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Robert Boyle

I. Life and works

Robert Boyle, natural philosopher, was born in 1627 to Richard Boyle and Katherine Fenton. Despite Robert Boyle's status as youngest son of a large family, his father's wealth, influence, and title (first Earl of Cork) afforded him an income and allowed him to devote himself to intellectual pursuits. The young Boyle's education included Eton and private tutoring (both at home and on the continent).

From 1645-55, he made his home in a family manor at Stalbridge in Dorset. There he suffered serious illnesses which left him with a delicate constitution and weak vision (as a result of which all his later publications were dictated to amanuenses). There also a new enthusiasm for experiment (both for its own sake and as a route to religious understanding) turned his attention away from his early ethical writings and towards scientific pursuits. His scientific interests drew him to Oxford, where he assembled a laboratory and became associated with an intellectual/social circle which included many prominent or rising figures in British natural philosophy such as John Wallis, Robert Hooke, and Christopher Wren. Members of this group worked towards founding the Royal Society of London for the Improving of Natural Knowledge, the first modern scientific society, which promulgated the virtues of experimentalism and helped to solidify the successes of the new science.

In 1668, Boyle moved to London, where he took up rooms in the home of his sister, Katherine, Lady Ranelagh. Again he established a laboratory. He also played a role in public life, most prominently in the Royal Society but also in the Society for the Spread of the Gospel in New England. He died in 1691, within a few days of his sister. In his will, he funded a series of sermons, the Boyle Lectures, which were intended, in his words, "for proving the Christian Religion against notorious Infidels, viz. Atheists, Theists, Pagans, Jews, and Mahometans, not descending lower to any controversies, that are among Christians themselves" (Boyle 1772, vol. 1, p. clxvii).

Boyle published prolifically throughout much of his life, but most notably around the 1660's, during which time much of his earlier work came to fruition. He wrote mainly in the areas of theoretical natural philosophy, experimental natural philosophy, scientific methodology, and natural theology. Each of these areas is discussed below, with Boyle's corpuscularian theory receiving special emphasis.

Some of Boyle's most influential individual publications are mentioned below. Until very recently, the standard (though problematic) edition of his works was Boyle 1772, The Works of the Honourable Robert Boyle, edited by Thomas Birch, 6 volumes. (Contemporary reprint editions of the Works are also available.) It now being superseded by the authoritative The Works of Robert Boyle, edited by Michael Hunter and Edward B. Davis (vols. 1-7, 1999, vols. 8-14, 2000). Still more accessible are Boyle 1991, Selected philosophical papers of Robert Boyle, edited by M.A. Stewart, and Boyle 1996, A Free enquiry into the

vulgarly received notion of nature, edited by Hunter and Davis. The Royal Society Boyle Papers (Boyle 1992), a large collection of Boyle manuscripts, is available on microfilm, with an accompanying guide—Hunter 1992. (References below, when not to Boyle 1991 or 1996 are to Boyle 1772, as it is at present still more widely available than Boyle 1999-2000 and most secondary literature is keyed to it.)

II. Theoretical natural philosophy: Boyle's corpuscularianism

The new mechanical philosophy

Boyle's most important philosophical contribution was his role in articulating and advancing the new mechanical philosophy of the seventeenth century. Boyle saw himself as part of a movement which sought to replace scholastic Aristotelian natural philosophy with a highly intelligible natural philosophy according to which bodies are machine-like, and bodily behavior is ultimately explicable in terms of the sizes, shapes, motions, and arrangements of the tiny particles of which bodies are composed.

More specifically, Boyle took on the project of defending a version of the new science which would be both valuable as natural philosophy and salutary for religion. He saw this project as necessary because extant versions of mechanism were flawed. Atomism, promoted by Gassendi, was tainted with atheism and libertinism (despite Gassendi's best efforts to free the theory from these associations), due to its roots in ancient Epicureanism. Cartesianism, the natural philosophy of René Descartes and his followers, was tainted with dogmatism and loaded down with excess baggage, both physical and metaphysical. Boyle coined the very term "corpuscularianism" in order to have a concept that would include the basic tenets shared by atomism and Cartesianism, while leaving out disputed points:

> …the Atomical and Cartesian hypotheses, though they differed in some material points from one another, yet in opposition to the Peripatetic and other vulgar doctrines they might be looked upon as one philosophy…. (Boyle 1772, vol. 1, p. 355)

Boyle's corpuscularianism could thus provide a unified front against its enemies, particularly Aristotelianism. (Boyle is <u>not</u> a sympathetic interpreter of the Aristotelian tradition, though he treats Aristotle himself respectfully. I cannot here consider the justice of his various characterizations of and charges against late Aristotelian natural philosophy.) The other "vulgar doctrine" frequently singled out by Boyle for attack is that promulgated by the "chemists" or "spagyrists" (those who purify substances by separating and recombining their component principles, Principe 1991, p.9), but, as is discussed below in section III, his attitude towards the chemists is in fact a complex one.

