Lockean Fluids

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Robert Boyle showed that air "has a Spring that enables it to sustain or resist a pressure" and also it has "an *active* Spring . . . as when it distends a flaccid or breaks a full-blown Bladder in our exhausted receiver" (Boyle 1999, 6.41-42).[1] In this respect, he distinguished between air and other fluids, since liquids such as water are "not sensibly compressible by an ordinary force" (ibid., 5.264). He explained the air's tendency to resist and to expand by hypothesizing

> the Air near the Earth to be such a heap of little Bodies, lying one upon another, as may be resembled to a Fleece of Wooll. For this (to omit other likenesses betwixt them) consists of many slender and flexible hairs; each of which, may indeed, like a little Spring, be easily bent or rouled up; but will also, like a Spring, be still endeavouring to stretch it self out again (Boyle 1999, 1.165).

If an inflated bladder were filled with tiny, half-compressed springs, that would explain both its tendency to resist compression and to expand when the ambient pressure were reduced.

Boyle's investigation of air was the zenith of pure corpuscularianism in the study of nature. Locke became friends with Boyle at Oxford in the early 1660s and took detailed notes on many of his works, including *New Essays on the Spring of the Air, Certain Physiological Essays,* and *The Usefulness of Natural Philosophy* (Stewart 1981, 22; Milton 1994, 37). He seems to have helped with some of Boyle's research into the physiological role of air in 1664 and 1665, and Boyle asked Locke to carry out some barometric observations in Somerset in 1666

[1] I'm grateful to Jan Cover, Antonia Lolordo, Paul Hoffman, and David Owen for helpful comments on drafts and to J. C. Walmsley for a note on the relations between Boyle and Locke.

(Stewart 1981, 22-23). Locke prepared Boyle's *General History of the Air* for publication during the latter's last illness in 1691, and Boyle's will gave Locke a role in the administration of his chemical and medical papers (Stewart 1981, 22-23, 36-43).

Given Boyle's place in the history of pneumatic chemistry, we should examine how this corner of the scientific revolution works itself out in Locke's treatment of liquids and gases. In this paper, I draw four lessons from such an examination. First, principles Locke adopts in the *Essay* help justify a corpuscularian account according to which both gases and liquids are portions of matter composed of freely moving particles that may or may not touch one another. Second, he believes that his theory of signification would be useful for natural philosophers, and, by way of illustration, denies that his contemporaries have access to an interesting conceptual distinction between gases and liquids. Third, understanding the corpuscularian background to the *Essay* clears up some puzzling things he says about the solidity of air and water. Fourth, Locke's belief in the hardness of the ultimate constituents of matter and the springiness of aerial particles show his commitment to intermediate explanations and his faith in the fecundity of mechanical explanations.

I. The Structure of Lockean Fluids

In explaining the inseparability of primary qualities from bodies, Locke asks us to contemplate the division of a grain of wheat into imperceptibly small pieces of flour. He's confident that we know what will happen,

> For division (which is all that a Mill, or Pestel, or any other Body, does upon another, in reducing it to insensible parts) can never take away either Solidity, Extension, Figure or Mobility from any Body, but only makes two, or more distinct separate masses of Matter, of that which was but one before, all of which distinct masses, reckon'd as so many distinct Bodies, after division, make a certain Number (2.8.9).

He appeals to conceivability considerations to reach a substantive conclusion. As Kenneth Winkler observes, Locke believes "we cannot comprehend the suggestion that division—

which after all merely 'makes two,' where before there was one—somehow does away with shape altogether" (Winkler 1992, 153). Indeed, Locke confidently asserts that the *only* thing that a mill or pestle can do to a grain of wheat is divide it, even when the divided parts are too small to be perceived. His corpuscularianism has dimmed his ability to conceive of genuine rarefaction or other sorts of deep chemical alteration in this situation. The inconceivability, Winkler (1992, 154) also notes, is like that which leads Locke to imply that pounding an almond can cause a real alteration only to its texture (2.8.20).

