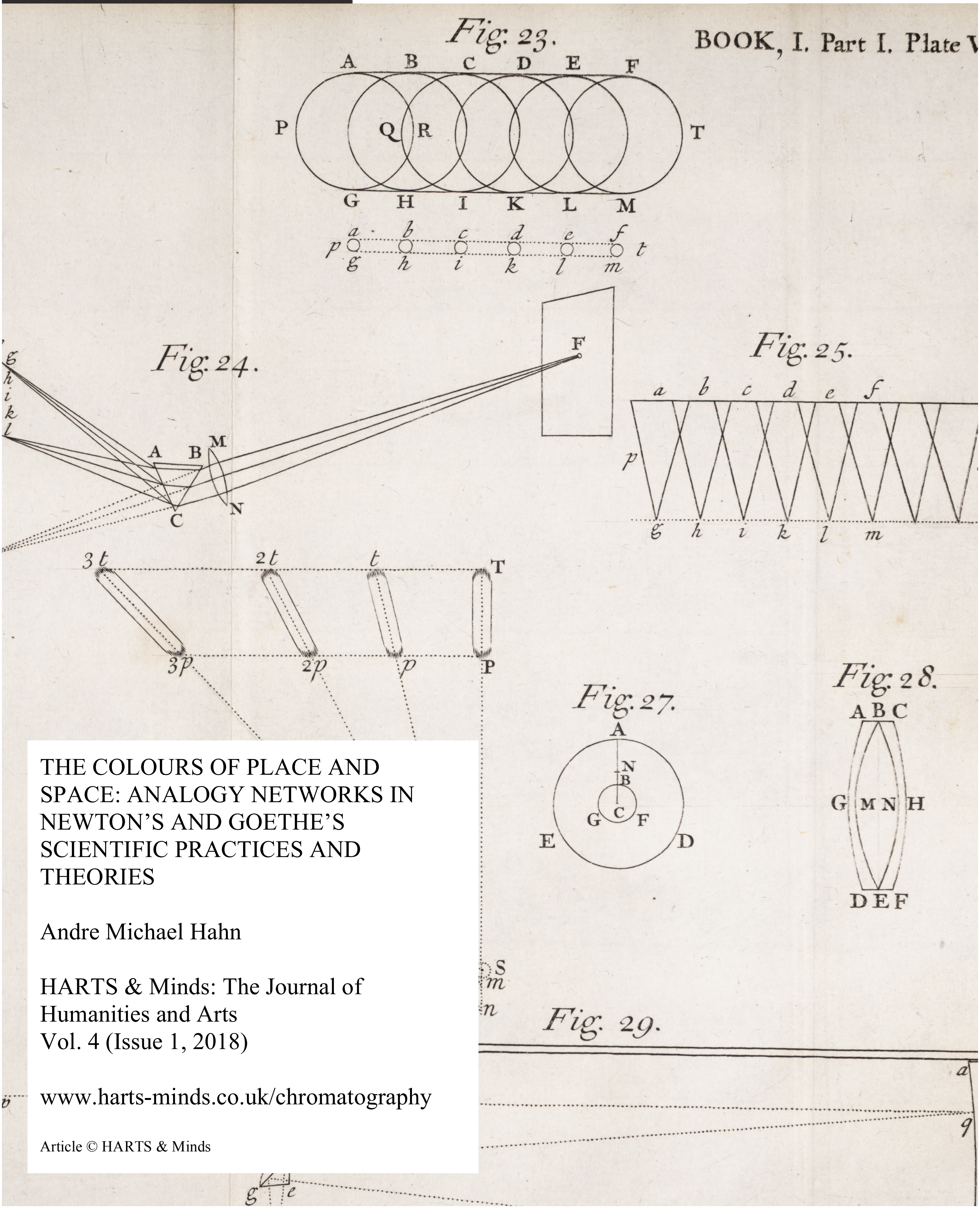

THE COLOURS OF PLACE AND SPACE: ANALOGY NETWORKS IN NEWTON'S AND GOETHE'S SCIENTIFIC PRACTICES AND THEORIES

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THE COLOURS OF PLACE AND SPACE: ANALOGY NETWORKS IN NEWTON'S AND GOETHE'S SCIENTIFIC PRACTICES AND THEORIES

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Abstract
While important differences existed between the colour theories of Isaac Newton (1643-1727) and Johann Wolfgang von Goethe (1749-1832), they did also share some commonalities. Looking at how they each conceived of and used place and space when presenting their theories, I will show how Newton and Goethe employed a shared method of constructing analogy networks. To investigate how analogies illuminated Newton's and Goethe's conceptions of place and space, I will explore Newton's 1672 letter to the *Royal Society of London* describing his initial investigations of colour along with the more formal geometrical treatment of colour in his *Opticks* (1704). Goethe's essay *Beiträge zur Optik* (1791-1792) and the didactic section of his *Zur Farbenlehre* (1810) will also provide similarly representative material.

Newton and Goethe both built up networks of analogies through relating observations of places to one another. In recognising this similarity, their differences also become more understandable. Newton linked his analogies of place by passing from one place to another, moving through geometrical space. This had the effect of creating two levels within his analogy network where abstract geometrical space existed as centralised nodes linking different sensate places. Goethe, conversely, related different places directly to one another, with little centralization, creating several flat networks that paralleled and intersected each other.

Key Words: Newton, Goethe, *Opticks*, *Zur Farbenlehre*, colour spectrum, analogies

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Place, Space, and Analogy

Rushed to return a prism he had borrowed from the physicist Hofrat Buttner and had been too busy to use, Johann Wolfgang von Goethe held it in front of his eyes and looked at a freshly painted wall in his home. The wall was white and, contrary to Goethe's expectation, continued to be white as he looked through the prism. Having gained his understanding of Isaac Newton's theory of colour second-hand as a student at Leipzig, Goethe had been prepared to see a coloured wall. The only colours Goethe did see were at the boundaries of light and dark areas.[1] As he would later recall:

> Es bedurfte seiner langen Überlegung, so erkannte ich, daß eine Grenze notwendig sei, um Farben hervorzubringen, und ich sprach wie durch einen Instinkt sogleich vor mich laut aus, daß die Newtonische Lehre falsch sei.[2]

> It required a long consideration for me to understand that a boundary is necessary to produce colours and I immediately said, as if by instinct out loud to myself, that the Newtonian teaching is false.[3]

Goethe's bold claim has since been the centre of much debate.[4]

The approach taken here seeks to establish a common intellectual context for Newton and Goethe built around the role of analogies in scientific thought.[5] Analogies are taken as a point of departure since, as I hope to demonstrate, their role is more fundamental than metaphysical - perspectives that themselves rely on analogies to things like machines, the macrocosm, and organisms. This approach additionally sets aside matters of accuracy of conclusions, purpose, and Goethe's polemical attitude against Newtonians for the sake of gaining a deeper sense of their scientific practice and theory formation.[6]

Analogies can be understood as linguistic and mental constructions, making them a subjective activity that can undermine absolutist claims to objectivity.[7] Here I am seeking to avoid these prescribed values that subjectivity is inherently detrimental to objectivity by acknowledging that analogies contain both subjective and objective elements, a perspective recognised for its usefulness in science and science education.[8] To bring into focus the objective element of analogies, particularly in the cases of Newton and Goethe, requires consideration of the role of place and space.

