Conceptions of ether

Studies in the history of ether theories 1740–1900

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CONTENTS

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PREFACE

This volume collects ten new studies of a topic central to the history of scientific thought in the last three centuries: theories of ether.

Typically conceived in the time of Newton (1642–1727) as subtle media, like air but much rarer and more penetrating, ethers were conjectured to be the mediating agents for such physical effects as light, magnetism, electricity, and nervous impulses. We might say, then, that this volume follows the fate of such conceptions of ether in the period since. For there is a striking contrast between 1751 and 1951. In 1751, Newton's and other ether concepts were dominating almost every branch of scientific theorising from electricity and chemistry to physiology and psychology. By 1951, however, we find an eminent physicist, P. A. M. Dirac, having to argue in the journal *Nature* (*168:*906–7) that although Einstein's 1905 principle of relativity led, reasonably enough, to ether's generally being abandoned, with the new quantum electrodynamics we may be, after all, 'rather forced to have an aether'.

With their many explanatory roles and metaphysical presuppositions, ether concepts introduce us to the broadest themes in the scientific thought of the eighteenth and nineteenth centuries. Ether theorising may even be seen as a unifying theme itself. We have not assumed, however, that it is such a theme. Our concern has been to use the history of this unruly family of concepts to raise and clarify general issues that any comprehensive analysis of those two centuries would have to recognise.

Most obviously, ether theories relate to controversies over the origins of classical field theory, and over the interpretation of Faraday's natural philosophy in particular. Again, ether theories often developed differently within distinctive national schools and styles of scientific work; so they raise the challenge of explaining the cultural differences, most notably in French, German, English, and Scottish science. Furthermore, conceptions of ether underwent especially striking transformations in the period from about 1800 to 1840; these transformations may then support the view, favoured by some historians but not all, that a second revolution in science, hardly less fundamental than the famous one of the seventeenth century, separates all the scientific ideas and institutions of 1840 from those of 1800. To take another theme, if we look to the theological uses made of ether concepts, we find plenty of evidence that science and religion have not been – as the older rationalist histories depicted them – always in conflict since the Enlightenment. Finally, we can see from the reflections made on the credentials of ether theories how wrong is the easy, cynical assumption that methodological theory and scientific practise have never learned from one another.

These, then, are some of the issues that surround the history of ether concepts and are sampled in the chapters prepared for this volume. No previous work has approached the subject quite as this one does. We would emphasise, however, that the editors and contributors are often deeply indebted to earlier studies. E. T. Whittaker's classic treatise still deserves mention before all others, even though its approach must often now be questioned. Of the more recent literature, the writings of M. B. Hesse, J. E. McGuire, Ernan McMullin, Kenneth Schaffner, and R. E. Schofield have naturally been invaluable.

The select bibliography at the end of this volume is limited to the more significant secondary literature on ether theories in the period 1740–1900. Here the reader will find all those works referred to throughout this volume by the name–date format (e.g., Whittaker, 1910). Included also are a number of other works not listed elsewhere. References to primary sources, and to those secondary sources that do not provide extensive discussion of ether theories, are contained in the endnotes to the individual chapters. It has at times been difficult to decide which secondary works should be included in the select bibliography, but in general only those have been included that contain comprehensive, detailed, or otherwise noteworthy discussions of ether theories.

In planning this volume we have benefited from advice kindly given by several colleagues, particularly John Brooke, Stephen Brush, Robert Fox, and Mary Hesse. To Richard Ziemacki, our editor at the Press, we are grateful for judicious counsel and encouragement. In writing the introduction and compiling the bibliography we have had very generous help from our contributors and from Michael Duffy. It gives us great pleasure to have this chance to thank them all. Our thanks go, too, to Andrea Charters and Gay Lowe, who prepared the typescripts of successive drafts.

Introduction: Major themes in the development of ether theories from the ancients to 1900

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We might introduce the historical study of ether theories by stating simply what ether is. But two reflections should make us pause before attempting this. First, although essentialism is now favoured again in reputable quarters, the lessons of Wittgenstein and others still stand. For many kinds of things it is futile to seek a common and distinctive essence. For many terms it is misleading to demand a definition specifying the conditions necessary and sufficient for their application. So it is with *ether*. We cannot usefully indicate properties that all ethers must and only ethers can have. Second, even if we could, we should not wish to make the attempt independently of historical inquiry. For any definitional demarcation of one kind of theory from others may serve merely to separate lines of theorising that in fact developed together, or to conflate those that developed apart.

However, although the complexities of history may make the abstract definitional problem difficult, they do allow solutions for particular purposes. For the purposes of a study of the period from 1740, we can find in the ether theories of Isaac Newton (1642–1727) cases exemplary enough to suggest an introductory characterisation of ether theories in general.

As every schoolboy is traditionally supposed to know, Newton's law of gravitation has bodies such as the moon and the earth attracting one another with a force proportional to the product of their masses and inversely proportional to the square of the distance between their centres. His ether theory of gravitation would explain this tendency as the effect of forces, not of attraction but of repulsion, exerted by the particles of a rarified medium dispersed unevenly throughout the vacuities in the gravitating bodies themselves and throughout the space that separates them. It is the medium itself that Newton calls an 'aether' Again, Newton traced the deflection of light rays passing through a prism to the action of a special medium whose particles exert distinctive forces of their own, and this medium he also calls an 'aether'.

Because Newton's gravitational and optical ethers were regarded at the time as typical of the genre, we may say that an ether was a spatially and temporally extended entity exerting but not merely identifiable with certain forces and supposed to fit most of the following descriptions: It may be present in spaces empty of ordinary solids, fluids, and gases; it is not perceivable as such ordinary materials are; it transmits actions or effects including or like those of magnetism, electricity, heat, and nervous impulses; it can penetrate and pass through ordinary solid, fluid, and gaseous materials; changes in its distribution or its state can cause observable changes in ordinary bodies.

Such a characterisation can and should allow for fundamental variations. For, as emerges from any survey of science from Newton's time on, some ethers approximating to this characterisation have been supposed material, others immaterial; some fluid, others solid; some continuous, others particulate; some conforming to various laws of mechanics, others not. Some, moreover, have been interpreted literally, as truly existing *in rerum natura;* others agnostically, as possible representations of real physical processes; yet others strictly as fictions useful in the correlating of sensible phenomena. However, no matter how radically later ether theorists departed from Newton's ideas, they were always prepared to acknowledge the precedents he had set.

Early ether theories

Aither in the classical traditions

In developing their ether theories, scientists of the eighteenth century – men such as Boerhaave, Hartley, and Newton himself – often saw classical, medieval, and Renaissance authors as setting important precedents for their own conjectures. We should, then, begin by looking to those traditions that they were most concerned to reject or correct, to vitiate or vindicate.

A tidy taxonomy of classical thinking cannot be given, of course, without misrepresenting the character of much of that thinking itself. For many writers, especially in Hellenistic times, were deliberately intent on mixing notions from different schools. To mention one obvious example, the *aither* of Aristotle and the *pneuma* of the Stoics were originally conceived as quite different in their place and action in the universe. Many authors, however, were willing to conflate any *aither* with any *pneuma.* Among the myriad conceptual permutations perpetrated in antiquity, a really diligent student of the ancients, such as Newton was, could eventually find a plausible precedent for almost any innovation he was about to make.

Moreover, to take the uses made of the word *αἰθήρ* (and its cognate *aether* in Latin) as an exclusive guide would be to risk missing much that is important in understanding the later influence of these traditions. *Aither,* as a word in Plato's dialogues, does not introduce us to his fundamental teachings about knowledge, reality, space, and matter. Nor does *aether* take us to the heart of Lucretius's science and metaphysics. Yet Plato's Platonism, especially through Henry More (1614–87), and Lucretius's atomism, especially through Pierre Gassendi (1592–1655) and Walter Charleton (1620–1707), were to be among the most decisive, indirect influences upon Newton's ether theorising. So, even in starting with the word *aither,* one should recognise that philological must be integrated with philosophical history.

There seems little doubt that the accounts of *aer* and of *aither* found in the Ionian philosophers of the sixth century B.C. derived partly from a commonplace picture of the world already reflected in the poetry of Homer. That picture was primarily a religious one; it dramatised the destiny of the soul. In it the sky is a solid hemisphere, a bowl, a canopy covering a round flat earth. Between the earth and the sky is *aer,* misty air. Beyond this *aer* is an upper part, a higher air, the *aither.* This higher air is shining, blazing, even fiery. Brilliant and pure, it is akin to men's souls. Indeed, it may be a kind of soul, a form of life itself. A human soul could achieve immortality by joining this everlasting heaven after release from the body at death. Appropriately, Socrates' contemporary Aristophanes has Euripides, in the *Frogs,* pray to *Aither* as to a god.[1]

One may see two Ionians, Anaximenes and Heraclitus, finding in this *aer* and in this *aither* the foundations for their cosmologies. Anaximenes indeed considered *aer* the original source from which all else arose: He evidently taught that water arises by the condensation of this air, fire from its rarefaction. He probably also made air the controlling agent in the resultant cosmos. Identifying the soul of an animal with its breadth, or *pneuma,* he may have made air the breath or *pneuma* and so the source of life and regularity for the world at large.[2]

Heraclitus by contrast seems to have associated soul not with air but with fire. Perhaps through this association he was led to make a special, pure form of fire the ordering and animating agent for the whole cosmos. It is probable, too, that he equated this pure, divine cosmic fire with *aither,* the blazing heavenly haven for the soul.

Heraclitus's theory concerns the control, not the generation, of the cosmos. But a conjunction of Anaximenes and Heraclitus could clearly yield an ethereal cosmogony. Equate fire with *aither* and *aither* with *pneuma,* and one has the world arising from the condensation and rarefaction of an original ethereal source. Although such equations were common in late antiquity, there is no such synthesis of *aither* and *pneuma* known among the Ionian authors themselves. But equally there was nothing in the early conceptions of *aither* to preclude it. For the status of *aither* remained very much unsettled in pre-Socratic science. It was still, like the *aer* it was so often compared and contrasted with, sometimes a region, sometimes an agency, and sometimes an ingredient, all according to context. The speculations of Anaximenes or Heraclitus were certainly rich in hints for later ether theories. But they themselves can hardly be said to have had theories of *aither*.

The first theory of *aither* as such is probably not to be found until Aristotle (384–322 B.C.), writing nearly two centuries later. For Aristotle had a general theory of elements and a specific theory of *aither* as an element.

Theories of elements in the two generations before Aristotle had been developed mainly as a response to the radical critique of cosmological theory explicit in the writing of Parmenides of Elea in Italy. Writing after Anaximenes and almost certainly after Heraclitus too, Parmenides had argued that the ultimate object of thought and discourse must be a single, undifferentiated, unchanging being behind all appearances. If accepted, such an argument obviously constituted a crisis for the contemporary science. For its various explanatory entities were all supposed to account for the diversity of the cosmos by underlying and giving rise to it in precisely the ways Parmenides had concluded were inconsistent with genuine reality.[3]

By Plato and his pupil Aristotle's time two very different responses had been made to the Parmenidean impasse. On the one hand, Anaxagoras and Empedocles had proposed theories of a mixture and separation of everlasting elements. According to Anaxagoras, infinitely divisible parts of matter, each containing the 'seeds' of all things, are moved by the universal agency of Mind; whereas according to Empedocles, everything traces to four 'roots', earth, air, fire, and water, worked upon by Love and Strife. On the other hand, Leucippus and Democritus had explained the world as a congregation of imperishable atoms moving in void space; the atoms themselves they supposed differentiated by the geometrical properties of size and shape; they may also have had them differ in weight.[4]

Plato's cosmogony, as found in the *Timaeus*, departed deliberately from both these lines of thought. He followed Empedocles only in making earth, air, fire, and water the basic kinds of matter. He followed Democritus only in seeking a geometrical ground for their qualitative differences. The entirely novel framework for the cosmogony of the *Timaeus* was, naturally, Plato's own solution to the Parmenidean problems: his theory of eternal, transcendent Forms serving as models for the work of Reason. For, in his cosmogonical narrative, the four elemental bodies as we know them arise when the Craftsman takes these Forms as recipes and standards for his work in ordering motion and differentiating space.[5]

Aristotle, of course, had his own forms but rejected Plato's separation of forms from things formed. With a sempiternal cosmos he also had no need for an original informing of the universe as a whole. His five elements – earth, air, fire, water, and *aither* – are thus, as kinds, sempiternal too. They are all, as essences or natures, forms embodied forever.