Since Locke believes that pestles can only reduce grains to insensible parts by division, we might expect him to give a similar analysis of the transformation of rigid bodies into fluids through application of fire. Indeed, that's what we find. The arguments he's offered in the chapter on primary and secondary qualities show, according to him, that such powers as that of fire "to make Lead fluid . . . result from the different Modifications of those primary Qualities" (2.8.23). He notes, "Fire has a *power* to melt Gold," and he explains what he means with "*i.e.* to destroy the consistency of its insensible parts, and consequently its hardness, and make it fluid" (2.21.1). Put together and generalized, the passages imply that loss of rigidity is the separation of solid parts caused by impulsive division.

Conversely, a rigid body arises when divided solid parts come to cohere with one another. Locke argues from the constant motion of water to the conclusion that it is composed of particles that don't stick to one another at all: "the Particles of *Water* are also so perfectly loose one from another, that the least force sensibly separates them. Nay, if we consider their perpetual motion, we must allow them to have no cohesion one with another" (2.23.26, cf. Boyle 1999, 138-39, Descartes *Principles of Philosophy,* Part 2, §§56-57). I gather that Locke believes that water particles move only through inertia and that if they cohered to any degree, the frictional force would always, inevitably, bring them to a perfect standstill.[2] "Yet," he continues, "let but a sharp cold come, and they unite, they consolidate, these little Atoms cohere, and are not, without great force, separable" (ibid.). He is prepared to hold this picture in the face of contrary empirical evidence:

the little Bodies that compose the Fluid, we call *Water,* are so extremely small, that I have never heard of any one, who by a Microscope, (and yet I have heard of some, that have magnified to 10000; nay, to much above 100,000 times,) pretended to perceive their distinct Bulk, Figure, or Motion (ibid.).

Nevertheless, he is sure that the particles are in there. This confidence is at least partially the result of *a priori* reasoning.

Locke's discussion of the fluidity of water confirms what would have been probable in any case, namely, that he adopted Boyle's account of fluidity. According to Boyle (1999, 2.120),

A Body then seems to be Fluid, chiefly upon this account, That it consists of Corpuscles that touching one another in some parts only of their Surfaces (and so being incontiguous in the rest), and separately Agitated to and fro, can by reason of the numerous pores or spaces necessarily left betwixt their incontiguous parts, easily glide along each others superficies, and by reason of their motion diffuse themselves, till they meet with some hard or resisting Body.

Notice that on this account fluids are not necessarily scattered objects. Their constituent corpuscles do touch one another in places, but leave gaps in others. The corpuscles aren't rigidly bound to one another, and the gaps allow them to easily move relatively to one another. We should be careful not to import into Boyle's work a modern conception of fluids as scattered collections of molecules, hovering on electron shells.

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2 Alas, I don't know how to square this interpretation with Locke's assertion, "Water . . . left to it self, would cease to be fluid" (4.6.11). Doesn't that suggest that water particles have some tendency to stick to one another?

Nor, I think, should we attribute any such notion of chemical repulsion to Locke. He rejected action at a distance until 1698 (Locke 1823, 4.467-68), and, after that, he still believes in a presumption against positing such forces, a presumption that he concedes has been overcome in the special case of gravitational attraction (Winkler 1992, 164n6, Jacovides 2002, 183-84). At the same time, Newton was taking some of the first steps towards adding repulsive and attractive chemical forces to corpuscularianism (Westfall 1971, 369-400, McGuire 1995, 197-207). Even though Locke's *Elements of Natural Philosophy* reflects the influence of Newton in its treatments of gravity and light, I don't see any such influence on its treatments of air and the atmosphere. In particular, I don't see any chemical forces that might let particles in fluids float above one another without touching anything.

This is just a point about Lockean physics. As a matter of metaphysics, surely he allows that a portion of matter might be scattered. Nothing in the grain of wheat example could possibly turn on whether the resulting flour is piled in a tidy heap or scattered in a dozen loaves.

Locke does not discuss whether the original grain of wheat continues to exist after being divided and sub-divided. The common sense answer, I suppose, is that breaking something into little pieces is a good way to destroy it. We get a similar answer if we consult Locke's chapter on identity and apply either the criterion of identity that he gives for "the same mass" (2.27.3) or the one he gives for the "same Plant" (2.27.4): upon being smashed, the grain ceases to exists, since it ceases to cohere and it ceases to live.