I define place and space respectively as the two fully abstracted end points of a spectrum (Fig. 1). The extreme of place is fully embodied and sensual, containing both subjective and objective elements. Edmund Husserl described this as the "natürliche Einstellung" [natural standpoint or attitude], a term emphasising the subjective aspect (i.e. a standing point) of being fully immersed in one's surroundings.[9] A more objective characterization of this would be the "lifeworld", or Jakob von Uexküll's "*Umwelt*", as they emphasise how one's surroundings are affected by one's subjectivity rather than the subjective mental state itself.[10] Both the subjective and objective perspectives describe the same thing: a standpoint, and its corresponding surrounding, with the quality that Maurice Merleau-Ponty described as "thickness" binding the objective and subjective elements together.[11] Shifts in consciousness, or a Husserlian "*Cogito*", break through this thickness, leading to Husserl's "theorizing" standpoints, one of which, for him, stands in the "arithmetic world". These worlds, though not completely separate from the natural standpoint suggest a higher degree of subjective independence from it and the potential for experiences that are disembodied and ideal. Thus, returning to my spectrum of place and space, opposite to an embodied place, or *Umwelt*, which contains both subjective and objective elements, is disembodied space, something most readily conjured up by, but not limited to, pure geometry. Goethe can help tie all this together:

> Ein weit schwereres Tagewerk übernehmen diejenigen, deren lebhafter Trieb nach Kenntnis die Gegenstände der Natur an sich selbst und in ihren Verhältnissen unter einander zu beobachten strebt: denn sie vermissen bald den Maßstab, der ihnen zu Hulfe kam, wenn sie als Menschen die Dinge in Bezug auf sich betrachteten. Es fehlt ihnen der Maßstab des Gefallens und Mißfallens, des Anziehens und Abstoßens, des Nutzens und Schadens; Diesem sollen sie ganz entsagen, sie sollen als gleichgültige und gleichsam göttlich Wesen suchen und untersuchen was ist, und nicht was behagt.[12]

> A difficult task arises when a person's thirst for knowledge kindles in him a desire to view nature's objects in their own right and in relation to one another. On the one hand he loses the yardstick which came to his aid when he looked at things from the human standpoint; i.e., in relation to himself. This yardstick of pleasure and displeasure, attraction and repulsion, help and harm, he must now renounce absolutely; as a neutral, seemingly godlike being he must seek out and examine what is, not what pleases.[13]

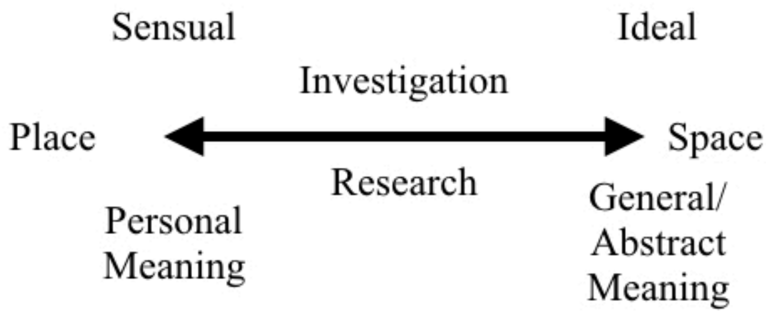

Fig. 1: Spectrum of Place and Space.

Goethe saw entering into scientific observation as an inner act of renunciation, an entering into Husserl's *Cogito*, that breaks through the thickness of the natural standpoint and takes up a scientific project. As I will explain, Newton also described this type of shift in consciousness when talking about his investigations of colour.

Acknowledging the shift in consciousness associated with the differences between embodied sensual place and disembodied ideal space leads to further complications of my original spectrum. As the realm of life, place is thickened by traditionally subjective qualities contributing to personal meaning, such as likes and dislikes. Shifts in consciousness bring about opportunities to disengage from that thickness and potentially formulate more general and abstracted types of meaning. This type of shift can be called research or investigation. It is open to both the perceptual and the conceptual, moving between the two until the researcher establishes a state a harmony for themselves. This is a realm of fluctuating theory in the Greek sense as a type of intellectualised or educated seeing, where the abstract meets the sensate. The central activities of both Newton and Goethe occur in the realm of research. For Newton, this was where the abstractions of a universal geometrical space met the phenomena he encountered in telescopes, prisms, and rainbows. Goethe, striving after a different type of universality, filled his space with several types of meaningful perspectives such as the historical, the chemical, the moral, and others. This brings us back to analogies.

Agnes Arber described "the perception of likeness and unlikeness" by means of comparison as taking a foundational role in scientific thinking.[14] As per above, these perceptions have a thickness to them, binding the subjective mental state of the scientist to their objective surroundings so that they do not merely compare perceptions of a place to other places, but also compare it to different spaces accessed through differences of *Cogito*. In making these comparisons, linking together various places and spaces, scientists construct analogy networks. As we shall see, these analogy networks were common to scientists as different as Newton and Goethe who merely constructed networks of different forms, with their respective *Cogitos* providing different colourings. Newton's geometric expertise allowed him to construct an analogy network centralised around nodes of ideal geometrical spaces linking various sensate places, creating a two-tiered network of meaningful disembodied spaces and less meaningful embodied places. Goethe admitted his lack of geometric facility kept him from taking a similar standpoint.[15] It did not stop him from taking several other standpoints as he related different places directly to one another, without strong central nodes, creating parallel yet interconnected networks.

In order to explore how analogies can illuminate Newton's and Goethe's conceptions of place and space we shall examine Newton's 1672 letter to the *Royal Society of London* describing his initial investigations of colour along with the more formal geometrical treatment of colour in his *Opticks*.[16] Goethe's essay *Beiträge zur Optik* and the didactic section of his *Zur Farbenlehre* provide similarly representative material.[17]

Newton's Use of Geometrical Space in Establishing Analogous Places

At the end of 1671, Isaac Barrow presented Newton's newly designed telescope to the Royal Society. Previous telescopes were dioptric, or refracting, and used only lenses for magnification. The process of refraction led to chromatic aberrations that distorted the colours of and produced halos around the objects in view. To avoid these aberrations, Newton developed the first catoptric, or reflecting, telescope by replacing the lens with a concave mirror that reflected light to a second, flat mirror, which then reflected the image through the eyepiece on top. In response to a request by Barrow, Newton sent a letter to the Royal Society in February 1672 explaining how his telescope was the result of a new discovery about the nature of light. The letter's reading was immediately met with applause.[18] Newton began his letter by introducing the scene of his investigations:

> To perform my late promise to you, I shall without further ceremony acquaint you, that in the beginning of the Year 1666 (at which time I applyed my self to the grinding of Optick glasses of other figures than *Spherical*,) I procured me a Triangular glass-Prisme, to try therewith the celebrated *Phaenomena* of *Colours*. And in order thereto having darkened my chamber, and made a small hole in my window-shuts, to let in a convenient quantity of the suns light, I placed my Prisme at his entrance, that it might be thereby refracted to the opposite wall. It was at first a very pleasing divertisement, to view the vivid and intense colours produced thereby; but after a while applying my self to consider them more circumspectly, I became surprised to see them in an *Oblong* form; which, according to the received laws of Refraction, I expected should have been *circular*.[19]

Newton went on to describe how he varied the circumstances of the experiment by altering the size of the hole the sun shone through and by moving the prism itself. He worked through various experiments aiming to disprove certain hypotheses until he came to a point where he could make a positive claim by presenting his *experimentum crucis*. Here, Newton placed a second board with a hole in between two prisms to catch one particular colour of light. The second prism then refracted the colour, which passed through the board a second time. After this second refraction, the colour remained the same, thus proving for Newton that the colours coming out of the prism were the ultimate constituents of light; that is, he found no way to break the colours down any further.

