CHAPTER 23

THE IMPACT OF NEWTON ON BIOLOGY ON THE CONTINENT IN THE EIGHTEENTH CENTURY

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In order to understand the reception of Newton in biology in the eighteenth century we must first decide what we mean by biology and characterize those aspects of Newton's work that can plausibly be thought to have had some impact on the life sciences in the eighteenth century. When Immanuel Kant (1724–1804) at the end of the eighteenth century despaired of a 'Newton' of the organic world, 'who could make comprehensible even the generation of even a blade of grass according to natural laws that no intention has ordered', he alluded to what must have been a widespread expectation (Kant 2000, 271). He concretized the hoped-for impact in a figure of argument that was to take on a life of its own in the nineteenth century: whereas Johannes Kepler (1571–1630) showed how the phenomena of nature could be subjected to lawlike mathematical description, Newton explained these laws on the basis of general natural causes (Kant 2007, 109). A Newton of the grass blade would have provided a mechanistic causal explanation of the organism in terms of general qualities of matter. We shall see that the impact of Newton on biology of the eighteenth century lay in the resources he provided for just such a mechanistic or reductionistic theory of the organism.

In the eighteenth century biology did not exist as an autonomous discipline. However after the work of John Ray (1627–1705) at the end of the seventeenth century, organic species came increasingly to be viewed as collections not so much of similar organisms as of successfully interbreeding organisms. Those types of organisms that can produce fertile progeny with one another belong to the same species, independent of whatever bodily similarities or dissimilarities may exist. Furthermore, in the preformation theory that dominated biological speculation in the first half of the eighteenth century, all future members of a species were seen to be pre-formed in the first pair, so that species membership became a genealogical affair. Thus in more than one way in the course of the eighteenth century, the two organic realms of traditional natural history come to be more closely associated with each other and distinguished from the third realm of minerals. As the organic realms of the traditional *historia naturalis* came to be viewed more in terms of their causal history and as analytical methods from human medical physiology were introduced into the study of other organisms, a gradual restructuring of natural history took place: the three distinct realms (animal, vegetable, mineral) were reorganized into a two-part organic realm and an anorganic realm. Zoology and botany (or *phytology*) join together to become biology by the end of the century, and the term *biology* also begins to appear in the prefaces and titles of books in the second half of the eighteenth century.[1] Although the university institution of biology in a recognizably contemporary sense is a post-Comtean development of the nineteenth century, we may nonetheless in a looser sense speak of an eighteenth-century science of biology.

Although Newton himself did propose some speculative hypotheses that fall within the area now called biology, his real impact on biology was not of a direct sort. Like most thinkers of his time, Newton seems to have adhered to the theory of preformation, but this was not part of the public image of Newton and there is no indication that anyone appealed to his authority on this issue. His electrical interpretation of the nerves presented in the *Opticks* was not influential; nor was the hypothesis of a crossover of the optic nerves relevant for the development of physiological optics until it was independently proposed. And Newton's metaphysical speculations in connection with the power of motion of animals had some following in England, but this is not the aspect of his work that was influential in biological thought on the Continent.[2]

Of some real significance was the experimental approach to science exemplified by the *Opticks* and the research programme for science sketched in the Queries appended to that work. This was certainly widely influential, but unspecifically so, and there is nothing to distinguish a purported influence in biology from that in physics, chemistry or any other experimental enterprise. Nor is there anything particularly Newtonian (as opposed to Harveyan, Halesian or even Cartesian) about biological experimentalism. Both Newton's *Rules of Philosophizing* added to the second edition of the *Principia* and his second order interpretation of his procedures as 'deducing' theories from the phenomena are widely cited throughout the century (see Helmut Pulte's Chapter 16 in this volume), but it is unclear what the actual effect on experimental practice was. When for instance Paul Joseph Barthez (1734–1806) claimed that his *principe vital* was 'rigorously deduced from facts',[3] it became clear that Newton's name was being invoked primarily as part of a legitimation strategy – even though in this particular case other aspects of Newton's heritage did indeed structure research.

A third dimension in which an impact of Newton could be seen is in physicotheology, which Newton once characterized as the point of doing physics in the first place.[4] Popular Newtonianism of the eighteenth century on both sides of the Channel often engaged in arguments from design. And Pieter van Musschenbroek in the Netherlands incorporated the teleological argument into his presentation of Newton's 'rules of philosophizing' in the most popular physics textbook of the period (Musschenbroek 1734, 2). In fact along

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[1] The current first sighting is Hanov 1766. See McLaughlin 2002.

[2] On the reception of Newton's *Opticks* I have benefitted from numerous conversations with Volkmar Schüller, who is preparing a critical analysis of the various editions and manuscripts of the *Opticks* in connection with his new German translation.

[3] 'sévèrement déduit des faits' (Barthez 1806, 45).

[4] 'This concludes the discussion of God, and to treat of God from phenomena is certainly a part of natural philosophy' (Newton 1999, 943).

with a *Newtonian* argument from design, the term *teleology*[5] itself was thus introduced into four modern languages as a fundamental Newtonian principle, so that the countless insecto-theologies of the mid-eighteenth century could be seen as genuinely orthodox Newtonian works. But like the experimentalism of the *Opticks* there is nothing specifically Newtonian about the argument from design.

