Francis Bacon's "perceptive" instruments

Abstract

Francis Bacon shared with many vitalists a belief in the radiative nature of bodies. Bacon's bodies emit material effluvia, species and virtues, and various forms of spiritual matter; they exchange heat and cold with the surrounding media, they expand in a "larger sphere," and they receive (and are modified by) celestial radiations. Meanwhile, Bacon also believed that each of these actions and virtues has a specific range of action, its own "orb of virtue" (Jalobeanu 2016a). Thus, a large part of Bacon's concrete and abstract physics is concerned with finding experimental strategies for determining the natural limits, borders and orbs of virtue in this radiative universe (Jalobeanu 2016b). In this paper, I reconstruct the preliminary steps of Bacon's inquiry into these natural limits, and "measures of space," by devising instruments "subtle enough" to be able to perform such an inquiry. I show that the development of such instruments was made possible by a remarkable conceptual innovation: the operationalization of the traditional natural philosophical concept of "perception." Bacon's definition of "perception" in terms of "orb of virtue" vindicated the use of instruments and provided his top-down project of measuring Nature with the means to take off the ground.

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1. Introduction and claims

This paper delves into one of the most vexing problems of Baconian scholarship, namely the relation between Francis Bacon's speculative philosophy of nature and the experimental and instrumental aspects of his works. As Graham Rees put it, more than two decades ago:

> Francis Bacon's natural philosophy may be viewed as a single philosophy with two aspects or as two philosophies each with its peculiar character. Either way it is useful to acknowledge that there is a doubleness in his enterprise. On the one hand, his philosophy appears as a programme for constructing a body of scientific knowledge that would yield practical benefits to release the human race from material privation. On the other, it appears as a strange corpus of theory, a speculative recreation, an attempt to picture the knowledge that might be produced once the programme was implemented. (Rees, OFB VI xxxvi)

As reconstructed by Rees, Francis Bacon's speculative philosophy is fundamentally qualitative and completely disjointed from his quantitative and experimental attempts to build

a corpus of 'scientific knowledge'.[1] And yet, these two aspects of Bacon's philosophy of nature can be found side by side in his mature natural and experimental histories; or in his posthumous *Sylva Sylvarum* where the appetitive, speculative theory of matter functions as a sort of background knowledge for the experimental and operative program of natural history and natural magic.[2]

The past two decades have seen the multiplication of detailed and thorough investigations in both aspects of Francis Bacon's natural philosophy. This has led to a better understanding of his peculiar appetitive and pneumatic matter theory,[3] and to an increased awareness of the complexity of his experimental methodology.[4] Fewer and fewer scholars are questioning today the fact that Bacon's natural histories are theory laden;[5] or that his experiments are guided by methodological considerations.[6] Moreover, many scholars increasingly agree on the need to bridge the gap between the speculative and the experimental aspects of Bacon's natural philosophical investigations. And yet, how to do this is far from clear.

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[1] It is important to note that Rees was actively involved in reconstructing both sides of Bacon's philosophy of nature; however, as the quote above witnesses, he saw an unbridgeable gap between Bacon's speculative matter theory and his program of experimental inquiries (whom Rees sees as having a fundamental practical orientation). See for example Graham Rees, "Francis Bacon's Speculative Philosophy," in *Cambridge Companion to Bacon*, ed. Markku Peltonen (Cambridge: Cambridge University Press, 1996); "Matter Theory: A Unifying Factor in Bacon's Natural Philosophy," *Ambix* 24(1977); "Quantitative Reasoning in Francis Bacon's Natural Philosophy," *Nouvelles de la republique de letttres* 1(1985); ibid.

[2] Dana Jalobeanu, "Learning from Experiment: Classification, Concept Formation and Modeling in Francis Bacon's Experimental Philosophy," *Revue Roumaine de Philosophie* 57, no. 1 (2013); *The Art of Experimental Natural History: Francis Bacon in Context*, ed. Vlad Alexadrescu, Foundations of Modernity (Bucharest: Zeta Books, 2015).

[3] Silvia Manzo, *Entre El Atomismo Y La Alquimia. La Teoria De La Materia De Francis Bacon* (Buenos Aires: Editorial Biblos, 2006); Sophie Weeks, "Francis Bacon's Science of Magic" (University of Leeds, 2007); G. Giglioni, "*Historia* and *Materia*: The Philosophical Implications of Francis Bacon's Natural History," *Early Science and Medicine* 17, no. 1-2 (2012); Guido Giglioni, *Francesco Bacone*, Pensatori (Roma: Carocci, 2011); "Mastering the Appetites of Matter: Francis Bacon's *Sylva Sylvarum*," in *The Body as Object and Instrument of Knowledge: Embodied Empiricism in Early Modern Science*, ed. C.T. Wolfe and Ofer Gal (Dordrecht: Springer, 2010); Doina-Cristina Rusu, "From Natural History to Natural Magic: Francis Bacon's *Sylva Sylvarum*" (Radboud University, 2013).

[4] Jalobeanu, "Learning from Experiment: Classification, Concept Formation and Modeling in Francis Bacon's Experimental Philosophy; *The Art of Experimental Natural History: Francis Bacon in Context*; "Disciplining Experience: Francis Bacon's Experimental Series and the Art of Experimentation," *Perspectives on Science* 24, no. 3 (2016); Laura Georgescu, "A New Form of Knowledge: Experientia Literata," *Societate si Politica* 5(2011); Laura Georgescu and Madalina Giurgea, "Redefining the Role of Experiment in Bacon's Natural History: How Baconian Was Descartes before Emerging from His Cocoon?," *Early Science and Medicine* 17, no. 1-2 (2012); Rusu, "From Natural History to Natural Magic: Francis Bacon's *Sylva Sylvarum*."

[5] For a discussion of the theory-ladeness of experimentation in Bacon's natural histories see Daniel Schwartz, "Is Bacon's Natural History Theory Laden," *Journal of Early Modern Studies* 3, no. 1 (2014).

[6] For a discussion see Georgescu, "A New Form of Knowledge: Experientia Literata; Jalobeanu, "Disciplining Experience: Francis Bacon's Experimental Series and the Art of Experimentation."

Recent attempts to bridge the gap have mostly taken into consideration various ways in which Bacon's experiments seem to illustrate and substantialize claims of his matter theory.[7] In this paper I propose a different route. I will begin from Bacon's experimental investigations, showing that his approach is a typical top-down approach to measuring Nature. After all, Bacon is quite specific:

> […] every thing to do with natural phenomena, be they bodies or virtues, should (as far as possible) be set down, counted, weighed, measured and defined. For we are after works not speculations, and, indeed, a good marriage of Physics and Mathematics begets Practice.[8]

Among things to be measured are not only visible phenomena of the natural (and experimental) history but also the (mostly invisible) simple and compound motions of the abstract physics. According to Bacon, these, too, have to be "brought closer to the mathematics or measures and scales of motions." More generally, everything in nature has to be "well counted," "weighed" and "defined."[9] Such claims raise the following questions: What instruments did Bacon have? And what instruments did he develop to fulfill such an ambitious project?