Boyle provides a nice outline of the points he sees as being in dispute <u>within</u> the new science, between atomists and Cartesians, in declaring his attention to rise above any such dispute:

> …I have forborne to employ arguments that are either grounded on, or suppose, indivisible corpuscles called <u>atoms</u>, or any <u>innate</u>

> motion belonging to them; or that the essence of bodies consists in extension; or that a vacuum is impossible; or that there are such globuli caelestes, or such a materia subtilis, as the Cartesians employ to explicate most of the phenomena of nature. For these, and divers other notions, I (who here write rather for the Corpuscularians in general, than any party of them) thought it improper needlessly to take in…. (Boyle 1991, p.7)

The distinguishing feature of atomism was its claim that there are ultimate unsplittable particles from which all bodies are composed, together with the claim that there is empty space, a void or vacuum, through which these atoms move. Further, atomists such as Gassendi maintained that atoms have an intrinsic tendency to motion. Descartes, on the other hand, held that because extension exhausts the essence of body, wherever extension exists, body exists; thus, the notion of empty space (vacuum or void) becomes self-contradictory. Instead of a vacuum, there is a plenum: The world is full. Speculative hypotheses about celestial globules or subtle matter are thus fuelled by the need to explain what apparently empty space is in fact full of.

The fundamentals of corpuscularianism

If these issues divide the new science, what unites it? In Boyle's view, it is exactly the principles that he lays out in The Origin of forms and qualities (1666), which, he tells us, may serve as "an introduction into the elements of, the Corpuscularian philosophy" (Boyle 1991, p. 4). In a welcome departure from his usual digressiveness and prolixity, Boyle provides the reader with a ten point sketch of his corpuscularian natural philosophy, occupying just a few pages (Boyle 1991, pp.50-52). A good way to begin an acquaintance with Boyle's theoretical natural philosophy is to consider these points in order.

The corpuscularians teach, first, "That the matter of all natural bodies is the same, namely, a substance extended and impenetrable" (Boyle 1991, p.50). Boyle thus assumes that matter is catholic (everywhere the same), that there is really only one kind of stuff that makes up the physical world. Of course, this is a substantive assumption, although Boyle is right in supposing that it is shared by atomists and Cartesians. It is rejected, however, by his opponents. The Aristotelians (setting aside the controversial notion of prime matter) hold that there are four fundamentally different kinds of material stuff: earth, air, fire, and water. The chemists, as Boyle characterizes them here, uphold the Paracelsian tria prima—mercury, salt, and sulfur—as the three basic ingredients of all bodies.

Partisans of the new science are also unanimous on the point that matter is extended (dimensional or spatial). The notion of impenetrability, however, is trickier. Cartesians suppose that impenetrability simply follows from extendedness, thus eliminating the possibility of a vacuum. For atomists, impenetrability (or solidity) is an additional quality, above and beyond extendedness, which differentiates body from mere space. Boyle attempts to give a neutral account here, but in effect he treats impenetrability as a distinct quality from extendedness, since he assumes that a vacuum cannot be ruled out a priori, as it could be if extension simply implied impenetrability. Thus his sympathies on this issue are more atomist than Cartesian. It is important to note,

by the way, that on any account impenetrability (or solidity) is not supposed to imply indivisibility. Indeed, Boyle sometimes lists divisibility as one of the general characteristics of matter qua matter. Rather, the term "impenetrability" refers to the property all bodies have of excluding other bodies from their location: No two bodies can occupy the same place at the same time. Though Boyle does not use this term, we may refer to extension and impenetrability as the catholic qualities of body.

Boyle's second point is simply to note that since all bodies have extendedness and impenetrability in common, we must look elsewhere for the source of their diversity. Motion has a unique importance here, as is clear from points three and four:

> 3. That motion, not belonging to the essence of matter … and not being originally producible by other accidents as they are from it, may be looked upon at the first and chief mood or affection of matter.
> 4. That motion, variously determined, doth naturally divide the matter it belongs to into actual fragments or parts; and this division obvious experience (and, more eminently, chemical operations) manifest to have been made into parts exceedingly minute, and very often too minute to be singly perceivable by our senses. (pp. 50-51)

Here Boyle gestures at a causal story according to which God adds motion to undifferentiated matter, thus creating particles. The specific causal account is not crucial to the theory, however. It is vitally important to Boyle to assert that motion is not essential to matter, for this is part of his effort to distance corpuscularianism from atheism. Matter moves, so if this motion cannot simply be derived from matter's essence, it must be somehow imposed by God. On the other hand, to endow matter with essential motion is to pave the way to atheism.

Also crucial is the implication that Boyle draws from experience and experiment, that the real action for the natural philosopher is typically at the micro-level. The minute parts of bodies must therefore be carefully characterized, which is the task of Boyle's fifth point. There he observes that each particle must have its own specific size (or bigness or bulk), its own shape (or figure) and must be in motion or at rest. Boyle tells us that size, shape, and motion/rest are thus the "primary … affections of the insensible parts of matter, considered each of them apart" (Boyle 1991, p.51). Boyle calls these minute particles "minima naturalia", a term that may seem to be in tension with his professed agnosticism about atomism. By calling them minima, Boyle means to identify them as the least parts that are ordinarily created by natural processes, particles so small that "nature doth scarce ever actually divide" them (Boyle 1991, p.41). Nevertheless, he denies that these minima are absolutely indivisible: They are divisible mentally (that is, we can conceive of them being divided, since they are extended) and divisible by God. The minima, then, function for practical purposes like atoms. Boyle also employs a molecule-like notion, that of "primitive concretions or clusters … of particles" (Boyle 1991, p.42), which are capable of being further broken down, but which tend to remain united through

most natural processes. Both minima and primitive clusters qualify as corpuscles, the submicroscopic particles relevant to corpuscular explanations.

Boyle's sixth point begins to bring out the reductive nature of the corpuscularian project. The catholic qualities and primary affections of bodies are their basic qualities; further properties of bodies arise from the corpuscles, qualified with these basic qualities, and their spatial relations. In point six, Boyle explains how the spatial relations among particles create further qualities: position (or posture) and order. He then introduces a corpuscularian term of art, "texture", which denotes the spatial structure of an array of corpuscles. For a corpuscularian, if we knew a body's texture (including the size, shape, and motions of the body's component corpuscles), we would know all there is to know about its intrinsic features.