It is in fact certain aspects of the theoretical argumentation of the *Principia* that are behind the notion of the Newton of the grass blade. The Newton of Kant's metaphor is the scientist who explains Kepler's descriptive laws by means of general physical, causal principles. Newton's impact on eighteenth-century biology lay in the fact that the arguments supporting the theory of gravitation provided resources for expanding the scope of reductionist explanation beyond the possibilities given in Cartesian mechanism. Newton provided resources necessary for the development of vitalism and of biology as an independent discipline: the reduction of the phenomena of biological systems to the properties and interactions of the parts without the reduction of the life sciences to physics. An analogy to the force of gravity in Newtonian mechanics is made by almost every major figure in the development of vitalism when introducing their particular vital force or proto-vital force.[6]

While it is surprisingly difficult to determine what it actually meant to be a Newtonian in physics in the eighteenth century (Watkins 1997), what it meant in biology is comparatively easy to determine: to do for the explanation of the organism what Newton did for the explanation of celestial mechanics. The impact of Newton on biology on the continent of Europe is mediated primarily through the French Newtonians, Georges Louis Leclerc de Buffon (1707–88) and Pierre-Louis Moreau de Maupertuis (1698–1759), and comes to full flower in German vitalism at the end of the eighteenth century. While these Newtonian resources may have been exploited by physicians and natural historians from all over Europe, the major figures in the Newtonian development of biology in the second half of the eighteenth century were active in France and Germany: Buffon, Maupertuis, John Tuberville Needham (1713–81), Théophile de Bordeu (1722–76), Barthez, Albrecht von Haller (1708–77), Caspar Friedrich Wolff (1734–94) and Johann Friedrich Blumenbach (1752–1840). In the following pages, I shall outline how these figures employed and developed resources provided by Newton and his followers in physics to transform the mechanism of Cartesian organic physics into the vitalism of Newtonian biology. The story will be told in four stages: (1) the nature of specifically Newtonian resources; (2) the nature of the problem in biology in the mid-eighteenth century; (3) the subsequent enrichment of mechanism by new, not quite-so-blind mechanical forces; (4) the replacement of these forces by vital forces, which – though material – played no role in physics.

[5] The first edition of the *Elementa physicae* (1734, 2) has *theology* instead of *teleology* – which is corrected on the erratum page. The book was also published in Dutch (1736), French (1739), English (1744) and German (1747).

[6] On the Newtonian character of eighteenth-century vitalism see Hall 1968 and Canguilhem 1955.

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1 Newtonian resources

Newton, like many other seventeenth-century thinkers, worked with a distinction between primary and secondary qualities, primary qualities being the subject matter of physics or natural philosophy and secondary qualities the subject matter of everyday sense perception. Primary (scientific) qualities were intrinsic to bodies as such; secondary qualities were taken to be relative to our sense organs – and sometimes qualities that were relative to other bodies were called *tertiary*. In Robert Boyle's famous thought experiment, primary qualities were those qualities of matter attributable to a single body (perhaps in empty space): 'And if we should conceive that all the rest of the universe were annihilated, except any one of these entire and undivided corpuscles [. . .] it is hard to say what could be attributed to it, besides matter, motion (or rest) bulk, and shape' (Boyle 1772 [1669], 22). The traditional primary (mechanical, essential, catholic) qualities of matter, however, turned out not to be sufficient even for celestial mechanics. Boyle's lonesome particle has bulk but no weight.[7] Newton introduced gravity, which as mutual gravitation exists only in a two-or-more-body system. In justifying himself, Newton famously insisted on a distinction between the *essential* or intrinsic qualities of bodies and such qualities as gravitation, which are universal in the sense that all bodies of our actual experience have them. Whereas in the *Principia* Newton merely omitted gravity when he listed the essential qualities and characterized qualities instead as universal when he wanted to include gravity, he did explicitly deny that gravity was essential to bodies in his correspondence with Richard Bentley (Newton 1961, 240; see Freudenthal 1986, chs. 1 and 13).

Newton's method consisted in tracing back the phenomenon to be explained to the essential qualities of particles (in the last analysis indivisible atoms). *Essential* qualities such as extension, impenetrability or inertia are attributed not merely to every body of actual experience, but also to every imaginable body independently of the existence of other bodies: that is, to a body even if it were the only body in an otherwise empty absolute space. Gravity, although it belongs to every body of experience, is not an essential quality of matter, because as *mutual* gravitation it presupposes the existence of a system of bodies containing at least two elements. A quality that is essential may not depend on external circumstances like the existence of other bodies. Newton furthermore rejected immediate action at a distance as self-contradictory,[8] since a thing cannot act where it is

[7] Two of Locke's most common examples of secondary qualities in the *Essay concerning Human Understanding* are colour and weight.

[8] As Freudenthal (1986, chs. 1 and 13) convincingly argues, the impossibility of action at a distance was a presupposition on both sides of the debate: for instance, the entry for 'axiom' in John Harris' *Lexicon Technicum* (1966 [1704]), a standard source of Newtonian and Lockean orthodoxy, lists the axiom 'that nothing can act where it is not' even before the law of non-contradiction. Some recent Newtonian scholarship has called Newton's rejection of action at a distance in question without however answering any of Freudenthal's arguments. See Janiak (2013) for a review and critique of this literature.

not, but he left it open whether the cause of gravitational acceleration is material and mechanical (for example, a stream of particles) or whether it is perhaps immaterial (for example, the immediate influence of God). Against Gottfried Wilhelm Leibniz's accusation that he had reintroduced a scholastic *qualitas occulta* into science, Newton protested, that Leibniz called 'those things occult qualities whose causes only are occult though the qualities themselves be manifest' (Newton 1976, 285). This was to become a standard figure of argument of eighteenth-century Newtonianism: manifest effects may be explained by a hidden cause.