My purpose in this paper is to unearth and explain some of the instruments which, I claim, play a fundamental role in Bacon's project of measuring nature. For reasons which will become clear in the following pages, I call them "perceptive instruments." Bacon's perceptive instruments are intended to measure all properties and virtues of bodies. In some cases, Bacon merely develops and improves existing instruments, (such as the weather-glass). In others, Bacon discusses instruments of his own making, or ingenious ideas for developing instrumental investigations. What all perceptive instruments have in common are a set of

[7] Giglioni, "Mastering the Appetites of Matter: Francis Bacon's *Sylva Sylvarum*; Rusu, "From Natural History to Natural Magic: Francis Bacon's *Sylva Sylvarum*."

[8] OFB XI 464-5. […] *ut omnia in Naturalibus tam Corporibus quam Virtutibus (quantum fieri potest) numerate, appensa, dimensa, determinate proponantur. Opera enim meditamur, non Speculationes. Physica autem & Mathematica bene commistae, generant Practicam.*

[9] OFB XIII 210-11; see also Cesare Pastorino, "Weighing Experience: Experimental Histories and Francis Bacon's Quantitative Program," *Early Science and Medicine* 16(2011); Jalobeanu, *The Art of Experimental Natural History: Francis Bacon in Context*; ""The Marriage of Physics with Mathematics:" Francis Bacon on Measurement, Mathematics and the Construction of Mathematical Physics," in *The Language of Nature: Reassessing the Mathematization of Natural Philosophy in the Seventeenth Century*, ed. Geoffrey Gorham, et al. (Minnesota Center for Philosophy of Science, 2016).

instrumental and operational aspects which display, in a creative manner, the interplay between speculative assumptions and experimental investigations. To date, Bacon's perceptive instruments, as well as most of the instrumental and quantitative aspects of his natural and experimental historical investigations have completely escaped the attention of contemporary scholars.[10]

The full extent of Francis Bacon's theory and practice of measurement has been obscured, so far, by three things. First, by some of the rather obscure assumptions of his speculative metaphysics, which scholars have tended to interpret as purely qualitative (and sometimes metaphorical). Second, by Bacon's peculiar ways of developing measuring instruments, which frequently took place without having a clear (and sometimes even without the faintest) idea of what is to be measured; a practice which looks counter-intuitive and bewildering to the modern eye. Third, by his anti-systematic way of recording experiments which are presented sometimes as independent units, and at other times as methodologically driven series of very diverse and apparently disconnected items.[11]

In the following sections of this paper I aim to clarify each of these three aspects. The first part of this paper investigates the speculative assumptions behind Bacon's project of measuring virtues and qualities; his beliefs in the radiative nature of bodies and the definite orbs, borders and limits of all virtues and effluvia. In the second and third parts, I show how Bacon's formulation of operational definitions for a couple of important natural philosophical concepts, such as "perception" and "orbs of virtue" made possible the development of a whole range of perceptive instruments which, in turn, increased significantly the sophistication of his experimental investigations.

[10] With three notable exceptions: Arianna Borelli's investigations on the weather-glass (where, however, Bacon plays only a marginal role), Cesare Pastorino's investigations into Bacon's experimental program of measuring densities and Graham Rees remarks of the quantitative aspects of Bacon's natural histories. See Arianna Borrelli, "The Weatherglass and Its Observers in the Seventeenth Century," in *Philosophies of Technology: Francis Bacon and His Contemporaries*, ed. Claus Zittel, et al., *Intersections: Yearbook for Early Modern Studies* (Leiden: Brill, 2008); Pastorino, "Weighing Experience: Experimental Histories and Francis Bacon's Quantitative Program; Rees, "Quantitative Reasoning in Francis Bacon's Natural Philosophy." However, neither of these investigations treats extensively of Francis Bacon's instruments or theory of measure.

[11] This last feature of Baconian experimentation led to many discussions about the apparent lack of order of Francis Bacon's most openly experimental work, i.e., the posthumous *Sylva Sylvarum*. On the methodologically driven experimental series see Jalobeanu, "Disciplining Experience: Francis Bacon's Experimental Series and the Art of Experimentation; "Bacon's Apples: A Case-Study in Baconian Experimentation," in *Motion and Power in Francis Bacon's Philosophy*, ed. Guido Giglioni, et al. (Dordrecht: Springer, 2016).

2. Francis Bacon's radiative universe and the orbs of virtue

One of the main assumptions of Bacon's speculative metaphysics is that of a radiative nature of the universe.[12] This is a belief Bacon shares with many of his vitalist contemporaries, such as Cardano, Telesio, Bruno and others. In Bacon's writings, this belief is metaphorically illustrated by the emblem of the hairy, bearded Pan, with:

> […] horns on his head, rising to a point and reaching to heaven; [….] his beard especially long; his figure biform, the upper part human, the lower part like a beast and ending in goat's feet. (SEH IV 319)

Bacon takes Pan to be a representation of Nature, or "the Universe, or the All of Things." Pan's biform shape is a reminder that Nature is "[….] the offspring of the Divine Word, through the medium of *confused matter* […] with the help of Sin, and by Sin Corruption, entering in."[13] These references to the confusion of things and the distortions introduced by the sin are not mere rhetorical flourishes; they are meant to emphasize the complex, irregular, disordered and distempered character of the natural world where bodies and phenomena are compositions and mixtures of species sometimes as different as the ones who are said to enter into the composition of the hairy, horny Pan. Every element in the emblem of Pan is taken to represent an aspect of the natural world. His horns touching the heaven stand for the pyramid of knowledge, while his hairy body reminds us of the "rays of things".

> For rays are as the hairs or bristles of nature, nor is there anything which is not more or less radiant. This is seen in […] magnetic virtue, and every effect which takes place at the distance. For whatever produces an effect at a distance may be truly said to emit rays. (SEH IV 320-2)

[12] This has been partially discussed by Graham Rees in his investigations of Francis Bacon's cosmology. See Graham Rees, "Francis Bacon Semi-Paracelsian Cosmology," *Ambix* 22(1975). However, Rees' discussion focused almost exclusively on the sources and the eclectic character of Bacon's cosmological speculations.