Though some have disputed the accuracy and honesty of Newton's descriptions, they likely provide a good representation of his initial conception of an experimental location.[20] In his description, Newton's chamber, as the location of his experiments, was minimally populated, containing only the relevant objects and phenomena of the experiment under question. These included his window, shutters, a prism, and the coloured image on the wall, which were also the only objects in a sketch Newton made of his experiment. He did not mention what else was there, rather only the basic necessities needed for his experiments and what others would need to repeat it.[21]

Newton's account also contained an important shift of consciousness relevant to how place related to meaning. Newton noted, while observing the initial conditions of his chamber after setting up the prism, that it was "at first a very pleasing divertisement". Newton's chamber appeared as a place of enjoyment and personal meaning, it was a place seen from a natural standpoint. The shift in Newton's consciousness occurred when he began "applying my self to consider them [the colours] more circumspectly", thus moving his chamber into the realm of research and himself towards a theorising standpoint. This transformed Newton's original pleasure into curiosity, allowing it to connect with the abstract and geometrical meanings of "the received laws of Refraction". Newton's subsequent account of his actions described a realm of research and experimentation as an intermediary location between the curiosity engendered by his own pleasure and the more universal relationships contained in abstract geometrical space.

This shift in how Newton both conceived of and perceived his chamber became more pronounced as he described his *experimentum crucis*. A term first used by Robert Hooke through possibly combining Francis Bacon's *experimenta lucifera* and *instantiae crucis*, the *experimentum crucis* was to be a single experiment that disproved several hypotheses at once.[22] Newton, however, used it in a more positive sense in that it proved his theory so thoroughly it was unnecessary to even consider others.[23] That Newton was able to present a positive experiment in this sense fully moved the *Umwelt* of his chamber into geometrical space, giving him a reliable basis for the sine laws he developed for each colour created by the prism.

Newton used these abstract sine laws to create an analogy between his room and his telescope, demonstrating that his conclusions on colour based on his experiences in his room could be transferred, via geometry, to explain aberrations in "any Telescope":

> And consequently, the object-glass of any Telescope cannot collect all the rays, which come from one point of an object so as to make them convene at its *focus* in less room than in a circular space, whose diameter is the 50th part of the Diameter of its Aperture; which is an irregularity, some hundreds of times greater, then a circularly figured *Lens*, of so small a section as the Object glasses of long Telescopes are, would cause by the unfitness of its figure, were Light *uniform*.[24]

Newton finished by explaining how his reflecting telescope avoided this problem since there was no opportunity for light to refract and break apart into its constituent parts.[25] Newton's telescope belonged to a different analogy network than dioptric telescopes.

Euclid's *Optics* (ca. 300 BCE) was the first geometric treatment to move beyond theories focusing on the nature of vision. Those theories often described vision as either active or passive, and light as bound up with darkness or comprised of atoms.[26] Though he accepted the active nature of sight, Euclid's approach largely neglected the theoretical assumptions, such as active vision, attached to it. In the eleventh century, Ibn al-Haytham reconciled geometrical optics with the passive reception of light by coupling them together with a theory reducing bodily radiation to specific points.[27] Newton's own views were a mixture of those before him as he described rays in terms of atoms, or corpuscles, using the assumption to reinterpret Rene Descartes's laws of refraction and reflection in terms of rays.[28] Newton's view that light was composite met with criticism, most significantly that of Hooke, who suggested that Newton's letter was based on certain assumptions. Newton responded that he did not depend on any assumptions about the nature of light and that his experiments were enough proof.

Newton revisited his original questions about the geometry of light and colour in his *Opticks* (1704), published the year after he assumed the presidency of the Royal Society. Newton's presentation was much more formal and exhaustive as it followed a Euclidian geometrical style beginning with definitions and axioms before moving onto propositions with proofs by experiment.[29] The propositions built upon and referred to each other so that there was a definite progression towards goals such as the improvement of the telescope.

After establishing that different coloured lights had different degrees of refrangibility, Newton wanted to prove that light was made up of rays in his second proposition. Here, he repeated similar experiments he had presented in his letter as follows:

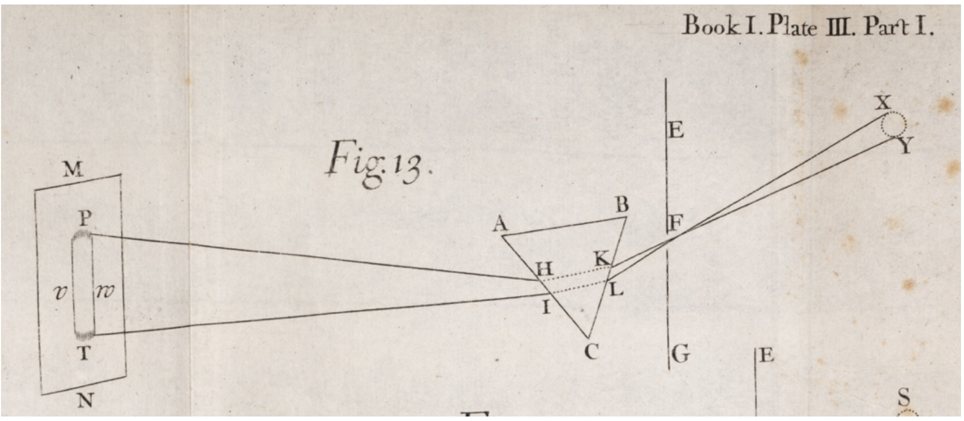

Fig. 2: Isaac Newton, *Opticks* (1704), Figure demonstrating geometrical relationships of light passing through a prism. Source: Linda Hall Library of Science, Engineering & Technology.

> In a very dark Chamber, at a round Hole, about one third Part of an Inch broad, made in the Shut of a Window, I placed a Glass Prism, whereby the Beam of the Sun's Light, which came in at that Hole, might be refracted upwards toward the opposite Wall of the Chamber, and there form a colour'd image of the Sun. The Axis of the Prism (that is the Line passing through the middle of the Prism from one end of it to the other end parallel to the edge of the Refracting Angle) was in this and the following Experiments perpendicular to the incident Rays. About this Axis I turned the Prism slowly, and saw the refracted Light on the Wall, or coloured image of the Sun, first to descend, and then to ascend. Between the Descent and Ascent, when the Image seemed Stationary, I stopp'd the Prism, and fix'd it in that Posture, that it should be moved no more.[30]

With this first experiment, Newton had already begun integrating natural and theorising standpoints by seeking a place of stillness as he moved his prism into the precise location to fit into his geometrical space (Fig. 2). Once he fixed the prism, Newton began a process of disembodiment by integrating geometrical space into his perceptual place more thoroughly than he had in his letter as he replaced sensate objects with geometrical notation using letters to denote points and the pairing of letters to denote lines.

> For let EG represent the Window-shut, F the hole made therein through which a beam of the Sun's Light was transmitted into the darkened Chamber, and ABC a Triangular Imaginary Plane whereby the Prism is feigned to be cut transversely through the middle of the Light. Or if you please, let ABC represent the Prism it self, looking directly towards the Spectator's Eye with its nearer end: And let XY be the Sun, MN the paper upon which the

> Solar Image or Spectrum is cast, and PT the Image it self whose sides towards *v* and *w* are Rectilinear and Parallel, and ends towards P and T Semicircular. YKHP and XLJT are two Rays, the first of which comes from the lower part of the Sun to the higher part of the Image, and is refracted in the Prism at K and H, and the latter comes from the higher part of the Sun to the lower part of the Image, and is refracted at L and J.[31]

The sun and Newton's window thus became lines, and the prism a triangle. With measurements, all sensual objects, which may create inconsistencies such as the movement of the sun or the bubbles within a prism, were exorcised. Geometrising a place in this way led Newton to what he was looking for: a geometrical relationship analogous to how light interacts with both his prism and a glass lens of his telescope.