Thus (point seven) the naïve view that sensory qualities (like color, heat, sound, and odor) are further, distinct qualities in bodies, over and above the corpuscularian ones (of extension, impenetrability, size, shape, motion, and spatial arrangement or texture), is mistaken. There is nothing in bodies resembling our perceptions of color, odor, etc. Rather, such qualities are "but the effects or consequents of the above-mentioned primary affections of matter" (Boyle 1991, p.51) on our organs of sense. Thus, Boyle formulates and defends a version of what has come to be called (following Locke's terminology) the primary/secondary quality distinction. Boyle rightly takes the project of explaining away the sensory qualities to be common to all parties of corpuscularians, and thus some version of the primary/secondary quality distinction can be found in his predecessors, notably Galileo and Descartes. Nevertheless, Boyle's version is both influential and philosophically interesting, as is discussed at more length below.

In points eight, nine, and ten, Boyle turns to the task of showing that corpuscularianism can replace every useful concept of Aristotelian natural philosophy. In doing so, he moves beyond his predecessors and extends the philosophical reach of the new science. Boyle is willing to agree with the Aristotelian that we can usefully talk about substances, that is, particular existent things that are members of kinds, e.g. this piece of gold. As Boyle understands it, an Aristotelian holds that what makes a piece of gold a piece of gold is the fact that the right sort of substantial form informs the matter that makes it up. Thus, the generation of a substance can be explained by the acquisition of a substantial form, and the destruction of a substance can be explained by the loss of the substantial form. Boyle finds such talk, when applied to physical things or bodies, to be mysterious and misleading. He argues first that people sort bodies into kinds based on their observable qualities, not supposed occult ingredients:

> …if (for instance) you ask a man what gold is, if he cannot show you a piece of gold and tell you 'This is gold', he will describe it to you as a body that is extremely ponderous, very malleable and ductile, fusible and yet fixed in the fire, and of a yellowish colour…. (Boyle 1991, p.38)

This convention of qualities is what is "essential" to gold, that is, what is required for something to qualify as gold.

However, the corpuscularians do hold, in effect, that there is a hidden source of these observable qualities, namely, the corpuscularian texture of the body-- the particular arrangement of particles, each with their own size, shape, and motion. This, Boyle allows, may be called the form of a body, as long as we understand that this is not something distinct from the matter of a body, but just the matter itself, considered with its particular corpuscular constitution (Boyle 1991, p.40). Now we are in a position to see that the generation or destruction of a substance takes place whenever a body gains or loses qualities so that it newly has all the members of that set of qualities which is required to be a body of a certain kind, or newly lacks one or more of those members. And that takes place whenever the corpuscular constitution of the body has changed in such a way as to change the relevant observable qualities. (Alteration, on the other hand, takes place when a quality is gained or lost which is not in the essential set; this change too will have its corpuscularian explanation.) Given that we do not have sensory access to corpuscular constitutions, this may not seem much of an advance over the Aristotelian view. However, Boyle takes his account to be superior in two crucial respects: (1) It makes clear that the sorting of bodies into kinds is done by us, not nature, and is done on the basis of sensible qualities. (2) The notion of a corpuscular constitution is a clear and intelligible one which anyone can be made to fully comprehend, unlike the notion of substantial form.

Qualities and corpuscularian explanation

Boyle has two favorite mechanical metaphors: the clock, which illustrates the idea that natural bodies and organisms are machine-like, and the lock & key. This second metaphor is the key to his conception of how further qualities of bodies stem from the catholic qualities and primary affections of body:

> We may consider, then, that when Tubal Cain, or whoever else were the smith that invented locks and keys, had made his first lock… that was only a piece of iron contrived into such a shape; and when afterwards he made a key to that lock, that also in itself considered was nothing but a piece of iron of such a determinate figure. But in regard that these two pieces of iron might now be applied to one another after a certain manner, and that there was a congruity betwixt the wards of the lock and those of the key, the lock and the key did each of them now obtain a new capacity…. And proportionably hereunto, I do not see why we may not conceive that, as to those qualities (for instance) which we call sensible, though, by virtue of a certain congruity or incongruity in point of figure, or texture (or other mechanical attributes) to our sensories, the portions of matter they modify are enabled to produce various effects upon whose account we make bodies to be endowed with qualities, yet they are not in the bodies that are endowed with them any real or distinct entities, or differing from the matter itself furnished with such and such a determinate bigness, shape, or other mechanical modifications. (Boyle 1991, pp.23-24)

Thus, the corpuscularian texture of one body, considered in relation to another body with its own texture, provides the first body with the ability, capacity, or power to affect and change the second. For example, we may suppose that the shape and motion of the particles of the acid aqua regia (actually, a mixture of nitric and hydrochloric acids) allow those particles to insinuate themselves into the pores between particles of gold, so as to dissolve gold. Thus, aqua regia has the power to dissolve gold, but this power is nothing over and above mechanical affections: the sizes, shapes, motions, and arrangements of impenetrable particles.