[13] This reminds the reader that Nature has fallen from a once perfect state; and this is perhaps why its more 'confused' and 'beastly' aspects are so pronounced and so important in its present state. See also DPAO and discussions in the secondary literature.

According to this picture, Bacon's universe seems to be mainly composed of radiative bodies, acting at a distance. This is particularly true for the celestial bodies. Bacon states:

> Pan's hair is especially long in the beard; because the rays of celestial bodies, especially of the sun, operate and pierce from a greater distance than any other; so that not only the surface, but even the interior of the Earth for some distance, is changed, wrought, and filled with spirit by them. (SEH IV 322)

We can find similar views in Bacon's cosmological writings, such as *Thema coeli* and *Descriptio globi intellectualis*, where this radiative view is further refined into what Graham Rees has called the "sandwich-view of the universe." Bacon's cosmos is said to be made of regions and layers endowed with dissimilar properties.[14] These borders and layers are partly the result of a complex unfolding of matter into the schematism of dense and rare;[15] and partly created by the direct radiations of the celestial bodies; or, indeed, of all bodies whatsoever. Because, as we have seen, radiative virtues are not limited to celestial bodies; they extend all the way down, and are a characteristic of all bodies. Sublunary bodies emit heat and cold, "materiate" and "immateriate" virtues. In the *Sylva Sylvarum*, Century X, Bacon distinguishes between eight types of effluvia or radiative virtues, discussed under the generic term "the transmission of spirits". They extend from the "most corporeal", such as "odours" and "infections," to the "least corporeal", such as the "astral influxes" and the operations of sympathy. Between these two extremes, Bacon organizes various types of action and "consent" (SEH II 602). What all these effluvia have in common is that they produce their effects at certain distances – long or short – in ways often too "subtle" to be fully understood.[16] Bacon does not attempt to discuss and classify these effluvia in terms of mechanisms of propagation. His proposed classification is based on two parameters: the range of action, and the role played by the intervening media. Some of the effluvia are short ranged; others can act at considerable distances. In some cases the action is strongly

[14] Graham Rees, "Francis Bacon on Verticity and the Bowels of the Earch," *Ambix* 26, no. 3 (1979).
[15] Manzo, *Entre El Atomismo Y La Alquimia. La Teoria De La Materia De Francis Bacon*.
[16] It is important to note that Bacon's notion of subtlety does not refer to the nature of effluvia but to the nature of perception; subtlety is a generic name for describing the complex ways in which fundamental processes taking place in nature escape the senses. See OFB XI 347, Jalobeanu, *The Art of Experimental Natural History: Francis Bacon in Context*; "Disciplining Experience: Francis Bacon's Experimental Series and the Art of Experimentation." For another perspective on subtlety see also Graham Rees, "Atomism and Subtlety in Francis Bacon's Philosophy," *Annals of Science* 37(1980).

dependent on the intervening medium (as in the case of light and sound). In some other cases "emissions of spirits and immateriate powers and virtues" "work by the universal configuration and sympathy of the world:"

> Of this kind […] are the working of the load-stone, which is by consent with the globe of the earth: of this kind is the motion of gravity, which is by consent of dense bodies to the globe of the earth: of this kind is some disposition of bodies to rotation […] These immateriate virtues have this property differing from others; that the diversity of the medium hindered them not; but they pass through all mediums; *yet at determinate distances.* (SEH II 644)

Even short-ranged effluvia, such as the electric virtue are said to be the effect of a motion which "does not or cannot work by contact alone."

> […] For the operation of electric bodies (about which Gilbert and others since have turned out so many tales) is nothing other than an appetite of a body excited by gentle rubbing, an appetite which does not put up well with air but prefers another tangible body if one can be found close by.[17]

But Bacon does not attempt to work out an explanation in terms of the mechanism of transmission. From the perspective of the investigator, the main difference between "materiate" and "immateriate" powers and virtues is that the latter can be investigated without taking into consideration the action of the intervening media in widening or shortening the range of action. By contrast, electric actions and other forms of sympathy depend on the medium in which bodies are placed; which means that by operating on the

[17] OFB XI 391.

medium, the investigator can obtain a wider-range action, or a less powerful attractive effect.[18]

Similar classifications of actions and virtues in terms of their range can be found in the *Novum organum* and the *Abecedarium novum naturae*. In the *Novum organum* Bacon proposes a tripartite classification of virtues: some operate by contact, others at small distances, and others at large and very large distances. In each case, regardless of the actual mechanism of transmission and interaction, the range of action is determinate.

> […] virtues and motions of things operate and work over distances which are neither indefinite nor random, but finite and certain, so that in the particular natures under investigation to grasp and take these distances into account, is of the greatest importance for practice. (OFB XI 369)

These distances are the "orbs of virtue;" a concept Bacon borrows from the magnetic philosophy of Giovan Battista Della Porta and William Gilbert, and generalizes it so that it refers, now, to any virtue whatsoever.[19] In the *Abecedarium novum naturae*, the "orb of virtue" is defined as:

> the distance which the powers of bodies may travel to, stop at, build up to and die down from – whether the operation occur by contact alone, or at a [greater or] lesser distance. (OFB XIII 211-13)

This is an operational definition which gives the investigator some of the necessary tools for an experimental investigation of virtues in terms of their range. First, one can imagine experiments designed to measure the orbs of virtue in particular circumstances, revealing the

[18] Bacon also attempted a more hands-on experimental classification of bodies into "attractive" and "not-attractive" and suggested a series of experiments to distinguish between them and to estimate and measure the attractive powers in cases as different as electric attraction, chymical interactions, the attraction of flame, air and fire towards electric bodies etc. See Francis Bacon, *Baconiana, or Certaine Genuine Remains of Sir Francis Bacon, Baron of Verulam, and Viscount of St. Albans in Arguments Civil and Moral, Natural, Medical, Theological, and Bibliographical*, ed. Thomas Tenison (London: I. D. for Richard Chiswell, 1679), 145-54.

[19] For a discussion of the ways in which Bacon takes over and change the meaning of this concept see Dana Jalobeanu, ""Boders," "Leaps" and "Orbs of Virtue:" Francis Bacon's Extension Related Concepts," in *Spaces, Knots and Bonds: At the Crossroads between Early Modern "Magic" and "Science"* ed. Koen Vermeir and Jonathan Regier (Dordrecht: Kluver, (2017) forthcoming).

natural limits, borders and boundaries which exist around particular bodies. Bacon claims that:

> […] there is a kind of *No further* which varies according to mass or quantity of bodies, or the strength and weakness of virtues, or the helps and hindrances of the media, all of which ought to come into the reckoning and to be noted down. (OFB XI 371)

Thus, what the investigator of nature has to do is, first, to find experiments able to detect such natural borders of virtues and radiative powers of bodies; and second, to devise instruments able to measure and perhaps map the geometry of these orbs of virtue. In the following sections of this paper I show that much of Bacon's natural historical investigations can be read as a development of these two points. Many of his experiments can be seen as developing ways to visualize and measure the limits of various orbs of virtue. And, at least in some of them, one can also see Bacon developing instruments to measure and map the orbs of virtue. In some cases, he is developing some of the instruments available already, such as the "weather-glass," or *vitrum calendare*; in some other cases, he imagines new, "perceptive" instruments of his own.