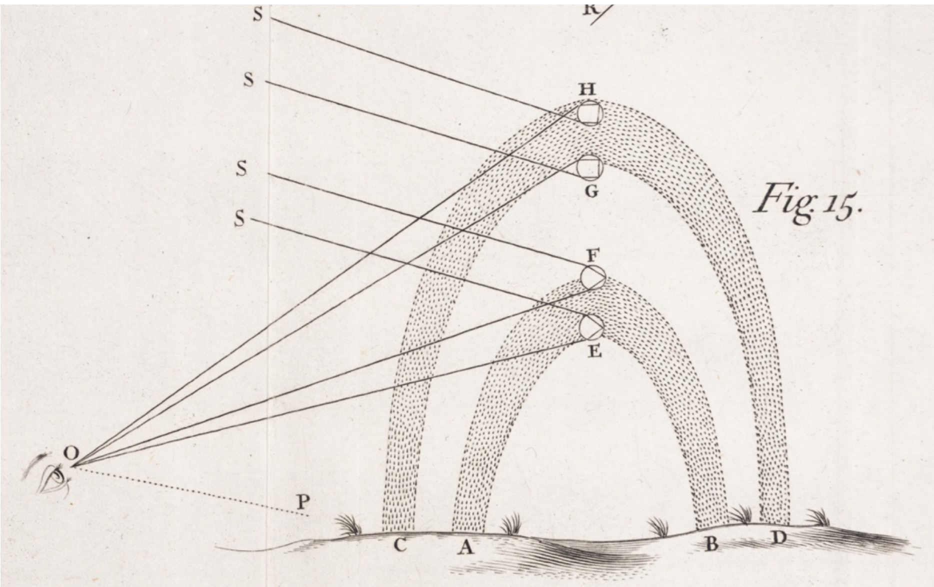

Fig. 3: Isaac Newton, *Opticks* (1704), Rainbow figure.
Source: Linda Hall Library of Science, Engineering & Technology.

Newton extended his analogy network further when he applied the geometrical conditions derived from his prism to a rainbow (Fig. 3). The colours of a prism were an obvious analogy to those of a rainbow: both contained the same series and order of colours. Newton had already explained the geometry of the prism in his chamber and linked it to the aberrations of refracting telescopes, so explaining a rainbow merely expanded his analogy by adding another element. Not all elements of the analogy network were equal, however. By using geometrical space as an intermediary between places like his chamber, his telescope, and a rainbow, Newton marked geometry as a special case among the elements of his network. The use of mathematics and geometry was a scientific virtue that carried rhetorical weight within the scientific community and helped place Newton ahead of all current investigations of the time.[32]

Goethe's Directly Analogous Places

Giving into an urge to leave Weimar six days after his thirty-seventh birthday in 1768, Goethe stole away at three in the morning to make his way to Italy. During the two years of his travels he took in the landscapes, art, and architecture of the country. One thing he noticed was that the paintings of Italy displayed a law-like understanding of perspective. Any lawfulness in the use of colours, however, was lacking.[33] When he returned to Weimar, Goethe began a study of colour in order that artists might have a suitable theory of colour from which to work.

His first effort came in 1791 with the small paper *Beiträge zur Optik* [*Contribution to Optics*], which did not attract much attention.[34] There, Goethe described his own initial experience of picking up a prism and looking through it, an experience that took him out of his natural standpoint. He noted how his focus moved from its original position towards areas of colour that appeared at the meeting of the edges of objects. At certain edges only red and yellow appeared and, at others, blue and violet. Where edges were close enough for these two groups of colours to meet, other colours emerged: green, where yellow met blue; and magenta, where red met violet. Goethe explored these edge conditions more methodically by looking through prisms at cards, some with white circles and squares, some with white and black strips.

Looking through the prism, the circles and square appeared slightly deformed with colours emphasising their misshapenness. The various widths of white and black strips created a metamorphosed series of colour relationships. Later for *Zur Farbenlehre*, Goethe had a plate made demonstrating some of these phenomena (Fig. 4). Out of these examinations in *Beiträge zur Optik*, Goethe formed general predictive rules delineating when one would observe the different colour phenomena. Here, as Goethe built up a collection of analogous phenomena, similarity with Newton begins to manifest. Rather than weaving his observations together with geometrical relationships, Goethe connected them through a generalised phenomenon of edge conditions.

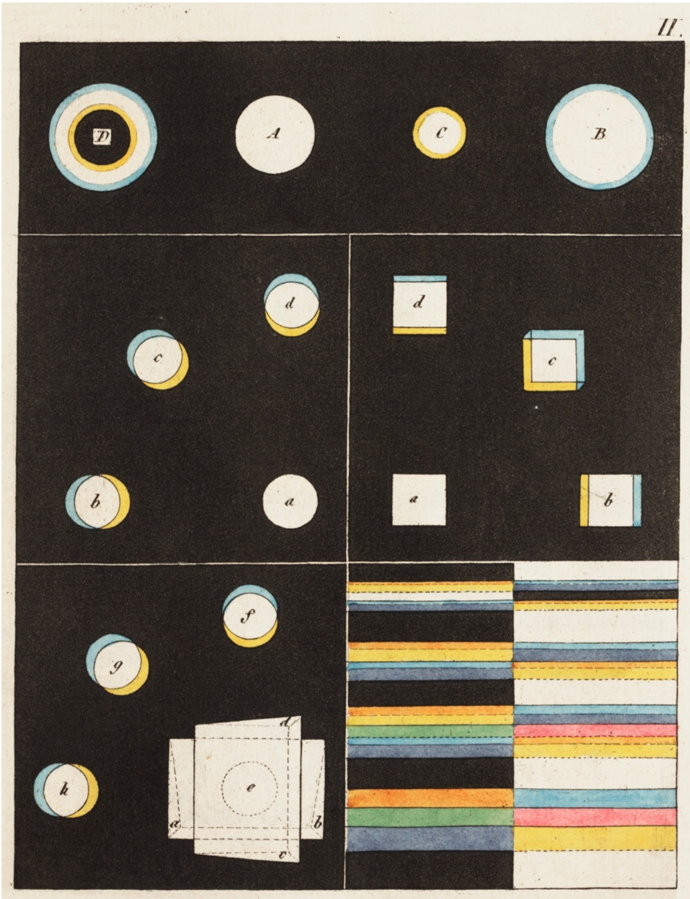

Fig. 4: Johann Wolfgang von Goethe, *Zur Farbenlehre* (1810). The bottom four sections of the plate demonstrated edge conditions. Source: Linda Hall Library of Science, Engineering & Technology.

Goethe did not stop with *Beiträge zur Optik*. After other brief contributions, he put his efforts towards a more thorough study of colour with *Zur Farbenlehre*.[35] Translated as *Theory of Colours*, *Farbenlehre* may more accurately be translated as *Colour Teaching* or *Colour Doctrine*. It consists of a didactic section containing Goethe's own observations and ideas on colour, a polemical section critiquing Newton's *Opticks* in detail, and a historical section recounting Goethe's in-depth study of the history of chromatics. Like Newton, Goethe sought to build up an analogy network, but one of a different form.[36]

More in-depth analysis of how Goethe organised the didactic section of *Farbenlehre* reveals something of the difference between the two forms. The form of Newton's *Opticks* used geometrical space as a central node connecting various sensate places, placing geometrical space in a position of more universal importance. Goethe's style was that of multiple perspectives with no centralised nodes. Goethe included accounts of colour from physiological, physical, chemical, and moral aspects. Additionally, he tied together these groups by relating them to other disciplines such as philosophy and mathematics. Goethe described the reasoning behind his presentation style:

Das, was wir in der Erfahrung gewahr werden, sind meistens nur Fälle, welche sich mit

