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The arguments on void in the seventeenth century: the case of Francis Bacon

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Abstract. Francis Bacon's position on the existence of void and its nature has been mostly studied with regard to his views on the atom. This approach is undoubtedly right, but it disregards further topics related to Bacon's account of void, namely the world system and the transmutation of bodies. Consequently, a more comprehensive study of Bacon's view on vacuum seems desirable where all the contexts are taken into account. To address this desideratum, the present paper examines Bacon's different views on vacuum drawing attention to the various contexts of the discussion. It also gives an evaluation of the arguments put forward in support of his positions. The first section presents a reconstruction of Bacon's consecutive positions and the reasons for his changes of mind. The second section lists the experimental facts traditionally cited in debates about vacuum and Bacon's interpretation of these. The final section evaluates the role that these experimental facts played in Bacon's arguments. As a result, it is shown that Bacon fits entirely into the general pattern of the early seventeenth century. Empirical arguments by themselves had little value for solving the question of the void; it was also necessary to have a formerly established theory.

The existence of void and its nature were a matter of continuous philosophical debate until the eighteenth century. The controversy was started by Aristotle who against the atomists staunchly denied the existence of any vacuum. The discussion continued during the Middle Ages, when most authors denied the actual existence in the world of vacua, while others argued for the hypothetical existence of an extracosmic void. In the Renaissance the polemic took new life and was reassessed from the perspective of anti-Aristotelian and eclectically oriented figures like Bernardino Telesio and Francesco Patrizi.[1] Francis Bacon's position on this issue follows this latter trend. He thought that the question as to how far a vacuum may be allowed is one of the most difficult to answer.[2] In fact he was concerned with this question persistently during a long period, the most fertile of his career. His views on void were changing: sometimes he favoured the existence of some kinds of void, while on other occasions he absolutely denied that there was any kind of void.

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1 See E. Grant, *Much Ado about Nothing: Theories of Space and Vacuum from the Middle Ages to the Scientific Revolution*, Cambridge, 1981; Ch. Schmitt, 'Experimental evidence for and against the void: the sixteenth-century arguments', *Isis* (1967), **58**, 353–65.

2 Francis Bacon, *The Works of Francis Bacon* (ed. J. Spedding, R. L. Ellis and D. D. Heath), 2nd edn., 14 vols., Stuttgart, 1989, iii, 116.

Certainly, Bacon's attitude towards a vacuum is closely related to his matter theory. Hence scholars have drawn attention to Bacon's treatment of void mainly with regard to his views on the atom. Mary Hesse has claimed that Bacon's change of mind about the void contributed to his rejection of the atoms. She has suggested that the denial of the existence of the void in the last period of his career might be grounded on three reasons. First, experiments on gases would lead him to the notion of the possible existence of a subtle matter; second, he concluded that Hero's theory about the interstitial void was not necessary; and third, he considered that matter was capable of folding and unfolding itself without a void, apparently assuming that density and rarity were the most important properties of matter. Graham Rees has held that Bacon never accepted 'the vacuum hypothesis'. According to him, Bacon's early discussion of Hero's vacuism implies no assertion that a vacuum indubitably exists. In Rees's account, Bacon seems to have thought of spirit and vacuum as in some way analogous, the main reason for rejecting the vacuum being its inconsistency with the pneumatic matter. Peter Urbach has suggested that Bacon abandoned his quite favourable attitude towards two sorts of vacuum by favouring a previously rejected explanation of expansion and contraction which implies the notion of folding and unfolding matter. More recently, Benedino Gemelli has argued that the void was a subordinated concept, which had to fulfil the methodological function of simplifying the account of the motion. Consequently, the void was diminishing its importance at the same time that the concepts of *particulae verae* and *materia fluxa* were increasing their force and the classic concept of atom was declining.[3]

Although it is right to analyse Bacon's views on the void in the light of his matter theory, as scholars have done, we should not disregard further topics also closely related with it, namely the world system and the transmutation of bodies. Consequently, a more comprehensive study of Bacon's view on vacuum seems desirable where all the contexts are taken into account.

Interspersed and collected void in *Cogitationes de Natura Rerum*

As a point of departure it is important to emphasize that Bacon does not consider the existence of vacuum as absurd per se;[4] whereas Aristotle and most of his followers maintained that the notion of vacuum was to be rejected, insofar as its definition involved absurdities. Aristotelian arguments claimed that the concept of vacuum contradicted the principle of impenetrability, according to which two bodies cannot occupy the same place at the same time. Furthermore, Aristotle thought the existence of vacuum to be superfluous, since if vacuum cannot be distinguished from the dimensions of a body occupying it, there is no reason to postulate the existence of vacuum. Other objections

3 M. Hesse, 'Francis Bacon', in *A Critical Survey of Western Philosophy* (ed. D. J. O'Connor), New York, 1962, 141–52; G. Rees, 'Atomism and "subtlety" in Francis Bacon's philosophy', *Annals of Science* (1980), 37, 549–71; P. Urbach, *Francis Bacon's Philosophy of Science: An Account and a Reappraisal*, La Salle, IL, 1987, 79–81; B. Gemelli, *Aspetti dell'Atomismo Classico nella Filosofia di Francis Bacon e nel Seicento*, Florence, 1996, 175–81.

4 Another view on this point is claimed by Rees, op. cit. (3), 557.

did not follow from the definition of vacuum itself but from the hypothetical relation of vacuum to motion. According to the Aristotelian doctrine, motion cannot happen in a vacuum. Since it is supposed that every part of the void is identical to every other part, there is no reason for a body to move in one direction rather than another. Consequently, bodies would remain at rest. And, even if it were possible for a body to start a motion in the void, it would move perpetually, for there is no reason for it to stop in one part of the void rather than in another. On the other hand, with the lack of resistance in the void, motion would be instantaneous and bodies would tend to move in any direction. Further, even if motion in a vacuum were finite, bodies of different weight would fall with equal velocity.[5]

Bacon's first opinion on vacuum appears in *Cogitationes de Natura Rerum*, composed about 1604, where atomism is considered a good hypothesis for explaining the subtlety of nature.[6] Bacon distinguishes two meanings of 'atom'. Here we are concerned with the second one, which presupposes the existence of vacuum and describes the atom as something that is deprived of it. In this context, two kinds of vacuum are introduced: collected vacuum – large empty spaces among bodies – and interspersed vacuum – minute empty spaces between the particles of matter.

In agreement with Hero of Alexandria,[7] Bacon accepts the existence of an interspersed vacuum because it is judged to be the most proper hypothesis to explain changes in volume. He comes to this conclusion after analysing three alternative hypotheses for explaining contraction: 1) that contraction is produced by emission of the interspersed vacuum; 2) that it is produced by 'the forcing out of some other body previously intermixted';[8] and 3) that contraction happens 'naturally'. To be sure, the rationale for Bacon's choice is not very clear. He rejects the second hypothesis because it contradicts the fact that the finer (*tenuior*, *subtilior*) a body is, the stronger the contraction it supports. Although cases like the contraction of sponges[9] and other porous bodies could make this hypothesis true, the high level of contraction reached by air invalidates it. If this hypothesis were assumed in order to explain the contraction of air, it would be necessary to postulate that air contains finer parts and, again, that these parts contain even finer parts, and so infinitely: 'Are we then to suppose that the finer part [*subtiliorem partem*] of the air is squeezed out, and out of that part another, and so for ever?' Thus Bacon indirectly seems to assume a limit to tenuousness.[10]

The third hypothesis is also rejected. It apparently represents the Aristotelian notion of *augmentatio* and *diminutio*, which in *Novum Organum* was characterized as a change in quantity of matter.[11] As rationale for the rejection of this hypothesis Bacon just says that,

5 Grant, op. cit. (1), 5–8.

6 Bacon, op. cit. (2), iii, 15.

7 Hero of Alexandria, *Spiritualium Liber*, a Federico Commandino Urbinate, ex graeco, nuper in latinum conversus, Urbino, 1571, A1v.