3. Experimental investigations: detecting the borders of the orbs of virtue

The concept of natural borders and boundaries plays an important role in Bacon's speculative philosophy of matter and in his experimental investigations. In cosmology, for example, borders are of essence since it is at such borders that relevant changes take place.

> […] almost all tumult, conflict and disruption take place only at the boundaries of the heaven and Earth, just as happens in political affairs, in which we often find that the borders of two kingdoms are afflicted by continual incursions and violence, while the interior provinces of each kingdom enjoy prolonged peace, and are disturbed only by greater and rarer wars. (OFB VI 149)

This means, for example, that all generation and corruption on the surface of the Earth takes place in a limited region, or crust, sandwiched between the aetherial tract and the unknown depths of the Earth.[20] Moreover, two types of change happen around these natural borders and boundaries: gradual, continuous variation of properties and virtues, and sudden leaps. Bacon claims that

> to the more diligent observer of nature it will be plainly apparent that nature is accustomed to advance for some distance by degrees, then suddenly by bounds [*subito per saltus procedure*], and to go back and forth between these two processes. (OFB VI 129)[21]

In his cosmological, speculative works, Bacon discusses such claims with respect to the general structure of the universe. However, they are more general than that since each body has "orbs of virtue" around it and most changes taking place in nature are either "gradual," or "by leaps" [*per saltus*].

Bacon claims for instance that heat can vary "in intension and remission, in leaps [*saltu*] and fine gradations.[22] This can be experimentally investigated; and indeed some of Bacon's suggestions in his *Investigation into the form of heat* are developed precisely in this direction. Such is, for example, the suggested experiment intended to show that a flame has different regions and degrees of heat; and hence a stick placed in a flame burns "quicker at the sides than in the middle of the flame."[23] More general claims describe the behavior of a body placed in the orb of virtue of another (hot) body, such as: "proximity to a hot body increases the heat and the nearer the hotter" [*Approximatio ad corpus Calidum auget Calorem, pro gradu approximationis*];[24] or that "the smaller a body's bulk [*moles*] the quicker it heats up when a hot body is brought near it."[25] Such claims lead naturally to the

[20] OF VI 231:" […] all entities which have in any way become known to us, even the heaviest, hardest, and those with the greatest depth, such as metals, stones and the sea, [are] made of earth in some degrees changed and worked up by the heat of the heaven, and which has already taken in some heat, radiation, tenuity and mobility, and accordingly partakes of a nature intermediate between the Sun and pure earth." For a discussion see also Rees, "Francis Bacon on Verticity."

[21] Bacon insists that the two types of change, gradual and sudden are a characteristic of nature. See for example OFB VI 177.

[22] DPAO, OFB VI 235.

[23] OFB XI 249. This experiment is described more fully in *Sylva Sylvarum*; see SEH II 353; 403-466.

[24] OFB XI 249.

[25] OFB XI 253.

idea that one needs instruments to measure degrees of heat or determine "leaps" in the variation of heat. Since "the susceptibility of bodies to heat is very variable" [*gradus autem in susceptione Caloris sunt complures*],[26] one is led to the conclusion that one simply has to find bodies subtle enough to perceive heat and measure such gradual changes and leaps. One such body is the weather-glass, one of Bacon's favorite instruments in his late natural and experimental histories. It is highly relevant that it is in this particular context, in the *Investigation into the forms of heat*, that one can find Bacon's most detailed description of the construction and functioning of a weather-glass.[27] One can almost say that Bacon is legitimizing, in this manner, the use of instruments in experimental investigations.

We can find a similar approach in the investigation of dense and rare. Bacon begins by stating that the "scale of the concentration of matter should be carefully noted, and how it goes from a greater to a lesser concentration and does sometimes by steps and sometimes by leaps [*idque interdum per gradus, interdum per saltum*]" (OFB XIII 501). A complex experimental investigation is developed in order to construct a table of densities which is taken to express this "scale of the concentration of matter."[28] This allows a particularly interesting inference: from "leaps" occurring in our *measurement* (i.e. the fact that the numerical results in the table are such that variation by small degrees seems to be interrupted by "gaps" and big variations of the numerical results) to "leaps" occurring *in nature* (i.e. differences of density and other properties between classes of substances such as "minerals" and "metals").

Every time the experimenter detects a "leap" or a sudden change in behavior of a given property or virtue (concentration of matter, heat, density, magnetic virtue etc.), he can infer from it the existence of some natural limits and boundaries, i.e. the borders of a particular "orb of virtue."[29] Each body has many such orbs around it since each body can

[26] OFXB XI 248-9.

[27] This is Bacon's description: "[….] take a glass with a concave belly, a thin ad elongated neck; turn it upside down and lower it belly up an mouth down into another glass vessel holding water, with the mouth of the inserted glass touching the bottom of the vessel receiving it, and the neck of the first glass leaning a little against the mouth of the second, so that it can stand up – and to achieve this more conveniently, put a little wax on the mouth of the second glass though not so much as to block it and, by interrupting the air flow, obstruct the extremely smooth and delicate motion I shall speak of now." OFB XI 249-51.

[28] For a discussion of the details of this experimental investigations see Jalobeanu, *The Art of Experimental Natural History: Francis Bacon in Context*; Pastorino, "Weighing Experience: Experimental Histories and Francis Bacon's Quantitative Program; Jalobeanu, ""The Marriage of Physics with Mathematics:" Francis Bacon on Measurement, Mathematics and the Construction of Mathematical Physics," 67-68.