One general moral that Boyle draws from this concerns the importance of relations to the powers or qualities of bodies: We must consider a body's position in the universe if we want a full understanding of its capacities. (In Tracts about the cosmical qualities of things (1670) Boyle extends this doctrine to special qualities which "depend upon… unheeded relations… to the determinate fabrick of the grand system or world…." Boyle 1772, vol. 3, p. 306.) Further, the sensible qualities of bodies (e.g. redness, tartness, and warmth) are capable of this sort of relational analysis. In such cases, our sensory organs are the second body. Saltiness, for example, might be explained by the stiffness and sharpness of salt particles, which thus affect our tongues in a certain way (Boyle 1991, p.149). However, special issues arise in the case of sensory qualities, since for a quality to be sensory, it must somehow be linked to a perception in the mind. Boyle, moreover, is a dualist, and thus believes that the mind is a spiritual, immaterial substance. Boyle tells us that because of the union of the human mind with the human body, the human mind perceives the effects that external objects have on the sense organs and gives them "distinct names, calling the one light or colour, the other sound, the other odour, &c" (Boyle 1991, p.31).

This raises the philosophical question of what exactly, say, the redness of an apple is: Is it (1) an idea/perception in the mind, (2) a change in or state of the sensory organ, here, the eye, (3) a power in the apple, (4) a corpuscular constitution or texture in the apple (or perhaps both (3) and (4) at once, if powers are to be identified with textures), or something else? Boyle does not seem overly concerned with this question, which he might well regard as excessively nice. What is important, in his view, is (1) that we realize what sensory qualities are not, namely, distinct qualities in bodies on a par with size, shape, and motion, and (2) that we understand the basic account of how corpuscularian bodies give rise to experience of sensory qualities via their relation to our senses. Boyle does make the following astute and philosophically suggestive observation:

> …bodies may be said in a very favourable sense to have those qualities we call sensible, though there were no animals in the world. For a body in that case may differ from those bodies which now are quite devoid of quality, in its having such a disposition of its constituent corpuscles that, in case it were duly applied to the sensory of an animal, it would produce such a sensible quality which a body of another texture would not. (Boyle 1991, p.33)

He concludes from this, however, that in a world with no animals, bodies would dispositively but not actually possess colors, tastes, etc., which implies that actual

redness requires actual perception (or, at least, the existence of beings capable of actual perception).

The grounds for and the status of corpuscularianism

We have examined Boyle's own sketch of the content of corpuscularianism and seen some of its implications. What status does this set of principles have for him? An initial answer is provided by the fact that Boyle consistently describes corpuscularianism as an hypothesis. It is a proposal about the fundamental nature of corporeal reality, not something he puts forward as known to be true. Although this fits with the characteristic diffidence of all of Boyle writings, his stance here is more than merely rhetorical. Boyle holds that the mechanical hypothesis should be confirmed or disconfirmed through experiment, but that neither has yet been accomplished. Further, he believes that although the hypothesis is capable of confirmation, it will at best be highly probable, never absolutely certain. Nevertheless, he (undiffidently) holds that corpuscularianism represents the only fundamental and systematic scientific program worth pursuing, and that scholastic natural philosophy should be abandoned.

Indeed, many of Boyle's defenses of corpuscularianism tend to be comparative: its virtues are displayed against the defects of its competitors. In drawing these comparisons in "About the Excellency and Grounds of the Mechanical Hypothesis" (1674), Boyle also provides a set of criteria for evaluating the worth of an hypothesis in natural philosophy. A primary virtue is intelligibleness or clearness. Boyle maintains that endless scholastic disputes about substantial forms and related notions exhibit their unclarity, and that several notions employed by the chemists (hypostatical principles, the archeus) are equally obscure.

> But to come now to the Corpuscular philosophy, men do so easily understand one another's meaning, when they talk of local motion, rest, bigness, shape, order, situation, and contexture of material substances, and these principles do afford such clear accounts of those things that are rightly deduced from them only, that even those Peripatetics or chemists that maintain other principles acquiesce in the explications made by these, when they can be had, and seek not any further…. (Boyle 1991, p.140)

Because of the mechanists' endorsement of a macroscopic/microscopic analogy, all of their central notions are clear ones. The qualities taken as basic by corpuscularians and attributed to the minimal particles are the very same sorts of qualities familiar from ordinary experience with macroscopic objects—size, shape, motion, impenetrability. Thus the clarity so vaunted by Boyle is a fundamentally empiricist notion.

Boyle cites as a further virtue of his hypothesis that there cannot be fewer principles than matter and motion. The point of the fewness of principles is that a good scientific theory, in Boyle's view, is reductive: it minimizes the number of entities and/or properties that must be taken as primitive, and then explains other phenomena in terms of those few basic ones. Mechanism is indeed a highly reductive theory, for the list of mechanical affections is very short. The

implicit contrast, again, is with scholasticism, which as Boyle understands it, is inclined to posit a real quality to explain every manifest quality: snow is white because it has a real quality of whiteness (Boyle 1991, p.16).

Boyle claims also that matter and motion are the most primary and simple principles, by which he seems to mean that we cannot conceive of them as arising from or reducible to anything else. This is an interesting thesis in that it attempts to provide conceptual foundations for the theory, but it is surely also a disputable one, if matter is taken in the substantive corpuscularian sense, as extended, impenetrable stuff.

Boyle is concerned to argue that the corpuscularian principles are very comprehensive. His worry is that they may seem so few and simple as to lack the explanatory capacity to account for the incredible variety of phenomena in the natural world. Here Boyle invokes the alphabet analogy: When we consider all the ways in which size, shape, motion, and arrangement may be varied, we will see that the corpuscularian basic qualities are like an alphabet, a small set of letters which can be used to create all of literature. Boyle also emphasizes that corpuscularianism can accommodate whatever genuine results are achieved by other theories. For example, if the chemists are right that sulfur has a special role in explaining some set of chemical reactions, the mechanical philosophy can accommodate this and then go yet further by explaining sulfur's properties in terms of the convening corpuscles that constitute it (Boyle 1991, p.147)

A more serious worry that arises at this point is that the corpuscularian principles may be too comprehensive, in that it seems that any result could be made to agree with them. If a corpuscularian story could be invented to account for any conceivable result, then corpuscularianism looks untestable and empirically vacuous. This charge has some merit, but Boyle has two different sorts of replies to it.