8 Bacon, op. cit. (2), v, 421–2; iii, 15: '*quod aliud aliquod corpus prius intermixtum exprimatur*'.

9 Bacon, op. cit. (2), v, 421–2; iii, 15. The example of sponges is a commonplace in the commentary literature on void.

10 Bacon, op. cit. (2), iii, 16–17.

11 Bacon, op. cit. (2), i, 177. Cf. K. Lasswitz, *Geschichte der Atomistik vom Mittelalter bis Newton*, 2 vols., Darmstadt, 1963, ii, 426. See Aristotle, *Physica*, IV, 9, 217a26–217b19.

since the theory is arbitrary and unfounded, its refutation does not deserve very much attention.

As a result, the first hypothesis remains as the right explanation. Like Hero, he claims that there is no other plausible reason to explain 'how this ingress and egress of bodies in their own places could happen except by means of a vacuum interspersed'.[12] At this stage, Bacon accepts the existence of interspersed vacuum as a good explanatory hypothesis for contraction and expansion. Envisaging that those who ground their theories only on what is not immediately perceptible could judge 'that it appears strange and almost incredible there should be an interspersed vacuum when a body is found everywhere',[13] he tries to fortify his assumption by extrapolating: in the same way that tiny particles of saffron are distributed in a larger volume of water, little empty spaces are distributed inside the matter of a body. When proposing this extrapolation, a usual recourse in the speculation on atomism during the seventeenth century,[14] Bacon conceives of the relation between matter and vacuum as a mixture. The two central ideas involved in this extrapolation are 1) different amounts of matter, no matter how large they could be, do not hinder the mixing; 2) the imperceptibility of the mixture does not imply that the pure particles of the components do not exist (juxtaposed but unaltered). That is to say, even though in the saffron water only a homogeneous liquid could be perceived (with no observation of saffron particles), at the corpuscular, imperceptible level the liquid was actually a mixture of saffron and water. In the same way, even though in large bodies we can only perceive matter, at the corpuscular level they do contain empty spaces.

Bacon mentions the saffron-water solution several times, twice alone in the *Cogitationes*, where he introduces it when he for the first time declares his acceptance of atomism. Here the saffron-water solution is offered as an instance of the subtlety of nature, to which the atom is seen to testify. Hero, mentioned by Bacon in this passage, had offered a similar example: the dispersion of a little quantity of wine in water. In order to explain this phenomenon, he argued that the empty parts inside the water were being occupied by wine.[15] However, it should be noted that Bacon does not use the example of the saffron-water solution in the same way that Hero had used the wine-water solution.[16] Although Bacon also assumes that the mixture of saffron and water is very 'subtle', he does not explain this property by appealing to an interspersed vacuum. Later, in his *Historia densi et rari* (1623), he claims that because no change in volume is produced but a change in figure, this kind of mixture should be called 'pseudo-dilatation'. In such dilatations bodies whose parts have been agglomerated become flattened through a change in the position of their particles (*positura partium*).[17] Moreover, he claims that this kind of mixture is enclosed within fixed quantitative limits, for nature's subtlety is not infinite. The atom is the ultimate unit of subtlety: 'this diffusion is confined to certain

12 Bacon, op. cit. (2), iii, 16; v, 420.

13 Bacon, op. cit. (2), iii, 16; v, 421.

14 Ch. Meinel, 'Early seventeenth-century atomism, theory, epistemology, and the insufficiency of experiment', *Isis* (1988), **79**, 76–81.

15 Hero of Alexandria, op. cit. (7), B4v.

16 In this point I disagree with Gemelli, op. cit. (3), 180.

17 Bacon, op. cit. (2), ii, 285.

spaces, limits, and quantities of bodies'.[18] In fact, Bacon presents the saffron-water solution case many times, only once relating it to the question of vacuum.[19]

Hero denied the existence of collected vacuum altogether, both on the Earth and in the heavens.[20] Bacon agrees with Hero only in his denial of a collected vacuum in the terrestrial realm. But, in opposition to him, he concedes the possibility that a collected vacuum exists in the ethereal region, since nothing impedes the idea that where bodies are larger, empty spaces are larger, too. According to Bacon, Hero was led to deny the collected vacuum in the ethereal region because he limited his attention to the terrestrial region and supposed that the entire universe was subjected to the same condition. The extrapolation, formerly applied to the microscopic level, is once again applied to the macroscopic level in order to examine the question of a collected vacuum. He supports this assertion by claiming that the collected vacuum stands in the same proportion with the rest of the world as the proportion established between interspersed vacuum and earthly bodies, this being one mark of nature's subtlety. The units of nature are submitted to such a uniform proportion that it is the same to think or to talk about a thousand moments as about a thousand years, for years are composed of many moments. Nature's proportions are developed uniformly (*ex aequo supputationi submitti*) through her different levels: corpuscular, macroscopic and macrocosmic.[21] The examples involved in these extrapolations are arranged according to an increasing level: interspersed vacuum to bodies is like saffron to water and like collected vacuum to the universe.

An important change of mind becomes visible in Bacon's works on astronomy, namely *Descriptio Globi Intellectualis* and *Thema Coeli* composed around 1612, unfinished and published posthumously. *Descriptio* introduces a list of questions concerning the natural history of the system of the world. One of the questions concerns the connection across the system. Bacon formulates two possible answers: either heavenly bodies are connected by an ethereal medium or by a vacuum. The answer to this question ultimately is reduced to a fundamental question about nature's principles: is there a vacuum?[22]

One of the defenders of the separated vacuum was William Gilbert. According to Bacon, Gilbert claims that the Earth, planets and fixed stars are composed of solid and dense matter. Each planet is surrounded by effluxes, composed of matter of the same nature as that of heavenly bodies, but imperfect, languid and attenuated. Although effluxes surround the celestial globes, they do not come to the point to cover all the interplanetary space, so that large extensions remain empty. The fact that celestial bodies are visible from the Earth is said to support this theory. If the interplanetary space were full of bodies of such diverse degrees of density, the refraction of rays of light would be such that they could never be seen from the Earth.[23]

18 Bacon, op. cit. (2), iii, 16; v, 420.

19 Bacon, op. cit. (2), i, 319; iii, 16–17; iii, 707.

20 Hero of Alexandria, op. cit. (7), B1v, C1r.

21 Lasswitz, op. cit. (11), ii, 426; cf. Bacon, op. cit. (2), i, 234–5.

22 Bacon, op. cit. (2), iii, 744.

23 W. Gilbert, *De Mundo Nostro Sublunari Philosophia Nova*, Amsterdam, 1661, Chapter 1, 20 and 22; Chapter 2, 2; *idem*, *On the Loadstone and Magnetic Bodies and on the Great Magnet the Earth* (tr. P. F. Mottelay), Chicago, London, Toronto, Geneva, 1952, Chapter 5, 4. First edn.: *De Magnete*, London, 1600.