So if primary qualities are inseparable from something that endures the process, it isn't the grain, which doesn't. What does? Locke will say that the pulverization hasn't destroyed any matter, since, according to him, a human being can "combine and divide the materials, that are made to his hand; but can do nothing towards the making the least Particle of new Matter, or destroying one Atome of what is already in Being" (2.2.2).

At this point, I think that it is helpful and appropriate to compare Locke's treatment of matter to Vere Chappell's. For Locke, matter is, at least so far as our ideas are concerned, unitary: "There is *one Matter of all Bodies*" and "we no more conceive, or speak of different *matters* in the World, than we do of different Solidities" (3.10.15). On Chappell's (1973, 683) treatment, different contemporaneous ordinary objects are composed of different matters. What Locke means by matter is thus different from what Chappell means by matter. Still, what Chappell means by matter helps us see what Locke is saying when he describes the inseparability of primary qualities.

Chappell (1973, 684) writes,

> It is true that mere pieces of bronze in general tend to have more durability than statues. They are able to keep on existing and maintain their identity through more kinds of change. But such things are still not as durable as the matter that constitutes them. A piece of bronze can be bent, dented, or crunched up, and not be destroyed, unlike a statue. But it cannot be melted or cut up into pieces and still be the same piece, or a piece at all: a puddle is not piece of bronze, nor is a collection of pieces a piece. Neither being melted nor being cut up, however, has any such effect on the bronze. It is still bronze that exists, and the same bronze, though now in liquid form or in pieces.

When a grain of wheat is split into pieces, Locke will say that it is destroyed. Even so, the matter (in Chappell's sense) of the wheat continues on, with solid, figured parts.

Since Locke believes that motion is impossible where there is no void (2.13.22), and motion is possible in fluids, he will have to posit interstices between the particles, even in fluids that aren't scattered. Though perhaps they never constituted a single rigid body, Lockean fluids thus turn out to be something like Chappellian matters, objects that may endure as divided collections of bodies.

II. Conceptual Remarks on Gas and Liquor

Locke distinguishes between civil and philosophical uses of words, where the philosophical use extends to natural philosophy, what we would call science. "By the *Philosophical Use* of Words," he writes, "I mean such an use of them, as may serve to convey the precise Notions of Things, and to express, in general Propositions, certain and undoubted Truths, which the Mind may rest upon, and be satisfied with, in its search after true Knowledge" (3.9.3). According to Locke, ordinary usage suffices to fix the signification of words for civil purposes, but it isn't good enough for philosophical purposes: "Common use *regulates the meaning of Words* pretty well for common Conversation; but no body having an Authority to establish the precise signification of Words, nor determine to what *Ideas* any one shall annex them, common Use is not sufficient to adjust them to philosophical Discourses" (3.9.8). Progress in natural philosophy requires more precision than ordinary language can provide, and sometimes more precision than anyone can provide.

By way of illustration, Locke recounts a debate over whether liquor flows through the nerves: "I once was in a Meeting of very learned and ingenious Physicians, where by chance there arose a Question, whether any Liquor passed through the Filaments of the Nerves" (3.9.16). 'Liquor' generally means liquid in seventeenth-century English, though occasionally it generalizes to signify gases as well (*OED, s.v.* 'liquor' def. 1). In the *Essay,* Locke uses the word to refer to amniotic fluid (2.1.21) and to the transparent blood serum visible through a microscope (2.23.11). Locke's description of the debate suggests that he considers efforts to draw a conceptual line between gases and liquids to be fruitless.