(1) Boyle holds that the general theory does have some definite empirical consequences. For example, since it maintains that sensory qualities arise from the relation between bodies and our sense organs (each possessing only mechanical qualities as basic qualities), it predicts a sort of relativity that is in fact observed (e.g. water feels cold to one hand, and warm to another, depending on the state of the hand). Further, Boyle holds that there are empirical results which favor corpuscularianism against its competitors. For example, Boyle argues that scholastic natural philosophy entails that if a chemical substance is disrupted by distillation into two clearly different substances, the original substantial form is destroyed, and one cannot restore the original substance simply by mechanically mixing the distillates. Yet, Boyle argues, this is exactly what he accomplished in his "redintegration" experiments with, e.g., turpentine. The result of mixing the distillates has all the properties of turpentine, a fact which corpuscularianism can explain and which scholastic Aristotelianism must find deeply mysterious, given the absence of the substantial form of turpentine (Boyle 1991, pp.90, 96). Chemists, on the other hand, maintain that their tria prima-- salt, sulfur, and mercury-- are simple and homogenous substances, not capable of further analysis, but, Boyle contends, experiment shows otherwise (Boyle 1991, p.147). Thus, the corpuscularian can account for experimental results which competing theories cannot.

Of course, as is noted above, Boyle held that empirical vindication of the corpuscularian theory was yet to come. And he shows a keen awareness of the

difficulties involved in devising particular mechanical hypotheses that will be fully adequate to their explananda:

> For it is one thing to be able to show it possible for such and such effects to proceed from the various magnitudes, shapes, motions and concretions, of atoms; and another thing to be able to declare what precise and determinate figures, sizes, and motions, of atoms will suffice to make out the proposed phenomena, without incongruity to any others to be met with in nature…. (Boyle 1991, p.170)

Nevertheless, it seems that he hoped that natural histories of particular qualities (organized observation and experiment relating to cold, color, etc.) could eventually allow natural philosophers to devise and test specific mechanical hypotheses (Boyle 1772, vol. 1, p.121). He thought, moreover, that he had already provided experimental evidence to support the hypothesis that qualities such as cold and taste have mechanical (rather than Aristotelian) causes (Boyle 1772, vol. 4, p.230-270). And he expressed optimism that corpuscularianism would eventually accumulate explanatory successes sufficient for it to merit the assent of reasonable people (Boyle 1991, p.152).

(2) Boyle also maintains that only corpuscularianism offers prospects for genuine explanation. Thus, we ought to pursue this research program whether or not we have much in the way of empirical evidence for it at this stage. This defense rests on a further conceptual claim: Only corpuscularianism, Boyle contends, offers prospects for rendering intelligible how particular effects come about, for we cannot conceive of any bodily action apart from local motion. Thus, Boyle concludes that "…by whatever principles natural things be constituted, it is by the Mechanical principles that their phenomena must be clearly explicated" (Boyle 1991, p.150). Boyle also acknowledges, however, that the reality of things need not always conform to our standards of intelligibility (Boyle 1772, vol. 4, p. 450). Nevertheless, in doing natural philosophy, we must seek to render the natural world intelligible.

III. Experimental natural philosophy and methodology

Boyle's experimentalism

Boyle's role as an exponent of a theoretical program in natural philosophy has been considered at some length. But Boyle's role in the new science was not confined to this sphere. He was, if anything, more prominent in his role as an experimentalist. Indeed, the majority of his published works are concerned with practice rather than theory. Boyle was best known for his work on pneumatology and chemistry, and he published tracts on the spring of the air, respiration and the chemistry of blood, cold, color, saltpeter, gems, the degradation of gold, medical remedies, etc. His work on the air pump was designed to create an "experimental vacuum," that is, a space devoid of air, while skirting more metaphysical debates about the existence of space devoid of all body whatsover (an issue that, as was noted in section II, divided atomists from plenist Cartesians). Boyle's New experiments physico-mechanical,

touching the spring of the air and its effects (1660) triggered a fascinating controversy with Hobbes, with Boyle assuming the role of a defender of experimentalism against a different and in some ways more rationalist conception of natural philosophy. Boyle also corresponded with Spinoza (through Oldenburg) about the proper interpretation of Boyle's experiments with niter (saltpeter).

Boyle defended the practice of experimentation against charges of artificiality and emphasized the importance of variation and repetition in order to ensure reliability and eliminate artifactual results. In compiling histories of qualities such as cold and color, Boyle was self-consciously working in the tradition of Francis Bacon. Boyle was no naïve inductivist, however. Rather, he exhibited a sophisticated understanding of the way in which theory and experiment should mutually inform each other, with empirical data guiding the formation of hypotheses, which in turn inspire further experimentation (Sargent 1995, ch. 7; Laudan 1966).

Intermediate explanations and subordinate causes

An important question can be raised at this point concerning the fit, or lack thereof, between Boyle's theoretical corpuscularianism and his experimental science. Alan Chalmers (1993) has pressed the case that there is in fact no connection at all, and that Boyle's experimental program was successful precisely because (unlike Descartes) he did not typically attempt to provide mechanistic accounts of the chemical and pneumatic phenomena that he considered.