Although he himself usually called it 'the first body', Aristotle's new element was to be identified by later writers as *quinta essentia*, the fifth essence. In calling it *aither* or *aether* they followed a hint of Aristotle's own.[6] Although but one among five elements, it is distinctive, not to say anomalous, when compared with the other four. For individual bodies compounded of the others can not only change in place; they can change in quality and quantity and can even come into or go out of being altogether. Moreover, samples of these four elements can themselves undergo transmutation. For the nature of each is constituted by a pair of qualities – for example, dry and cold for earth – so that for there to be stuff of that nature in a particular place is merely for the matter there to be so qualified. Now, the prime matter that these qualities ultimately qualify has no nature, no qualification in and of itself. If the qualifications are exchanged, then, in, say, a switch of wet for dry or hot for cold, earth and air may arise from fire and water.[7]

This theory of qualification and transmutation has no application to *aither*. That element is capable only of local motion, change of place, not any other. Indeed, for Aristotle, the circular motion so distinctive of the heavens is above all what calls for the addition of *aither* as an element beyond the traditional four. For those four are distinguished by natural motions up and down, motion in straight lines towards the centre or towards the periphery of the spherical cosmos.[8]

How then can an endless circling of *aither* in the heavens yield motion in the terrestrial realm? For, after all, Aristotle's cosmos is moved, it is driven and is led, from the outside in. In two ways, at least, *aither* can move the rest. First, in moving against fire it ignites fire to give heat and light. From the daily and seasonal variations in the sun's heat and light arise many changes among animals, plants, and minerals. Second, *aither* has a representative, an analogue here on earth: *pneuma*. Not soul as such, but the instrument of animation in plants, animals, and men, *pneuma* is breath and is spirit; it is what brings life to the body at conception and leaves it cold and still on departing at death. The hot air of this *pneuma* is analogous to the *aither* of the heavens. For like the special heat of the sun that fertilises the earth in spontaneous generations, the *pneuma* in semen can initiate the movements of a new life at conception. Moreover, in this action it shows that it has circular motion natural to it: the circling of a life cycle. In the conclusion enthusiastically reiterated by all Aristotelians from the master himself to William Harvey (1578–1657) two millenia later, just as the *aither* has the heavenly bodies endlessly returning as individuals, the *pneuma* ensures that earthly life does so as species. The celestial moves the terrestrial as a permanent object of emulation; thus do both emulate the perfect immutable being of the ultimate, the unmoved, mover.[9]

The Stoics integrated *aither* and *pneuma* even more fully, eventually identifying them explicitly with one another, although the precise details of this and other developments of Stoic thought are beyond reconstruction on the evidence surviving. Zeno of Citium founded the tradition, in the generation after Aristotle, in lecturing (*c*. 300 B.C.) on the Painted Porch (*Stoa Poikile*) in Athens, but the physics of the Stoics must be gathered mostly from untrustworthy biographies and scraps of commentary written much later.[10]

The Stoics made the ability to act and be acted upon the criterion for real existence, and they argued that only corporeal entities meet this criterion. Corresponding to these two abilities are the two ultimate principles of all bodies, the active and the passive principles. These two are thus inseparably present throughout the continuum, the plenum of the universe. The passive principle is matter itself, in so far as it is an inherently inert stuff that Nature is forever at work upon. The active principle, Nature or God, embodied as *pneuma*, a blend of fire and air, sometimes equated with *aither*, is everywhere actively mixing with matter, penetrating and shaping it so as to constitute bodies that can themselves act and be acted upon. This active principle, as God or Nature, is an immanent *logos*, a rational, providential intelligence, the very life of the universe itself from which all plant, animal, and human life draws its diverse animation and faculties. However, its action, through its embodiment as the *pneuma*, the *aither*, is left very unclear. This is mainly because, being continuous, not particulate, and being inseparable from passive matter, it cannot be conceived as one ingredient juxtaposed with others in the composition of a solid or fluid body.[11]

Its primary physical function is to give coherence or cohesion, *hexis*, to bodies. This *hexis*, no mere structural unity, is indeed the source of all the qualities in a body. Its own ground lies not in a static constraint but in a continual motion. With this motion comes a tension, a *tonos*. On one ancient account, 'there is a tensional motion in bodies which moves simultaneously inwards and outwards', the outward motion giving rise to 'quantities and qualities', the inward to 'unity and essence'.[12] The commentators help us little, though, in understanding these simultaneously contrary movements. The inward one was sometimes associated with the contraction owing to the cold in the air of the *pneuma*, the outward with the expansion owing to the heat in its fire.[13] In our own time such Stoic notions are often glossed with talk of dynamic continua and equilibria, of forces, of energy, and even of fields of force. But, in themselves, these are largely empty, not to say misleading, moves, adding little to our understanding of the Stoic *pneuma* as a physical theory.

That theory had its rationale in the principal problems it was originally meant to solve. In an ultimately continuous corporeal cosmos there are different degrees of activity, coherence, unity, and integration in bodies as one passes from minerals through plants and animals up to man. The Stoics would explain this diversity, and this hierarchy, by referring it to active and passive principles and so to the universal ability to act and be acted upon.[14]

A similar preoccupation with a cosmic hierarchy from merest matter up to God is of course dominant in the neo-Platonic authors, most notably Plotinus (*c*. 205–70 A.D.) and Proclus (410–85). However, although Stoic notions, especially of *spermatikoi logoi* (seminal reasons), were drawn on by these men, there is nothing in their theories truly equivalent to the Stoic *pneuma*, nor indeed to the Aristotelian *aither*. For the neo-Platonists have their hierarchical cosmos arising eternally as a graduated series of emanations ultimately deriving from the One that is above even Mind and the World Soul. All bodies are activated by the World Soul, whose immaterial animation is directly contrasted with the inertness of matter itself. The emanational dependence of bodies on the One, who is also Being and the Good, is understood by analogy with light. For, like a radiant source, this God is in no way diminished even as He brings forth the visible from the darkness that is matter. The neo-Platonists derived their emanationism largely from what they took to be the central themes in Plato's writings. Consistently enough, when elaborating accounts of the elements, they kept closest to Plato's account in the *Timaeus* of earth, air, fire, and water and their movement by the World Soul; and they avoided any special *aither* as a fifth element.[15]

The Stoic and neo-Platonic unifications of heaven and earth contrast radically with one another. Contrasting no less radically with both was the unification presented by the Roman poet Lucretius (*c*. 99–55 B.C.) in his development of the atomism of Leucippus, Democritus, and their follower Epicurus. Lucretius's cosmogony starts with the formation of the earth from a mindless rushing together of atoms driven only by their weight and their collisions with others. As the heaviest atoms making up the earth become packed and linked together, they squeeze out those going to make the heavens: These are smoother, rounder, smaller, and lighter; ejected, then, they rise up as a fiery *aether*, before congealing to form the moon, sun, stars, and planets. Once formed, these heavenly bodies are swept round in their orbits by further streams of air and of *aether* that are themselves deflected into circular paths by surrounding material even further out in space. The *aether* has a special place in Lucretius's cosmos that is determined by the distinctive geometry and gravity of its atoms, but in the matter, and so in the natural motions of those atoms themselves, it is not, ultimately, special at all.[16]

The contrasts among even the few classical cosmologies mentioned here are, needless to insist, striking and real. They may seem to preclude any significant generalisations about the resources classical texts could later provide for early modern ether theorists. There are, however, four that may be worth suggesting, naturally with a warning as to the exceptions one could easily bring against them. First, the conceptions of *aither* often depend directly on ontologies, on theories of being and of substance. Second, it is in integrating accounts of the heavens and of spirits that the classical writers most often faced the problems their theories of *aither* and *pneuma* were to solve. Third, as solutions to those problems, these theories often raised in turn further problems of how these entities were related to the one matter or many matters making up the bodies we see and touch. Fourth, these ideas were given by many writers vague and analogical characterisations that made them plausibly invoked in contexts and in combinations never contemplated by their original authors. For this last reason, if for no others, the classical inheritance has proved as difficult for the modern historian to trace in well-defined lines as it has proved fruitful for medieval, Renaissance, and Enlightenment scientists to develop.

The classical traditions in the Middle Ages and the Renaissance

The medieval centuries saw deployment of the Greek ideas of *aither* and *pneuma* whenever – and that was often – doctrines of spirit or of heaven were being given a physical interpretation.

Two examples must serve to stand for many. First, Christian philosophers elaborated accounts of a 'spiritual body' to go with St. Paul's teaching (1 Corinthians 15:44) that, upon resurrection to everlasting life, a person would be given a new body distinguished from his earthly one by its spiritual nature.[17] Again, problems of conception and incipient animation, in natural, not to mention virgin, births, prompted theories integrating the immortality of the soul, its bodily instruments, and its potential for joining God and the angels in heaven.[18]

Whether among Islamic, Jewish, or Christian writers, however, the Middle Ages saw no radical innovations setting major direct precedents for later ether

theorists. One reason for this is familiar enough. With few exceptions, most writers on natural philosophy were consciously continuing traditions tracing ultimately to Plato and to Aristotle rather than to the Stoics or the Atomists. So either their cosmologies followed neo-Platonic modes of unifying the heavens and the earth through an emanationist metaphysics of light rather than *aither* or *pneuma*, or they perpetuated the Aristotelian division of the heavenly and the terrestrial, with its confinement of *aither* to the one and *pneuma* to the other.

The neo-Platonic tradition of light metaphysics found notable expression in the writings of Robert Grosseteste early in the thirteenth century. In Grosseteste's case one may discern at least four appeals to optical metaphors and analogies.[19] First, the intellect's gazing upon the Platonic forms parallels the seeing we do with our eyes; second, God as Christ is viewed as the Light irradiating the soul; third, light is identified as the ultimate form of corporeal substance as such, so that the material creation can be interpreted as if produced by an original point of light propagating itself in three dimensions; fourth, all subsequent action in the physical world may be understood as like the radiation of light. From these last two themes, Grosseteste derives explicitly the requirement that all explanatory causes of natural effects be specified geometrically, in lines, angles, and figures. Descartes was to have his own reasons for reaching similar conclusions four hundred years later. But there are perhaps traces of light metaphysics in his cosmology and in his influential ethereal theory of light itself.

Naturally, Renaissance scholars ensured that all the classical traditions we have mentioned were actively discussed in the generations before Descartes' own. They often studied, also, the Hermetic writings, supposedly deriving from that venerable Egyptian source of priestly wisdom Hermes Trismegistus, but probably in fact composed mostly in Alexandria in the second and third centuries A.D. These writings present a rich blend of ideas, mainly of Stoic, Platonic, Judaic, and Christian origins, as a cosmological foundation for a gnostical faith and magical practice.[20] Two treatises particularly are relevant here. The Latin *Asclepius* matches the grades of soul in plants, animals, and men with the lower and higher elements, so that the soul of animals is sustained by the ceaseless motions of fire and air, whereas the intellect unique to man comes from *aether*. The Greek *Poimandres*, or in Latin, *Pimander*, has the more sluggish elements, earth and water, moved by a spiritual word, *pneumatikos logos*, that provides an obvious link between Stoic physics and Hebrew cosmogony. Many unresolved issues still surround the vexed question of the influence of the Hermetic teachings on sixteenth- and seventeenth-century science. It is often hard to be sure that a concept traces to Hermetic teachings, if only because for most concepts there are several other classical sources.[21]

The scientific tradition most thoroughly permeated with Hermetic views was the alchemical one, notably represented in the Renaissance by Paracelsus (1493–1541) and by later chemists like Van Helmont (1577–1644), who shared his Hermetic interests.