> einiger Aufmerksamkeit unter allgemeine empirische Rubriken bringen lassen. Diese subordinieren sich abermals unter wissenschaftliche Rubriken, welche weiter hinaufdeuten, wobei uns gewisse unerläßliche Bedingungen des Erscheinenden näher bekannt werden. Von nun an fügt sich alles nach und nach unter höhere Regeln und Gesetze, die sich aber nicht durch Worte und Hypothesen dem Verstande, sondern gleichfalls durch Phänomene dem Anschauen offenbaren. Wir nennen sie Urphänomene, weil nichts in der Erscheinung über ihnen liegt, sie aber dagegen völlig geeignet sind, daß man stufenweise, wie wir vorhin hinaufgestiegen, von ihnen herab bis zu dem gemeinsten Falle der täglichen Erfahrung niedersteigen kann.[37]

> In general, events we become aware of through experience are simply those we can categorize empirically after some observation. These empirical categories may be further subsumed under scientific categories leading to even higher levels. In the process we become familiar with certain requisite conditions for what is manifesting itself. From this point everything gradually falls into place under higher principles and laws revealed not to our reason through words and hypotheses, but to our intuitive perception through phenomena. We call these phenomena archetypal phenomena because nothing higher manifests itself in the world; such phenomena, on the other hand, make it possible for us to descend, just as we ascended, by going step by step from the archetypal phenomena to the most mundane occurrence in our daily experience.[38]

Despite Goethe's hierarchical language, he never fully shifted into a pure abstracted space as Newton had done with geometry. What connected the colours of a prism, chromatic aberrations, and rainbows for Newton were sine laws occupying geometrical space. Goethe's *Urphänomene*, like edge conditions, appeared in the same world as the phenomena they linked. They were never completely abstract but were symbolic phenomena formed from individual observations and experiments.[39] For Goethe, the more one became acquainted with similar phenomena, the more individual phenomena became symbolic for the group to which it belonged. Goethe thus built a network of phenomena connected, not by geometrical abstractions, but by direct analogies between all similar phenomena. In Goethe's words:

> Bei einer jeden Erscheinung der Natur, besonders aber bei einer bedeutenden, auffallenden, muß man nicht stehen bleiben, man muß sich nicht an sie heften, nicht an ihr kleben, sie nicht isoliert betrachten, sondern in der ganzen Natur umhersehen, wo sich etwas Ähnliches, etwas Verwandtes zeigt; denn nur durch Zusammenstellen des Verwandten entsteht nach und nach eine Totalität, die sich selbst ausspricht und keiner weitern Erklärung bedarf.[40]

> We must not come to a standstill when confronted by individual phenomena in nature, especially those which are significant or striking; we must not dwell on them, cling to them, or view them as existing in isolation. Instead, we should look about in the whole of nature to find where there is something similar, something related. For only when related elements are drawn together will a whole gradually emerge which speaks for itself and requires no further explanation.[41]

Goethe began his own 'looking about' by describing very simple experiences of darkness and light, a polarity that had been central a characteristic of Aristotle's ether and thus his explanation of colour:[42]

> Wenn wir die Augen innerhalb eines ganz finstern Raums offen halten, so wird uns ein

> gewisser Mangel empfindbar. Das Organ ist sich selbst überlassen, es zieht sich in sich selbst zurück, ihm fehlt jene reizende befriedigende Berührung, durch die es mit der äußern Welt verbunden und zum Ganzen wird.
>
> Wenden wir das Auge gegen eine stark beleuchtete weiße Fläche, so wird es geblendet und für eine Zeit lang unfähig, mäßig beleuchtete Gegenstände zu unterscheiden.[43]
>
> With our eyes open in a completely dark room we sense a certain deprivation. Our organ of sight is left to itself, it withdraws into itself and loses the stimulating, fulfilling contact which unites it with the outer world and makes it whole.
>
> When we turn our eyes to a strongly illuminated white surface they are blinded and for a time unable to distinguish less brightly illuminated objects.[44]

Like Newton, Goethe presented the basic necessities of what was needed for him to carry out his observations and what someone else would need to reproduce them. In this case all that was necessary was a dark place and then a place with a bright surface. There was no mention of particular objects like the type of surface. This was characteristic of how Goethe presented his experiments, and it betrays that he had already taken a step in identifying "leading facts" and removed himself from a natural standpoint. Though these descriptions do not emphasise place, they do point to the direct experience of an embodied place rather than the disembodied space Newton aimed for.

On occasion, Goethe did emphasise specific places by bringing in observations made while out doing other, everyday sorts of things. In these cases, Goethe more clearly expressed how he could emerge from the thickness of a natural standpoint through a shift in consciousness. While discussing the afterimages of the eye he wrote the following:

> Indem ich nämlich, auf dem Felde sitzend, mit einem Manne sprach, der, in einiger Entfernung vor mir stehend, einen grauen Himmel zum Hintergrund hatte, so erschien mir, nachdem ich ihn lange scharf und unverwandt angesehen, als ich den Blick ein wenig gewendet, sein Kopf von einem blendenden Schein umgeben.[45]
>
> Seated on the ground, I spoke with someone standing at a distance against a gray sky. After looking at him intently for a long time, I shifted my gaze slightly and his head appeared to be surrounded by a brilliant light.[46]

Though this instance merely explains an experience, it stands as a link with the mundane in Goethe's network of directly analogous places.

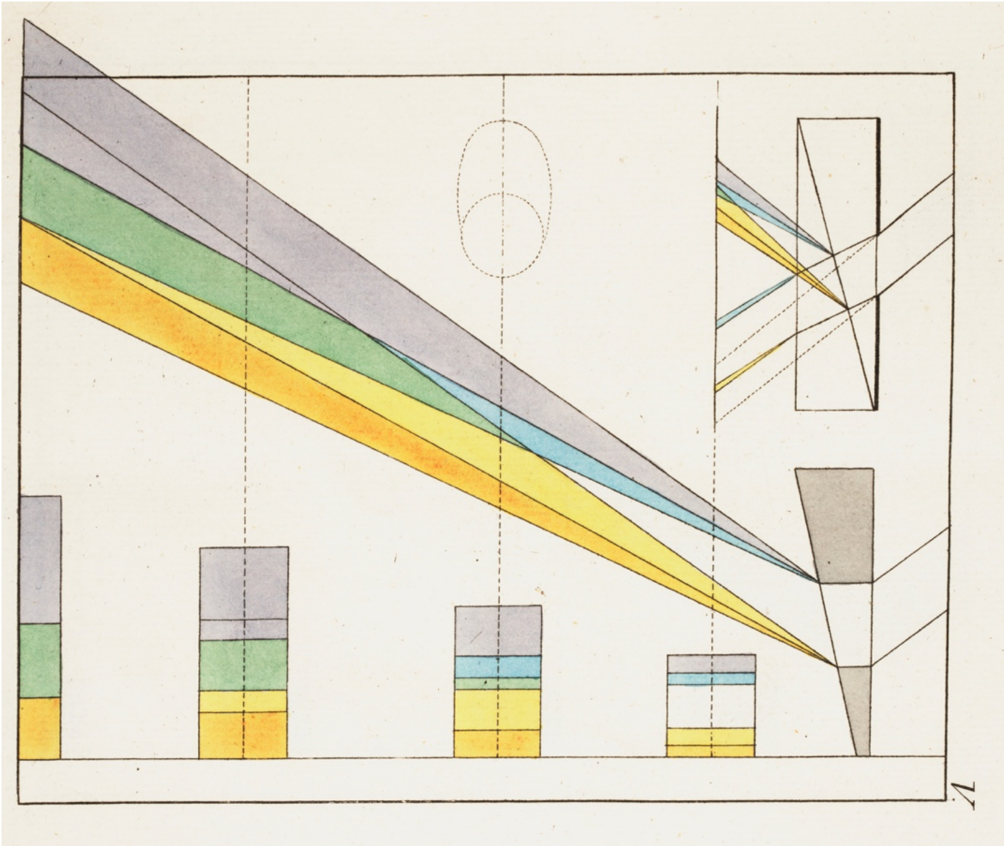

Fig. 5: Johann Wolfgang von Goethe, *Zur Farbenlehre* (1810), Plate demonstrating the light spectrum and its constituents.
Source: Linda Hall Library of Science, Engineering & Technology.