Boyle himself characterizes and explains the gap between (much of) his experimental work and his theoretical first principles (as Chalmers acknowledges, p. 556). In the "Proëmial Essay" to Certain physiological essays (1661), Boyle notes that he has not for the most part had "immediate recourse to the magnitude, figure, and motion of atoms" (Boyle 1772, vol. 1, p.308). In defending this practice, he addresses the issue of scientific explanation:

> I consider then, that generally speaking, to render a reason of an effect or phænomenon, is to deduce it from something else in nature more known than itself; and that consequently there may be divers kinds of degrees of explication of the same thing. For although such explications be most satisfactory to the understanding, wherein it is shewn, how the effect is produced by their more primitive and catholick affections of matter, namely, bulk, shape and motion; yet are not these explications to be despised, wherein particular effects are deduced from the more obvious and familiar qualities or states of bodies, such as heat, cold, weight, fluidity, hardness, fermentation, &c. though these themselves do probably depend upon those three universal ones formerly named. For in the search after natural causes, every new measure of discovery does both instruct and gratify the understanding; though I readily confess, that the nearer the discovered causes are to those, that are highest in the scale or series of causes, the more is the intellect both gratified and instructed. (Boyle 1772, vol. 1, p. 308)

Boyle's defense of corpuscularianism in "Excellency of the Mechanical Hypothesis", as was discussed in section II, suggests that only corpuscularianism explains. Here, in Certain physiological essays, Boyle lays out a fuller and more subtle account of scientific explanation. Only corpuscularianism provides a complete and fully satisfying explanation of how a particular effect is produced. However, intermediate explanations (which do provide a sort of genuine scientific explanation) can be gotten by reference to subordinate causes, as long as those subordinate causes are better known than what they are meant to explain. For example, Boyle takes it to be legitimate to invoke the heaviness of bodies in explaining their behavior, even though no natural philosopher has given a satisfactory corpuscular account of gravity (Boyle 1772, vol. 1, p.309). Boyle shows a delicate appreciation of the difficulties that confront the natural philosopher on this issue. On the one hand, there is the danger of jumping too quickly to a particular mechanical hypothesis, motivated by theoretical/systematic considerations (Clericuzio 1990, pp.573-4). On the other, he who invokes gravity and "desires no further account desists too soon from his enquiries, and acquiesces long before he comes to his journey's end" (Boyle 1991, p.156).

Clearly there is no contradiction here between Boyle's experimental practice and his corpuscularianism. Boyle's acceptance of intermediate explanations does not contradict his stance that ideally these intermediate causes should themselves receive mechanical explanation. But is Boyle's corpuscularianism, then, of any positive use in his scientific practice? Boyle would defend the following answer: It is of use, for it encourages one to look for mechanical explanations, where they may be found. Where full mechanical explanations are not forthcoming, we may appeal to familiar empirical phenomena (gravity, the spring of the air) whose existence is not subject to dispute. Most importantly, however, corpuscularianism rules out appeal to mysterious entities which clearly conflict with mechanist assumptions, such as substantial forms, the soul of the world, the archeus, etc., and thus clears the way for us to ascend the scale of causes.

Boyle and chemistry

As is noted above in section II, Boyle sometimes sets up "the chemists" as the source of one of the vulgar doctrines opposed by the mechanical philosophy. However, he himself contributed greatly to experimental chemistry. Moreover, recent scholarship has made clear that (1) it is difficult, if not impossible, to draw a clean distinction between chemistry and alchemy in the seventeenth century (Newman 1994b) and (2) Boyle's natural philosophy was influenced by alchemical texts, and Boyle himself was heavily involved in experimentation directed at traditional alchemical ends, including the transmutation of metals (Newman 1994a, Principe 1994, Principe 1998).

Boyle's public stance vis-à-vis chemistry was to emphasize (indeed, to champion) its importance as an experimental science, while deploring its associated obscurity (Boyle 1991, p. 120). Further, he rejected any attempts to set up some chemical theory (e.g. Paracelsianism with its associated tria prima) as a basic natural philosophy in opposition to corpuscularianism. In the Sceptical chymist (1661), he draws the distinction this way:

> …for though I am a great lover of chymical experiments, and though I have no mean esteem of divers chymical remedies, yet I distinguish these from their notions about the causes of things, and their manner of generation. (Boyle 1772, vol. 1, p. 459)

Of course, as is discussed above in section II, he also held that corpuscularianism was comprehensive enough to accommodate the empirical discoveries of the chemists, and perhaps a good deal of (al)chemical theory as well.

IV. Theology, metaphysics, and natural philosophy

It bears repeating that Boyle's natural philosophy was meant to harmonize with and support religion. Thus, he was an active participant in seventeenth-century debates concerning the relation between God and nature, religion and natural philosophy, faith and reason. What role does God play in a corpuscularian cosmos? Boyle seems to answer this question definitively in the Origin of forms and qualities:

> …according to my apprehension, it was at the beginning necessary that an intelligent and wise Agent should contrive the universal matter into the world (and especially some portions of it into seminal organs and principles) and settle the laws according to which the motions and actions of its parts upon one another should be regulated…. But the world being once framed, and the course of nature established, the naturalist (except in some few cases where God or incorporeal agents interpose) has recourse to the first cause but for its general and ordinary support and influence, whereby it preserves matter and motion from annihilation or desition; and in explicating particular *phenomena* considers only the size, shape, motion (or want of it), texture, and the resulting qualities and attributes, of the small particles of matter. (Boyle 1991, pp.70-71)

Boyle continues by employing the clock/watch analogy, emphasizing that such an automaton obviously requires an intelligent designer, but that once set in motion, its behavior should be explained in terms of its mechanical affections.