[29] In the case of the table of densities, gaps in the table mark, for Bacon, natural distinctions between different kinds of substances, such as "minerals" and "metals." Thus, the leap does not mark the borders of the orb of

emit a multitude of radiative effluvia, such as smells, sounds, electric effluvia, heat, electric or magnetic virtues, "celestial influxes," etc. Bacon's experimental investigations are often concerned with ways to distinguish between these different kinds of virtue in terms of their range of action, i.e. by measuring their respective orbs of virtue. The general principle of all these investigations is the same: it involves finding a suitable second body which, placed in the proximity of the first, and moved around, displays certain "leaps" in its behavior.[30] Such leaps are taken to be indicative of the fact that the limits of a certain orb have been reached. Like Gilbert before him, Bacon treats body-body interaction in terms of active versus passive, with the stronger body directing the weaker, and the weaker, passive body, acting as a test-body with respect to the first.[31] His claim is that:

> […] it is quite certain that a body is not affected except by another body, and that no local motion occurs which is not prompted either by the parts of the moving body itself; by adjacent bodies, be they contiguous or close at hand, or at least by ones within their orbs of virtue. (OFB XIII 133)

According to this view, heavy bodies are not heavy because they tend towards the center of the earth; they are heavy because they happen to be in the orb of virtue of the Earth. The further away from the Earth, the less heavy they are; and at the borders of the Earth's orb of virtue, they would simply be "hanging there like the Earth itself and not fall down at all."[32] In fact, Bacon drafts a list of "topics of inquiry" into the nature of "gravity" and "levity" which

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virtue with respect to density, the borders of other orbs, corresponding to the respective properties of the "minerals" and "metals." See also ""Boders," "Leaps" and "Orbs of Virtue:" Francis Bacon's Extension Related Concepts."

[30] See for example the *Inquisitio de magnete* where a piece of iron is placed just outside the orb of virtue of a magnet and then another piece of iron is placed between the two which results in the 'extension' of the initial orb of virtue. Bacon claims that this happens because iron is more conducive of magnetic virtue than the air itself. See OFB XIII 239.

[31] Jalobeanu, ""Boders," "Leaps" and "Orbs of Virtue:" Francis Bacon's Extension Related Concepts." The condition for a body to become a test body is for it to be predisposed and to "give in" to a particular configuration of appetites. From the perspective of the experimental inquirer, the first step into devising topic of inquiry into the nature of heat, magnetism or gravitation is to identify which bodies are "susceptible" [*susceptibilia*] to respond to that particular virtue (SEH I 636). Bacon discusses in several places this issue; see DAS SEH I 636-640; IV 426-428. I will address this particular issue in the next section of this paper, in connection with the discussion of the notion of perception.

[32] OFB XI 329. Bacon claims that this is the case of the lower comets, but also that of large clouds over the seas. See also OFB XI 317-319. Bacon also suggests various ideas of experiments attempting to find a quantitative relation between weight and the actual position in the orb of virtue. See SEH II 353-354.

are clearly set to determine both the "bonds" of gravity and levity [*terminus levitates*] and the gradual variation of the two virtues within the sphere of a particular orb of virtue.[33] In this investigation, "leaps" are said to occur in two cases; when the test-body reaches the limits of the orb of virtue of the attractive body, or when a more powerful virtue steals the show.[34] For example, article 14 of Bacon's "topics of inquiry into the gravity and levity" suggest the following line of investigation:

> Inquire touching the motion of gravity as compared with other motions; what motions it overcomes, and what overcome it. As in violent motion […] the motion of gravity is overpowered for a time; and as when a little magnet lifts a piece of iron much heavier than itself, the motion of gravity yields to the motion of sympathy.[35]

Similarly, magnetic bodies behave magnetically while in the orb of virtue of another magnet; once outside it, another virtue or force can take over their behavior. Thus, Bacon is especially interested to determine the distance at which a magnet ceases to behave "magnetically" and begins to behave gravitationally. In *De augmentis scientiarum* he uses precisely this example to illustrate the prevalence of a "common good" over the "individual good". He claims:

> Iron in particular sympathy moves to the loadstone, but yet, if it exceed a certain quantity it forsakes its affection to the loadstone, and like a good patriot moves to the earth, which is the region and country of its connaturals.[36]

Bacon is also interested to determine bounds and leaps in between orbs of virtue of the same kind; for example, when a body is "torn" between the Earth's magnetic orb of virtue and the

[33] DAS SEH I 639, IV 427.
[34] Bacon devotes an extended discussion in the *Novum organum* to what he calls "instances of wrestling" or "instances of ascendancy." These "draw attention to the ascendancy of virtues over each other or their submission to each other, and which of them is stronger and gets the upper hand and which the weaker and goes under." (OFB XI 383)
[35] DAS SEH IV 426-7; I 639.
[36] SEH V 7.

smaller orb of virtue of a particular magnet. In an experiment very similar to Gilbert's types of investigations, Bacon suggests the following configuration of orbs:

> […] take a terella made of loadstone and mark its poles, and place its poles pointing from east to west, not north to south, and let them stay like that, and then put an unstroked iron needle above it an let it stay there for six or seven days. Now the needle [….] while it stays over the loadstone with desert the poles of the world for those of the loadstone; and so, as long as it stays like that, it points to the world's east and west. [37]

The question is what happens once the needle thus magnetized, with a verticity contrary to the verticity of the Earth, is "removed from the loadstone and placed on a *versorium*"? Two outcomes are possible, according to Bacon. First, the experimenter might observe a "leap:" the *versorium* thus "freed" from the terella's orb of virtue "immediately gravitates north-south." In the second scenario, the *versorium* does not move from its acquired position or loses its verticity altogether.[38]

By analogy with these examples, and in virtue of Bacon's very general definition of the "orb of virtue," it is easy to imagine similar limiting cases for other virtues, such as heat, electric attraction, various forms of contagion, the effects of medicines which "by similarity of substance draw humours,"[39] or even the effects of the imagination. Thus, one can detect here the contours of an experimental program specially designed to investigate borders and leaps. By placing bodies in the orbs of virtue of other bodies, by moving them around, and by observing various leaps, the investigator can first detect the natural limits and bounds of a particular virtue. This can have, first, a classificatory benefit. One can range all virtues by their "definite […] orb of virtue" (OFB XI 369). At the same time, the experimental investigation into what affects the boundaries of the orb can also have important epistemic

[37] OFB XI 330-1. For a discussion see Rees, "Francis Bacon on Verticity."
[38] Bacon offers this experiment as a crucial instance for deciding whether verticity is fundamentaly determined by the magnetic field of the Earth, as claimed by Gilbert, or whether it is a sort of inner modification of the nature of matter which is largely independent from the Earth. Interestingly enough, in formulating his crucial instance in this way Bacon may be seen as taking a stand on contemporary debates over the nature of magnetism.
[39] OFB XI 397.

and practical ramifications: the investigator can inquire into the factors which can reduce or extend these limits. Thus, Bacon's measuring project goes beyond the mere determination of bounds and limits and develops into a more sophisticated attempt of mapping the orbs of virtue with respect with the various relevant parameters in a given experimental situation.