On Paracelsus's view, spirit of various kinds is the true object of the chemical and medical arts. For all minerals, plants, and animals embody and so imprison spirits ultimately of divine origin and celestial nature. From these hidden, invisible spirits they derive the secret powers elicited, concentrated, and coordinated by the scientific adept whose skill and wisdom arise likewise from heavenly powers implanted with the soul in his own body.[22]

The various metaphors and ancient teachings invoked by Paracelsans hardly cohere well enough to make a single, definite theory of *spiritus;* its constitution and relation to bodies, especially, remain obscure, not to say mysterious. For, it seems, no one spirit is common to all bodies, there being, rather, as many as distinct kinds of bodies. In any case the full powers of a body's spirit lie dormant until roused by the right agent. In the alchemists' work, fire is the great awakener; it can purify bodies by liberating their essences, their spirits, because it is itself a ubiquitous embodiment of spirit in nature.[23]

There are strong echoes here of the material Stoic *pneuma* and of the immaterial neo-Platonic *anima mundi*. The interpretation of the corporeal world is hierarchical and dualistic: hierarchical in that bodies are assigned to grades of perfection from minerals to man; dualistic in that these grades are thought to be diverse degrees in the informing and enlivening by spirit or soul of the inchoate and inactive.

Many difficulties in understanding eighteenth-century ether theories arise because those theories drew sometimes on such hierarchical and dualistic philosophies of nature, and sometimes on the most radical alternatives to them. Few texts are more important for those eighteenth-century theories than the long chapters on the element fire in the *Elementa chemiae* (1732) of Hermann Boerhaave (1668–1738). Although Boerhaave's teaching on fire is plainly indebted to chemists in the Paracelsan tradition, it is no less obviously derived from the natural philosophy deliberately developed by René Descartes (1596–1650) as a comprehensive replacement for any hierarchical and dualistic interpretations of the corporeal world.

Such complexities in the origins of the eighteenth-century ether theories necessitate discussion of several broad and deep problems in the historiography of early modern science. Is one to follow Duhem in seeing important continuities between fourteenth-century and seventeenth-century natural philosophy? Or was modern science, as Koyré came close to saying, born in a revolutionary new victory for Plato over Aristotle, won by Kepler, Descartes, Galileo, and Newton? Or did it arise in a gradual mechanisation of the *Weltbild* consummated by Huygens, as Dijksterhuis would suggest? Or was the Aristotelian cosmos destroyed by an incongruous, even unwitting, collaboration between the magical and the mechanical philosophers; or should one say, rather, by the combined forces of the Hermetic, the neo-Platonic, and the Epicurean traditions? Of late the possibilities proffered have proliferated even as persuasive probabilities have remained elusive.[24]

Our aim, of course, can only be to raise such questions here in suggesting their relevance to eighteenth-century ether theories considered in their native contexts. This we can do by concentrating on the extent to which two crucial authors, Newton and Boerhaave, were both, in their very different ways, following and yet departing from, even radically, Descartes and other mechanical philosophers of the previous century.

Descartes, subtle matter, and the mechanical philosophy

Descartes' conjectures for any specific explanatory purposes in physics always invoke his most general conjecture of all: the hypothesis that matter has been differentiated from the beginning of creation into three elements. He usually calls these three simply the first, second, and third elements. However, he also identifies them as 'fire', 'air', and 'earth' respectively, although insisting that they are not to be equated with what have customarily gone under those names.[25]

His avowedly mythic sketch of this cosmogonical differentiation, in his *Le monde* (published posthumously in 1664), begins with the formation of the second element. This element arose everywhere as minute spheres formed like grains of sand rubbed round as they roll about in running water. The other two elements arose as products and residues from this process, for the first element comprises simply the portions rubbed off, and the third comprises any particles left unrounded because too large or packed too firmly in irregular lumps and those formed by conglomeration.[26]

The portions of this first matter were, in their very formation, filling the changing and indefinitely small interstitial spaces. So they have no fixed shape; and by having to move round the spheres of the second element, they have acquired very quick motions. In any large, swirling vortex, the excess first element matter, not needed to fill the interstices between the second element particles, will have moved towards the centre to form there a liquid of perfect fluidity. The sun formed as a vast turning globe of this first element.

Now, as it turns it presses on and moves the surrounding layers of minuscule second element spheres. Light as a physical action is the transmission of this pressure through the second element, whereas movements of the first element constitute heat, fire that is without light.[27]

All Descartes' most influential physical hypotheses deploy second element and hence, too, first element material. In the 1637 treatises, *La dioptrique* and *Les météores*, the two were not distinguished. There, 'matière subtile' includes whatever particles transmit light. However, in *Le monde* and *Principia philosophiae* (1644) – the works later generations took as definitive – Descartes' subtle matter, his celestial matter, what his contemporaries called 'the Cartesian aether', comprises the second element permeated, as always, by the first.[28] His science was thus ethereal throughout, in that all observable changes in the gross, sensible bodies made of the third element are traced to actions upon them of the second and first.

His science offered moreover a comprehensive alternative to all hierarchical and dualistic cosmologies. For its foundations, as Newton and others insisted – as did Descartes himself – lay in Descartes' famous division of all created substances into minds and bodies, together with his conclusion that the essence of bodily substance is simply extension in the geometer's three dimensions of height, breadth, and depth. By confining the mental to the human, the angelic, and the demonic, Descartes made all other creatures purely corporeal and so of a common essence – extension, the one essential property of matter itself and hence of body in general.

Principia philosophiae drew the corollaries decisive for physics. Extension (and so matter) is divisible without limit; there are therefore strictly no atoms, no absolutely indivisible bodies; even corpuscular components of the three elements are ultimately interconvertible if subject to suitable motions. Since there is matter wherever there is extension, the material world is, like space, unlimited in its extent; and within it there is no empty space, no vacuum void of bodily substance. And since this substance is everywhere, the heavens and the earth are all made of the same continuous material. A body is rarefied not by expanding its own matter, but by distension with invading matter, as cotton wool is swollen on absorbing water. This invasion, like all motions, is possible only if there is a circulation wherein every material portion moves instantly into the place left by that next to it, the last filling the place left by the first.[29]

As Descartes emphasised, his metaphysical theory of material substance as essentially extended led very directly to a world of bodies moved in swirling vortices of continuous material.

For Descartes, as for many earlier philosophers, a substance is whatever needs nothing else in order to exist. God is, then, the only substance, strictly speaking. But among creatures, whatever needs God alone in order to exist may be called substance. We know any substance only as having attributes. And its essential nature is constituted by the attributes it must retain to remain in existence. Any portion of matter may lose its colour, its smell, or its solidity. But if it loses all its extension it ceases to exist altogether. The extension of a body and of the space it fills are the same extension. So, if the extension of the body is the extension of a substance, then presumably the extension of the space is, too, even though there is no ground for deciding whether it is the extension of the same substance. We know matter and we know space as possessing the same attribute. So, in thinking of either, we are clearly and distinctly perceiving the same essence.[30]

This conclusion depends on Descartes' application of the category of substance to space as well as to God and to matter. Newton, disagreeing, will argue that spatial extension, as a condition of all substantial being, even God's, is no substance itself; whereas Leibniz will propose that, as a relational order among contemporaneous bodies, space depends on unextended monadic substances being apprehended by human minds through those extended appearances that constitute bodies. Where Descartes reckons space a substance of the same essence as matter, Newton judges it more, and Leibniz less, basic than the substance of any created entity.

Descartes claimed that with extension and motion he would make the world. These two are what God created in the beginning, and all natural phenomena have arisen from God's subsequent conservation of them. Motion is introduced into matter by God, but not as another substance with another essence. For motions are, as shapes are, merely modes of extension, ways for extended substance to exist, requiring it only to be extended. A body of a particular shape is present wherever all the matter within a volume of that shape is at rest relative to itself and in motion relative to adjacent matter. In Descartes' natural philosophy nothing active, nothing substantial – nothing like the spirits of the Paracelsans, much less the *anima mundi* of the neo-Platonists – comes between the intrinsically active substance that is God and the intrinsically inactive substance that is matter. God moves this matter directly; no hierarchy of intervening created agents stands below God but above the common stuff of creation.

The ultimate and universal laws of nature are, then, the laws that God has prescribed for himself as an immutable supplier of motion to matter and so conserver of motion in matter, and hence of shape and motion in bodies. Left alone by other bodies, alone with God, a body would keep its shape and its state of motion or of rest; and, if moving, would continue with constant speed in a straight line. In the collisions between bodies, likewise, God conserves the total quantity of motion measured as the product of the speed and the volume of the matter moving.[31]

In the world of Descartes' plenum, of course, no body is ever free from the action of others. Every portion of matter is continually agent and patient. The necessary and sufficient condition for all such interactions is motion and contact. To affect the shape or motion of another now at a distance, a body must move so as to collide with the other or move some intermediate that will do that; to affect one already adjacent it must move so as to press upon it. These effects can be wrought and suffered by bodies because they are only changes in the modes of their extension. Their extension itself cannot be changed; none of it can be lost or exchanged for another attribute. The power of a moving body as a mover, upon contact, of others is a force; but this force is strictly the effect of the mover's motion. In Descartes' physics, the forces possessed by a moving body are the consequences, not the causes, of its motion.[32]

That bodies owe all their differentiations and motions to God and his conserving laws for their actions as movers Descartes claims to know with certitude from the very natures of God, matter, and motion themselves. But what of the general hypothesis of the three elemental forms of matter? And what of specific hypotheses about the shapes of bodies and figures of motions that may be responsible for the particular phenomena of heat, light, gravity, magnetism, muscular contraction, and so on? Here, by contrast, Descartes insists that we must settle for plausible conjecture constrained only by agreement with the fundamental laws of conservation and with the phenomena themselves.[33]

It is customary to stress how highly speculative all Descartes' ethereal hypotheses were, and to suggest that his main influence was in convincing people of the coherence of mechanical explanation in general, not of the probability of any conjectured mechanism in particular. But Descartes was influential at both levels. His restriction of physical explanation to homogeneous matter, local motion, and contact action was, of course, very influential as a general ideal. But so too were his particular hypotheses. One has only to look at Huygens on gravity, Newton on colours, Leibniz on planetary motion, or Boerhaave on animal heat to see that whether later physicists, chemists, and physiologists accepted or rejected, modified or replaced, Descartes' proposals, they often took them very seriously in their own efforts to solve those problems.

The planets, mostly composed as our own earth is of the third element, have stable orbits, Descartes suggests, because the second element is more concentrated away from the centre of any vortex; the density of each planet therefore determines a distance from the centre where it has no tendency to spiral inward or outward. The proportion of terrestrial (third element) to celestial (second and first element) matter explains also the weight and falling of heavy bodies near the earth. With its greater speed, the ambient celestial matter has greater centrifugal force. So, rising from below, it displaces a terrestrial body downwards with a force dependent on the proportion of solid and celestial matter in it.[34]

A prism can produce the spectrum of different colours only if its surface is struck obliquely by the incident ray of white light. To explain this, Descartes conjectured that the light particles are thereby acquiring different rotational tendencies and so the power to initiate in our eyes and nerves the motions causing different sensations of colour.[35]

The motions causing such sensations are those in the 'spirits' – matter predominantly subtle – in the nerves and in the brain itself. Likewise, in the muscular responses to such sensations, the motions are transmitted by surges of spirits in nerves and other tissue.[36]

Fire – the motion in first element matter constantly agitating second element spheres – can initiate burning by detaching and expelling as vapour the solid parts of a combustible body of wood, say, or paper. Air is needed for combustion to allow the expelled vapour to escape, just as wine cannot leave a tapped barrel unless air is free to enter it.[37]

Our contributors trace some of the influence such Cartesian conjectures had in later generations. What is needed here is a clarification of the sense in which Descartes' ethereal hypotheses were mechanical explanations. The word *mechanical* was so much used then, and has been so much used by historians in our own time, that without some settled sense for it we will be liable to misunderstand the whole development of ether theorising ever since.