The isolating view of things, which was shared by Newton's followers (see Freudenthal 1986, 27–28), led in the course of the eighteenth century to serious problems whenever properties that could only be sensibly conceived as interactions had to be pressed into the seventeenth-century mechanistic mould: gravitation, electrical phenomena and magnetism (Clarke 1738, 760). If the new forces or properties were to be considered secondary, they should be reducible in the end to the primary qualities, which were to be conceived in classical corpuscular terms. And if primary, they should be intrinsic to bodies. To escape the dilemma – either corpuscular-mechanical or secondary – a new class of properties was needed.[9] One solution introduced by Newton's followers was to postulate new qualities not essential to matter but somehow superadded to it by God; their second option was to have God himself cause the required effect immediately. George Cheyne (1671–1743) exemplifies the first option:

> [. . .] so *Attraction* or *Gravitation* is not *essential* to Matter, but seems rather an *original Impress* which continues in it, by virtue of the *Omnipotent* Activity, [. . .] and so may now be reckon'd among the *primary* Qualities of Matter, without which, as it is now constituted Matter cannot be, but did not *Originally* belong to it as a *Materia prima*.
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> *Cheyne 1715, 40–41*[10]

Samuel Clarke (1675–1729) presents us with the second option:

> And *Gravitation* itself, is not a Quality inhering in Matter, or that can possibly result from any Texture or Composition of it; but only an Effect of the continual and regular Operation of some other Being upon it; by which the parts are made to tend one towards another.
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> *Clarke 1738, 760*

Neither of these alternatives yields a stable solution to the problem of how to deal with phenomena that are not easily pressed into the mechanistic mould, for they

[9] Seventeenth-century philosophy tended to speak of primary and secondary *qualities*, reserving the term *property* for *propria* or essential (as opposed to accidental) properties; this usage continues (inconsistently) into the eighteenth century. See Ayers 1981.

[10] See also John Locke (Second Reply to Stillingfleet, *Works* vol. 4, 461–63) who argues that God might indeed have superadded the power of thought to matter, just as he did gravity and other powers visible in the organic world.

institutionalize the direct intervention of God in the material world to explain the existence of otherwise unintelligible physical qualities. The distinction between essential or intrinsic qualities and merely universal qualities, insisted upon by Newton and his immediate followers, turned out to be unsustainable. Although in England from Clarke to William Paley (1743–1805) it seems to have been common to consider all active forces – for *semantic* reasons, since laws presuppose mental agents to obey them – to be immaterial, on the Continent gravity was soon taken to be just as essential to matter as the other primary qualities. By the mid-eighteenth century, Thomas Kuhn tells us, the notion that gravity was indeed innate had been almost universally accepted.[11] But this necessitated a reconceptualization of the notion of a primary quality.

To sum up the options for the introduction of new forces and qualities into a mechanistic science of biology, there would seem to be three possibilities. The new force/ quality can be:

1. emergent – that is, a secondary quality that is in fact ultimately reducible to the intrinsic primary qualities;
2. immaterial or superadded – that is, neither reducible to primary qualities nor itself a primary quality but divinely ordained as if it were primary;
3. primary – that is, an intrinsic property of every body, but dependent in its expression on external conditions: for instance gravity or magnetism or electric attractions could be latent qualities of an isolated particle but only display effects in a system or in systems of a particular kind. Variants of this approach sometimes mimic the first option by introducing a new quality and then later reducing it to a combination of intrinsic forces that also turn out to be latent.

The first option (had anyone pursued it) would have led to a revival of Cartesian mechanism. The second option was pursued to a certain extent by British physicotheologians and perhaps also by some sympathizers on the Continent. The third option leads us down the Newtonian high road to vitalism in France and Germany.

2 Preformation (pre-existence) and epigenesis

The theory of the organism from 1740 to the end of the eighteenth century was characterized by a conflict between new theories of epigenesis and the traditional mechanistic theory of preformation.[12] The development of this conflict can be seen as the further articulation of the Cartesian theory of the organism with Newtonian means.

[11] 'Unable either to practice science without the *Principia* or to make that work conform to the corpuscular standards of the seventeenth century, scientists gradually accepted the view that gravity was indeed innate. [. . .] Innate attractions and repulsions joined size, shape, position, and motion as physically irreducible primary properties of matter' (Kuhn 1996, 105–6). For the role of Maupertuis in facilitating this change, see Downing 2012.

[12] The best and most comprehensive study of theories of the organism in this period is Roger 1997.

René Descartes (1595–1650) had tried to integrate not merely the function of the animal machine into his mechanical-corpuscular view of the world, but also its production. The entire complexity and heterogeneity of the organic body was to be materially represented in and determined by the germ:

> If one *knew* exactly in detail all the parts of the seed of a particular species of animal, for instance Man, one *could* deduce from that alone for reasons entirely mathematical and certain, the whole figure and conformation of each of its parts, just as the other way around *knowing* some particulars of this conformation one can deduce from this what the seed is.[13]

There is a one-to-one correlation between particles of the germ and parts of the body. Descartes' own somewhat obscure notions as to how the germ might be gradually produced by various chemical processes acting under heat were not taken up by his successors, but the idea that the germ contains all one needs to explain the organism was almost universally accepted. The most common simile used to express the relation of body to germ was the small image of the body in a convex mirror (Gassendi 1658, 275; Legrand 1672, 797–98). The first generation after Descartes returned to the traditional Hippocratic theory of pangenesis to explain the production of the germ. According to pangenesis each part of the body sends a particle representing it through the blood (or – with the Hippocratic tradition – through the nerves) to the organs of generation where they coalesce into a miniature organism. Pierre Gassendi (1592–1655) tried to explain how these particles could produce a rudimentary organism ('epitome') by invoking the workmanship of the soul (Gassendi 1658, 275). At the same time Nathaniel Highmore (1613–85) tried out a similar argument and started down an infinite regress by distinguishing the 'material atoms' that pangenetically form the body (through the workmanship of the soul) from the 'formal' or 'spiritual' atoms that pangenetically form the soul (Highmore 1651, 83). The origin of organic form – or *organization* as it came to be called – remained an unsolved problem. This led to the rise of the theory of the preformation or pre-existence of the germ, which attributed the production of the germ directly to God.