In Bacon's view, if celestial bodies are solid, then Gilbert's theory must be true. In contrast, if they are composed of rare matter, then matter would extend into the heavens without interruption of continuity.[24] The rejection of Gilbert's system appears in *Thema Coeli* where Bacon asserts categorically that heavenly bodies are composed of rare matter, specifically of highly pure fire. In addition, he explains the process by which the multiplicity of material properties is produced throughout the cosmos. From this explanation he concludes that changes in nature happen by continuity as well as by contiguity. Given these premises, Bacon seems to have thought that Gilbert's theory of effluxes is wrong because it presupposes changes by continuity only. In other words, for Bacon, Gilbert's theory supposes that dense matter of celestial bodies would be rarefied gradually to a point at which it would be impossible to become rarer. As a consequence the space where matter effluxes are extinguished is empty. Instead, Bacon thinks that since nature changes not only *per gradum* but also *per saltum*, the matter of celestial bodies is surrounded by a much rarer matter, namely ether, which fills the interplanetary space. As a result, Bacon defines his final position on collected vacuum in the heavens by denying 'Gilbert's collected vacuum between scattered globes'[25] and by affirming that interplanetary spaces are filled either with airy or with fiery matter.

At least in this astronomical context, Bacon still maintains the existence of an interspersed vacuum. He judges the reasons given in support of an interspersed vacuum to be more acceptable than those given in support of a collected vacuum. The argument preferred by Bacon is not based on the analysis of matter's constitution, where changes by contraction and dilatation happen as discussed in *Cogitationes*. Now the argument is concerned with the fixed proportions which determine earthly matter, whatever its constitution may be. Bacon ascribes to Democritus a similar argument in the following terms: 'vacuum is bounded and enclosed, so that beyond certain limits dividing or sundering bodies is no more possible than forcing together and compaction'.[26] The point of departure of such a postulate of a vacuum *intra certos fines* arises from the co-infinity of matter and space, the principle of Democritean atomism. Because of this co-infinity Bacon thinks that 'a vacuum is necessarily confined within certain limits, ... that a certain limit may be set on the unfolding or expansion of bodies due to the vacuum coupled with them'.[27] In fact, if the separation of the parts of matter might happen without limit, the world system would vanish.

Apparently, Bacon thinks the existence of a closed world system to be grounded on two conditions: 1) a fixed centre; 2) lack of a collected vacuum. The second condition is needed in order to guarantee the cohesion of the system, because it obstructs the tendency of celestial matter towards dispersion. Thus the cohesion of the world cannot be possible if an unlimited vacuum exists. In this point, Bacon seems to hold that the quantity of

24 Bacon, op. cit. (2), iii, 743.

25 Bacon, op. cit. (2), iii, 771. The English translation quoted belongs to F. Bacon, *The Oxford Francis Bacon* (ed. G. Rees and L. Jardine), 13 vols., Oxford, 1996–, vi, G8v, 177.

26 Bacon, op. cit. (2), iii, 744; Bacon, op. cit. (25), vi, E7r, 127.

27 Bacon, op. cit. (2), iii, 744; Bacon, op. cit. (25), vi, E7r, 127.

vacuum which the system of the world tolerates is confined to the microscopic portions of interspersed vacuum.[28]

The explanation of tides in *De Fluxu et Refluxu Maris* follows coherently the evolution of Bacon's ideas on vacuum.[29] This short treatise, unfinished and posthumous, was probably written in 1611, after *Phaenomena Universi* (written in the same year) and shortly after the works on astronomy. Bacon proposes two possible descriptions of what a tide is: 1) a progressive motion, 2) a motion of ascent and descent of water. If it is assumed that the tide is a motion of kind 2), its causes could be: a) an increase in the amount of water emanated from the bottom of the sea; b) an increase in volume (rarefaction) of water without a change of quantity; c) a rise of water without increasing its volume. In *De Fluxu* alternative c) is rejected because it would involve the existence of a vacuum between the bottom of the ocean and the sea water.[30]

Later, in *Novum Organum* (published in 1620), the question of the tides is considered in order to illustrate the famous crucial instances. The explanatory scheme of *De Fluxu* is slightly modified. One of the alternatives proposed in *Novum Organum* assumes that the ascent of water is caused by a magnetic force which attracts water by consent. This consent can attract all the sea or some zones, in which case a descent in non-attracted zones is produced simultaneously. The first case coincides with explanation c) proposed in *De Fluxu* and is rejected for the same reason: 'if the waters had any such tendency to rise, it would be broken and restrained by the bonds of nature [*nexus rerum*], or (as they commonly say) to prevent the occurrence of a vacuum'.[31] Consequently, the second case is said to be plausible.

The point which matters here is the rejection of vacuum involved in both arguments on tides. In *De Fluxu* alternative c) is said to presuppose the existence of vacuum. Without appealing to any additional justification, Bacon points out that the falsity of this presupposition is obvious enough to reject such an alternative. The question of tides reappears in *Novum Organum*, about ten years later, in a quite different framework: Bacon's natural philosophy is now more mature and has developed its own vocabulary. The treatment of tides is based on a specific theory of motion according to which, when distinct appetites for motion coexist in the same body, the motion which tends to the greatest good for the universe will prevail.[32] In the case of tides, two appetites coexist: the appetite for ascent and the appetite for contact. According to the rule of dominance, the appetite for contact will prevail, since its purpose is the union of the universe. Instead, if a vacuum existed at the bottom of the sea, an interruption of the cohesion of the

28 Bacon, op. cit. (2), iii, 744, 772. *Descriptio Globi Intellectualis* is a topic of natural history, so that Bacon rarely makes categorical affirmations. Therefore we must not consider that his acceptance of an interspersed vacuum was absolutely indubitable in the sense that he affirms it categorically.

29 Bacon's theory of tides was influenced by Gilbert and Patrizi. He knew also Galileo's theory as we can see in Bacon, op. cit. (2), i, 327. Cf. S. Kelly, 'Gilbert's influence on Bacon: a re-evaluation', *Physis* (1963) 5, 249–58 and P. Rossi, 'Galileo e Bacone', in *Saggi su Galileo Galilei* (ed. Carlo Maccagni), 3 vols., Florence, 1972, ii, 248–96.

30 Bacon, op. cit. (2), iii, 49.

31 Bacon, op. cit. (2), i, 296. The translation quoted belongs to F. Bacon, *New Organon* (ed. L. Jardine and M. Silverthorne), Cambridge, 2000, 161.

32 Bacon, op. cit. (2), i, 349.

universe would occur. Hence motion of ascent is subdued because it only affects the water and the astral bodies.