The clarification must naturally be historical. The best hope lies, then, in seeing why Robert Boyle (1627–91) explicitly included 'the Cartesians' among the 'mechanical philosophers' in his instructive essay *Excellence and grounds of the corpuscular or mechanical philosophy* (1674).[38] Boyle's principal disagreements with Descartes are important. After all, he denies that extension is the one property essential to matter, distinguishes solid matter from empty space, and admits that much of space is void. In the essay, however, Boyle is careful not to rest his characterisation of a 'mechanical account' of phenomena or of the 'mechanical philosophy' on any theses separating him and Descartes. That characterisation is deliberately rested on the common ground.

The common ground is that a mechanical philosophy admits but two 'grand' principles: matter and motion; and it restricts the 'affections' of material particles to the two 'mechanical' ones of figure or shape and motion. Moreover, it restricts the powers of bodies to act on others – whether large bodies or minute 'corpuscles' – to those they acquire from being in local motion, and it restricts the actions they can exert to changing the local motion of others upon contact – in impact or pressure – with them.[39] A mechanical philosophy, Boyle insists, is corpuscular, if it has the same laws of motion holding for the indefinitely small parts of bodies as for those bodies themselves. A corpuscular philosophy is mechanical, if those laws are restricted to the conservation of local motion and to the powers and actions that arise in particles from their local motions.

Boyle can, then, find the Cartesian physics, ether and all, within these restrictions. Indeed, the Cartesian ether is, he argues consistently enough, in principle detectable through its mechanical effects; although his 'attempt to examine the motions and sensibility of the Cartesian Materia Subtilis, or the Aether' – with a pair of bellows in a receiver exhausted of air – gave only negative results.[40]

More generally, Boyle takes the Cartesian ether to show that any apparently unmechanical agent may well be given an underlying mechanical interpretation. In its constitution and operation the Cartesian subtle matter is explicitly corporeal and mechanical, of course. But it is hardly, Boyle urges, any less ubiquitous and active than the 'universal spirit of some spagyrists [i.e., Paracelsans], not to say, the *Anima Mundi* of the Platonists'. Like these agents, it is, in Boyle's words, an 'active principle'.[41]

Boyle's point, though obvious, is indispensable for the historian. Far too often even scholarly specialists in this period have tried to establish that some entity, one of Newton's ethers, for example, derived historically from some other entity, the Paracelsan *spiritus* perhaps, on the grounds that the general effects and so explanatory roles of the two were similar, as widespread, hidden, penetrating, and activating agents.[42] Boyle reminds us, however, that almost all the traditions of natural philosophy had some such entity filling some such role. What distinguished these traditions was not the cosmic work these various entities did, but how they were essentially constituted and how they ultimately operated. Boyle is right: There are manifest overall functional analogies between Descartes' ether and the Platonists' *anima mundi* – and all the other entities in that explanatory family, too, from the Stoic *pneuma* and the Epicurean *aether* to the Paracelsan *spiritus*. Equally, though, Boyle shows us that what the historian of scientific traditions in this period needs to concentrate on is not those surface resemblances, but the deep differences in the theories of matter, soul, substance, essence, causation, providence, and law that divide those traditions from one another in their fundamental conceptions of these and all other entities.

Boyle saw himself and Descartes as two mechanical philosophers standing close together and separated by vast metaphysical gulfs from any Platonists or, equally, any Paracelsans. Newton, on the other hand, was, from early on, deliberately to distance himself from the metaphysical foundations of Descartes' science and so from any form of the mechanical philosophy. There is a striking contrast – between the treatment of Cartesian metaphysics, largely but not always implicit, in Boyle's essay on the mechanical philosophy and that, totally explicit, in Newton's extremely revealing manuscript 'De gravitatione', written about 1670.[43] To understand this contrast we must consider briefly the criticisms being made by Platonists, at the time, of the Cartesian mechanical philosophy.

A new Platonism versus the new mechanical philosophy

The mechanical philosophy was opposed, often vehemently, by many who drew their inspiration either from ancient neo-Platonists like Plotinus and Proclus or from Plato himself. Nor was the opposition confined to metaphysical abstractions. It touched directly on the explanation of observable phenomena. The action of magnets provides an especially good illustration.

At the opening of the century, in his pioneering study of magnetism, *De magnete* (1600), William Gilbert went beyond the phenomena to articulate a conception of nature drawing heavily on neo-Platonic ideas. He considered that magnetism was an incorporeal power or agent, indeed, the very soul of the earth. Without such a soul there would be, he insisted, 'neither life, nor primary activity, nor motion, nor coalition, nor controlling power, nor harmony, nor endeavour, nor sympathy'; instead, 'the whole universe would fall into wretchedest Chaos, the earth in short would be vacant, dead, and useless'.[44]

Gilbert argued that the action of a magnet on a lodestone could not be explained by material effluvia but was instead owing to the soul associated with each and with the earth whose nature they share; for to this soul and common nature they owe their tendency to come together like one body in a single action.

Following Gilbert himself, Kepler – a devotee of Proclus – concluded that magnetism was active as such a spiritual power throughout the world. In explaining the elliptical orbits of the planets, he traced their motions to the magnetic action of the rotating sun.[45]

Descartes, of course, offered a quite different explanation of magnetic action in his *Principia philosophiae*. He conjectured that the magnet caused an effluvium of subtle matter to circulate through the body of the magnet and the surrounding space in a closed loop. This flux of subtle matter rarefied the air between the magnet and a block of iron so that they were forced together by the pressure of the external air. In order to account for the specific interactions between two magnets – the positions of their poles determining whether attraction or repulsion occurred – Descartes postulated that the particle streams were aligned, that the particles had screw threads, and that channels in the magnets were similarly threaded.[46] Whatever the difficulties with this conjecture, Descartes' intention was clear; he would eliminate from natural philosophy the type of soul envisaged by Gilbert and Kepler and instead reduce magnetic action to the motion of particles of matter.

In the latter half of the century the neo-Platonic position was most extensively, if not coherently, elaborated by Henry More, Ralph Cudworth, and their Cambridge associates. Initially an admiring correspondent of Descartes, More subsequently, in his *Divine dialogues* (1668) and *Enchiridion metaphysicum* (1671), made a direct attack on Cartesian physics and metaphysics as inconsistent with true theology.

Central to More's critique was the extension, and action in the world, of spirits.[47] For Descartes, of course, all spirits, and even animal and plant souls, though not the rational human soul, were material and therefore extended only as any other matter and as space itself is. In reply, More argued that the natures and extensions of space, of matter, and of spirit are entirely unalike. The extension of a body is physically divisible. By contrast, the extension of a spirit, like the extension of space itself, is not divisible into physically separable parts. Matter, moreover, is in itself inert, whereas spirit is naturally active and initiative of motion. To move our material bodies, our souls must be extended so as to be indivisibly present and active throughout our bodies. The body does not, therefore, fill its place in space to the exclusion of extended spirits. These can penetrate, expand, and contract within bodies and the places they fill. Body and spirit, as substances of entirely different natures and different extensions, can be present together without thereby ceasing to be distinct. Although one piece of matter excludes another from its place in space, many spirits can be present together there. The density of spiritual substance can vary with the number and concentration of the spirits present. The one spirit present everywhere is God; indeed space, in Cudworth's words, is 'the infinite extension of an incorporeal Deity'.[48]

So, in More's and Cudworth's philosophies of nature, any region of space, empty and void of material particles, as much of space is, may be permeated not only by God himself but by many created, active, spiritual substances.

The Cartesian position was ostensibly upheld by Henry Power – a student at Cambridge originally – in his *Experimental philosophy* (1664). He there argued strongly against magnetism's being an immaterial principle and, drawing explicitly on Descartes' own conjecture, referred it to the motion of particles of subtle matter. Elsewhere, however, he identified animal spirits as 'the very top and perfection of all Nature's operations, the purest and most aetherial particles of all Bodies in the World whatsoever (and so consequently of nearest alliance to the Spiritualities) and the sole and immediate instrument of the Soul's operations here'. He speculated, moveover, that this pure ether was the Pauline 'spiritual body'. From these passages doubt may remain whether Power was thoroughly Cartesian or whether, as Rattansi has claimed, he was partially influenced by the Cambridge Platonists. The decisive question, difficult to answer with confidence, is whether his perfect and pure ether particles are supposed to possess any activity except that deriving from the motion given them by God or by other creatures.[49]

The extended, intrinsically active, immaterial spirits of More and Cudworth certainly could move themselves and bodies in precisely the ways denied any mechanical ether like Descartes'. Accordingly, these Cambridge Platonists attributed the action at a distance of magnets, for example, to a spiritual substance that acts 'fatally, magically and sympathetically' (meaning, presumably, without volition, that is, fatalistically; secretly and powerfully; and in accord with the inclinations of like natures to act and suffer similarly).[50] In such an action, needless to say, there is no mechanical impact or pressure, those being actions possible only between bodies, and so not between bodies and spirits nor between one spirit and another.

This clash – between the mechanical philosophies of men like Descartes and Boyle and the neo-Platonic alternatives deliberately opposed to them, especially by More and Cudworth during Newton's early years at Cambridge – provides the indispensable background for Newton's physics and metaphysics, and so for his ether theorising. We cannot expect here to establish once and for all precisely what he did or did not owe to these two traditions. We can only show why no fuller analysis of Newton's philosophy of nature could avoid that question.

Newton's ethers

Exegesis of Newton's ethers is fraught with difficulties. He constructs several different, even incompatible theories, but works none out in detail. The many, sketchy conjectures, scattered through his published and unpublished writings alike, do show clearly, however, that at two periods ethers were among his central concerns. The first period was the 1670s. For it was then that he composed two documents destined to have notable influence when eventually printed: (1) his second paper on light and colours, read at the Royal Society in 1675/6 but not published until 1757, when Thomas Birch's *History of the Royal Society* appeared, and (2) his ether letter to Boyle written in 1678/9 and printed by Birch in his edition of Boyle's *Works* in 1744.[51] The second period begins about 1710 and is signalled by new texts included in the second edition of the *Principia* (1713) and, even more so, by those in the second English edition of the *Opticks* (1717).

Recent historical research has made possible a coherent account of Newton's involvement with ethereal media at these two periods, especially by clarifying the problems those ethers were to solve and, equally, those they were to raise.[52]

Newton followed the mechanical philosophers, at least in supposing ordinary gross bodies to be composed of hard, impenetrable particles. In conformity with the 'analogy of nature' he conceived that aeriform fluids, light rays, and ethereal fluids were likewise formed of such particles, the ether particles being the smallest. Discussing the constitution of ether in the manuscript 'De aere et aethere' (written in the 1670s) he suggested that 'just as bodies of this Earth by breaking into small particles are converted into air, so these particles can be broken into lesser particles [comprising the ether] by some violent action'.[53] Newton could not, however, easily reconcile this conception of the microscopic realm with his general philosophy of nature. The central problem was that this conception invoked inert matter, whereas nature was indubitably active. His solution, as Heimann (this volume) discusses, was to insist that as well as inert matter there must be 'certain active Principles, such as that of Gravity, and that which causes Fermentation, and the Cohesion of Bodies'.[54] He was thus led to reject Descartes' identification of extension as the essence of matter and space alike, and hence to reject also the Cartesian material plenum and restriction of action to contact action. For these 'active Principles' involved forces that were causes and not mere consequences of motion: They were principles of active causation among bodies. It is in describing such interactions that Newton sometimes invokes, for example, the metaphor of 'sociability' used by alchemists and also by the neo-Platonists.[55]

As to what constituted these 'active Principles', Newton gave several different accounts. At times he considered them the immediate exertions of God's will, as if He were directly supplying all activity in the universe. At other times, particularly in writings during the quarter century beginning early in the 1680s, it seems, rather, that the various forces between particles were themselves the active principles. However, throughout much of the remainder of his working life, Newton attributed this activity to one or more ethers (McMullin, 1978:75–110).