The ineliminability of God's role as a designer is emphasized by Boyle in a number of works, notably A Disquisition about the final causes of natural things (1688; Boyle 1772, vol. 5, pp. 392-444) and the "Essay containing a requisite digression concerning those that would exclude the deity from intermeddling with matter" (1663; Boyle 1991, pp.155-175). Boyle consistently maintains that our admirably organized world could not have emerged via unguided processes from an initial chaos, and posits instead that God initially organized the world he created. Moreover, we are entitled to draw conclusions about God's existence and his general purposes from the natural world (Shanahan 1994). In addition to classic examples such as the eye, Boyle often invokes "seminal principles" in this context, finely and intricately designed seeds required for animal (and perhaps mineral) reproduction.

God's role in the natural world, then, includes creation and initial organization/design of matter. What else is required of him in Boyle's cosmos?

Boyle tells us (1) that God must settle the laws of nature and (2) that God must uphold the cosmos via his ordinary support and influence. These roles might seem to be distinct, since the former is done by God "at the beginning", while the latter seems to be a continuous process. Elsewhere, however, Boyle expresses deep reservations about the application of the notion of law to nature:

> … I look upon a law as a moral, not a physical cause, as being indeed but a notional thing, according to which, an intelligent and free agent is bound to regulate its actions. But inanimate bodies are utterly incapable of understanding what a law is, or what it enjoins, or when they act conformably or unconformably to it; and therefore the actions of inanimate bodies, which cannot incite or moderate their own actions, are produced by real power, not by laws; though the agents, if intelligent, may regulate the exertions of their power by settled rules. (Boyle 1772, 5: 521)

The real power in question must be exercised by bodies or by God—laws are not entities and cannot do anything. Boyle saw both bodies and God as having a causal role, although he does not express a very precise view about how the causal labor is divided between them. It cannot be that bodies have all the causal power, for Boyle describes a thought experiment wherein the laws of impact are changed, while everything else (including, presumably, the qualities of bodies) remains constant (Boyle 1772, vol. 5, p.140). Boyle had a favorable opinion of occasionalism (Anstey 1999), the doctrine that assigns all the causal power to God, yet he never adopts that position in his published works. In A Free enquiry into the vulgarly received notion of nature (1686; Boyle 1996), Boyle specifically attacks the idea (found most prominently in Cudworth and More) that some third thing-- the spirit of nature, plastic nature, or hylarchic principle-- distinct from both God and bodies, directs the behavior of the natural world. Rather it seems that for Boyle matter itself has certain powers—e.g. the ability to transmit motion at impact—but that those powers require continual regulation or supplementation by God in order for our particular, regular, law-like universe to result (Anstey 2000, chapter 7). This is part of God's ordinary concourse, his ordinary support of the created universe, and thus should not be described as divine intervention in nature.

V. Boyle's influence

Perhaps Boyle's greatest historical influence was as a propagandist for experimental science. Together with Bacon, who had already attained that status, he became a sort of patron saint of British natural philosophy. Almost equally influential was his articulation and defense of corpuscularianism. This was the site of his most distinctively philosophical contributions. John Locke, who worked in Boyle's Oxford laboratory and afterwards remained a close friend of Boyle's, was clearly influenced by Boyle's theoretical natural philosophy, as well as by the empiricism that Boyle shared with many of his contemporaries. Locke's distinctions (in his Essay concerning human understanding, Locke 1975) between primary and secondary qualities and between real and nominal essences are closely connected to positions advanced by Boyle in the Origin of forms and qualities.

Of course, Boyle achieved lasting scientific successes as well, which there is little space to address here. His program of pneumatic experimentation established many new results about vacua and air, including, most famously, "Boyle's law," the inverse proportionality of pressure to volume in gases. His work on hydrostatics was also notable. Boyle's systematic chemical experimentation aided the development of empirical methods for identifying chemical substances (Hall, 1970). More importantly perhaps, his (qualified) championing of chemistry as a legitimate empirical science with strong connections to the new corpuscular physics was crucial to chemistry's attaining that status. Boyle also exerted a continuing influence on British natural theology, both through his own writings and through his endowment of the Boyle lectures.

It is indicative both of Boyle's standing in the period and of the multiple aspects of his influence that both sides of the great dispute between Newton and Leibniz tried to mobilize him on behalf of their cause. This battle, whose origin was the priority dispute over the calculus, soon grew to include natural philosophy more generally, particularly the question of the cause of gravity and the status of attraction. Newton, in attacking mechanist theories of gravity which posit swirling vortices in the plenum, cited Boyle qua experimentalist as having demonstrated the existence and properties of vacua (more precisely, as having shown that bodies moving in an airless space experience no resistance-- Newton 1962, vol. 2, p. 543, the 1713 "General Scholium"). Leibniz, however, invoked Boyle qua corpuscularian theorist in his attack on the "chimerical" notion of attraction:

> In the time of Mr. Boyle, and other excellent men … no body would have ventured to publish such chimerical notions. […] Mr. Boyle made it his chief business to inculcate, that every thing was done mechanically in natural philosophy. But it is men's misfortune to grow, at last, out of conceit with reason itself, and to be weary of light. (Leibniz 1956, p.92)

Both uses of Boyle's work are legitimate, if one-sided.

References:

Anstey, Peter. (1999.) Boyle on occasionalism: An unexamined source. Journal of the History of Ideas, 60, 57-81.