Until now we have drawn attention to the question of vacuum as discussed in very different works of Bacon's. The perspective and context of the works on astronomy and *De Fluxu* actually differ from those of the *Cogitatio I*. In the first works, the topic suggests taking as a reference the largest cosmic masses. In contrast, the reflection of *Cogitationes* concentrates on the minute parts of bodies. However, both perspectives in some way coincide in the use of extrapolations in their arguments on vacuum. In other words, Bacon insists on nature's uniformity, and consequently on the application of quantitative extrapolations, both in *Cogitationes* and the astronomical texts, even though his position on collected vacuum changes from the former work to the latter. In *Cogitationes*, from the microscopic saffron-water solution he infers the cosmic mixture which could exist between collected vacuum and interplanetary ether. In *Descriptio*, in contrast, the reasoning is upside down: there cannot exist a collected vacuum in interplanetary space, for if the proportion between starry matter and collected vacuum is the same as the proportion between the matter of minor bodies and the interspersed vacuum then the world would disperse.

Again, this reasoning conforms to the experimental results presented in *Phaenomena Universi* – a work composed during the same period as *Descriptio* and *Thema Coeli*. There, Bacon reports his first experimental researches on the degree of contraction and dilatation tolerated by several substances, especially fluids. As a result, he starts to define his ideas on the necessary limits of an interspersed vacuum in order to explain the observed degrees of contraction and dilatation. The research continues in *Historia Densi et Rari*, where Bacon finally rejects not only collected vacuum but also interspersed vacuum.

De Principiis atque Originibus, an unfinished work on Democritean and Telesian philosophies composed before 1611, deals shortly with the question of vacuum in the section concerned with Telesio. Bacon understands that Telesio and Democritus believe in an infinite collected vacuum 'so that individual entities may lay aside and sometimes even desert the one contiguous to them, with difficulty (as they say) and against their will, when indeed subdued and compelled by some greater violence'.[33] According to Bacon, Telesio tries to support his opinion with the same experiments that others had used in order to establish the non-existence of vacuum.[34] After shortly criticizing Telesio by stating that his arguments are as abstruse as those of his opponents, Bacon postpones the central exposition on vacuum. He only announces what questions are to be dealt with in the section on vacuum. All of them are concerned with quantitative aspects of nature: to what degree is a vacuum admissible? How far can the seeds of things (atoms) be congregated and separated? What quantities are absolute and necessary?[35]

The question of vacuum is once again considered in *De Principiis*, when discussing the cosmology of Anaximenes, who postulated that air was the basic principle of nature.

33 Bacon, op. cit. (2), iii, 115; Bacon, op. cit. (25), vi, M7v, 261.

34 B. Telesio, *De Rerum Natura Iuxta Propria Principia*, Naples, 1586, lib. I, Chapter 25; cf. Schmitt, op. cit. (1) and Grant, op. cit. (1), 97–8.

35 Bacon, op. cit. (2), iii, 116; Bacon, op. cit. (25), vi, M8v, 263.

Bacon thinks that, if the criterion for determining which body is the first principle is the volume of this body, then air must be the primordial principle of nature. In fact,

> unless a separated vacuum be granted, or that superstition concerning the heterogeneity of heavenly and sublunary bodies be adopted, it seems that all the space from the globe of the Earth to the extremities of the heavens, and all that is not star or meteor, is filled with an airy substance.[36]

This fragment has been interpreted as a denial of collected vacuum.[37] It seems to me, however, that such a conclusion is not tenable. Bacon confines himself to saying that Anaximenes' thesis is correct, unless there be a collected vacuum – as the atomists claim – or ether – as Aristotelians declare. The second alternative is said to be superstitious, whereas the first is simply mentioned. If Bacon's purpose was to conclude that both alternatives are false, why did he not reject the thesis of a collected vacuum in the same way that he explicitly rejected the ether theory? It is likely that at this stage Bacon did not want to express a definitive position on vacuum. Maybe the projected but unwritten section on vacuum would have been clearer. It is also very probable that in this planned section Bacon would have denied a collected vacuum in the same way that he did in the works on astronomy, written at about the same time as *De Principiis*.

Before we get to the next stage, we may speak about the unfinished *De Viis Mortis*, a work which was probably composed between 1610 and 1619. An important section of this work is concerned with Bacon's theory of pneumatic matter. In this part there is a fragment especially interesting for Bacon scholars. When trying to make clear what is understood by 'spirit' Bacon wrote, 'we are not talking about cavities or vacuities or spaces in things, but simply about a material body ... which fills [*implet*] spaces'.[38] Even though the passage does not talk about the question of vacuum, it affirms that spirits fill the cavities or vacuities of bodies. Actually, spirits themselves are responsible for the construction of such cavities in bodies as a result of their motion. Thus it is indirectly assumed that bodies are conceived as filled with tangible and pneumatic matter. Maybe Bacon did not realize the implications of his matter theory at the moment he was writing *De Viis*, but this passage seems to contain potentially the conclusion to which he will come later in *Sylva Sylvarum* and *Abecedarium Novum Naturae*. Unfortunately the range of possible dates for the drafting of *De Viis* is too broad to allow drawing any definite conclusions about its role in the chronology of Bacon's views on vacuum.[39]

During the period between the writing of *Phaenomena Universi* and *Historia Densi et Rari*, *Novum Organum* represents a turning point. For non-empirical reasons, Bacon denies that atoms are solid bodies moving in a vacuum. Now he conceives of matter as being flexible (*fluxa*), provided with, as he says, *plicae* (folds), which enabled matter to change its volume without any need for interspersed vacua.[40] Moreover, in the

36 Bacon, op. cit. (2), iii, 88; Bacon, op. cit. (25), vi, K6, 215.

37 Rees, op. cit. (3), 557.

38 Bacon, op. cit. (25), vi, 23r, 338. I have modified the translation which reads 'occupies' for 'implet'.

39 On the date of *De Viis Mortis* see Bacon, op. cit. (25), vi, pp. xxxi–xxxiii.

40 For an interpretation of the reasons for this change in *Novum Organum* see S. Manzo, 'Francis Bacon and atomism: a reappraisal', in *Late Medieval and Early Modern Corpuscular Matter Theories* (ed. Ch. Lüthy, J. Murdoch and W. Newman), Leiden, Boston, Cologne, 2001, 209–43.

classification of motions he relegates to the second plane of importance the 'motion of connection', a motion by which bodies avoid the occurrence of vacuum. Although this motion is said to be very powerful, Bacon is not yet sure that it prevails over every other motion.[41]

However, Bacon does not yet express an absolute disapproval of the existence of vacuum, collected as well as interspersed. He is only convinced that the reasons adduced in favour of the existence of vacuum are false. It is remarkable that these are the same reasons by which in *Cogitationes* he had accepted the existence of an interspersed vacuum:

> We are still uncertain whether the motion of *bonding* is invincible. And we have not stated for certain that there is a vacuum, whether collected [*coacervatum*] or interspersed [*permixtum*]. But we are certain that the reason why the vacuum was introduced by Leucippus and Democritus (namely because without it the same bodies could not enclose and fill spaces of varying size) is false. For there are folds in matter [*plicae materiae*] which wind and fold through space, within fixed limits, without the intervention of a vacuum; and there is not two thousand times more vacuum in air than there is in gold (as there would have to be).[42]

An important point will be noted here. We can see that in spite of the modification of his view on vacuum between *Novum Organum* and earlier works, an important conceptual continuity is apparent. In *Novum Organum*, Bacon still attaches great importance to the necessity of fixed limits (*termini certi*) in the processes of contraction and dilatation, in the same way that he resorts to *termini certi* referring to celestial vacuum in *Descriptio*. For that reason, it is not a surprise that Bacon appeals to an empirical fact involving quantitative relationships when discussing vacuum in *Novum Organum*.[43] According to his calculus, air is a hundred times rarer than water, and the proportion of density between gold and water is approximately 1000:56.[44] Therefore he must have estimated that the density of gold is 1900 times higher than the density of air. At the same time, the calculation of the vacua contained in air can be derived from the proportion of vacuum contained in gold (approximately two thousand parts of vacua to one part of gold).