Descartes (following Galen to some extent) had argued that nerves "are like little threads or tubes coming from the brain and containing, like the brain itself, a certain very fine air or wind which is called the 'animal spirits'" (Descartes 1985, 1.330, cf. Bennett and

Hacker 2003, 19-20, 27-28). The debate that Locke reports over whether those animal spirits are a liquor probably took place at Oxford in the 1660s, since it seems more theoretical than discussions we would expect to hear in Sydenham's circle. He continues,

> I (who had been used to suspect, that the greatest part of Disputes were more about the signification of Words, than a real difference in the Conception of things) desired, That before they went any farther on in this Dispute, they would first examine, and establish amongst them, what the Word *Liquor* signified . . . . This made them perceive, that the Main of their Dispute was about the signification of that Term; and that they differed very little in their Opinions, concerning some fluid and subtle Matter, passing through the Conduits of the Nerves; though it was not so easy to agree whether it was to be called *Liquor,* or no, a thing which when each considered, he thought it not worth the contending about (3.9.16).

Since nineteenth-century chemistry has securely grounded the distinction between gases and liquids, we may reconstruct a substantive debate out of what was agreed to be semantic quibbling. The physiologists were (in effect) arguing over whether animal spirits are a gas or a liquid. Locke's question made the gathered theorists realize that they didn't have a clear criterion for distinguishing between the two. Once they agreed that the stuff in nerves was a non-viscous fluid, they couldn't enunciate a further, definite question about whether it was a liquor.

Gas isn't a concept that Locke uses in *An Essay Concerning Human Understanding*. Jean-Baptiste van Helmont had introduced the term in works that Locke carefully studied (Milton 2001, 237-38), and, as a matter of fact, Locke befriended van Helmont's son, Franciscus Mercurius (Brown 1997, §3). Even so, van Helmont's concept was embedded in an idiosyncratic theory (Pagel 1982, 60-70), and Locke eventually soured on the theory (Milton 2001, 240-43). Locke went so far as to deny that he and his contemporaries understood the difference between gases and liquids.

Instead of thinking that matter has three phases, Locke follows Boyle (1999, 2.119) in thinking that there are two: the firm and the fluid. In the *Elements of Natural Philosophy,* Locke (1823, 3.313) writes,

> Besides the springy particles of pure air, the atmosphere is made up of several steams or minute particles of several sorts, rising from the earth and the waters, and floating in the air, which is a fluid body, and though much finer and thinner, may be consider in respect of its fluidity to be like water, and so capable, like other liquors, of having heterogeneous particles floating in it.

Notice that Locke calls the air a fluid and implies that it's a liquor. One might think that the 'spring' of gases besides air offers a historically available criterion for distinguishing between gases and liquids, but in this passage, he implies that the steams in the atmosphere aren't composed of springy corpuscles as pure air is. For Locke, gases and liquids are all collections of freely moving corpuscles, and he didn't think that either ordinary English speakers or his learned friends drew a further intelligible distinction between 'liquors' and gaseous fluids. The ideas signified by 'gas,' 'liquid,' and 'liquor' aren't "settled and certain" (3.9.16) enough for that.

III. The Solidity of Air and Water

E. J. Lowe offers the following worry about whether solidity will turn out to be a primary quality by Locke's inseparability criterion:

> Solidity, while clearly a property of physical objects, is not one that indisputably qualifies as primary by the criteria of Locke and other contemporary authors. After all, a 'solid' object can be made liquid or gaseous by the application of heat, so the solidity of an object, at least in the ordinary sense of the term, is not 'inseparable' from it. It is true that Locke's 'solidity' is probably better construed as meaning something more like 'impenetrability'—but spelling out an acceptable sense in which a *gas,* say, is 'impenetrable' is no easy matter (Lowe 1995, 48-49).[3]

In this section, I'll try to spell out an acceptable sense in which a gas may be solid.

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[3] Cf. O'Connor 1967, 67. I first learned of the problem from Andrew Hsü, who posed it to me when I was in graduate school.

Locke resists giving a definition of solidity. According to him, it is a simple idea, and he denies that any such idea can be defined (3.4.7). He compares the challenge of defining it to the challenges of defining simple ideas of sight:

> the simple *Ideas* we have are such, as experience teaches them us; but if beyond that, we endeavour, by Words, to make them clearer in the Mind, we shall succeed no better, than if we went about to clear up the Darkness of a blind man's mind, by talking; and to discourse into him the *Ideas* of Light and Colours (2.4.6).