The solution to the problem of the origin of organization that was to become dominant for the next hundred years was first publicly formulated by Nicolas Malebranche (1638–1715), who like Descartes, William Harvey (1578–1657) and Highmore had systematically studied embryological development by opening eggs at different stages of development. Malebranche allowed that God had created all the germs

[13] 'Si on *connoissoit* bien quelles sont toutes les parties de la semence de quelque espece d'animal en particulier, par exemple de l'*homme*, on *pourroit* deduire de cela seul, par des raisons entierement mathematiques & certaines, toute la figure & conformation de chacun de ses membres; comme aussi reciproquement, en *connoissant* plusieures particularitez de cette conformation, on peut deduire quelle est la semence' (Descartes 1909 [1648], 277; italics P.M.).

in the beginning and had stored them in the first female of each species – one encased within the reproductive organs of the next (Malebranche 1972, 82–83).

As a mechanistic theory of the organism, preformation plus pre-existence had a number of significant advantages. It was a completely mechanistic approach: an organic system was explained by the system-independent properties and the interactions of the parts. But the purely mechanical forces and properties need not suffice to explain the origin of the organization. As Leibniz put it: 'The organism of animals is a mechanism which supposes a divine preformation. What follows upon it is purely natural and entirely mechanical' (Leibniz 1956, 93). On this view organisms can be recognized as significantly different from inanimate physical systems, for there is a certain contingency in the realization of organic forms – not all physically possible and viable forms need be realized, but only those that God chose to realize. However, God is called upon only once, and since the deists needed God to produce matter in the first place, he was merely somewhat busier on that day: God created matter, motion, directed the motions of the original particles and formed some of them into germs. Preformation could become the deist theory par excellence. Each individual was personally divinely produced and encased with its conspecifics to be unfolded in the course of time by purely mechanical processes.

The empirical question in preformation was where the germs were stored at creation: in Adam or Eve, or strewn with the winds. Animalculism (Adam) and ovism (Eve) competed for allegiance on the Continent, while panspermism (called 'dissemination') achieved a sort of religiously conformist orthodoxy in Britain.[14]

The notion that organic form might develop gradually and simultaneously with the growth of the system had been called *epigenesis* by William Harvey in 1651. But the opposition between preformation and epigenesis in the eighteenth century was not at first really an embryological dispute. Epigenesis before 1750 was associated with growth by 'apposition' (external adding on) not by 'intussusception' (internal integration).[15] The strong point of preformation was that the system that was growing or expanding in size was actually alive all the time, so that whatever happened between different stages, there always existed a system that was viable in some way: there was a continuity of life. The shipbuilding metaphor that Harvey adopted from Hieronymus Fabricius (1537–1619) for epigenesis obviously did not convey this idea: a ship is built gradually in dry dock and only when it is completed does it float. This is fine if a soul is literally working upon matter; but until epigenesis sloughed off the connotation of sequential external addition of parts to a not-yet-viable system, preformation of some kind was a matter of course for

[14] *Panspermie* is the late nineteenth-century term for such scattered germs; it unfortunately seems also to have been Aristotle's term for the Hippocratic theory of generation that came to be called *pangenesis* after Darwin. Typical examples can be found in Wollaston 1974 [1724], 89–90 and Reid 1967 [1895], 53–54.

[15] The association of epigenesis or gradual development with apposition is well illustrated by Albrecht von Haller's English translator, who took Haller's simple 'generatio[] partium corporis humani non subito, sed sensim factae' (Haller 1747, 435) to mean 'that the generation of the parts of the human body is not made suddenly or together but slowly or by apposition' (Haller 1754, 271).

most scientists. Such later *epigeneticists* as Buffon and Maupertuis envisioned only a rather quick phase of production of the germ, so that after the formation of the germ, their theories are practically indistinguishable from preformationist conceptions. Thus many (or most) eighteenth-century figures who are considered to be representatives of epigenesis were actually dealing with the body's production of the germ and not with the germ's production of the body.

It is also often difficult to decide how literally a preformationist was really committed to the existence of homunculus-like miniature entities; some may have merely taken the miniature as the simplest visualization of the (Cartesian) one-to-one representation of part by particle. If we wish to conceptualize a microscopic material system that: (1) *determines* and *represents* the organic body; (2) is alive at every stage of its growth; and (3) somehow remains identical to itself over developmental time, the easiest way is simply to envision a miniature organism. If we place emphasis on the common Cartesian presupposition that the germ (once formed) somehow *is* the body, then basically all early modern speculations before vitalism are in a sense preformationist, and even the vitalists subscribed to what Kant called 'generic preformation' in the sense that the entire species-specific heterogeneity of an organic body is materially represented in the germ.

3 Expanding mechanism

A new approach to explaining the production of organic form began to be put forward in the fifth decade of the eighteenth century. In 1745 Pierre-Louis Moreau de Maupertuis, a natural philosopher with impeccable Newtonian credentials in physics and mathematics,[16] published some critical speculations on the theory of generation under the title of *Venus physique*, which included some vaguely pangenesis-like suggestions (Maupertuis 1745, 120–21) and the idea that all the particles in the semen might partake of 'animal instinct' which could explain their joining together. He considers whether this instinct 'is spread among all the parts like the spirit of a republic'.[17] This work is generally taken to mark the revival of epigenesis and pangenesis. In the later *Système de la nature* (1751) he claimed that a uniform and blind force of attraction does not suffice to explain the successful production of complex organic form: 'we must have recourse to some principle of intelligence, to something similar to what we call *desire*, *aversion*, *memory*'.[18] The forces must in some sense be more biologically specific, but Maupertuis is still looking for qualities common to all the particles.