Why did Bacon propose this empirical example? By this time he had probably tried experiments concerning the density of pneumatic bodies and prepared the comparative tables of densities. It is possible that he aimed at comparing the amount of empty spaces of extremely rare and extremely dense bodies. Now, according to the table of *Historia Densi et Rari*, gold and fire are the densest and the rarest bodies respectively. However, for several reasons he did not make such a comparison. Although in *Historia Densi et Rari*, against a scholastic quantitative rule, he denies that fire is ten times rarer than air,[45] he does not establish a proportion between fire and other substances. In the second place, he maintains that terrestrial fire does not have the same properties as celestial fire, for it is extinguishable, distributed in little amounts and surrounded by air. In contrast, celestial

41 Bacon, op. cit. (2), i, 347; iii, 115; Bacon, op. cit. (25), vi, 19r, 326.
42 Bacon, op. cit. (2), i, 347; Bacon, op. cit. (31), 206. Original emphasis.
43 Urbach, op. cit. (3), 79–81.
44 Bacon, op. cit. (2), ii, 245, 259.
45 Bacon, op. cit. (2), ii, 259.

fire is 'favourably' situated, constant and able to form planetary bodies. Bacon must have concluded that these differences somehow modify the density of fire.[46] Further, it would be empirically impossible to compare two equal weights of gold and fire, for it would be necessary to obtain a very large mass of fire. This may be the reason why he contrasts gold with air, the latter being highly rarefied and actually available in large masses. In opposition to terrestrial fire, air is 'well' situated surrounding the surface of the Earth and not hindered by any substance.[47]

Although the non-necessity of vacuum for changes in volume is clearly established, Bacon does not come to deny categorically any kind of void. This observation could seem to overlook *Thema Coeli*, where he pronounced his opposition to the assumption of a collected vacuum. However, we should take account of the role of *Novum Organum* in Bacon's career. This work was designed to be a key part added to the presentation of the Great Instauration to the public. Its main purpose was to set the tone for the methodological rules aimed at the renovation of sciences. Hence theoretical aspects of philosophy are only touched implicitly. In contrast, *Thema Coeli* is an eminently speculative text. Bacon did not want to publish it immediately, maybe because he deemed his assertions not to be sufficiently investigated according to his own methodological rules. Thus, without facing the risk of public diffusion, he felt free to say openly what he thought about the world system.

A few years later, in *Historia Densi et Rari*, Bacon affirms that the cavities of tangible bodies are filled with pneumatic matter (air or spirits) rather than by vacuum, 'for these cavities of tangible things do not admit of a vacuum, but are filled either with air or with the proper spirit of the thing'.[48] Probably the image of matter-folds as the concept to explain changes in volume is inspired by the idea of pneumatic matter. Experimental reports of contraction and dilatation, which he shortly dealt with in *Phaenomena*, are expressed in terms of plenum of matter. Thus in 1623 (*Historia Densi et Rari*), in the light of experiments which easily agree with the cosmological grounds assumed a priori in 1612, the doubts that had persisted in 1620 (*Novum Organum*) were dissipated. At this point Bacon comes to his more decisive conclusion on vacuum: 'There is no vacuum in nature, either collected or interspersed.'[49] Thus Bacon's vacillations on vacuum come to an end.

Experiments on void

After presenting Bacon's successive positions on vacuum, we can analyse his arguments by drawing attention to the experiments traditionally cited in polemics on vacuum which Bacon mentioned and discussed.[50] From antiquity, a number of experimental instances in favour of or against the existence of vacuum had been collected which medieval and Renaissance thinkers were re-examining. These experiments can be grouped in three

46 Bacon, op. cit. (2), i, 359; iii, 769–70.

47 Bacon, op. cit. (2), iii, 762–3.

48 Bacon, op. cit. (2), ii, 213; v, 321.

49 Bacon, op. cit. (2), ii, 303; v, 398; cf. ii, 121, 284, 374.

50 We use 'experiment' in the wide sense that the word had for Bacon. See L. Jardine, *Francis Bacon: Discovery and the Art of Discourse*, Cambridge, 1974, 136–7.

classes: experiments on changes in volume, experiments on absorption, experiments on dissolution of continuity.

As for the first class, one of the most famous examples is the experiment of the candle, known through Philo of Byzantium and Hero of Alexandria.[51] A burning candle is placed in a vessel which contains water at the bottom. A glass covers the candle, resulting in the flame vanishing and the water rising inside the glass.[52] Some scholars, for example Peter of Auvergne, claimed that the ascent of the water was caused by the attraction that heat produced on it.[53] Bacon rejects this explanation and assumes that the real cause of the water rising is the motion of bonding. In so far as the flame is being extinguished, because of the decrease of air, water goes up very slowly. Once the flame is completely extinguished, a rapid ascent of water is observed, apparently because the space formerly occupied by the flame is now gradually being occupied by air. Bacon reports variations of the experiment consisting in using different substances instead of water (meal, sand and oil). He recognizes that in the case of oil, heat causes a slight attraction just when the glass is put upon the bowl. This experiment is linked with the effect of cupping glasses which Bacon also explains in terms of the motion of bonding.[54] The warmed air, once in contact with the flesh, decreases abruptly its temperature and contracts. Consequently, it attracts the flesh in order to fill the space formerly occupied by the dilated air.[55]

Another instance of the first class of experiments is the supposed decrease of the volume of water upon freezing. Concretely, it starts with the question of what would happen if the water filling an absolutely closed container became frozen. The anti-vacuist interpretations, for example Toletus', normally assumed that, even though water would contract, no vacuum would be produced inside the container, for the exhalations of water fill up the empty space. Other anti-vacuists, like the Coimbran commentators, maintain that either water does not freeze well or, if it does, the receptacle breaks up naturally in order to avoid the formation of a vacuum. On the contrary, Telesio and Patrizi assume that the contraction of water is produced without breaking the receptacle and, hence, that a vacuum is produced. It is interesting to note that it seems to be commonly assumed (the only late medieval exception I am aware of being Paulus Venetus[56]) that water decreases in volume upon freezing.[57]

51 Bacon, op. cit. (2), i, 351–2; ii, 635. Fludd, von Guericke and van Helmont also describe this experiment. Cf. J. R. Partington, *A History of Chemistry*, 4 vols., London and New York, 1961–70, ii, 595; A. G. Debus, *The English Paracelsians*, London, 1965, 116–18 and *idem*, *The Chemical Philosophy: Paracelsian Science and Medicine in the Sixteenth and Seventeenth Centuries*, 2 vols., New York, 1977, ii, 329–59.

52 Bacon, op. cit. (2), i, 351; iii, 24.

53 P. Duhem, *Le Système du monde*, 10 vols., Paris, 1913–59, viii, 132–3.

54 The case of cupping glasses and its relation to vacuum was considered by Plato and the Hippocratic school. Cf. C. De Waard, *L'Expérience barométrique. Ses Antécédents et ses explications*, Thouars, 1936, 14. See also Hero of Alexandria, op. cit. (7), B1v.