Such complex investigations can be seen, for example, in Bacon's several attempts to discuss what he calls "operations working by consents." Of this kind are, for example, "the attraction of some herbs to water, though at a distance," "attraction in gold of the spirit of quicksilver, at a distance,"[40] or the attraction hidden in purging medicines, between the "purger" and a "particular homour."[41] Unlike his predecessors, Bacon does not discuss such examples within the convention of a theory of "sympathies" and "antipathies" between natural kinds.[42] In fact, circumventing the natural philosophical discussion altogether, he proposes a top-down experimental investigation of the same kind as those described above, an investigation centered on the same operational concept of "orbs of virtue."

Such investigations play an important and visible role in the posthumous *Sylva Sylvarum*. For example, Bacon imagines various situations in which water is placed at a certain distance from a particular porous body, or a particular plant, in an attempt to identify the distance to which one can still see the body "willingly drink the water or liquor."[43] In one such experiment, a wet sponge is placed beneath a pot of earth which contains freshly sown seeds, to inquire whether the seeds can "attract" water through a number of intervening material layers, i.e. "whether the great consent between plants and water, which is a principal nourishment of them, will make an attraction at distance, and not at touch only."[44] In another

[40] SEH II 644, SEH II 636.

[41] Bacon claims: "I do not deny, but that purging medicines have in them a direct force of attraction; as drawing plaisters have in surgery: and we see sage or betony bruised, sneezing-powder, and other powders or liquors […] put into the nose, draw phlegm and water from the head; […] And note also, that besides sympathy between the purger and the humour, there is also another case why some medicines draw some humour more than another." (SEH II 356)

[42] Although sometimes speaking of sympathies and consent, Bacon is radically rewriting the traditional theory of sympathies in such ways that it does not refer to individuals anymore, but to the hidden configurations and combinations of first motions present in matter.

[43] This particular form of attraction is further theorized in *Novum organum* where it is classified, according to a more complex scheme, under "motion of gain/lack" and, respectively, "motion of lesser congregation." Mark, however, that this classification also takes into consideration the respective "orb of virtue," i.e., range of that particular type of motion. See: OFB XI 391. For experiments of these kind see SHE II 372; SEH II 498.

[44] This is how Bacon records the experiment: "Therefore take a vessel, and in the middle of it make a false bottom of coarse canvas: fill it with earth above the canvas, and let not the earth be watered; then sow some good seeds in that earth; but under the canvas, some half a foot in the bottom of the vessel, lay a great spunge thoroughly wet in water; and let it lie so some ten days; and see whether the seeds will sprout, and the earth

experiment, a cucumber is placed at a certain distance from a bowl of water; Bacon claims that the cucumber not only attracts and "drinks" the water, but also "creeps" towards it, expanding considerably in size.[45]

Incidentally, if one looks at Bacon's *Sylva Sylvarum* from this perspective, the bewildering diversity of his experimental investigations loses much of its apparent ad hoc character. In view of Bacon's general experimental strategy about mapping orbs of virtue described the previous paragraphs, it makes perfect sense to group together investigations into things as different as the attraction of plants for their nutrients, the magnetic virtue, purging medicines, or the various influxes and virtues manifested by the moon. There is a unity behind this diversity of content, given by the methodological and instrumental approach. In all such cases, the common purpose is to identify the borders of the respective orbs of virtue. In some cases, Bacon devises experimental investigations of an increased complexity, intended to also map the orb of virtue, determining its geometrical configuration.

One can see this in the example of grafting. Again, this is most probably another development of a suggestion Bacon picked from Gilbert's *De magnete*. Gilbert's claim is that the "harmony of magnetic form" can be seen in the procedure of grafting: one cannot graft a branch on a tree otherwise than in the direction of the circulation of the sap.[46] Only the correct orientation of the scion in the orb of virtue of the mature plant can ensure the success of the operation. Bacon develops a wide range of experiments and investigations into grafting of one plant upon another, on grafting in the trunk, in upper branches, in the root, etc.[47] He is also attempting cross-species grafting, where scions of apples are inserted into trees such as elms or poplars, "the moistest of trees," which have, thus, plentiful nourishment for the scion.[48] In each case, what the experimenter must preserve is a directionality and orientation of the scion "upwards", i.e. in the direction of the circulation of the sap. Thus, some of

become more moist, and the spunge more dry. The experiment formerly mentioned of the cucumber creeping to the pot of water, is far stranger than this." (SEH II 498)

[45] SEH II 489.

[46] William Gilbert, *De Magnete, Magneticisque Corporibus, Et De Magno Magnete Tellure; Physiologia Nova, Plurimis & Argumentis, & Experimentis Demonstrata* (Londini: Excudebat Petrus Short, 1600), 131.

[47] For Bacon, grafting is a method of nourishing the plant; the scion is 'eating' the sap produced by the host tree. For a discussion see Rusu, "From Natural History to Natural Magic: Francis Bacon's *Sylva Sylvarum*." My thanks to Doina Cristina Rusu for many illuminating discussions on Bacon and grafting.

[48] SEH II 487.

Bacon's experiments about grafting can be seen as attempts to establish various geometrical configurations of the corresponding orbs of virtue.[49]

4. Instrumental investigations: mapping the orbs of virtue

Bacon's experimental investigations into the limits and shape of such orbs of virtue depend on a further theoretical layer: his conception of perception. In the examples treated above, the cucumber "perceives" the pot of water before drawing and attracting the water; while the newly sown seeds also perceive the wet sponge – and this perception is a prerequisite of attraction. He also gives examples of replanted trees "perceiving" a change of their own north-south orientation (and consequently withering).[50] More generally, he claims that the experiment with the cucumber is of a "higher nature" than others for "it discovereth perception in plants to move towards that which should help and comfort them, though it be at a distance."[51]

In fact, for Bacon, perception is a fundamental property of each natural body, a prerequisite and preliminary of all action. This is how perception is described in the posthumous *Sylva Sylvarum*:

> It is certain that all bodies whatsoever, though they have no sense, yet they have perception: for when one body is applied to another, there is a kind of election to embrace that which is agreeable, and to exclude or expel that which is ingrate: and

[49] Other attempts to establish the configuration of a tree's orb of virtue can be found in Bacon's experiments and suggestions for replanting trees in such a way that their original orientation north-south is preserved. See for example SEH II 491. Bacon also claims that plants "have a natural motion to get to the sun" (SEH II 510) which leads him to a very interesting "inversion" of the experiment of grafting where he is burying some of the trees' branches in soft clay to see whether they will develop roots, according to the novel configuration (and orientation) of their orb of virtue. See SEH II 515. Last but not least, his *Experiments in consort touching the several figures of plants* seem to be put together in order to establish a correlation between the speed in the circulation of the sap and the ensuing figure of the tree. See SHE II 522. Some of these experiments made a career in the seventeenth century; they were picked up, re-tried and criticized by Ralph Austen and John Evelyn. See for example Ralph Austen, *A Treatise of Fruit-Trees* (Oxford: William Hall for Amos Curteyne, 1665). For a discussion on Austen and Bacon see Oana Matei (forthcoming). For a more general discussion on grafting and husbandry see also Oana Matei, "Gabriel Plattes, Hartlib Circle and the Interest for Husbandry in the Seventeenth Century England," *Prolegomena: časopis za filozofiju* 11, no. 2 (2012).