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[16] Maupertuis defended Newtonian gravitational attraction against Cartesian vortices in his *Discours sur les differentes figures des astres* of 1732, characterizing gravity with such terms as *primitive*, *primordial* and *inherent* (1965 [1732], 14–21).

[17] 'Cet instinct, comme l'esprit d'une République, est-il répandu dans toutes les parties qui doivent former les corps?' (Maupertuis 1745, 132).

[18] '[. . .] il faut avoir recours à quelque principe d'intelligence, à quelque chose de semblable à ce que nous appellons désir, aversion, mémoire' (Maupertuis 1968 [1751], 147).

The most significant figure in the early development of epigenesis was Georges- Louis Leclerc de Buffon, who moved from mechanics and probability theory to natural history in the 1730s. Buffon had advocated Newtonian physics in a number of minor publications in mathematics and mechanics, including a French translation of Newton's *Fluxions*, before becoming director of the Jardin du Roi in 1739 and turning almost exclusively to biology. He was seen by other Newtonians as a leader of the movement, Voltaire claiming to be merely an 'errant child in a party of which M. Buffon was the chief'.[19]

In the second volume of his *Histoire naturelle* published in 1749 Buffon (1749, 50–51) goes out of his way to praise Descartes for showing what mechanism could accomplish: Descartes reduced all phenomena to the extension, figure, divisibility etc. of the particles of matter. This was a grand step, said Buffon, but he also criticized the limits of Cartesian mechanism and the refusal of the Cartesians to introduce additional fundamental qualities of matter such as gravity even though the explanation of the phenomena seemed to demand this.

General causes, Buffon maintains, cannot be further explained, since this would mean reducing them to more general causes. Buffon subscribed of course to universal gravitation, but he also introduced an additional new force called the *moule interieur* in order to explain generation, growth and regeneration:

> In the same manner as we make moulds by which we can bestow on the external parts of bodies whatever figure we please, let us suppose, that Nature can form moulds by which she bestows on bodies both an external and internal figure; would not this be one method by which reproduction might be effected? [. . .] This quality or power acts not in proportion to the surfaces, but to the masses, or the quantities of matter. Thus there are in Nature powers, and even of the most active kind, which penetrate the internal parts of matter. We are unable to form distinct ideas of such qualities; because, not being external, they fall not under the cognisance of our senses. But we can compare their effects, and may draw analogies from them, in order to account for the effects of similar qualities.
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> *Buffon 1785, 31–32*

'These internal moulds,' Buffon concludes, 'though beyond our reach, may be in the possession of Nature, as she endows bodies with gravity, which penetrates every particle of matter' (Buffon 1785, 32). This passage illustrates the basic pattern of argument: a new force or quality *of all bodies* is introduced to explain a specific type of phenomenon. The phenomenon is empirical or manifest; the new quality is internal or hidden. An explicit

[19] 'Je ne sais comment je m'y prendrai pour envoyer une courte et modeste réponse que j'ai faite aux antineutoniens. Je suis l'enfant perdu d'un parti dont M. de Buffon est le chef, et je suis assez comme les soldats qui se battent de bon coeur sans entendre les intêrets de leur prince'. . . . ('I . . . prince') . . . 'I don't know how to set about sending a short and modest reply which I have made to the anti-Newtonians. I am the errant child in a party of which M. Buffon is the chief, and I am rather like the soldiers who fight bravely without understanding the intentions of their prince (Letter to Helvétius, 3 October 1739; Voltaire 1953, 246).

or implicit analogy to gravitation is made. In introducing the *moule*, however, Buffon reaffirmed the basically Cartesian commitment to explanation as the reduction of the phenomena to the fundamental qualities of matter. Just as Newton, according to Buffon, rightly added a new fundamental quality of matter when this was needed to explain the phenomena of celestial mechanics, so too, Buffon was determined to introduce a new fundamental quality to explain the main phenomena of life. And like Maupertuis, Buffon is looking for a 'republican' quality common to all particles.[20] Force is defined by its phenomenal effects and Buffon can expect that the *moule* is in fact a consequence of some fundamental forces of attraction and repulsion.

Buffon's procedure illustrates the possibilities inherent in the Newtonian position. Once gravity is taken to be an inherent quality of matter, the effects of which only occur under the condition of a system of matter, then qualities have been introduced which are essential to matter but whose *effects* depend on circumstances. Bodies may have intrinsic qualities that are latent and not always empirically expressed: there can be system-independent qualities whose expression is system-dependent. Celestial mechanics set a precedent. It was but a small step to introduce essential qualities whose expression depended on a particular *kind* of system. Attractions and repulsions in chemistry, magnetism and electricity can be seen as effects of primitive qualities of matter which depend on the existence of specific system conditions. The effects of these qualities are manifest (empirically observable), only the causes are hidden (occult), and not in principle observable in an isolated body.

Buffon's one time co-worker John Turberville Needham introduced a 'vegetative force' in similar fashion in order to explain many of the same phenomena. Here, too, it is a force common to all the particles: 'It seems plain therefore, that there is a vegetative force in every microscopical point of matter, and every visible filament of which the whole animal or vegetable texture consists' (Needham 1749, 39). Like Buffon's *moule* this force, too, was thought to be basically a consequence of 'contrary simple forces, that of expansion and that of resistance'.[21] But although someone might object that these two terms 'express only two occult qualities, it seems to me that we have known them clearly enough through their effects, which is enough for my present purposes'.[22] Whether the vegetative force is a fundamental quality or reducible in principle to other non-standard attractive and repulsive forces makes no great difference as long as the reducing forces themselves are not among the traditional mechanical ones.