If asked to define the term, he directs the questioner to circumstances where the relevant simple idea may be distinctly produced: "I send him to his Sense to inform him: Let him put a Flint, or a Foot-ball between his Hands; and then endeavour to join them, and he will know" (ibid.).

Just because Locke believes that solidity is indefinable does not mean that he thinks that nothing can be known about it or that the idea cannot be used to deduce consequences. He sets out five. As a result of solidity, a body 1) "fills space," 2) "excludes all other solid Substances," and 3) will "for ever hinder any two other Bodies, that move towards one another in a strait Line, from coming to touch one another, unless it removes from between them in a Line, not parallel to that which they move in" (2.4.2, cf. 2.27.2). Solidity is also the cause of 4) the "resistance" of bodies and 5) their "mutual Impulse" (2.4.5).[4] The last consequence is one of the two examples of primary qualities having "a necessary dependence, and visible connexion one with another" that Locke lists in 4.3.14. All of the dependencies that he draws from solidity are explanatory relations, though not, of course, relations of efficient cause and effect.

Robert Wilson (2002, 218) quotes the passage where Locke directs someone looking for a definition of solidity to "put a Flint or a Foot-ball between his Hands; and then

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[4] Locke also lists "protrusion" at 2.4.5, but I suppose that's the same thing as filling space.

endeavour to join them" and remarks, "the notion of solidity that one would get from the experience Locke describes . . . is one of *incompressibility,* the sort of resistance that keeps bodies out of one another's place that Locke mentions elsewhere in II.iv, including at the end of iv.4 in discussing hardness and softness." I don't think that Locke believes that incompressibility, ordinarily so called, is an intuitively obvious consequence of solidity. We may observe that the football that Locke mentions would have been a compressible object, probably an inflated pig's bladder with a leather casing. In defense of his postulation of air particles, Boyle (1999, 2.22) had observed, "if the sides of a blown Bladder be somewhat squeez'd betwixt ones hands, they will, upon the removal of that which compress'd them, fly out again, and restore the Bladder to its former figure and dimension." I think that Locke intends his football to be a similar example of a compressible but solid object.

Having examined the consequences that Locke draws out of solidity, let us return to the question of whether he considers gases to be solid. Temporarily setting aside our fussiness about attributing the concept of gas to him, it seems as if he must. He treats air in tandem with water in contrasting solidity with hardness, and Locke emphatically does not consider "an Adamant one jot more solid than Water" (2.4.4). As we have seen, he denies that matter is naturally destructible. Since matter includes solidity as part of its nominal essence (3.10.15), he commits himself to the natural ingenerability and indestructibility of solidity, even when a rigid body is transformed into a gas.

Locke challenges him who thinks "that nothing but Bodies that are hard, can keep his hands from approaching one another, . . . to make a trial, with the Air inclosed in a Football" (2.4.4). The air in a football is not hard, but it meets Locke's third criterion—unless it moves aside, bodies coming towards it from opposite directions cannot touch. Very strictly speaking, all this shows is that meeting criterion 3 need not entail hardness. The point of the section, however, is to distinguish solidity from hardness,[5] so his implication is that air is solid in the relevant sense.

If we assume that Locke maintains a strict agnosticism with respect to physical theory in the *Essay,* then we'll have difficulty understanding his discussion of softness and solidity. If air is a solid substance, it seems as if it might not meet criterion 2, since it doesn't exclude other substances from being where it is. So, what is Locke thinking when he offers air as an example of a solid?

Consider also Locke's description of an experiment involving a golden globe under pressure.[6] In arguing that solidity is distinct from hardness, he reports,

> the Experiment, I have been told, was made at *Florence,* with a hollow Globe of Gold fill'd with Water, and exactly closed, farther shews the solidity of so soft a body as Water. For the golden Globe thus filled, being put into a Press, which was driven by the extreme force of skrews, the water made it self way through the pores of the very close metal, and finding no room for a nearer approach of its Particles within, got to the outside, where it rose like a dew, and so fell in drops, before the sides of the Globe could be made to yield to the violent compression of the engine, that squeezed it (2.4.4).