55 Bacon, op. cit. (2), i, 351–2; ii, 267; iii, 25, 711.

56 Paulus Venetus, *Expositio Pauli Veneti super octo libros Physicorum Aristotelis necnon super commento Averrois cum dubiis eiusdem*, 1499, liber IV, fol. xiiii v. Isaac Beeckmann denies the condensation of water upon freezing, arguing against Bacon's conception of the relation between cold and condensation. See Gemelli, op. cit. (3), 207–8.

57 De Waard, op. cit. (54), 16 ascribes to Johannes Canonicus the claim that water contracts when freezing. Schmitt, op. cit. (1), 357–9; Grant, op. cit. (1), 81–2.

Bacon mentions this fact indirectly and in a context independent from the polemic on vacuum. His purpose is to determine what happens in bodies when they are contracted by cold. In the process of freezing, he says, 'the whole body [of water] does not diminish in size, but rather swells'.[58] Condensations are produced in some parts of water more than in others, but the total volume remains invariable. In another part of *Historia Densi et Rari*, devoted to the investigation of dilatations produced forcibly, he again makes observations on ice, specifically on the spirits inside frozen water. Bacon concludes that they dilate inside ice because of the contraction of the water. For this reason, in places where formerly there was air, channels are produced filled with spirits. The motion of connection or motion of bonding is appealed to for explaining this phenomenon: 'the more gross parts are contracted by cold, so that they leave place within the body; hence, if no body comes on, the pre-existent spirits extend by means of the motion of connection'.[59] Finally, Bacon denies that a vacuum is produced by freezing and discards the evidence of the decreasing volume of water traditionally assumed. It seems that he grounded his conclusion on his own direct experience, not on thought experiments.

The best-known experiment of the second class uses a vessel filled with ashes absorbing water. According to the version of the experiment going back to Aristotle, a vessel filled with ashes can absorb as much water as if it were empty.[60] Hence vacuists conclude that ashes have minute and imperceptible empty spaces which are being filled in as long as water enters in the vessel. Aristotle denied that conclusion, asserting that the alleged coming of the water would imply that two bodies occupy the same place at the same time.[61] Bacon not only, for the first time in history, questions the validity of the experiment,[62] but also criticizes the attitude of the Ancients towards received experimental reports:[63]

> It is strange how the ancients took up experiments upon credit, and yet did build great matters upon them. The observation of some of the best of them, delivered confidently, is, that a vessel filled with ashes will receive the like quantity of water that it would have done if it had been empty. But this is utterly untrue; for the water will not go in by a fifth part. And I suppose that that fifth part is the difference of the lying close or open of the ashes; as we see that ashes alone, if they be hard pressed, will lie in less room; and so the ashes with air between lie looser, and with water closer. For I have not yet found certainly, that the water itself, by mixture of ashes or dust, will shrink or draw into less room.[64]

58 Bacon, op. cit. (2), ii, 294; v, 389.

59 Bacon, op. cit. (2), ii, 284–5; v, 380.

60 Averroës affirms never to have witnessed the experiment. He thought that the coming of so much water was not produced because of the pre-existence of an interspersed vacuum but because ashes corrupt portions of the water. Scholastics were more prone to this interpretation than to Aristotle's. Cf. Grant, op. cit. (1), 81–2.

61 Aristotle, *Physica*, IV, 6, 213b21–22; 214b7–8.

62 Meinel, op. cit. (14), 85–9. As usual at that time, Buridan had pointed out that it is impossible that exactly the same quantity of water comes into a vessel filled with ashes as into an empty vessel, but rather a smaller quantity of water. However, he does not seem to have confirmed this experimentally. Cf. Grant, op. cit. (1), 71–2.

63 Bacon, op. cit. (2), i, 401. For the social criteria for the evaluation of experimental reports in seventeenth-century England see S. Shapin, *A Social History of Truth: Civility and Science in Seventeenth-Century England*, Chicago, 1995.

64 Bacon, op. cit. (2), ii, 354.

The experiment with the ashes is linked with Bacon's concept of the expansion of bodies, largely explained in *Historia Densi et Rari*.[65] In the comment on the comparative tables of specific gravities of compact bodies with regard to their dusts, he points out that the difference between these gravities indicates the degree of porosity of the body. In porous bodies the posture (*positura*) of corpuscles is more separated; that is to say, there are minute spaces among them. Bacon does not say whether those spaces are empty or filled with matter with negative weight (namely pneumatic matter). Later, in agreement with *Sylva Sylvarum*, this omission is made up for when he recommends, with the purpose of researching the condensations produced by saturation (a kind of pseudo-contraction), measuring accurately how much water comes into a receptacle filled with compressed ashes in order to fill the places formerly occupied *intermisto aere*. Bacon himself suggests the similarity between this experiment and the image of the saffron-water solution. In *Sylva Sylvarum*, he generalizes the phenomenon by ascribing it not only to ashes but also to any kind of dust, as he compares saffron with dust in *Cogitationes* where he affirms that saffron is much subtler than any other dust so that it allows for a very fine mixture.[66]

Experiments of the third class were traditionally understood in terms of the appetite of matter for its own continuity. Many authors supported their arguments against the existence of vacuum by appealing to the principle according to which matter does not tolerate being separated and, consequently, 'abhors a vacuum'.[67] From this point of view, for example, they explain the working of water clocks, one of the most famous models throughout the centuries.[68] Bacon knew the experiment very well. In *De Principiis*, he describes Telesio's vacuistic view of it. According to Telesio, if a water clock has a very small aperture through which the water drips, it will need an air hole to let the water descend. In contrast, if the aperture is larger, the water – because of the pressure caused by the larger volume – will descend even without a vent. Antivacuists, in contrast, were convinced that if the water clock is filled with water, water will not go out because a vacuum would result. Yet, if the clock is half full of water, water can drip because the air in the upper part is rarefied.

Like Hero, Bacon does not refer strictly to water clocks but to pots which have a similar structure to water clocks.[69] In *Spiritualium Liber* Hero maintains that wine enclosed in a semi-filled receptacle with a tiny aperture at the bottom cannot run out because no air can come in to fill the place left by the wine.[70] In the same way, Bacon says that the water contained in closed water pots cannot run down through its holes, because there is a

65 Bacon, op. cit. (2), ii, 253.

66 Bacon, op. cit. (2), ii, 301, 354; iii, 15.

67 The Coimbrans, Bartholomeus Keckermann and Giovanni Battista Della Porta are some defenders of this argument. Cf. De Waard, op. cit. (54), 61–2; E. Grant, 'Medieval explanations and interpretations of the dictum *Nature abhors a vacuum*', *Traditio* (1973), **29**, 327–8 and *idem*, op. cit. (1), 96.

68 De Waard, op. cit. (54), 15 mentions Philo of Byzantium as trying the experiment. Cf. Aristotle, *Physica*, IV, 6, 213a25–213a27. On clepsydra experiments in the Middle Ages and in the sixteenth century see Schmitt, op. cit. (1), 359–61 and Grant, op. cit. (1), 83–6.