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[20] The *Encyclopédie* article on generation by d'Aumont follows suit: '[. . .] il faut ranger la cause de la formation de l'animal parmi les causes premieres, telles que celles du mouvement & de la pesanteur, dont nous ne pourrons jamaiscconnoître que les résultats' ('It is necessary to include the cause of the formation of the animal among the primary causes, such as those of motion and gravity, of which we can never know more than the results') (d'Aumont 1757, 562).

[21] 'Cette force composée se résolvoit naturellement en deux forces simples contraires, celle de résistance et celle d'expansion' (Needham 1750, x–xi).

[22] 'Au reste, je ne crois pas qu'on puisse objecter que ce deux termes, de forces expansive & résistante, n'expriment que deux qualités occultes, il me semble que jusqu'ici on les connoît assés clairement par leurs effets, ce qui suffit pour mon présent dessein' (Needham 1750, 277).

This first generation of French Newtonians introduced new forces or qualities in order to explain the formation of the germ, which then expands by internal assimilation of particles (intussusception) in just the same way as the preformation theory had postulated. Although these theories are subsumed under the heading of epigenesis by historians (and were so subsumed by later contemporaries) there is little simultaneous articulation and growth of structure to be seen. The first major attempt to conceptualize growth differently than the preformation theory is Caspar Friedrich Wolff's work a decade later. Wolff introduces an 'essential force' to explain growth and the articulation of structure in plants (and animals). This force is a sort of chemical expanding and contracting force which along with the ability of the vegetable fluids to solidify is used to explain the successive formation of plants and consequently also of their seeds. Wolff however gives little characterization of the nature of this *vis essentialis*:

> However this force may be, whether attractive or repulsive [. . .] it in any case performs the effects mentioned and is assumed as soon as one ascribes to plants nourishing fluids, which is confirmed by experience: This is sufficient for the present purpose, and I will called it the essential force of plants.[23]

This is an openly declared characterization of the force by its phenomenal effects.

We can contrast the position thus far characterized instructively with another, seemingly similar Newtonian argument used by Albrecht von Haller. In the first edition of his *Primae lineae physiologiae* (Haller 1747, 478–79) when he was still groping for an epigenetic explanation of organic form,[24] Haller speculated that organic form was most probably due to the same attractive force at work in the solidification of organic fluids (*vis adtractrix viscidum liquidum*) and also doubtless due to the divine laws (*legibus divinis*) responsible among other things for the formation of crystals. But these seem to be merely local forces that themselves need explanation, rather than universal qualities. And when Haller shortly thereafter introduced the new force of irritability, which he took to be *innate* to fibres (a *vis insita*), he made an analogy to gravity, but since neither irritability nor gravity was taken to be universal, the argument came out a bit different from Buffon's:[25]

> Matter does not have its powers of its own accord. It could be without gravity, without elasticity, without irritability; a new quality but one essential to the structure of plants and animals. These qualities don't participate in matter's essence,

[23] '*Quaecunque vero sit haec vis*, sive attractrix, sive propulsiva, sive aeri expanso debita, sive composita ex omnibus hisce et pluribus; *modo praestet enarratos effectus, et ponatur, posita planta et humoribus nutritiis applicatis*, id quod experentia confirmatum est: *sufficiet ea praesenti scopo, et vocabitur a me vis vegetabilium essentialis*' (Wolff 1759, 13 (§4)).

[24] Haller began as an animalculist like his teacher Herman Boerhaave but developed epigenetic proclivities in the 1740s before reverting to preformation, this time in the ovist form, sometime in the 1750s. See Haller 1772, 298.

[25] Irritability is characterized by Haller (1762, 461) as a *vis insita*, an inherent force; Newton himself had reserved this term for inertia since he did not want to consider gravity to be inherent to matter. But as we have seen, his followers ignored this subtlety.

they are alien to it, and are not common to all parts of matter. Light and fire are not heavy, water is not elastic, minerals are not irritable.[26]

Whereas Maupertuis, Buffon, Needham and even Wolff considered their new forces and qualities to belong to every particle of matter – even if only latently – Haller ascribes his new force of irritability only to specific subsystems of matter. He views it (and apparently all active forces) as superadded to matter or even as immaterial in origin.

Buffon's generation seems to have stuck to physical or chemical forces of attraction and repulsion, perhaps guided in some way; but its members did not introduce biological forces that acted in a goal-directed manner. Buffon's *moule interieur* is conceptualized as the result of a dialectic of attractive and expansive forces, and even Maupertuis' 'principle of intelligence' is merely a phenomenal description specifying what the physical and chemical forces of attraction and repulsion have to achieve.

This approach to explanation increases the number of basic properties of matter with a view to explaining biological phenomena. The appearances of an organic system are traced back to the basic properties and interactions of matter; some of the properties do indeed play no role in mechanics, but they are still physical in a recognizable sense: variations on the theme of attractive and repulsive central forces that cause the motion or cohesion of particles. These material forces can bring bodies together or remove them from one another, but the 'direction' of development is determined by the mechanical circumstances – the structure of the vessels, the selection of particles in the germ or perhaps even a template. Thus the explanation of the organism remains strictly reductionist in two senses: the phenomena of a system are reduced to the properties and interactions of the parts and biological explanation is reduced to physical explanation, albeit somewhat enriched in comparison with simple corpuscularian mechanics.

The next step was to enrich the basic qualities of matter with genuinely biological elements.

4 Vitalism

According to Hans Driesch vitalism ascribes to the phenomena of life an 'autonomy' that cannot be reduced 'to a special constellation of factors, known from the sciences of the anorganic'[27] and although he traces its roots back to Aristotle, it is clear to him that the vitalism of the latter eighteenth century has a new quality. The various life forces introduced by the Newtonians in the generations after Buffon are not emergent qualities

[26] 'La Matière ne tient pas d'elle-même ses pouvoirs. Elle pourroit être sans gravité, sans élasticité, sans irritabilité; qualité nouvelle, mais essentielle à la structure des Plantes & des Animaux. Ces qualités n'entrent pas dans son essence, elles lui sont etrangères, elles ne sont pas communes à toutes les parties de la Matière. La Lumiere & le Feu ne pèsent pas, l'Eau n'est pas élastique, les Mineraux ne sont pas irritables' (Haller 1751, 86).