Although Newton's presentations differ, on his main account ether consisted of very minute particles that (1) repelled one another, and (2) repelled and were repelled by particles of gross matter. The first of these forces accounted for ether's great elasticity; thus, Newton often claimed that ether was 'much of the same constitution as air, but far rarer, subtler, and more strongly elastic'.[56] In framing this theory of the elastic ether predicated on the notion of interparticulate forces, Newton had, therefore, to reject Descartes' contact-action plenal ether. In support of this rejection he appealed to theology, to methodological arguments about the role of hypotheses, and to the physical inadequacy of the Cartesian theories of planetary motion and of light; he even cited, too, the 'oldest and most celebrated Philosophers of *Greece* and *Phoenicia*'.[57]

The question arises where the activity of this ether resided, since at first sight it appears to be merely a subtle form of aeriform fluid that would therefore have no intrinsic activity. Newton provides two solutions, both of which are problematic. He appears to have thought the activity of the medium related to its elasticity; ether being highly elastic, it was therefore exceedingly active. Moreover, since the elasticity itself depended on the short-range repulsive forces between particles, the activity of ether was ultimately owing to the great strength of the repulsive forces. However, in some writings he suggested that the minuteness of the particles themselves provided a further explanation of activity. For example, in query 21 of the 1717 *Opticks* he argued that since 'attraction is stronger in small Magnets than in great ones in proportion to their Bulk . . . [the] exceeding smallness of its [ether's] Particles may contribute to the greatness of the force by which these Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastick than Air'.[58] Yet with either source of activity, particularly the second, Newton seemed to be attributing to subtle matter that very property he wanted to deny to *all* matter, namely, activity. This was Newton's dilemma, and one he failed to resolve (McMullin, 1978).

As for the repulsion between ether and gross matter particles, Newton's model implied that ether is less dense inside bodies than in the ambient space. Moreover, he assumed that at any interface ether density does not alter discontinuously but that there is a density gradient extending a small distance either side of the interface. This hypothesis he used to explain several sorts of phenomena, including the refraction of light.

A ray of light passing, say, from air into glass and so from a region of denser to one of rarer ether would, Newton reasoned, be 'most pressed, urged, or acted upon by the medium on that side towards the denser aether, and receive a continual impulse or ply from that side to recede towards the rarer [i.e., it is deflected towards the normal], and so is accelerated'.[59] Similarly, in passing from glass into air, the ray is both deflected away from the normal and – in conformity with the dynamic account of refraction – retarded. These hypotheses could also explain the deviation (inflection) of light towards any body close to where it is passing. However, although Newton employed this explanation in the 1670s, by the time he wrote the *Opticks* experimentation had convinced him that light rays were, rather, deflected away from such bodies.[60]

Newton also attempted to explain gravitational attraction by this kind of ether theory (although in the 1670s he had employed a very different model that utilised different sizes of ether particle). The postulated repulsion between ether and gross matter suggested, if it did not directly imply, that the ether density increased progressively with distance from the sun. So a body such as a planet would be, as it were, squeezed from the denser ether towards the rarer ether closer to the sun. At the more fundamental microscopic level this analogy needs to be replaced by an analysis of the forces acting on the spherical body of the planet. Ether being more dense on the side of the body away from the sun, the repulsive forces acting on that side would exceed those acting on the other hemisphere. Hence the body would experience a net force towards the sun and move in that direction (McGuire, 1977:110–11).[61]

These examples illustrate two of several classes of phenomena that Newton considered an ether theory could explain. There was, however, one obvious physical problem that the existence of a ubiquitous ether raised. Since Newton had shown in the *Principia* that a resisting medium would affect the motion of bodies, ether should produce secular accelerations in the planets and so spiral trajectories towards the sun. As these expectations did not agree with astronomical observations, Newton resorted to arguing that ether should produce only unobservable effects on the planets. In query 22 of the *Opticks* he assumed that both the elasticity and the rarity of ether were 700,000 times greater than those of air. The resulting resistance, he claimed, would be so small as 'scarce[ly to] make any sensible alteration in the Motions of the Planets in ten thousand Years'.[62]

The exact nature of Newton's ether and of its relation to specific subtle fluids is obscure. In his second optical paper, he suggested that ether was not composed of 'one uniform matter' but was a mixture of 'the main phlegmatic body of aether', which was inactive, together with active and more subtle 'aethereal spirits'.[63] Moreover, he considered that this mixture of ethers could, as many chemists believed, be condensed to produce diverse forms of matter. In the same paper, Newton cited the ability of electrical action to be propagated through glass as evidence for very subtle effluvia capable of penetrating the pores of solid bodies. It was by equating these effluvia with the 'aethereal wind' that Newton reached an account of electrostatic phenomena fairly close to many seventeenth-century electrical theories.

Guerlac (1963, 1967) has suggested that Newton's interest in electrical phenomena helps explain his renewed interest in ether theory during the early 1700s. At that time, Francis Hauksbee, the curator of experiments at the Royal Society, was, with Newton's encouragement, carrying out attrition experiments apparently indicating that subtle streams of matter were emitted from a rotating glass globe. With this further strong evidence for ethereal matter that was highly active, Newton began to prepare a second part of book 3 of the *Opticks* devoted to the role of ether, particularly in electrical effects; indeed, there are manuscripts showing that he considered electricity to be the subtle spirit that produced all natural phenomena, including animal motion. However, in the event, he suppressed publication of this addition to the *Opticks* and instead cautiously tailored some of his material into the seven ether queries added to the 1717 edition.

In that edition he published further experimental evidence favouring ether's existence. This is the famous two-thermometer experiment showing that a vacuum posed no resistance to the propagation of heat. Heat thus appeared to be 'convey'd through the *Vacuum* by the vibrations of a much subtiler Medium than Air, which after the Air was drawn out remained in the *Vacuum*'.[64] This experiment was performed at the Royal Society under Newton's direction but this time by J. T. Desaguliers in the autumn of 1717 (Guerlac, 1967).

Like other ether theorists, such as Descartes and Power, Newton also employed ethers to account for both animal motion and perception. In his second optical paper he gave a detailed explanation of muscular action in which he differentiated the 'aethereal animal spirit' from the 'common aether'. He saw the first of these acting as an intermediary capable of binding the 'muscular juices' and the more subtle common ether. Thus, when the soul injected a small quantity of the 'aethereal animal spirit' into the muscles, this radically altered the degree of combination of the other two fluids and so changed the muscular tension. Likewise, in the *Opticks* of 1717, Newton's account of vision has rays (i.e., streams of corpuscles) of light striking the retina and there setting the medullary ether into vibration, the ether vibrations then travelling along the optic nerve to the 'place of Sensation'.[65]

For Newton, then, ethers were at least putatively the cause of a wide variety of phenomena; and in almost all cases ether's role was principally as an active agent initiating in bodies new motions that they would not otherwise have acquired. Obviously unlike Descartes' subtle matter in not being mechanical in Boyle's sense, Newton's ethers are not quite like More's spirits either. For his ethers are often, if not always, explicitly material, their constituent particles arising indeed in the division and dispersion of standard nonethereal material. It was not their matter as such, then, that distinguished them, but rather the short-range forces those particles possessed. Indeed, the closest analogues to More's spirits in Newton are not ethers themselves, but these active forces, forces, that is, not reducible to the force of inertia. It is these forces, these penetrating, immaterial sources of motion, after all, that enable Newton to count ethers as active principles of motion. Thanks to the repulsive forces between its particles, the gravitational ether, for example, can serve as the source of the power in heavy bodies to acquire new motions and not merely to retain old ones.

Even if some such interpretation of them is correct, however, much remains unclear about Newton's ethers, his ethereal spirits. In resolving this unclarity, it is tempting to interpret them as akin to the spirits of various earlier writers. But any arguments for their conceptual affinities and historical connections with those other spirits must respect their most distinctive features: They are active and material – but not mechanical in the sense of the mechanical philosophy.[66]

Boerhaave and fire as a subtle imponderable fluid

As Heimann (this volume) explains, the lectures on fire and heat of the Dutch physician and chemist Hermann Boerhaave (1668–1738) had a remarkably pervasive influence upon the ether theorising of the eighteenth century.[67]

The lectures had a curious career as public documents. In 1724 a publisher printed, without permission, as Boerhaave's *Institutiones et experimenta chemiae*, texts of the lectures given annually since 1718. Peter Shaw and Ephraim Chambers soon put this work into English as *A new method of chemistry* (1727), credited to Boerhaave and with extensive notes added, especially from Boyle's and Newton's works. By 1732, Boerhaave had himself arranged for an authentic version of the lectures to appear as *Elementa chemiae*, and Timothy Dallowe published an English version in 1735. Not deterred, however, Shaw produced in 1741 his own English version of the *Elementa*, but once again under the old title, *A new method of chemistry*, and with almost all the same notes as before.[68]

As Love has emphasised, Boerhaave's account of the material constitution of fire as an element is ultimately closer to Descartes' and Boyle's than to any other previous ones.[69] Like Descartes' first element, fire, it is a ubiquitous, imponderable, penetrating, and active material. Consistently, too, with the general constraints of Boyle's corpuscular philosophy, the particles, naturally indivisible and not transmutable into particles of other elements, are solid, hard, smooth, and rounded. However, Boerhaave was familiar with the attractive and repulsive forces judged by Newton as important for chemistry as for optics. Recognising that such powers were not 'mechanical', Boerhaave explicitly denied trying to explain all chemical operations by mechanical principles; and insisted that powers of attraction and repulsion between complex, compound particles were needed in accounting, for example, for the action of solvents.[70]

Placing Boerhaave's fire in relation to the natural philosophies of Descartes, of Boyle, and of Newton is therefore no straightforward task, as Shaw recognised in his notes. On one principal point, Shaw rightly found Boerhaave at odds with Boyle and Newton and in agreement with several Continental chemists and with Newton's Dutch follower s'Gravesande: Fire was formed as such at the beginning of things and has not been 'mechanically producible' since from other kinds of bodies. The physical cause of sensible heat is therefore not conceived, à la Boyle, as consisting merely of the movements of the parts of hot bodies; for then, of course, it would be producible mechanically.[71]

But does this mean that fire as a material substance incorruptible and inaugmentable since creation is itself not a mechanical agent in Boyle's sense? Boerhaave appears never to face this issue directly. What he says about fire would seem to leave it perhaps deliberately unsettled. The particles of fire have no one direction of motion natural to them. Fire is thus without gravity or levity. Left to itself, a pure sample of elementary fire expands and disperses itself in all directions. However, whether this dispersal arises from forces of repulsion acting between the particles or from mere collisions in their jostling motions is unclear. The rarefaction of the gross bodies it acts upon is a universal and reliable sign of fire as an agent. And this rarefaction is possible because fire is repelled by the corpuscles of the invaded, rarefied body. In being reflected as light is from solid surfaces, streams of fire particles are not merely bouncing back upon contact, but are, Boerhaave seems to imply, actively repelled by the particles of the surface, as Newton's light particles are. Unlike any other material, fire is equably distributed throughout the world except where concentrated or dispersed. And the convergent motions of ordinary bodies that are attracting one another are the main cause of its concentration, but again for reasons left obscure. Apart from these repulsions and expansions, the motions of the fire particles and their actions on each other and on other particles remain, then, also obscure.