69 The term 'clepsydra' was used to denote a number of different vessels designed to contain liquids, as for example pipettes, siphons and so on. Cf. Duhem, op. cit. (53), viii, 135–6.

70 Hero of Alexandria, op. cit. (7), D3v.

retractiva natura which impedes it.[71] In spite of its apparent being at rest, the tendency of water to run down continues. In fact, water tries to run down but, since no new air can be introduced to fill the places which would be empty after the running out of the water, it does not actually run. Thus Bacon's explanation implicitly presupposes the abhorrence of vacuum.

Since according to Bacon's view motion and tendency to motion are actually the same thing, in water pots water 'moves', even though it does not run down. There is no absolute rest in nature. By assuming the non-existence of absolute rest, he maintains a clear distinction between *solida natura* and *liquida natura* (also called 'consistent' and 'fluid', respectively). Bacon discards the opinion according to which solid substances remain at rest while liquid substances move constantly. Every body has an appetite for continuity, rejecting the separation of its parts. The appetites of both classes of substance only differ in the degree of intensity: it is weaker in liquid substances. That is the reason why the motion of gravity dominates in liquid more than in solid substances.

The appetite for continuity was characterized by Bacon as being a special kind of motion of bonding. In fact, it also was named *motus nexus secundi* (motion of second bonding): 'Bodies also put up with separation of their parts and disruption of their continuity unwillingly, some however with more difficulty (like stable bodies), others more easily (like fluids).'[72] This appetite led bodies to want to be always in contact with themselves. A typical example of this is water, which extends in tiny threads, resists being separated and, once the thread is broken, tries to congregate its parts again in the form of drops.[73]

The water pot experiment reappears in *Novum Organum*. The intention of interpreting the experiment is the same as in *Cogitationes*: to make it clear that the state of rest is only apparent and that there is always a resistance against it. However, in contrast to *Cogitationes*, in *Novum Organum* the rejection of vacuum is made explicit in the explanation of the experiment. Bacon maintains that in water pots a conflict of appetites occurs: the appetite for gravity competes with the appetite for contact. But because of the rule of domination of common good over private good, the motion of bonding prevails because it involves the union of the universe, while the motion of gravity only affects the union of dense bodies.[74]

This is the only example where Bacon interprets the abhorrence of vacuum by means of an argument used by some Aristotelians appealing to the superiority of the appetite for continuity, as they thought that although all bodies are submitted to a particular nature (which tends to its own private good), there is a universal nature which strives towards the common good and, in case of conflict, prevails over the particular nature. This

71 Bacon, op. cit. (2), iii, 25.

72 Bacon, op. cit. (25), xiii, fo. 29v, 193.

73 Bacon, op. cit. (2), i, 273, 333, 561. A similar view is to be found in *Commentarii Collegii Conimbricensis Societatis Iesu in Octo Libros Physicorum Aristotelis Stagiritae*, Coloniae, Haeredum Lazarus Zetznerus, 1616, liber IV, cap. IX, quest. I, art. III, col. 79. The union of water in drops drew the attention of many authors; see De Waard, op. cit. (54), 159–60, 164–5.

74 Bacon, op. cit. (2), i, 177, 717.

teleological argument, whose first exponents are to be found in the thirteenth century,[75] was used in a similar way by Toletus and the Coimbrans to explain why bodies react in an extraordinary way when they try to avoid the formation of a vacuum.[76]

The case of bellows was widely discussed. A commonly assumed experiment shows that if bellows are well closed, their sides cannot be separated, unless an orifice be made or the bellows be somehow broken by force.[77] Antivacuists hold that, like in the former case, matter abhors a vacuum and for that reason the sides do not tolerate separation. Because of the principle of common good, the sides are said to prefer being abruptly broken rather than allow the creation of a vacuum. Bacon examines the question in his *Phaenomena Universi*, with the purpose of exploring the limits of condensation tolerated by air:

> If there is no valve in a pair of bellows, the bellows are suddenly raised and opened, they break; and of course they do so because when its belly suddenly goes from flat to expanded a quantity of air large enough to fill it cannot be drawn in through the narrows of the bellows' bill, and the air inside them cannot be stretched sufficiently.[78]

Implicitly, Bacon thinks that the bellows break because it is impossible to introduce new matter in order to fill the vacuum which would be produced after the aperture. The mass of air which they enclose when they are closed cannot be expanded to the point of filling them during the opening. Matter can only be expanded (by means of its *plicae*) up to a fixed point, because the appetite for continuity impedes an excess of expansion producing a vacuum. For the same reason, Bacon affirms that an inflated bladder tolerates as much compression as does the air, but its toleration has a limit after which the bladder bursts.[79]

Arguments and strategies

The reconstruction of Bacon's different positions on vacuum and his analysis of the experimental instances shows that he tackles the question from two perspectives: a theoretical a priori and an experimental viewpoint. Sometimes one of them prevails in certain periods. But at other times they coexist in the same work. It cannot be said that one has been more important than the other. Each of them seems to have complemented and influenced the other. Moreover it is not possible to speak of a 'pure' theoretical and a 'pure' experimental standpoint as two absolutely different views. However, there is no doubt that some approaches are predominantly empirical and others are predominantly theoretical. I make no claim that Bacon indeed used experimental techniques in order to

75 Grant, op. cit. (1), 69–70 deems it probable that the distinction between natures ultimately stems from the anonymous *Liber de Causis* translated from Arabic to Latin in the twelfth century. In the thirteenth century it was adopted, for example, by Roger Bacon and Walter Burley. On universal nature in medieval thought see Duhem, op. cit. (53), viii, 134–68.

76 D. Des Chene, *Physiologia: Natural Philosophy in Late Aristotelian and Cartesian Thought*, Ithaca and London, 1996, 174–6; Grant, op. cit. (67), 329–31; Schmitt, op. cit. (1).

77 De Waard, op. cit. (54), 17; Schmitt, op. cit. (1), 355–7 and Grant, op. cit. (1), 82–3.

78 Bacon, op. cit. (2), iii, 704; Bacon, op. cit. (25), vi, Q1r, 45.

79 Bacon, op. cit. (2), i, 323; iii, 703.

investigate the void. What I do claim is that Bacon dealt sometimes with the question of vacuum by means of arguments which referred to experimental evidence. Most of the experimental evidence that he referred to was probably originated in mental experiments, a quite common practice.

The dual treatment of the problem is already visible in *Cogitationes*. On the one hand, the theoretical approach is used when arguing about the possible existence of a collected vacuum in the heavens. In this case, Bacon conceives of nature as subjected to universal proportions, which would make it licit to apply quantitative extrapolations. The extrapolation which links the solution of saffron in water with the interspersed vacuum in bodies and the collected vacuum in the heavens is grounded in the uniform quantitative relationships within nature. On the other hand, the experimental approach is to be found in the search for an explanation of contraction which led Bacon to affirm the existence of an interspersed vacuum, just like it was defended by Hero and the atomists.

As for the works on astronomy, experimental data do not play any direct role. In contrast, the theoretical approach pervades them. For quantitative reasons, Bacon claims that the hypothesis of a collected vacuum hinders the cohesion of the universe. This quantitative view must have been influenced by the experimental research of the contraction and dilatation tolerated by different substances reported in *Phaenomena Universi*, where Bacon was concerned with the quantitative limits of expansion and contraction in macroscopic bodies. In the same way, he thought of the limitations of the universe in order to guarantee its cohesion as an inviolable principle of a teleological view of nature.