[27] 'Nicht die Frage, ob Lebensvorgänge das Beiwort "zweckmäßig" verdienen, macht das Problem des "Vitalismus" aus, sondern diese Frage: ob das Zweckmäßige an ihnen einer besonderen *Konstellation* von *Faktoren* entspringe, welche aus den Wissenschaften vom Anorganischen *bekannt* sind, oder ob es Ausfluß ihrer *Eigengesetzlichkeit* sei' (Driesch 1905, 1).

of organic systems caused by a certain physical constellation. On the contrary they are autonomous fundamental qualities, but qualities of a specifically biological nature.

As Georges Canguilhem once pointed out, the vitalists of the Montpellier school far from being 'metaphysical speculators' were rather 'prudent positivists', and 'most of the vitalists appeal explicitly to Newton as a model' of judicious observational science; vitalism was characterized by 'the simultaneous refusal of all metaphysical theories about the essence of life'.[28] Life, according to Theophile Bordeu, 'consists in the faculty which animal fibers have to sense and to move themselves. This faculty, innate in the first elements of the living body, is no more strange than is the gravity, the attraction and the mobility that appertain to various bodies'.[29]

In his *Nouveaux éléments de la science de l'Homme* (New Elements of the Science of Man, 1778) Paul Joseph Barthez introduced a basic life force called the 'Principe Vital' in order to explain the specific phenomena of life in human organisms. In the long and rambling Preliminary Discourse and in the first chapter amid references and allusions to Newton, Barthez makes it clear – especially in the expanded second edition – that his new and merely phenomenally characterized 'Principe Vital' is a fundamental principle 'which resides essentially in matter' and that 'all the parts have a vital faculty and even a sort of perception'.[30]

The clearest formulations on the nature of this new biological fundamental quality are to be found in Johann Friedrich Blumenbach's works that introduce and explain his theory of the 'Bildungstrieb' or *nisus formativus* (formative drive or impulse). Although some of Blumenbach's earliest formulations contain some ambiguities (see McLaughlin 1982), his position becomes clearer and more clearly articulated during the 1780s.[31] In his most important exposition of the theory in *Über den Bildungstrieb* (1789) Blumenbach

[28] '[L]es vitalistes du xviiie siècle ne sont pas . . . d'impénitents métaphysiciens mais plutôt de prudents positivists, ce qui revient à dire, pour l'époque, des newtoniens. Le vitalisme c'est d'abord le refus simultané de toutes les theories métaphysiques concernant l'essence de la vie. Et c'est pourquoi la plupart des vitalistes se referent explicitement à Newton comme au modèle du savant soucieux d'observations et d'expériences et n'utilisant, dans leur interpretation, que des notions aptes à permettre l'énoncé, sous forme des principes, de faits sinon toujours perçus, du moins toujours induits, dont la cause n'est pas recherchée sous formes d'hypothèses' (Canguilhem 1955, 113).

[29] 'En poussant plus loin les recherches sur la vie, on voit qu'elle consiste dans la faculté qu'a la fibre animale de sentir et de se mouvoir elle-même. Cette faculté innée dans les premiers élémens du corps vivant, n'est pas plus étrange que ne le sont la gravité, l'attraction et la mobilité qui appartiennent à divers corps' (Bordeu 1775, 331).

[30] 'Cette activité qui réside essentiellement dans la Matière, n'est pas seulement indiquée par les divers Principes de mouvement qu'on observe dans les différens corps. Elle peut l'être encore par la Nature propre de cette substance; òu, suivant un grand nombre de Philosophes Anciens et Modernes, il faut reconnoître que toutes les parties ont une faculté vitale et même une sorte de perception; si l'on veut trouver une raison générale et suffisante des phénomènes de l'Univers' (Barthez 1806, 49).

[31] This type of argument was not confined to the Continent. In a lecture given in 1786/87 the most prominent contemporary English vitalist John Hunter said: '[A]nimal matter has a principle of action in every part, independent of the others, and whenever the action of one part (which is always the effect of the living principle) becomes the cause of an action in another, it is by stimulating the living principle of that part, the action in that second part being as much the effect of the living principle of that part as the action of the first was of the living principle in it. The living principle, then, is the immediate cause of action in every part; it is therefore essential to every part, and is as much the property of it as gravity is of every particle of matter composing the whole. Every individual particle of matter, then, is possessed of life, and the least imaginable part which we can separate is a much alive as the whole' (Hunter 1835, 223).

makes it clear that the *Bildungstrieb* is a universal force of all matter that becomes 'excited' (*rege*) . . . in certain kinds of structure that have gone through a particular process of ripening ('Reife'). Once it has been triggered, the *Bildungstrieb* takes on a species-specific 'direction' determined by the nature of the initiating system and retains it for life:

> That the unorganized matter of generation, after being duly prepared, and having arrived at its place of destination takes on a particular action, or nisus, which nisus continues to act through the whole life of the animal, and that by it the first form of the animal, or plant is not only determined, but afterwards preserved and when deranged, is again restored [. . .] that it is the chief principle of generation, growth, nutrition and reproduction [. . .].[32]

This formative drive is known only by its phenomenal effects, which however are regular and manifest, just as the force of gravity is known only by its lawlike and manifest operation:

> It is to be hoped that there is no necessity for reminding the reader, that the expression Formative Nisus, like that of Attraction, serves only to denote a power whose constant operation is known from experience, but whose cause, like the causes of most of the qualities of matter is a *qualitas occulta* to us.[33]