What is explicit and emphatic in Boerhaave is that without the continual motions of fire particles all nature would fall into a cold, stiff, dead stillness. So once again we see that this fire plays the role played in different ways by the neo-Platonic *anima mundi,* Stoic *pneuma,* Cartesian subtle matter, and Newtonian active principles. It can play this role on earth, tirelessly, because it is continually circulating through the sun; there the parallel streaming of its particles is restored and so, too, is its power as an active mover of other bodies.

As Shaw's notes stress, Boerhaave's fire is a subtle, active, ubiquitous, conserved, spontaneously dispersive, expansive, imponderable fluid. But it is not presented by Boerhaave within a general theory of fluid bodies as compared with aeriform and contrasted with solid bodies. It is an ether, that much is clear. What is not clear, as Shaw urged, is how Boerhaave or Newton himself would have related it to Newton's ether. The challenge of making such connections was one to be often and fruitfully taken up later in the century.

Newton and Boerhaave were, needless to say, not the only sources for ether theories at that time. Our contributors have introduced prominently many others. But we may allow Newton and Boerhaave to raise the major issues that any comprehensive history would have to encompass. For these issues epitomise, in turn, many challenging complexities in the relationships between the scientific developments of the eighteenth and what it is now customary to call the scientific revolution of the seventeenth century.

Major issues *c.* 1740–*c.* 1905

The diversity of ether concepts

If we ask what is new and what is old, in the ether theorising of the 1740s, the answer is hard to give with precision. On the one hand, we have several publications that greatly increased knowledge of Newton's ether theories and interest in them. Bryan Robinson, in 1743, published a *Dissertation on the aether of Sir Isaac Newton,* drawing mainly on the *Principia* and *Opticks*. Then in 1744 the letter, already mentioned, of Newton to Boyle was published for the first time in Birch's *History of the Royal Society;* it was quickly included by Robinson in 1745 in a new book entitled *Sir Isaac Newton's account of the aether.*[72] As Heimann (this volume) has explained, there were several reasons for these publications' being of special interest in the 1740s. He stresses three: the growing emphasis on the role of repulsive forces and on a balance in nature between repulsive and attractive actions; the spreading influence of Boerhaave's conception of fire; and the increasing preoccupation with electrical experiments.

On the other hand, however, we must always recognise that several older lines of thought continued to sponsor ether theories. Most obviously, the Cartesian tradition in natural philosophy was represented by numerous effluvial explanations especially for optical, electrical, and magnetic phenomena. These explanations kept, more or less strictly, within the constraints originally placed by the mechanical philosophy on the understanding of subtle matter. Again, among physiologists the Galenists' spirits were very much alive and so, too, the Stoic conceptions of *pneuma* and *aither* that Galen himself had drawn upon.

Clearly, then, the ethers of mid-eighteenth-century science were highly diverse in their constitutions and operations. A brief glance at three active sites of ether theorising in this period can provide a general indication of the diversity.

1. By mid-century it was agreed that electrified bodies can, like magnets, sometimes attract and sometimes repel other bodies. Theories to explain these attractions and repulsions abounded. Some theories attempted to follow the precedent set by older Cartesian explanations of magnetic action. Streaming effluvia were posited whose parts acted on one another and on particles of gross bodies solely by contact.

On these theories the action of the electrified body is propagated by an intermediary, the effluvium, that is itself in motion as a whole. As Heilbron (this volume) notes, the contrast is thus direct and fundamental with a theory such as Benjamin Franklin's highly influential one. On Franklin's theory the repulsive or attractive action is propagated by a stationary medium surrounding the electrified body. The medium, following the precedent of Newton's ethers, consists of particles repelling each other with forces acting across the short distances between them. Although these particles may be subject to various motions, the medium propagates the electrical action without moving as a whole.

2. For a second example of ether theorising, we may turn to that crucial area of overlap between the physics and the chemistry of the late eighteenth century: the caloric theory of the three states of matter. Caloric itself, the matter of heat, was supposed to consist of small particles that, once again, repel one another across the distances between them. The caloric introduced into a body therefore distributes itself so as to surround each of the particles of that body. Consider now the net force exerted upon any two particles each coated with particles of caloric. If rather few caloric particles are present, the original mutual attraction between the ordinary matter particles will predominate and the body will remain solid. Add more caloric, more heat, however, and the body will become fluid when there is a net repulsive tendency but one

still small enough to be counteracted by the pressure of the atmosphere. Add still more and there will eventually be a net repulsion great enough to overcome that pressure; the fluid now will become aeriform or, as one said by the end of the century, gaseous.

Recent scholarship has increasingly emphasised how central this conception of bodily states was to the revolution in chemistry associated with Antoine Lavoisier and epitomised in his *Traité élémentaire de chimie* of 1789.[73] Perhaps, however, as Christie (this volume) suggests, its full significance for Lavoisier's whole career as a chemical theorist has yet to be appreciated. One issue may indicate how fundamental it was. For nothing is more important to Lavoisier's chemistry than a distinction that has no equivalent in earlier chemists: his distinction between two ways in which two elements may leave a solid or fluid and enter the surrounding atmosphere. They may leave separately: That is, all the particles may have each their own coating of caloric particles, in which case the gas produced is a mixture of the two elements. Or they may leave together: That is, particles of the elements may be associated in clusters with each such cluster coated with caloric particles, in which case the gas formed is a compound of the two elements. We see, then, that Lavoisier's very conceptions of principles, elements, mixtures, and compounds as applied to gases in general, and to oxygen, hydrogen, and water in particular, depend directly on this caloric theory of the states of matter. So, too, therefore, did his innovations in the theory of acidity and combustion, directly dependent as they were on his conceptions of principles, elements, mixtures, and compounds in the gaseous state. The evidence that Lavoisier's chemical researches were knowingly guided by this ethereal theory must take on major significance once one appreciates how it eventually provided the main unifying foundation for the reorganisation of chemical science presented in the *Traité*.

3. In physiology and in theology, as French and Cantor (both in this volume) bring out, the main problems often involved the transmission of action not between bodies but between body and soul or mind. Early in the eighteenth century, one such issue was raised directly by Georg Stahl and Friedrich Hoffmann. Stahl insisted that spirits were either material or immaterial; so they must fall on one side or other of the gulf between soul and body and cannot therefore bridge it. As he concluded, subtle spirits could not be used to eliminate souls from physiology by taking over their traditional role as active sources of bodily motions. To this conclusion Hoffmann responded, as French explains, by supposing that whereas most matter was essentially inert, the animal spirits were by contrast active sources of motions, although quite distinct from the mind itself. Such controversies highlighted a problem met with in many forms in the eighteenth century. If one admitted anything like the Cartesian dualistic distinction between mind and body, then the question naturally arose how any of the various ethereal entities under discussion would fit in with that distinction, or whether they should rather be thought to refute it.

We cannot understand the ether theorising of the eighteenth century unless we appreciate its diversity. Equally, we cannot understand the science of that century unless we recognise the central place in it of such diverse ether theorising.

A tentative taxonomy of ethers

One possible way of distinguishing between ether models is to examine how they solve some particular problem, such as electrical attraction. However, ether theories tend to be problem relative and therefore the choice of any one problem is likely to exclude many popular ether theories. Yet all the ether theories discussed in this volume do in some way or other claim to account for the interaction between two entities, either the action of body A on body B, or the influence of mind (M) on body B. In either case we are concerned with some 'change' in body B mediated by the ether that in some way or other has been 'disturbed' by body A or mind M. The kinds of 'disturbance' are what we intend to classify, but there is a difficulty in deciding when an account of 'change' is required, since this decision is theory dependent. Newton, for example, unlike Kepler, considered that no account was required to explain a body's constant rectilinear motion. It should also be noted that if we were to confine our discussion to the accounts of observable motion we would be omitting a number of subject areas in which no manifest motion occurred. For example, the 'change' in body B could be an increase in its temperature or illumination.

Five types of ether model are here described and illustrated by appropriate examples. Before discussing these models it will be helpful to remind ourselves of two ways in which changes in B might be discussed without appealing to an ether. First, an extreme kind of 'positivist' might account for the change in B by appealing to the regular correlation between the parameters of A and B.[74] Thus, for example, he would claim that the acceleration of B towards A could be described only in terms of the 'masses' of A and B and their distance apart. Second, for others, including less extreme positivists and several of the writers discussed in the next section, the motion of B might, instead, be attributed to some 'power' or 'force' associated with A.

1. According to the first ether model body A (or mind M) must determine the motion of a stream of ether particles that carry B along with it. If space is

considered a plenum this flux of ether would form part of a larger circulatory current, but otherwise the ether particles might merely be projected like a volley of arrows. In the first case ether particles would be in contact with *B*, but in the second interaction might involve short-range forces. Examples of the first include the Cartesian explanation of magnetic action and planetary motion; LeSage's explanation of gravitation by the flux of ultramundane particles provides an example of the second (Aronson, 1964; Laudan, this volume). These illustrate what might be called projectile models of ether.

2. If body *A* (or mind *M*) were responsible for altering the density of ether so that, for example, its density increased with distance from *A*, then the density gradient in the neighbourhood of *B* would produce its motion. Body *B* would, as it were, be squeezed from the denser ether to the rarer closer to *A*. In his queries to the *Opticks*, Newton utilised this kind of model, and it may be termed a density gradient model of ether action.[75]

3. A paradigm for the third model is Franklin's theory of electrostatic action in which the force between *A* and *B* is principally due to the forces associated with the ethereal atmospheres surrounding the two bodies. Thus, among other forces, the ether particles around *A* repel the ether particles surrounding *B*.[76] According to this model – the interactive atmospheric model – the attractive and repulsive powers of the ether particles are of central importance.

4. Franklin's discussion of electricity also involved a very different model to account for electrodynamic phenomena; when two differently charged bodies were brought close together, ethereal matter flowed from the more to the less highly charged one. The short-range repulsive forces acting between the ether particles accounted for the fluidity of ether and its tendency to flow from a more densely packed region to one with a lower surface density of ether particles. This kind of model was also used extensively in heat theory to explain heat 'flow', but in this case the fluid of heat, caloric, permeated the whole of a body's volume and did not principally accumulate at its surface. Implicit in this model are the assumptions that the quantity of the fluid is conserved, and this in turn had strong empirical implications.[77] Partly for this reason this ether model and to a lesser extent the previous one were fairly successful during the later eighteenth century. Owing to the close analogy between this ether and well-known hydrodynamical principles, it should be called the hydrodynamical ether model.

5. Ethereal media might also transmit action from *A* to *B* but without translational motion; instead, the ether elements or particles themselves merely undergo a minute vibratory motion, a rotation or deformation or, perhaps, no motion at all. Moreover, the elements or particles are able to affect only their neighbours and do not therefore act over measurable distances. A paradigmatic example of this kind of ether model is Descartes' theory of light, which attributed light to a pressure across the plenum. Another is Fresnel's wave theory incorporating an elastic solid ether consisting of vibrating particles constrained by short-range forces.[78] Paradoxically then, according to this classification, Descartes and Fresnel employed similar ether models; however, on the grounds of this single similarity we should not associate these two writers who faced very different problems and proposed radically distinct ether theories. A variant kinematic ether would be Faraday's early theory of electrostatic action according to which particles of the medium closest to a charged body become polarised and thus in turn polarise the 'contiguous', but spatially separated, particles. Action is thus propagated along a line of particles, just as magnetic action can be propagated along a line of freely suspended magnets. This theory, as Heilbron (this volume) shows, had many earlier precedents. It was, however, criticised by Robert Hare on the ground that it still involved action at a distance. Initially at least, Faraday did not fully appreciate Hare's criticism, and as Gooding argues, he saw no difficulty in the interaction between neighbouring, though separated, particles.[79]

Opposition to ethers

Although the chapters in this volume concentrate on the uses to which ethers were put, we should not neglect the body of opinion that rejected ethers from science. French (this volume) shows, for example, how physiological animists attributed activity to living matter and thus rejected the option of employing subtle fluids as the source of activity. Likewise, Laudan (this volume) discusses Mill's reaction to Whewell, which exemplifies a form of inductivism incompatible with ether theories. There are many other contexts in which the legitimacy of ethers formed a major explicit issue in scientific controversy; indeed, the question of ethers has repeatedly been a subject of contention dividing different schools of philosophers and scientists. Just as there were certain philosophies of science that either permitted or necessitated ether theories, there were others that precluded them on ontological or epistemological grounds.