The preceding examples were what Goethe called "physiological colours", which were perceptions of colour that were obviously dependent on the body. Goethe also gave an account of physical colours, which moved him onto similar ground to Newton's experiments. Here, observations from daily life diminished, and the use of apparatus and artificial environments increased. Because of their similarity, this is the most fruitful section of Goethe's to compare with Newton to see in detail their differing analogy networks and use of place and space.

Goethe's examination of refraction betrayed an experimental place of exploration and mirroring. There was no sense that he sought an *experimentum crucis* as Newton had. Goethe began by describing how the sunlight cast upon a transparent and open cube could be restricted to just the side of the cube. After pouring in water, the light also fell upon the bottom of the cube. With the same basic set-up, Goethe then placed himself (or, more specifically, his eye) in place of the sun. His view changed as the light did: before pouring in water he saw the side of the cube, after pouring in water he saw part of the bottom in addition to the side. Here, mirroring came into the realm of the experiment, shifting between what Goethe qualified as subjective and objective experiences of refraction. The subjective experience was one in which his vision experienced refraction by looking through the prism. The objective experience was one in which he witnessed light undergo refraction through the

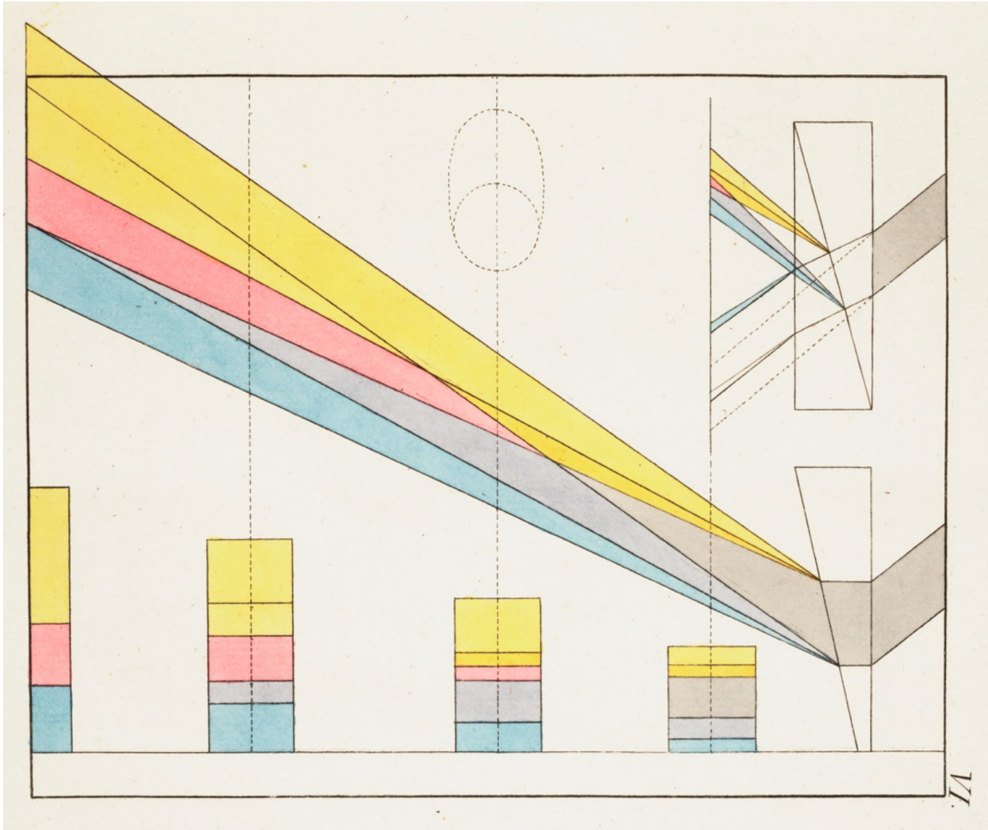

Fig. 6: Johann Wolfgang von Goethe, *Zur Farbenlehre* (1810), Plate demonstrating the dark spectrum and its constituents.
Source: Linda Hall Library of Science, Engineering & Technology.

prism. By carrying out subjective and objective experiments, Goethe linked two analogy networks whose phenomena might otherwise have been kept separate: the activity of seeing and the activities of light.[47] Goethe also suggested a third analogy network similar in form to that of sight and light: darkness.

In the strictly objective physical experiments, Goethe continued to approach light in several different ways. He repeated the experiment of passing light through a prism, just as Newton had done, and produced a colour spectrum on his wall. In contrast to Newton, Goethe did not seek the best arrangement to produce a spectrum, but rather moved the prism to display the range of phenomena produced by passing light through a prism. To heighten the effect of this movement, Goethe sprinkled fine powder over the beam of light to bring into full view its path from the prism to the wall. Goethe demonstrated not one, but two spectrums merging together across the length of space between the prism and the wall (Fig. 5). Recalling edge conditions, one spectrum was yellow-red, the other was blue-violet. The two met at yellow and blue, producing green. In another instance of mirroring, Goethe then created a spectrum from darkness by allowing a large amount of light to fall on the prism on which he has attached a small piece of pasteboard. In this way, Goethe sent a beam of darkness surrounded by light through the prism rather than a beam of light surrounded by darkness. Different from his light spectrum, Goethe found a spectrum where the yellow-red spectrum met with the blue-violet spectrum at the red and violet ends to produce magenta (Fig. 6).

With his mirroring experiments, Goethe's experimental place took on different perspectives to further expand his analogy networks of types of embodied places. Though the experiments themselves did not contradict each other, they could present contradicting circumstances, a light spectrum and a dark spectrum, which exhibited more general phenomenon that encompassed both light and darkness. Together with the mirroring of subjective and objective experiments, the mirroring of light and dark suggested light, darkness, and sight were similar phenomena.

Unlike Newton, Goethe spent extensive time examining the colours of solid objects, what he called "chemical colours". This again further expanded the network of analogous colour phenomena to include colours found in dyes, minerals, plants, and animals. Chemical colours described a different type of objective colour, one that attached to objects and remained attached. This contrasted with objective physical colours that appeared only under specific conditions such as those involving prisms, rainbows, or sunsets. The two types were linked through "Wie sich das Bewegliche und Vorüberghende der physishcen Farben Nach und nach an den Körpern firiere" ["how the changeable and temporary element of physical colors became more and more permanent in objects"].[48]

Goethe found a further connection between chemical and physical colours in transparent substances. When salt or glass were ground up, they appeared white. The transparency of the substance, along with its atomisation, thus produced the colour white. Newton came to a different conclusion when viewing bubbles at a distance that made sense within his analogy network that relied on his use of geometrical space.[49] For Newton, bubbles were not only clear, but had various amounts of colour on them when inspected closely. The case was the same with salt and glass. Focusing on the colours rather than the transparency of the bubbles, Newton concluded that white was made up of colours and that when viewed from a distance their coloured aspects blended to become white, another analogy to his geometrical work with the prism.

Further expanding his scope, Goethe included how his work with colours might relate to other areas of study. Of particular interest when comparing him to Newton is what Goethe said about mathematics. Here Goethe admitted the deficiency of his mathematical ability without discounting its importance, and called for others to fill in the gap he had left. He did not discount the importance of mathematics in respect to colour, as some have claimed, but he admitted his own shortcomings in it. [50] Goethe had a mathematician friend who was going to help him with his investigation of colour but was unable to do so. As Goethe framed it:

> Aber so mag denn auch dieser Mangel zum Vorteil gereichen, indem es nunmehr des geistreichen Mathematikers Geschäft werden kann, selbst aufzusuchen, wo denn die Farbenlehre seiner Hilfe bedarf und wie er zur Vollendung dieses Teils der Naturwissenschaft das Seinige beitragen kann.[51]

> But this failing might be turned to good advantage if the gifted mathematician will discover where his help is needed in the theory of color, and how he can contribute to the perfection of this branch of science.[52]

Goethe thus expanded his analogy network to potentially include geometrical space alongside his parallels between vision, light, and darkness. Goethe's network was open to further construction.