After the first discussion offered in *Cogitationes*, Bacon's view on interspersed vacuum mainly depended on the experimental instances reported in *Phaenomena Universi* and later works. The influence of these experiments can be found clearly in *Novum Organum*, where the thesis according to which contraction and dilatation occur without an interposed vacuum is connected with experimental facts. On the one hand, we observe the important repercussions of the table of specific gravities and the table of bulks (*exporrectiones*) of pneumatic bodies, from which Bacon calculates the proportion of vacua which a quantity of air and gold should contain. On the other hand, experiments to find out the limits of contraction and dilatation tolerated by pneumatic matter must have led Bacon to devise the model of matter's *plicae*. The extreme mobility and adaptation of gases indicate that they fill the places by unfolding themselves: 'This is clear enough to us from the powerful virtues of pneumatic bodies (which otherwise would swim in a vacuum like tiny specks of dust), and from many other demonstrations.'[80] Bacon homogenizes his image of nature once again: departing from the observation of the properties of a particular kind of matter (namely pneumatic matter) he applies its properties to every matter. Given this new conception of matter, the interspersed vacuum is, consequently, unnecessary. Finally, the definitive denial of both kinds of vacuum arises in the predominantly experimental context of *Historia Densi et Rari*, after exposing in more detail the experiments of contraction and dilatation formerly introduced in *Phaenomena Universi*.

80 Bacon, op. cit. (2), i, 347–8; Bacon, op. cit. (31), 206.

Some historians have interpreted the antivacuist position of the last works by examining again the three alternative explanations of contraction proposed in *Cogitationes*. Thus they have asked which of those three hypotheses have become the favourite in Bacon's last position. Peter Urbach points out that when denying vacuum Bacon accepted the second alternative, which had been rejected in *Cogitationes*. In other words, contraction would be produced by the ejection of the subtler matter.[81] Mary Hesse indirectly suggests that Bacon finally accepted the explanation according to which contraction is produced by a change of quantity without an alteration of other properties, an assumption that he apparently ascribed to Aristotle,[82] though he had rejected it in his *Cogitationes*.

However, it seems to me that Bacon's final position on vacuum may not be reduced to and reinterpreted in the same terms he used to expose the question in *Cogitationes*. In *Historia Densi et Rari* Bacon enumerates the following causes of contraction: actual cold or remission of heat, potential cold, dominance of a denser and more active body, flight, antiperistasis and external force. Yet none of the three causes proposed in *Cogitationes* reappears in *Historia Densi et Rari*. Undoubtedly the differences between both works are correlated to the different conceptions of matter maintained in each of them: in *Cogitationes* Bacon assumes the hypothesis of solid atoms, whereas in *Historia Densi et Rari* he defines matter as flexible.

We do not ignore the fact that Urbach's interpretation might have some ground, especially if attention is drawn to *Abecedarium Novum Naturae*, composed around 1622. There Bacon clearly holds that the interspersed vacuum postulated by Democritus is nothing but tiny spaces filled with pneumatic matter.[83] This could seem to lend support to Urbach's idea, according to which in *Historia Densi et Rari* contraction is conceived as being caused by ejection of the subtler matter. However, it should be observed that in *Historia Densi et Rari* Bacon affirms that the ejection of subtle matter does not produce a real but a pseudo-contraction.[84] In fact, a real contraction implies a change in volume without a decrease of quantity. Therefore, *pace* Urbach, the second alternative was never accepted by Bacon.

When Bacon criticizes the experimental base of Telesio's defence of vacuum, he claims that the experiments are not sufficiently conclusive, not satisfactory or decisive about the question of vacuum. Certainly, Bacon's arguments on interspersed vacuum are sometimes based on empirical facts. Thus, when in *Cogitationes* he analyses the hypotheses for the explanation of contraction, he speaks of experiments (thought or real experiments) and concludes that the assumption of an interspersed vacuum is necessary. In *Cogitatio I*, where he introduces its adherence to atomism, the saffron-water solution is said to be an example of the imperceptible subtlety of nature. However, this fact does not play the role of a crucial experiment. Although the minute saffron particles inside a big mass of water are comparable to the empty interstices inside bodies, Bacon does not introduce the fact as a proof of the existence of an interspersed vacuum. In other words, even though the

81 Urbach, op. cit. (3), 80–1.
82 Hesse, op. cit. (3), 148.
83 Bacon, op. cit. (25), xiii, fo27r–v, 184–6; cf. Bacon, op. cit. (2), ii, 380.
84 Bacon, op. cit. (2), ii, 262, 301.

existence of an interspersed vacuum is affirmed, the case of the saffron-water solution does not aim to prove the existence of vacuum, but only to evoke a picture of how subtle nature is.

The same happens in Bacon's natural histories, where the tolerance of matter for expansion is experimentally investigated. Bacon does not aim to confirm or to disprove the existence of vacuum by this means. Instead, he rather tries to find the most accurate way to explain the imperceptible motions of matter without contradicting its perceptible properties.

As for the collected vacuum between earthly bodies, Bacon denies its existence by appealing to ordinary observation.[85] Later, in *Novum Organum*, he provides an argument supporting this thesis by establishing that the motion of bonding is one of the most common motions in nature. Actually, when Bacon interprets a change as being caused by *fuga vacui*, he does so by arguing that no collected vacuum is observed in the Earth, like he has done in *Cogitationes*. The reasons why Bacon in *Cogitationes* conjectures the existence of vacuum in the middle region of the air were a priori, by extrapolation from what can be observed in macroscopic bodies. This argumentative strategy was mainly grounded on his quantitative approach and, further, on his tendency to generalize the rules in order to bring a homogenized picture of nature by means of extrapolations. The reasons for falsifying the conjecture were a priori and quantitative. A closed and ordered universe must be contained within fixed limits; therefore an interplanetary vacuum cannot exist. Bacon's final position is based on theoretical insights, by appealing to teleological premises linked to his image of the world system, or by extrapolating experimental data from the Earth to the sidereal cosmos.[86] In the result, these mixed and interacting strategies led Bacon to deny the existence of the collected vacuum in the interplanetary space and to favour the denial of collected vacuum of any kind.

A-priori arguments prevail over experimental evidence in medieval and early modern debates on atomism. Arguments for and against the existence of atoms were metaphysical, theological, mathematical, empirical and epistemological. However, empirical proof was not the key for a final and definitive decision.[87] The polemic on vacuum seems to bring us to the same conclusion about the role of experience and theory: experience does not offer enough proof for accepting or rejecting definitively the existence of vacuum. Bacon's case fits entirely into this general pattern. His treatment of void takes into account that theory-free, isolated experimental evidence was insufficient to decide if vacuum were a real component of the universe. Empirical arguments by themselves have little value for solving the question of the void: it was also necessary to have a formerly established theory.

85 Bacon, op. cit. (2), iii, 16.

86 On apriorism in Bacon's natural philosophy see G. Rees, 'Francis Bacon's semi-Paracelsian cosmology', *Ambix* (1975), **22**, 100–1 and *idem*, 'Francis Bacon's semi-Paracelsian cosmology and the *Great Instauration*', *Ambix* (1975), **22**, 163–73.

87 Meinel, op. cit. (14), 101–3.