A number of opponents of ethers have held reductionist philosophies of nature founded on the notion of force, or later energy. In the eighteenth century many attempts were made to explain all the activity of matter, and often mind also, in terms of forces, such theories frequently drawing on query 31 of the *Opticks* rather than the preceding ether queries. A good example of this position is provided by Joseph Priestley (1733–1804), who employed the notion of force to explain all physical activity. Moreover, this move allowed him to overcome, or rather circumvent, the traditional mind–body problem by making both mind and body aspects of force and therefore not distinct and antithetic entities. Paradoxically, one of Priestley's major sources for his account of mind was David Hartley, who had proposed a physiological account of perception and mental action employing the vibrations of a medullary ether. Priestley's debt to Hartley was, however, partial, for although he adopted much of Hartley's theory of mind, and particularly his associationist theory, he neglected, or rather rejected, his ethereal physiology.[80]

Priestley was not, of course, unique in adopting forces without employing ethers. Roger Boscovich, John Michell, John Robison, Henry Cavendish, and William Herschel provide further well-known examples of late eighteenth-century force theorists who accounted for activity in the physical world by forces but without evoking ethereal fluids.[81] In adopting this position they argued that perfectly adequate and simple explanations were obtained by referring observable motions to the forces that produced them. Moreover, they claimed, there was positively no need to evoke any ad hoc explanatory entities like ethers. These writers also articulated theories of matter employing centrally directed forces. It should be noted, however, that they shared no consensus over whether those forces were centred on points – as in Boscovich's point atomism – or on hard material particles of finite volume or whether, as in the case of Priestley, discussed subsequently, the forces alone were sufficient. They also differed over the general form of the force 'curve'. This diversity, together with some indications of the different routes taken in formulating their force theories, suggests that these writers cannot simply be labelled 'Boscovichian atomists'.

A further set of arguments against ether theories came from those who adhered to a particular interpretation of ontological dualism. Thomas Reid, for example, held the traditional distinction between matter, which was inert, and the active incorporeal mind, yet his account of this dualism was related to his interpretation of Newton's first rule of philosophy. Reid considered that any cause evoked by the scientist had to be true in the sense that its existence was observable. Thus the ether, not being open to direct sensory examination, could not count as a legitimate cause, and he dismissed it as a mere phantom of the imagination. Reid was specifically concerned with Hartley's ether, which was supposed to fill the nerves and thus act as the immediate cause of animal motion. However, Reid complained, such a hypothetical entity did not explain how the mind and body interacted, and instead he attributed this interaction to some 'power' beyond our comprehension. Likewise, the mutual attraction between two masses was due to the 'power' of gravitation, which could be expressed as a law but whose cause was unknown. Reid rejected both the kind of materialism that he attributed to Hartley and also the immaterialist ontology associated with Berkeley's writings. However, in discussing the nature of matter he drew heavily on the sensationalist epistemology set out in Berkeley's early writings and employed this approach to reject ethers.[82]

In the nineteenth century sensationalism often became incorporated into the broader current of positivism, which likewise was antipathetic to ethers. Auguste Comte, for example, was cited by those who rejected ethers, since like Reid he considered that science should not be concerned with uncovering hidden causes, but should instead aim at discovering the exact invariable laws that governed phenomena.[83] At one end of the spectrum are writers like Friedrich Engels, for whom gross matter alone was acceptable; at the other are instrumentalists who had no use for ethers.[84]

Symbolic of the attitudes of many towards ethers was Lord Salisbury's somewhat uninformed comment in his presidential address before the British Association in 1894; he claimed that ethers occupy 'a highly anomalous position in the world of science'. He proceeded to describe ether as 'a half-discovered entity' that had been hypothesised merely to provide a medium for the transmission of light. However, his address is probably best remembered for his jibe that 'the main, if not the only function of the word ether has been to furnish a nominative case of the verb "to undulate" '.[85]

Just as certain late eighteenth-century writers attempted to explain all physical, and often also mental, activity in terms of forces, so a century later energy came to fulfil a similar role. By that time the principle of the conservation of energy had become a pillar of physics and was employed, as discussed by Siegel and Wise (both in this volume), by ether theorists as a necessary postulate governing the propagation of light or electrical disturbances in ether. Though it was used mathematically in these physical theories, there were a number of writers, particularly in Germany, who sought in 'energetics' a general metaphysical principle. Thus, Wilhelm Ostwald, for example, considered that science should be remodelled so as to avoid the untenable hypothesis of material atoms; instead, the mathematical formalism of thermodynamics should be given a physical interpretation solely in terms of the ontology of energy.[86]

The opponents of ether theories have, at least until this century, been confronted by a battery of arguments why ethers are acceptable, even necessary, in science. Although the chapters in this volume discuss these pro-ether arguments in some detail, it may be helpful to list them, or at least the more common ones, briefly:

1. One argument is that science should be concerned primarily with causes, as well as laws. Ethers are therefore required, since they provide causal accounts of phenomena; see the chapter by Christie.
2. A variation on (1) was propounded by those writers who attempted to explain all physical activity in terms of mechanics and who therefore insisted that the propagation of light, for example, be explained by ethers acting according to the principles of mechanics; see 'The rise of "mechanical" ethers' in this Introduction and the chapters by Laudan and Buchwald.
3. Many scientists have also claimed that a well-formulated ether theory will have great explanatory and predictive value and may also aid the conceptualisation of complex phenomena (Siegel).
4. Potentially, at least, ether theories offer the possibility of unifying disparate phenomena and diverse branches of science (Heimann; Wise; Siegel).
5. Ethers can be employed in extra-empirical contexts, for example, to solve theological problems (Cantor) or to account for physiological activity (French).
6. Ethers have been demanded by certain philosophies of nature. For example, whereas many field theorists filled space with ether, some German Kantians even required space to be in some sense active (Wise).

So far in this section the division has been drawn rather too sharply between the supporters and opponents of ether theories. The position, however, is far more complex: There can be many shades of opinion among both ether theorists and their opponents, and some scientists have had no strong commitment either for or against ethers. Again, ether theorists probably form a continuum between those who believe ether really to exist and instrumentalists who consider ethers merely useful but fictitious hypotheses by which phenomena may be explained and predicted. Henri Poincaré provides us with an example of the latter position, since, although he bequeathed to the metaphysicians the problem of whether ether existed, he asserted that 'what is essential . . . is, that everything happens as if it existed'.[87]

The range of attitudes is illustrated by the British and Irish responses to Fresnel's wave theory of light. George Airy asserted that the wave theory was true, but he conceived it solely as a mathematical theory of wave propagation and did not commit himself on either the existence of the ether or the value of ether models. By contrast, David Brewster strenuously denied the existence of ether and rejected the wave theory as the true physical theory; nevertheless, he acknowledged the theory as a useful mathematical hypothesis that, owing to its high degree of corroboration, must include some true law of nature. At the other end of the spectrum, William Whewell adopted the realist position, equated the wave theory with ether, and asserted that ether was a necessary constituent of the physical universe. Less extreme positions were adopted by John Herschel, Baden Powell, and Humphrey Lloyd, all of whom held that the wave theory, although not perfect, was certainly superior to any rival. Moreover, they accepted the ether hypothesis as a useful one that was in some limited sense about a real entity, and they encouraged research into its precise constitution (Cantor, 1975).

Forces, ethers, and fields

With these developments, especially in the work of Fresnel, Cauchy, and, later, Maxwell, we are brought to face some very broad issues concerning the relations between the science of the nineteenth and that of the preceding century. In taking up these issues systematically we would, naturally, have to go even further back to consider the place of eighteenth-century natural philosophy in the whole history of modern science.

The ether theories of that century can help here, provided, of course, that a familiar truism is kept in mind: namely, that innovations in those theories could often be made as conscious departures from seventeenth-century positions but never as deliberate approaches to nineteenth-century ones.

A sustained attempt to interpret the eighteenth, quite properly, as the sequel to the seventeenth century is made in Robert Schofield's monograph *Mechanism and materialism: British natural philosophy in an age of reason*. Of its three parts, the second, 'Aether and materialism, 1740–1789', offers as careful and detailed an examination of that century's ether theorising in physics, chemistry, and physiology as is available anywhere.

However, Schofield's highly informative book does not succeed in providing an adequate, general framework of interpretation for its subject. To simplify severely, there are three major difficulties.

1. His fundamental distinction contrasts (*a*) explanations that refer phenomena to particles of homogeneous matter acting upon one another with attractive and repulsive forces with (*b*) those referring them to various material substances – often ethers – characterised by special qualities. Thus, according to the first – 'mechanism' – in heating a body one merely gives its parts increased motions; according to the second – 'materialism' – one is introducing a special matter of heat. Now this contrast may seem to work well enough for many cases; although, as Schofield acknowledges, it would appear defeated by any theories tracing phenomena to motions, but motions whose production and propagation require the action of a special material

agent, as in Rumford's theory of heat, for example, where heat arises as a vibratory motion, caused only in and by a special ether.[88] However, in reality, the contrast is fundamentally unsound. For, as the very case of Newton himself shows clearly, there was no sense in which ethereal explanations were alternatives to explanations by forces; the forces possessed by the ether particles were essential to ethereal explanations, as the decisive sources of the motions putatively responsible for the phenomena.

Certainly, Schofield is right to emphasise that the new ethereal theories of heat as a special material substance implied a fruitful conception of a conserved quantity of heat quite unlike any quantitative conservationary conception implicit in older theories equating heat with motion. However, ethereal matters were taken to stand in many very different relations to the observable qualities and measurable quantities they were to explain. Granted, caloric really was supposed to be heat even if it was not thought to be sensibly hot; but the gravitational ether was not weight itself nor even heavy, any more than optical ether was light or illuminating. Certainly, Schofield is right to stress that an electrical ether and an optical ether, say, were often conceived as being, in an important sense, different kinds of matter. But he is mistaken in his insistence that the differences were like the differences distinguishing Aristotelian elements. For the distinctness of one ether from another depended, in many explanations, on the assumption that the particles of each exerted no forces on the particles of the other. Such a distinctness of ethereal matters presupposed, then, a distinctness among ethereal forces that had no equivalent in any Aristotelian theory of elements. Tracing the phenomena to forces as causes of motion in corpuscular particles and tracing them to the distinctive properties of ethereal matters cannot, then, be seen as contrasting explanatory strategies in Enlightenment science.

2. Schofield's developmental application of his distinction is open to many objections. He finds two legacies from Newton: 'mechanism' from the *Principia;* 'materialism' from the *Opticks* and other ether writings. Then he has post-Newtonian natural philosophy going through three stages: 'mechanism' up to about 1740, 'materialism' for the next generation, and, finally, a return to 'mechanism'. However, this proposal involves three unacceptable corollaries. First, there is no evidence that Newton or his followers saw his legacy as divided in the way Schofield suggests; second, the natural philosophy of the 1740s (as exemplified by Franklin, say) saw no revival, such as Schofield proposes, of 'qualitative', even 'Aristotelian', modes of explanation dominated by taxonomic aims; third, the natural philosophy of the late eighteenth century in no sense marked a return to that of its opening years. In particular, the suggestion that with Joseph Priestley, a key figure for Schofield, we are going back pretty much to Boyle represents a radical misunderstanding of Priestley, as McEvoy for one has emphasised.[89]

3. Schofield's scheme misconstrues the relationship of eighteenth-century natural philosophy with both earlier and later thinking. On his account, the differences between Newton (in the *Principia*) and the mechanical philosophers, like Boyle and Huygens, are ultimately not very important (they are all 'mechanists'); and, on the other hand, the gap between his 'neo-mechanists', such as Priestley, and nineteenth-century 'field theorists', such as Michael Faraday (1791–1867), is also implied not to be very wide, being bridged by such natural philosophers as Humphry Davy (1778–1829).