Blumenbach goes on to contrast his new force with the *vis essentialis* of Caspar Friedrich Wolff, insisting that it does more than merely distribute nourishment by moving the organic fluids. It cannot be reduced to chemical attraction and repulsion. It seems irreducibly to contain some kind of representation of the species form as a goal for development. Wolff responded by criticizing Blumenbach for just this position:

> I must yet add, that a faculty or force driving the fluids in particular directions, such as Mr. Blumenbach [. . .] seems to stipulate, cannot occur. If this driving occurs within vessels, then its direction depends not on the driving faculty or force

[32] 'Dass keine präformirten Keime präexistiren: sondern dass in dem vorher rohen ungebildeten Zeugungsstoff der organisirten Körper nachdem er zu seiner Reife und an den Ort seiner Bestimmung gelangt ist, ein besonderer, dann lebenslang thätiger Trieb rege wird, ihre bestimmte Gestalt anfangs anzunehmen, dann lebenslang zu erhalten, und wenn sie ja etwa verstümmelt worden, wo möglich wieder herzustellen. Ein Trieb, der folglich zu den Lebenskräften gehört, der aber eben so deutlich von den übrigen Arten der Lebenskraft der organisirten Körper (der Contractibilität, Irritabilität, Sensibilität etc.) als von den allgemeinen physischen Kräften der Körper überhaupt, verschieden ist; der die erste wichtigste Kraft zu aller Zeugung, Ernährung, und Reproduction zu seyn scheint, und den man um ihn von andern Lebenskräften zu unterscheiden, mit dem Namen des *Bildungstriebes* (*nisus formativus*) bezeichnen kann' (Blumenbach 1789, 24–25).

[33] 'Hoffentlich ist für die mehresten Leser die Erinnerung sehr überflüssig, dass *das Wort* Bildungstrieb, so gut, wie *die Worte* Attraction, Schwere etc. zu nichts mehr und nichts weniger dienen soll, als eine Kraft zu bezeichnen, deren constante Wirkung aus der Erfahrung anerkannt worden, deren *Ursache* aber so gut wie die Ursachen der genannten, noch so allgemein anerkannten Naturkräfte, für uns *qualitas occulta* ist' (Blumenbach 1789, 25–26).

> itself but rather on the structure of the vessels, which resist motion in all directions but one and in this manner determine the direction. A repulsive force that acts between two bodies can produce nothing more than a removal of the two bodies from one another. [. . .] The direction along which the repelling bodies are removed from one another depends in any case on other circumstances: on their relative positions, on their shapes, or on other bodies located nearby which resist their motions in particular directions and leave motions in other directions open thus determining the direction.[34]

The difference between Blumenbach's vitalism and Wolff's tentatively enriched physicalism lies in the way they determine the *direction* of development in the formation of the organism. For Wolff, as for Buffon, the force determines only motion; the direction is determined by complex boundary conditions – in this case the structure of the vessels mechanically determines the direction in which the fluids move. For Blumenbach, as for other vitalists, the direction is determined by the force itself.

5 Conclusion

How should we characterize the reception of Newton in biology on the Continent? In a quite specific sense biology itself was one form of Newton's reception in the life sciences on the Continent. The attempt to do for the explanation of the regeneration, growth and propagation of organisms what Newton had done for the explanation of the motion of the planets, the tides and falling bodies led to a new science. The phenomena of the organism were traced back to the action of a universal force of matter. Such diverse phenomena as the regeneration of the hydra, the growth of plants, the propagation of animals were unified as instances of one fundamental process of the production of organic form. Late eighteenth-century vitalism provided a reductionistic explanation of the phenomena of an organic system in terms of the intrinsic qualities and interactions of the parts. However, since at least one of these qualities (*Bildungstrieb*, *principe vital*, living force) had no role to play in mechanics – or anywhere in physics – the science of life was not reduced to the science of moving bodies. Biology emerged as a discipline that was in principle irreducible to physics. This (in modern terms) ontological reductionism

[34] 'Ich muß noch hinzusetzen, daß ein Vermögen oder eine Kraft, Säfte nach bestimmten Richtungen fortzutreiben, wie Herr Blumenbach [. . .] fest zu setzen scheint, nicht statt haben könne. Findet eine solche Forttreibung in Gefäßen statt, so dependirt ihre Richtung von dem Bau der Gefäße, die der Bewegung nach allen übrigen Richtungen, eine einzige ausgenommen, wiederstehen, und auf diese Art die Richtung bestimmen, nicht aber von dem Vermögen, oder der Kraft fortzutreiben, selbst. Eine repellirende Kraft, die zwischen zween Körper statt findet, kan weiter nichts als eine Entfernung der beyden Körper von einander [. . .] hervorbringen [. . .]. Diese Richtung also nach welcher sich repellirende Körper von einander entfernen, dependirt allemahl von andern Umständen: von ihrer Lage gegeneinander und von ihrer Figur, oder auch von andern in der Nähe befindlichen Körpern, die ihrer Bewegung nach gewissen Richtungen widerstehn, nach andern aber dieselbe frey lassen, und so die Richtung bestimmen' (Wolff 1789, §32, 22).

without theory reduction seems to have been behind Kant's despair at a Newton of the grass blade – he really wanted a Descartes of the grass blade.

There are many reasons why the Newtonian solution in vitalism was unstable. One is of course the inconsistent reductionism – Kant would not be the only one to demand that theory reduction also be achieved. Perhaps more importantly: there is no empirical difference between the emergence of a new force at a particular level of organization and the triggering of an intrinsic but otherwise unobservable latent force at a particular level of organization. The distinction with which the Newtonians started out is philosophically or ideologically motivated but in the long run not scientifically tenable since it makes no empirical difference.