Conclusion

The examples here of Newton's and Goethe's examinations of colour are only the beginning of the possible connections between their theories.. Both used many more experiments and made many more observations. What I have been able to present is some of their primary claims about colour, how they each thought it ought to be investigated, and how they each sought to make it meaningful. Both shared the natural standpoint as a point of departure for their accounts of colour. Newton sought to leave it behind completely by entering into a disembodied geometrical space so he could describe relationships that could be brought back into embodied experiences like rainbows and the chromatic aberration of telescopes. Goethe, on the other hand, sought to directly link embodied places to one another to build up a network of different perspectives surrounding a common phenomenon, like edge conditions.

Though both shared a movement between place and space in their presentations, Newton's approach was more spatially oriented and Goethe's was oriented more towards place, situating them in different regions of my spectrum (Fig. 1). This gave unique forms to each of their analogy networks. Newton established analogous relationships, linking phenomenal places through centralised nodes of geometrical spaces and marking a special place for geometry in making sense of colour. Goethe's network was, in one sense, less centralised as it connected phenomena directly to each other while not giving any place of importance nor excluding mathematical relationships. Goethe's network also contained more complexity, in that he linked parallel networks such as subjective and objective experiences of light as well as light and darkness. Despite the different forms andcolourings of their analogy networks arising from their differing approaches, Newton and Goethe both constructed their analogy networks from places and spaces. What may ultimately come of examining how Newton and Goethe employed analogies within a framework of place and space is not to see how they contradicted each other or where one may have pointed to the mistakes of the other, but rather how each were consistent or not with themselves, and at a deeper level, with each other as scientists.

Notes

[1] Dennis L. Sepper, *Goethe Contra Newton: Polemics and the Project for a New Science of Color* (Cambridge: Cambridge University Press, 1988). Sepper especially brings home the point that Goethe's understanding of Newton was doomed from the beginning since the accounts of Newton's theory that he likely read were either false or inadequate representations of the theory.

[2] Johann Wolfgang von Goethe, *Zur Farbenlehre*, ed. by Peter Schmidt, Sämtliche Werke (München: Carl Hanser Verlag, 1989), X, p. 910.

[3] My translation is based on Dennis L. Sepper, *Goethe Contra Newton*, with an important difference. Sepper's translation runs: "It did not take much deliberation for me to recognize that a boundary is necessary to produce colours, and I immediately said to myself, as if by instinct, that the Newtonian teaching is false". Sepper supplemented his mistranslation by explaining that Goethe's reaction may not have been so immediate, but his translation itself suggests that Goethe was more impulsive, and not as thoughtful, in his response to Newton.

[4] Frederick Amrine, *Goethe in the History of Science*, 2 vols (New York: P. Lang, 1996) has over seventy bibliographic entries that relate to Goethe and Newton between 1810 and 1990. Work since then includes Myles W. Jackson, 'A Spectrum of Belief: Goethe's "Republic" Versus Newtonian "Despotism"', *Social Studies of Science*, 24.4 (1994), 673–701; Dusan Bjelic and Michael Lynch, 'Goethe's "Protestant Reformation" as a

Textual Demonstration: Comment on Jackson', *Social Studies of Science*, 24.4 (1994), 703–24; Heather I. Sullivan, 'Seeing the Light: Goethe's Märchen as Science—Newton's Science as Fairy Tale', *Goethe Yearbook*, 14 (2007), 103–27; James A. Marcum, 'The Nature of Light and Color: Goethe's "Der Versuch Als Vermittler" Versus Newton's Experimentum Crucis', *Perspectives on Science*, 17.4 (2009), 457–81; Olaf L. Müller, *Mehr Licht Goethe Mit Newton Im Streit Um Die Farben* (Frankfurt am Main: S. Fischer, 2015).

[5] Agnes Arber, 'Analogy in the History of Science', in *Studies and Essays in the History of Science and Learning Offered in Homage to George Sarton on the Occasion of His Sixtieth Birthday 31 August 1944*, ed. by M. F. Ashley Mantagu (New York: Henry Schuman, 1944), pp. 219–35.

[6] The differences between Newton and Goethe have been thoroughly explored elsewhere. See especially Frederick Burwick, *The Damnation of Newton: Goethe's Color Theory and Romantic Perception* (Berlin: Walter de Gruyter, 1986) and Sepper, *Goethe Contra Newton*.

[7] George Lakoff and Mark Johnson, *Metaphors We Live By* (Chicago: University of Chicago Press, 1980), pp. 6, 195. While they largely deal with metaphors, Lakoff and Johnson address comparative processes: "The most important claim we have made so far is that metaphor is not just a matter of language, that is, of mere words. We shall argue that, on the contrary, human thought processes are largely metaphorical". This eventually leads them to challenge the "Myth of Objectivity" and, for that matter the "Myth of Subjectivity".

[8] 'Special Issue: The Role of Analogy in Science and Science Teaching', ed. by Ronald G. Good and Anton E. Lawson, *Journal of Research in Science Teaching*, 30.10 (1993); Peter Aubusson, Allan G Harrison, and Steve Ritchie, *Metaphor and Analogy in Science Education* (Dordrecht: Springer, 2008); S. Brown and S. Salter, 'Analogies in Science and Science Teaching', *Advances In Physiology Education*, 34.4 (2010), 167–69; Devin Griffiths, *The Age of Analogy: Science and Literature between the Darwins* (Baltimore: Johns Hopkins University, 2016).

[9] Edmund Husserl, *Ideas: General Introduction to Pure Phenomenology*, trans. by W. R. Boyce Gibson (London: Routledge Classics, 2014), pp. 53-54.

[10] David Seamon, *A Geography of the Lifeworld: Movement, Rest, and Encounter* (New York: St. Martin's Press), p. 20; Jakob von Uexküll, *A Foray into the Worlds of Animals and Humans: with a Theory of Meaning*, trans. by Joseph D. O'Neil (Minneapolis: University of Minnesota Press, 2010). The point being made here is that the terms "*natürliche Einstellung*" and "*Umwelt*"/"lifeworld" are seeking a balance between objectivity and subjectivity that can be difficult to achieve because of the limitations of language. All three describe the same experience, but the choice of noun in each points the meaning in one direction that is either subjective or objective. As a noun, "*Einstellung*" points to the subjective while "*Welt*" and "world" draw attention to the objective. These nouns are then balanced by their respective adjective/preposition towards the other direction: "*um-*" and "life-" are subjective and "*natürliche*" is objective. The adjectives and prepositions, however, are never completely enough to override the sense given by the nouns.

[11] Maurice Merleau-Ponty, *Phenomenology of Perception* trans. by Colin Smith (London: Routledge, 2002), p. 61.

[12] Johann Wolfgang von Goethe, 'Der Versuch Als Vermittler von Objekt Und Subjekt', in *Wirkungen Der Französischen Revolution 1791-1797*, ed. by Klaus H. Kiefer and others, Sämtliche Werke (München: Carl Hanser Verlag, 1986), 4.2, pp. 321–322.

[13] Johann Wolfgang von Goethe, *Scientific Studies*, trans. by Douglas Miller, *Goethe's Collected Works*, 12 vols (Princeton: Princeton University Press, 1995), XII, p. 11.