[50] SEH II 491.

[51] SEH II 489.

> whether the body be alterant or altered, evermore a perception precedeth operation; for else all bodies would be alike one to another. […] And this perception also is sometimes at distance, as well as upon the touch; as when the loadstone draweth iron; or flame fireth naphtha of Babylon, a great distance of. [52]

As in the case of the orbs of virtue, Bacon does not give a natural philosophical definition of perception; and he is silent when it comes to its mechanisms of operation. In fact, "perception" occurs sparsely in Bacon's earlier writings and it is absent from his first two published natural and experimental histories.[53] But it figures prominently in the posthumous writings, such as *Sylva Sylvarum* and *Historia densi et rari*. Most of these occurrences refer to experimental and instrumental investigations. As in the experiments described above, one line of experimental investigation attempts to show that perception necessarily precedes the establishment of a particular configuration of appetites leading to action. This is the case of the cucumber which "perceives" the water and moves towards it. Another series of experiments involves placing freshly shorn wool next to a source of water; be that on the wet ground, on the top of a closed barrel containing verjuice, or hanging at the end of a rope, in a well, just above the level of the water. In each case, the wool becomes moist; and Bacon takes this to mean that the wool freshly shorn (and, thus, still containing a "degree of heat") first "perceives" the water, then contributes to its evaporation, and then condenses (drinks) the ensuing vapours.

Another line of Bacon's investigations is directed at distinguishing between perception and other appetites. For example, in his *Inquisitio de magnete* one can find a series of experiments intended to prove that even if, by laboratory manipulations, one can destroy the active power of a magnet, its "passive power" of perception cannot be destroyed (SEH V 403-5). Bacon shows that loadstone reduced to powder is still attracted by magnetized iron; and the same happens if the magnet is burned into the fire; in both cases, the remains "retain its passive virtue in some degree" (SEH V 405).

It is clear that there is a close link between "perception" and the "orb of virtue." And indeed, in the *Abecedarium novum naturae*, Bacon uses the concept of perception to further

[52] SEH II 602.
[53] In the *Novum organum* Bacon refers to the "sense" rather then perception; as, for example, when explaining that air sense the variations in heat, or the weather-glass is sensible to the modifications of the surrounding air with respect to heat etc.

operationalize his theory of the orbs of virtue. Orbs are said to define the "the distance that perception reaches to."[54] This second operational definition of the orbs of virtue allows a further refinement of the experimental program. Perception can be stronger, i.e. extending in a larger orb of virtue, and weaker, i.e. extending in a smaller orb. This allows the investigator the possibility of devising ingenious and subtle trials using a choice of perceptive bodies. This operational definition of perception legitimizes the use of instruments because in this approach instruments are simply bodies "perceptive enough" to detect motions and "leaps" which, otherwise, escape the senses. The weather-glass is said to be an instrument with "a fine sense or perception of hot and cold" which can "pick up subtle difference and degrees"[55] as well as leaps otherwise imperceptible to the human senses. This is partly due to the general perception of air to heat and cold, and partly due to the particular geometry and configuration of the weather-glass. In fact, Bacon discusses possibilities of improving the contemporary instrument, by replacing water with oil, or with spirit of wine. Again, this is done with the help of an experimental investigation, and not in virtue of the natural philosophical speculations. In *Historia densi et rari* we can find the following suggestion:

> Take two calendar glasses of the same size. Put water in the one and spirit of wine strong and sharp in the other, and so heat the glasses that the water and spirit climb to the same height. Put them together and leave them for a while and see them if the water stands higher than the spirit of wine. For if that is what happens it is obvious that the potential heat of the spirit of wine has dilated the air so as to push down the spirit of wine.[56]

Of the two instruments, the second is more "perceptive" to heat; and the leaps of the liquid column against the scale are more visible. A more subtle, perceptive weather,-glass allows the extension of investigation into what Bacon calls "potential heat," and "potential cold," i.e. heat and cold which is beyond the natural sense-perception and can be detected solely by post-factum effects.[57] They can be investigated with a modified weather-glass. Bacon

[54] OFB XIII 195.
[55] OFB 107.
[56] OFB XIII 109.
[57] For a discussion on potential heat see Sebastian Mateiescu, "Francis Bacon on Potential Heat," *Societate si Politica* 7(2013).

suggested a wide range of such investigations, which involve, for example, smearing the inside of the weather glass with substances potentially hot, or potentially cold.

The subtle perception and the appetite of plants from water can also be exploited to construct a perceptive instrument which can measure the degrees of moisture in the atmosphere or the sudden leaps which indicate particular limits of an orb of virtue. Bacon has a number of ingenious ideas about how to develop a hygrometer starting from a pack of wool or other porous fibers, such as "the beard of a wild-oat."[58]

To sum up: the operationalizing of perception can be seen as vindicating the experimental approach and legitimizing the creation and use of various "perceptive instruments." By placing such instruments, i.e. suitable "perceptive" bodies, close to one another, one can detect various changes of behaviour – gradual or "by leaps" and infer from these to the borders and leaps in nature.

In practice, the experimenter meets with several different situations in this process of "mapping." The simplest situation is when the simple motion or the particular configuration of motions is already given. This is the case of "mapping" the variation of weight with distance.[59] Bacon claims that the weight of a body decreases with height and suggests a series of experiments intended to map this gradual decrease.[60] The case of magnetic virtue is slightly more complicated, because it involves at least three different simple motions (coition, verticity and the motion of situation).[61] Even more complex are the cases in which one does not know the prevailing configuration of motion. Bacon formulates an experimental investigation of this type in Century IX of *Sylva Sylvarum*: a complex series of experiments intended to map "the inequalities of the air" in a given region. Without knowing what produces these inequalities, and without actually discussing what these "inequalities of the

[58] This experiment has an interesting posterity in the seventeenth century. It figures in Robert Hooke's *Micrographia*; and the development of a hygrometer using beard of wild oat as materials becomes part of the English seventeenth century discussions in the Royal Society. Michael Deckard has discuss several of these examples, as well as Margaret Cavendish' criticism of them in "Of the beard of a wild oat: Cavendish and Hooke on the microscope," paper presented at the workshop *Manipulating Flora* (University of Bucharest, 21-22 January 2016).