Does the experiment show that the golden globe is not solid? By criteria 2 and 3, it is supposed to be impossible for one solid body to move through another without the second moving out of the way. In the Florentine experiment, the water (described as solid) moves through the globe without the globe moving out of the way.

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[5] The marginal summary reads "From Hardness," which, given the two previous summaries, is elliptical for "Solidity is distinct from hardness."

[6] David Knight discovered that Locke was misreporting an experiment run by the Academie del Cimento with a silver globe. The experimenters "found that a golden globe distends itself and does not show the effect" (Knight 1973, 45).

One might think that we are thus presented with a choice between taking Locke's consequences of solidity seriously and taking his examples of solidity seriously. Peter Alexander does the former. He distinguishes between "absolute" and "relative" solidity. Only corpuscles possess absolute solidity. "We get the idea of absolute solidity through our senses," he tells us, "although absolute solidity is not strictly observable" (Alexander 1985, 140). Wilson (2002, 218) distinguishes between 'experiential solidity' and 'theoretical solidity', where experiential solidity is the solidity of ordinary objects and the idea of theoretical solidity is "the idea of completely filling the space within one's boundaries". According to Wilson, the important kind of solidity for Locke is experiential solidity, the kind of solidity that ordinary objects possess.

Neither of these interpretations fits well with passages where Locke emphasizes the univocity of solidity. At 2.4.1, he tells us that we acquire the idea of solidity from perceptibly large masses of matter and then the mind attributes it to all bodies, perceptible and imperceptible:

> though our Senses take no notice of it, but in masses of matter, of a bulk sufficient to cause a Sensation in us; Yet the Mind, having once got this *Idea* from such grosser sensible Bodies, traces it farther, as well as Figure, in the minutest particle of Matter, that can exist; and finds it inseparably inherent in Body, where-ever, or however modified.

At 3.10.15, in explaining why 'matter' is not a count noun, Locke implies that 'solidity' is an unequivocal term, referring to a determinate, invariant idea: "we no more conceive, or speak of different *Matters* in the World, than we do of different Solidities; though we both conceive, and speak of different Bodies, because Extension and Figure are capable of variation."

Alexander is stuck with saying that when Locke calls water solid and implies that air is solid, he doesn't mean solid in the strict and important sense of being absolutely solid. On Wilson's account, the examples are solid in the most important sense, but what Locke says about them is false. An experientially solid body does not exclude other bodies from the same place and does not prevent other bodies from passing through it.

I say Locke can eat his cake and have it too. He is just talking about what Alexander calls 'absolute' solidity and what Wilson calls 'theoretical' solidity, and he believes that ordinary objects possess this kind of solidity. It is true that fluids and ordinary bodies aren't absolutely solid, if these are taken as agglomerations of matter and void. Locke, however, thinks of them as entirely material, with no part that is a void. That is, he thinks of them as divided, gappy objects, made only of matter, and only present where matter is present. Locke's commitment to corpuscularianism comes through. Yes, the water starts on one side of the globe and ends up on the other. He makes it clear that he thinks that the water doesn't pass through the matter of the globe. Rather, it passes through the 'pores' in the gold.

A gappy object, existing only where its matter is, excludes other fluids from being in any part of the same irregular place. Still, air may be compressible in that its parts may be pushed closer together, it may pass through the pores of rigid objects, and its particles may mingle with the particles of another portion of matter. Alexander's and Wilson's choice between taking Locke's assertions seriously and his examples seriously turns out to be a false dilemma.

If Lockean air is present only where its corpuscles are, we may also answer Lowe's worries about the solidity of gases. Gases and liquids may be considered as strictly solid and as possessing all the consequences that Locke draws from solidity. They fill space, they exclude other matter from being in the very same places at the same time, and they prevent corpuscles from passing through their locations without pushing corpuscles aside. They may resist other bodies and push against them. *A fortiori,* the constituent corpuscles themselves are also solid.

IV. Hardness and the Spring of the Air

As we have seen, Locke does not believe that solidity generally entails hardness, where hardness is "a firm Cohesion of the parts of Matter, making up masses of a sensible bulk, so that the whole does not easily change its Figure" (2.4.4). According to Locke, fluids are solid, though soft, and their softness consists in the changeability of "the Situation of its parts upon an easie, and unpainful touch" (ibid.).