[14] Arber, p. 220.

[15] Goethe's relationship to mathematics was complex. He both admired it privately and kept his distance in his published work. He admitted in *Zur Farbenlehre*, (1989), p. 217: "Der Verfasser kann sich keiner Kultur von dieser Seite rühmen und verweilt auch deshalb nur in den von der Messkunst unabhängigen Regionen" ["The author cannot boast of any accomplishment in this field, and therefore restricts himself to those areas which involve no geometry"]. Goethe went on to describe that, while physics had gained much from its relationship with mathematics, the relationship had also caused harm, particularly in the understanding of colour. For Goethe's more private interests in mathematics see Martin Dyck, 'Goethe's Views on Pure Mathematics', *The Germanic Review: Literature, Culture, Theory*, 31.1 (1956), 49–69; Martin Dyck, 'Goethe's Thought in the Light of His Pronouncements on Applied and Misapplied Mathematics', *PMLA*, 73.5 (1958), 505–515.

[16] Isaac Newton, '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*, 6.80 (1671), 3075–87; Isaac Newton, *Opticks: Or, a Treaties of the Reflexions, Refractions, Inflexions and Colours of Light. Also Two Treatises of the Species and Magnitude of Curvilinear Figures* (London: Sam Smith and Benjamin Walford, 1704). Newton's letter can also be found at Isaac Newton, 'A Letter of Mr. Isaac Newton … Containing His New Theory about Light and Colors', *The Newton Project*, 2003

<http://www.newtonproject.ox.ac.uk/view/texts/normalized/NATP00006> [accessed 3 November 2017]. I will use Isaac Newton, *Opticks : Or, A Treatise of the Reflections, Refractions, Inflections and Colours of Light*, 4th edn (London: William Innys, 1730).

[17] Originally published as Johann Wolfgang von Goethe, *Beiträge Zur Optik* (Weimar: Industrie-Comptoirs, 1791); Johann Wolfgang von Goethe, *Zur Farbenlehre*, 2 vols (Tübingen: J.G. Cotta, 1810).

[18] Dennis L Sepper, *Newton's Optical Writings: A Guided Study* (New Brunswick: Rutgers University Press, 1994).

[19] Newton, "A Letter of Mr. Isaac Newton".

[20] J. A. Lohne, 'Isaac Newton: The Rise of a Scientist 1661-1671', *Notes and Records of the Royal Society of London*, 20.2 (1965), 125–39; Richard S. Westfall, *Never at Rest: A Biography of Isaac Newton* (Cambridge: Cambridge University Press, 1980), 157-158. When Newton was to have carried out the experiments, the sun would have been too low in the sky to have allowed for its light to have passed through his chamber as he describes it.

[21] J. A. Lohne, 'Experimentum Crucis', *Notes and Records of the Royal Society of London*, 23.2 (1968), 169–99. Lohne suggests that Newton even fails at this, owing to the number of times he reworks this experiment into different forms.

[22] Sepper, *Goethe Contra Newton*, p. 134.

[23] Allan D. Franklin, 'What Makes a "Good" Experiment?', *The British Journal for the Philosophy of Science*, 32.4 (1981), 367–74 (p. 367). Franklin describes the crucial experiment in this way, noting that it decides "between two or more competing theories or classes of theories". He goes on to note that such experiments have lost favor and now have more merit in attracting attention to science than actually aiding its progression.

[24] Dennis L. Sepper, *Newton's Optical Writings*, p. 40-41. Sepper gives a good summary of what this means, since it is in the mathematical style of Newton's time and not our own. What Newton is getting at is that refraction that causes chromatic aberrations occurs to such a high degree in the lenses of telescopes that it is best to look for something besides glass lenses.

[25] Ibid., p. 42.

[26] Olivier Darrigol, *A History of Optics: From Greek Antiquity to the Nineteenth Century* (Oxford: Oxford University Press, 2016), pp. 8-11.

[27] David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450* (Chicago: University of Chicago Press, 1992), pp. 308-311.

[28] Darrigol, pp. 80-85.

[29] Thomas Nickles, 'Justification and Experiment', in *The Uses of Experiment*, ed. by David Gooding, Trevor Pinch, and Simon Schaffer (Cambridge: Cambridge University Press, 1989), pp. 299–333. Nickles explains that this format targets a scientific audience allowing Newton to make assumptions that were commonly known.

[30] Newton, *Opticks* (1730), pp. 21-22.

[31] Ibid., pp. 25-26.

[32] A. Rupert Hall, *All Was Light: An Introduction to Newton's Opticks* (Oxford: Oxford University Press, 1993), p. 65.

[33] Johann Wolfgang von Goethe, *Italienische Reise*, ed. by Andreas Beyer and Norbert Miller, Sämtliche Werke (München: Carl Hanser Verlag, 1992), XV.

[34] Johann Wolfgang von Goethe, 'Beiträge Zur Optik. Erstes Stück', in *Wirkungen Der Französischen Revolution 1791-1797*, ed. by Klaus H. Kiefer and others, Sämtliche Werke (München: Carl Hanser Verlag, 1986), 4.2, pp. 264–299.

[35] Goethe, *Zur Farbenlehre* (1989).

[36] For the specific differences in Goethe's and Newton's projects and Goethe's cricicisms of Newton, see Sepper, *Goethe Contra Newton*.

[37] Goethe, *Zur Farbenlehre* (1989), p. 74.

[38] Goethe, *Scientific Studies*, p. 95.

[39] Arthur G. Zajonc, 'Goethe's Theory of Color and Scientific Intuition', *American Journal of Physics*, 44.4 (1976), 327-333 (p. 331): "The archetypal phenomena *is* a self-evident manifestation of physical law. One attains through it a genuine perceptual encounter with the laws of physics".

[40] Goethe, *Zur Farbenlehre* (1989), pp. 88-89.

[41] Goethe, *Scientific Studies*, p. 203.

[42] Darrigol, pp. 6-7 and Lindberg, pp. 105-108. The ether, for Aristotle, was the medium that allowed for the transmission of colour. Its effects were realised with the actualisation of transparency.

[43] Goethe, *Zur Farbenlehre* (1989), p. 28.

[44] Goethe, *Scientific Studies*, p. 168.

[45] Goethe, *Zur Farbenlehre* (1989), pp. 33-34.
[46] Goethe, *Scientific Studies*, p. 171.
[47] Heather I. Sullivan, 'Goethe's Colors: Revolutionary Optics and the Anthropocene', *Eighteenth-Century Studies*, 51.1 (2017), 115–24. Sullivan contextualises Goethe's objective and subjective approaches as an expression of the Anthropocene value of ontological flatness, placing humans within a material network that integrates the human body with its surroundings. In Heather I. Sullivan, 'The Ecology of Colors: Goethe's Materialist Optics and Ecological Posthumanism', in *Material Ecocriticism*, ed. by Serenella Iovino and Serpil Oppermann (Bloomington: Indiana University Press, 2014), pp. 80–94, Sullivan described this flatness as ecological.
[48] Goethe, *Zur Farbenlehre* (1989), p. 159; Goethe, *Scientific Studies*, p. 242.
[49] Newton, *Opticks* (1730), pp. 149-150.
[50] See note 15. George A. Wells, 'Goethe's Qualitative Optics', *Journal of the History of Ideas*, 32.4 (1971), 617–26 found an aversion in Goethe to mathematics.
[51] Goethe, *Zur Farbenlehre* (1989), p. 218.
[52] Goethe, *Scientific Studies*, p. 272.

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Biography

Andre Michael Hahn is undertaking a PhD at Oregon State University, US. His research covers the influence Goethe's morphological thought on Anglophone botany and biology in the twentieth century as a way to explore the conceptualisation and mathematicisation of plant forms inside and outside of academia.