[59] This is a simple situation because, in Bacon's view, "motions of major congregation" (also called "the great magnetic motions") always prevail in competition with other motions. This is why one can investigate weight and the motion of gravity independently of any other motion; OFB XI 417.

[60] OFB XI 329; SEH II 353-354.

[61] Most of the time, any assessment of the orb of magnetic virtue has to take into consideration weight as well. Bacon usually gives examples where magnetic virtue "gives way" to gravitational attraction. However, in the *Inquisitio de magnete* there are also cases where the experimenter screens off the gravitational attraction in order to concentrate on either coition or verticity.

air" are, the investigation attempts to find limits, borders and leaps in a given region with the help of a wide range of perceptive instruments. In this particular case, Bacon uses a series of perceptive instruments. Some of these are traditional, such as the weather-glass; some other are of his own making, such as a primitive "hygrometer" made of a pack of wool.[62] Other perceptive bodies involve pieces of flesh and fish distributed around a particular surface in order to map the "predispositions" of the air to putrefy. Two identical weather-glasses are said to offer comparative measurements which can chart the dispositions and temperaments of the air in the given certain region,[63] while placing suitable porous perceptible bodies in the same region can supplement the map with information regarding humidity.

> Lay wool, or a spunge, or bread, in the place you would try, comparing it with some other places; and see whether it doth not moisten, and make the wool, or spunge, &c, more ponderous than the other; and if it do, you may judge of that place as situated in a gross or moist air. (SS 810, SEH II 605)

All these perceptive instruments are recording "changes" in the "inequalities of the air," and can be used to "map" a given region, for a given time. The recording of certain "leaps" is taken to be indicative of the discovery of natural limits and borders in nature. In this case, Bacon claims that the accuracy of this "mapping" depends primarily on the "subtlety" of the perception of the particular body used as an instrument.[64]

It is important to note that the mapping of the orbs of virtue is more complex than the mere determination of their limits. Bacon devises numerous, quite interesting experiments to show that, for example, gravity decreases with weight (SS II 353-4) or that – to take another example – a flame has "different force" "in the midst and on the sides." The latter set of experiments involve placing an arrow in the fire and observe that it is burned differently in the middle and in the extremities, proving Bacon's theoretical conjecture that flame burns

[62] For a discussion see Jalobeanu, "Learning from Experiment: Classification, Concept Formation and Modeling in Francis Bacon's Experimental Philosophy."
[63] Bacon is, to my knowledge, the first experimenter to discuss calibration and the possibility of having identical weather glasses. On Bacon's own weather-glass see the prefatory material to the collection of remains published in 1679, *Baconiana*, in which a "philosophical glass" is described; Bacon, *Baconiana*, 18-19.
[64] The accuracy of mapping also depends on the application of the proper methodology of experimentation. Jalobeanu, "Disciplining Experience: Francis Bacon's Experimental Series and the Art of Experimentation; *The Art of Experimental Natural History: Francis Bacon in Context*..

less strongly in the middle (SS I 32, SEH II 353). [65] Another dimension of this experimental mapping lies in Bacon's attempts to detect the relevant parameters which determine the orb of virtue of a particular body; whether it is mainly a question of size and quantity, a particular geometry,[66] or a secret accord or sympathy between bodies and virtues.[67] The latter is extensively discussed in Bacon's various medical recipes: dealing, for example, with the attractions contained in the "purging medicines,"[68] or with the sympathy between "cantharides" and the human bladder, etc.[69] Bacon approaches all these cases in a similar manner. He begins with an attempt to establish the limits of the phenomenon, and the range of a particular interaction, i.e. the borders of that particular orb of virtue. Then, he looks for quantitative correlations, attempting to "measure" either exactly or "by estimates" the given effect. In more complex experimental investigations, he attempts, as a third step, to map the particular geometry of the orb of virtue by using one or more perceptive instruments. It is true, not all his experimental investigations are fully developed. Some go little beyond interesting and challenging suggestions to the reader as to how to proceed in a given situation. However, the set of operational concepts discussed so far and the particular conception of perceptive instruments delineate with sufficient clarity the main elements of Bacon's experimental procedure of inquiry.

5. Conclusion

My purpose in this paper was to bridge the two main aspects of Bacon's philosophy of nature, the speculative and the experimental. I have shown that what unites the two is a sophisticated set of experimental approaches constructed upon a theoretical and methodological set of premises. Chief among these are the operational definitions of traditional natural philosophical concepts such as "orbs of virtue" and "perception." Originating in Bacon's speculative philosophy, such and like concepts are gradually striped of their natural philosophical content and acquire operational content in the context of

[65] See also the discussion of different flames at OFB XI 245.
[66] See Bacon's investigations into the shapes and geometry of musical instruments and the geometry of their orbs of virtue, SEH II 221 ff., or his discussion of round and armed (i.e. pointed) magnets etc.
[67] One example here are the "experiments in consort touching the sympathy or antipathy of sounds with one another" where Bacon determines the "unison" as the important factor in the producing of a resonance. SEH II 433.
[68] SEH II 356.
[69] SEH II 379.

specific experimental investigations. The operational definition of the "orbs of virtue" opens up the possibility of classifying actions in terms of range and suggests ways of devising experimental investigations directed towards measuring "borders," and "leaps" in nature. Defining perception in terms of the "orbs of virtue" vindicates the use of instruments, i.e. bodies "perceptive enough" to detect borders and measure "leaps" and "gradual change." The use of perceptive instruments is, in turn, guided by methodological considerations which allow the investigator of nature a purely top-down approach. As we have seen, this involves devising complex programs of measuring the limits and geometry of various orbs of virtue, sometimes using multiple perceptive instruments; and this can be done even the investigator knows next to nothing regarding the nature of measured quantities.

More needs to be done in order to obtain a fine-grained picture which will take into consideration Bacon's various kinds of perceptive instruments in the context of his more general theory and practice of measurement. Such an enterprise is worth pursuing for two main reasons. First, because this gives us insight into the complex interplay between speculative considerations, operational definitions, methodological discussions and the various ingenious instruments one can find in Bacon's late works. Second, this approach brings to the fore an unexpected and much more orderly picture of Bacon's natural and experimental histories than previously thought. Most particularly, it gives the reader the sense that behind the bewildering diversity and apparent "ad-hocness" of the posthumous *Sylva Sylvarum* there is a "hidden order," given precisely by Bacon's instrumental investigations into the borders and limits of various orbs of virtue.

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