He also believes, as it happens, that their smallest parts are hard. In "Solidity and Elasticity in the Seventeenth Century", Alexander (1994, 144-46) argues that Locke considers corpuscles to be absolutely hard. I agree with the conclusion, but I don't believe that the texts Alexander cites suffice to establish it.

A *prima facie* difficulty with Alexander's account is that Locke follows Boyle in using fleece as a model of the atmosphere and in describing the corpuscles in air as "springy". (1823, 3.312-13) This difficulty is only superficial and leads to better evidence for Alexander's conclusion. According to Locke, if we could "see the Configuration of the minute particles of the Spring of a Clock," we would be able to "observe upon what peculiar Structure and Impulse its elastick Motion depends" (2.23.12). If this is to be a substantial and non-circular explanation of elasticity, then the microphysical structures that explain elasticity will be inelastic in some sense. Inelasticity (lacking the tendency to return to an initial shape) is not quite the same quality as hardness (tending to preserve a shape), but the similarity is suggestive.

In my opinion, the passage that best supports Alexander's conclusion may be found at 2.15.4. There, Locke wants to show that there's a metaphysical analogy between duration and solidity. In defending that conclusion, he makes a philological point about the kinship between the Latin expressions '*durare'* (to last) and '*durum esse*' (to be hard).[7] Since Locke has distinguished hardness and solidity at 2.4.4, he parenthetically notes that solidity "is apt to be confounded with, and if we will look into the minute atomical parts of Matter, is little different from Hardness" (2.15.4). That is, at the macroscopic level, people confuse solidity and hardness, so the philological point still stands, and (what's important for our purposes) at the corpuscular level, the two qualities are "little different," and so, presumably, co-extensional.

Why does Locke hold this view? J. R. Milton reproduces a notebook entry from the early 1660s entitled '*Elasticus motus*.' In it, Locke argues "that springs move after the manner that heavy things do downward. & both from an externall impulse" (Milton 2001, 221n2). Locke argues that both returning springs and falling bodies accelerate and, from the premise that falling bodies accelerate due to the cumulative pounding of external subtle matter, infers that elastic restoration probably accelerates for the same reason. That can't be a complete explanation, since it doesn't tell us what distinguishes elastic from inelastic bodies, but it gives us some idea of the sort of explanation that he has in mind.

Perhaps Locke's optimism that with much better sight we could figure out the distinctive characteristics of springs stems from his happiness with earlier first steps towards

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[7] Actually, according to Lewis and Short, '*durare'* also means 'to harden' (as Locke observes) and '*durum'* can mean hardy. These senses strengthen Locke's point, while making it more difficult to explain.

an explanation. More generally, perhaps it is just an expression of his confidence in the explanatory power of corpuscularianism. Though he doesn't have a secure and robust explanation of the elasticity of a spring, it seems to him to be the sort of thing that you would have, if your eyesight were good enough. If there were such an explanation, then there would be no need to posit elasticity among the fundamental qualities of nature. Also, as Alexander observes (1994, 161-62), if Locke thinks that he can explain the softness of bodies by appeal to the motion of relatively harder parts, then he has a reason to postulate that bodies are ultimately constituted out of absolutely hard parts.[8]

As for an external explanation, Boyle and Descartes thought that bodies were ultimately constituted by perfectly rigid corpuscles,[9] and Edmé Mariotte was the first to doubt it in his *Traité de la Percussion* in 1673 (Scott 1970, Ch. 1).[10] Boyle (1999, 6.77) claimed to have shown in an unpublished treatise entitled "Notes about the history of Elasticity," that "there is no need to assert, that in all Bodies, that have it, the Elastical power flows

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[8] This isn't exactly the way that Alexander puts it, since, in the course of his interpretation of Locke, he assimilates solidity and hardness in a way that I wouldn't. Still, I think that I've captured the spirit of Alexander's (1994, §4) remarks. He has other good things to say about this problem, and I'm generally indebted to his formulation and discussion of it.