Anstey, Peter. (2000.) The Philosophy of Robert Boyle, *Routledge Studies in Seventeenth-Century Philosophy*. London: Routledge.

Boyle, Robert. (1772.) The Works of the Honourable Robert Boyle. 6 vols. London: Birch.

Boyle, Robert. (1991.) Selected philosophical papers of Robert Boyle. M. A. Stewart (Ed.). Indianapolis: Hackett.

Boyle, Robert. (1992.) Royal Society Boyle papers. Bethesda, MD: University Publications of America.

Boyle, Robert. (1996.) A Free enquiry into the vulgarly received notion of nature. E. B. Davis and M. Hunter (Eds.). Cambridge: Cambridge University Press.

Boyle, Robert. (1999-2000.) The Works of Robert Boyle. M. Hunter and E. B. Davis (Eds.). 14 vols. London: Pickering and Chatto.

Chalmers, Alan. (1993.) The lack of excellency of Boyle's mechanical philosophy. Studies in History and Philosophy of Science, 24, 541-564.

Clericuzio, Antonio. (1990.) A redefinition of Boyle's chemistry and corpuscular philosophy. Annals of Science, 47, 561-89.

Hall, Marie Boas. (1970.) Boyle, Robert. In C. C. Gillispie (Ed.). Dictionary of Scientific Biography (377-382). New York: Charles Scribner's Sons.

Hunter, Michael. (1992.) Letters and Papers of Robert Boyle: A Guide to the Manuscripts and Microfilm. Bethesda, MA: University Publications of America.

Laudan, Larry. (1966.) The Clock Metaphor and Probabilism: The Impact of Descartes on British Methodological Thought, 1650-65. Annals of Science, 22, 73-104.

Leibniz, G.W., and Samuel Clarke. (1956.) The Leibniz-Clarke correspondence. H. G. Alexander (Ed.). Manchester: Manchester University Press.

Locke, John. (1975.) An Essay concerning human understanding. P. H. Nidditch (Ed.). Oxford: Clarendon Press.

Newman, William R. (1994.) Boyle's debt to corpuscular alchemy. In M. Hunter (Ed.). Robert Boyle reconsidered (107-118). Cambridge: Cambridge University Press.

Newman, William R. (1994.) Gehennical fire: The lives of George Starkey, an American alchemist in the scientific revolution. Cambridge: Harvard University Press.

Newton, Isaac. (1962.) Mathematical principles of natural philosophy. Translated by Andrew Motte, Florian Cajori. 2 vols. Berkeley: University of California Press.

Principe, Lawrence M. (1994.) Boyle's alchemical pursuits. In M. Hunter (Ed.). Robert Boyle reconsidered (91-105). Cambridge: Cambridge University Press.

Principe, Lawrence M. (1998.) The Aspiring adept: Robert Boyle and his alchemical quest. Princeton: Princeton University Press.

Sargent, Rose-Mary. (1995.) The Diffident naturalist: Robert Boyle and the philosophy of experiment. Chicago: University of Chicago Press.

Shanahan, Timothy. (1994.) Teleological reasoning in Boyle's *Disquisition about Final Causes*. In M. Hunter (Ed.). Robert Boyle reconsidered (177-192). Cambridge: Cambridge University Press.

Further reading:

Alexander, Peter. (1985.) Ideas, qualities, and corpuscles : Locke and Boyle on the external world. Cambridge: Cambridge University Press.

Des Chene, Dennis. (1996.) Physiologia. Ithaca: Cornell University Press.

Frank, Robert Gregg. (1980.) Harvey and the Oxford physiologists. Berkeley: University of California Press.

Hall, Marie Boas. (1958.) Robert Boyle and Seventeenth-century chemistry. Cambridge: Cambridge University Press.

Hall, Marie Boas, and A. Rupert Hall. (1964.) Philosophy and natural philosophy: Boyle and Spinoza. Mélanges Alexandre Koyré (241-256). Paris: Hermann.

Harwood, John T. (Ed.). (1991.) The Early essays and ethics of Robert Boyle. Carbondale: Southern Illinois University Press.

Henry, John. (1986.) Occult qualities and the experimental philosophy. History of Science, 24, 335-81.

Hunter, Michael (Ed.). (1994.) Robert Boyle by himself and his friends. London: Pickering and Chatto.

Hunter, Michael. (1995.) How Boyle became a scientist. History of Science, 33, 59-103.

Macintosh, J.J. (1994.) Locke and Boyle on miracles and God's existence. In M. Hunter (Ed.). Robert Boyle Reconsidered (193-214). Cambridge: Cambridge University Press.

Mandelbaum, Maurice. (1964.) Philosophy, science, and sense perception: historical and critical studies. Baltimore: The Johns Hopkins Press.

McGuire, J.E. (1972.) Boyle's conception of nature. Journal of the History of Ideas, 33, 523-542.

More, Louis Trenchard. (1944.) The Life and works of the Honourable Robert Boyle. London: Oxford University Press.

O'Toole, Frederick J. (1974.) Qualities and powers in the corpuscular philosophy of Robert Boyle. Journal of the History of Philosophy, 12, 295-315.

Shapin, Steven, and Simon Shaffer. (1985.) Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life. Princeton: Princeton University Press.

Spinoza, Benedictus de. (1985.) The Collected Works of Spinoza. Translated by E.M. Curley. E. M. Curley (Ed.). Vol. 1. Princeton: Princeton University Press.

Wojcik, Jan W. (1997.) Robert Boyle and the limits of reason. Cambridge: Cambridge University Press.