[9] Antonia Lolordo informs me that Epicurus and Lucretius did as well (*Lives of Eminent Philosophers* 10.43, *De Rerum Natura* 2.87).

[10] Locke owned various works of Mariotte's, but the *Traité de la Percussion* isn't in his Library catalog (Harrison and Laslett 1971, 184). Locke read part I of Leibniz's *Specimum Dynamicum* in 1697, but most of Leibniz's defense of elasticity in collisions occurs in part II, and Locke didn't appreciate the part that he read (Locke 1823, 9.407).

immediately from the Form, but that in divers of them it depends upon the Mechanical structure of the Body." Locke may well have seen this treatise, and it may have been another source of his thought that elasticity rests on the workings of rigid bodies.

As Stevin Shapin and Simon Schaffer (1985, 51-52) emphasize, Boyle was much more confident with the spring of the air as an observed matter of fact than he was with spring-like corpuscles as the postulated cause of the phenomenon. They conclude, "Boyle's criteria and rules for making preferred distinctions between matters of fact and causes have the status of *conventions*" (1985, 52). Alternatively, his criteria might be assigned the status of good sense and insight.

Though Boyle believed that the spring of the corpuscles could be mechanically explained in turn, he describes the task as "a matter of more difficulty, then at first sight one would easily imagine it" (Boyle 1999, 1.166). As Alan Chalmers (1993, 550-51) argues, the suggestiveness of an analogy between macroscopic springs and springy corpuscles goes no distance at all to showing that elasticity can be explained through shape, size, and motion alone. However Boyle's unpublished mechanical account of elasticity ran, it seems clear that he didn't have much confidence in it.

Boyle's insecurity that he understood the ultimate foundations of the spring of the air didn't undermine his confidence in the value of his project. He denied that lacking an ultimate explanation of a phenomenon strips intermediate explanations of worth (Boyle 1999, 2.22). Shapin and Schaffer note that, in contrast, Hobbes denied that true natural philosophers use such halfway explanations.[11] They observe, "No argument against Boyle's

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[11] The denial occurs in Hobbes's *Dialogus Physicus,* a short text that Shapin and Schaffer translate and append to their book.

position could have been, if accepted, more devastating" (Shapin and Schaffer 1985, 141). Like Boyle and unlike Hobbes, Locke allows for explaining phenomena through qualities that contain unresolved explanatory puzzles (Jacovides 2002, 180). So, for example, Locke treats the watchmaker's prediction "that a little piece of Paper laid on the Balance, will keep the Watch from going, till it be removed" (4.3.25) as a paradigm of understanding, even though it rests on assuming without explanation the elasticity of the mainspring.

Boyle and Locke's treatment of the elasticity of corpuscles as an intermediate cause leaves room for the possibility of perfectly hard corpuscles as foundational causes. Leibniz (1969, 446), in contrast, believed in the elasticity of collisions as a consequence of "the principle that *no change occurs through a leap.*" A rebound after a collision between two inelastic bodies would have at least one of the bodies change direction of velocity without going through all the intermediate velocities. This argument, unlike Boyle's experimental reasons for believing in the spring of the air, applies to bodies of any size.

Boyle's caution about the proper explanation of the spring of the air also leaves room for the possibility that all bodies might be flexible. Likewise, Locke expresses his belief in the hardness of the ultimate constituents of matter obliquely and hypothetically in the *Essay*, once in a reverie about microscopical eyes and a second time in a philological aside. The thesis that he insists upon and argues for directly is that there's a difference between the idea of solidity and the idea of hardness. This distinction allows conceptual space for solid elastic corpuscles, even if Locke did not choose to take up that option.

On Locke's account, the relation between fluids and the corpuscles that compose them resembles the relation between a doll and its rigid moving parts. Both the doll and its parts are solid, since they fill space and hinder the passage of other bodies, but only the parts of the doll are hard, since the doll as a whole will easily change its figure. Arrangements of hard parts also, he supposes, give rise to elasticity of some things, including air. He suggests that the way this works would be apparent, if only our vision were to be radically improved.

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