Overall, then, too many of Schofield's leading assumptions and conclusions are problematic for his interpretative scheme to be acceptable as a whole.

Another, very different proposal may hold more promise for any attempt to map the place of prominent eighteenth-century natural philosophies between those of the preceding and succeeding centuries. It has been developed by Heimann and McGuire in several papers and is perhaps most crisply expounded in McGuire's 'Forces, powers, aethers and fields'.[90] Their analysis, concerning metaphysics as much as physics, is abstract and complex, not to say convoluted in its arguments; but we do not need here to decide for or against the analysis as a whole. It is mainly their specific suggestions about Priestley and Faraday that are of direct concern.

Consider, once again, Boyle, Newton, Franklin, Priestley, and Faraday as representative figures, writers any broad generalisations must fit. On the Heimann–McGuire analysis, Newton departs radically from Boyle; Franklin departs rather little from Newton; Priestley, however, departs radically from Newton; and Faraday develops but hardly rejects the position held by Priestley. So, as they see it, with the two big moves away from Boyle's mechanical philosophy, the first by Newton and the second by Priestley, one is getting close to Faraday's 'field theory of matter'.

Now, this use of the phrase *field theory* requires us to make a brief excursus on its possible ambiguities. For, too often, scholarly specialists have risked being at cross purposes with one another through failure to disentangle these ambiguities.

It may help to distinguish three very different reasons a historian of natural philosophy might have for using the word *field*.[91]

1. He might be identifying a set of theories by indicating the *explicanda* they were about. So – granted quite unhelpfully – he might simply refer to Aristotle's, Descartes', Newton's, and Einstein's fundamentally different explanations for the downward falling of unhindered heavy bodies near the

earth's surface as their respective theories of the earth's gravitational field. To refer to them thus would presumably imply nothing definite about what sorts of explanations are given by these theories, but would merely designate the specific kind of effect they were to explain and note that it is an effect explained today by a field theory. Whether such a usage ever serves a useful historical purpose is dubitable; but in any case we can and will do without it here.

2. He might be discussing various late eighteenth-century theories explaining, for example, the attraction of suitably electrified bodies for bits of paper and chaff at a distance from them. Among these explanations, he might distinguish some as field theories of electrostatic action. And how would he decide when a theory of electrostatic action is and is not a field theory? This question, it turns out, is not a straightforward one at all, for neither the physicists themselves nor the philosophers of physics have ever settled on a clear and coherent explication for the notion of field theory.

We would not presume here to offer such an explication. However, we would like to provoke further discussion, and to do this by pointing to some ambiguities in the notion of field theory that are especially troublesome for historians of physics.

To look ahead briefly, there would seem to be a tension between two historical conclusions: First, there is no disputing that the English word *field* was first made part of the vocabulary of physics in the 1850s and 1860s by William Thomson (Lord Kelvin) and Maxwell. Nor is there much difficulty in discerning why they wanted to use the word; as we shall see, they wanted to draw attention to some particular features of certain electromagnetic theories, and they made it pretty clear which features these were. The trouble is that these features do not serve by themselves to demarcate those theories as a family from theories that admit action at a distance: Hence, then, the seeming conflict with another historical conclusion. For, second, it does seem (as Wise, this volume, emphasises) that these theories were deliberately constructed in order to avoid action at a distance in physical theory. So the question arises: Were the features of these theories that made it appropriate for Thomson and Maxwell to call them field theories not, in fact, the same features that made it reasonable for these theories to be taken as alternatives to action-at-a-distance theories?

We would suggest that this may well be so. We would suggest, too, that if it is so, then one may have a resolution of a further historical difficulty. For there does seem a tension between two other historical conclusions: The first theories to have the word *field* used of them by Thomson and Maxwell were novel and unprecedented in many respects; however, as Heilbron (this volume) brings out, in the features that made it appropriate to use that word of them, they hardly seem novel at all, having, rather, plenty of precedents in the eighteenth century, if not earlier.

Perhaps, then, we may do well, on combining all these historical points, to ask whether the first theories to be called field theories were indeed novel and were indeed deliberate alternatives to action-at-a-distance theories, but, equally, were neither novel nor demarcated from action-at-a-distance theories in those features that made it appropriate to call them field theories.

Consider next how Thomson and Maxwell introduced the word *field* to refer to the region of space beyond the boundaries but in the 'neighbourhood' (Maxwell's word) of an isolated magnet or electrified body. Consider, more particularly, the space in the neighbourhood of an isolated, spherical electrified body. Any point in this space has, of course, a property that it would not have were the electrified body removed to an infinite distance, namely, that a suitable test body placed there moves and moves, let us suppose, towards the electrified body. The region is then the field of the body's electrical action, the field of the force the body exerts – just as (although no Victorian physicists seem to have invoked this lexical precedent explicitly) the area of ground that a regiment would move to defend, if entered by the enemy, was traditionally identified as its field of action.

Now, to ascribe such properties to these points in space would not commit us to any explanation, any account of the causes, for these motions in the test body. Nor would one make any such commitment in going on to map the paths, the directions and accelerations, of these motions – for all the points on a plane in this space intersecting the centre of the body – with two sets of lines: (*a*) straight lines, converging on the centre of the electrified body, with arrows on them to represent the directions of motion, and (*b*) circular lines, drawn like contours about the electrified body as a centre, to mark points of equal acceleration in a test body. Moreover, even to call this mapping a representation of the field of force around the electrified body would hardly be to venture an explanatory, even less a causal, theory for the apparent actions at a distance. For this would be little more than another way of referring to what is still only a mathematical representation of the effects, the accelerated motions, themselves. Suppose, further, that we introduced lines marking points not of equal acceleration but of equal potential energy, the potential energy at a point being defined as the work done in bringing the test body there starting from an infinite distance away. Then, of course, in some cases involving more than a single electrified sphere, we might have points where the potential energy was not zero, but where a test body was subject to no net force and so no acceleration. However, even with this mapping of equipotentials, we would still be describing the form of the apparent attractions at a distance, rather than considering what their underlying causes may be. Nor would we have a causal theory of the field if we added the assumption that the actions of the underlying causes are propagated at finite velocities, so that an instantaneous annihilation of the electrified body would be followed only after an interval of time by a change in the potential energy at a point beyond its former boundaries.

Suppose now, though, that a theory is proposed concerning the constitution and operation of a physical agency whose noninstantaneous causal activity is presumed to be distributed as this mapping of its effects implies. Then surely we would have passed to a physical theory of the field, the spatial region, of that action. Notice, however, that we would be calling it a field theory not because it invokes one kind of physical agency rather than another, but because it is a theory constructed as a causal explanation of the field of action as understood to be mappable and noninstantaneously changeable in these ways. It counts as a field theory not because its *explanans* is of one sort rather than another, but because the *explicandum* is conceived as coming under a distinctive sort of description.

Such a use of the word *field* not only respects Maxwell's and Thomson's original intentions; it also requires the historian to face a number of decisions. For various *apparent* actions at a distance have been recognised, of course – and physical explanations for them offered – from time immemorial. So the origin of field theories of these actions must have awaited not the recognition of the effects, but the conclusion – and the historian has to decide when that may have been reached, implicitly or explicitly – that they can be mapped in some special way: either as lines of variably accelerated motion in a test body or as lines of continuously variable force, or rather, perhaps, as lines of equal potential energy. And as for potential energy as a concept: Again, the historian would have to decide whether it presupposed the general concept of energy that emerged with the earliest specifications, in the 1850s, of the first and second laws of thermodynamics.

There are thus two historiographical implications in this sense of field theory. First, as Hesse (1961, 1967*a*) has stressed, in considering the relevant eighteenth-century developments in natural philosophy and in mathematics, it may be wrong to assume that one must have been the cart and another the horse. Innovations in the conceptual analysis and experimental measurement of forces and in the algebra of potentials all helped to promote the quest for field theories of specific physical actions. Their precise, respective roles need still to be traced in detail, however. Second, in this sense of field theory we *cannot* contrast field theories as a family with action-at-a-distance theories.

The reason is already plain. Any such theory provides an explanation for *apparent* action at a distance. Indeed, being primarily explanations specifically of electrostatic action, or of magnetic action or of gravitational action and so on, we may call them field theories of specific bodily actions or forces. They do not, as such, presuppose a denial of the everyday distinction between the region of space beyond the active body and the space that this body occupies. For although the field is not taken to have an edge, a boundary, the body may well be so taken. There is, moreover, no presupposition made about whether the *apparent* action at a distance is mediated with or without *underlying* action at a distance – whether, for example, by an ether comprising particles acting upon one another over short or even long distances, or by one with interactions only between contiguous particles, or, again, by a continuous medium.

Now, this last point does not resolve but may clarify the historical difficulties we noted earlier. For we must ask, surely, how there arose the traditional association between field theories and opposition to all actions at a distance. We have seen that the way the word *field* came into physics does not ensure the association as a matter of definition. Why then was the association there from the start as a matter of fact? And why was it so close an association as to have become, since, almost a matter of definition?

This question is again far from a straightforward one, as Siegel, Heilbron, and Wise (all in this volume) show (and as Wise has made even clearer in a personal communication). There is one consideration, however, that makes an obvious point of departure. Physical theories for the field of a specific bodily action were to explain a transaction between two bodies that was presumed to be mediated and so to be propagated with finite velocity. So, naturally, as Faraday and Maxwell both reflected, one did not want to duplicate in the medium exactly the sort of action at a distance apparently exerted by the two bodies, since then the theory would hardly offer an explanation of that apparent effect: Hence, therefore, the historical importance of ethers that admitted action at a distance only between neighbouring or contiguous particles. Whatever other difficulties there might be with such mediation of macroscopic bodily action, at least it would not merely and precisely duplicate these actions at a smaller scale. More generally we might say that since a main rationale for mediation theories was to avoid such duplication, then, as *physical* theories, theories of fields naturally tended to reduce and limit actions at a distance even if they did not necessarily aim to eliminate them. This tendency would, moreover, be reinforced in *mathematical* analyses of the field considered not simply as the field of the body's action but as constituted by the actions of the medium itself. For, with the whole action transmitted with finite velocity, the component actions falling within any region of the field can be analysed mathematically as actions exerted by one part on another and so without separate consideration of the action of the body itself upon the field. In this way the field's actions and energy can be treated as having an independent existence. Further, in considering the transmission of activity and changes in energy distribution over distances much greater than any separating the physical parts of the medium (if it is supposed to have such separate parts), any discontinuities may be, as Wise (personal communication) puts it, ignored or smoothed over. Such an ether as a physical entity may still be assumed to involve actions at a distance; but once the object of mathematical analysis is taken to be the field itself considered as a set of spatial elements, characterisable in terms of the energy distribution over them, then actions at a distance are dispensed with if not rejected.

The extent to which a historian of physics understands field theories of specific bodily actions by contrast with action-at-a-distance theories may well depend, then, on whether he is concentrating on the sorts of physical entities introduced by the theories or whether he is, rather, concentrating on the sorts of mathematical analyses for which the theories were providing physical representations. If his emphasis is on the first he will also incline (as Heilbron, this volume, does) to stress the eighteenth-century precedents for nineteenth-century field theories like Faraday's. If his emphasis is on the second he will be likely to stress (as Wise does) their novelty.

3. A third use for the word *field* would imply a direct contrast with actions at a distance. For the historian might wish to characterise a theory of matter – as both McGuire (1974) and Hesse (1967*a*) have characterised the one Faraday developed in his later years – as a field theory of matter. Now, on a field theory of matter one cannot distinguish where a body is from where it acts, for it is wherever it acts. So there is denial of bodily action at a distance. For, the body being denied a boundary, there is no spatial neighbourhood beyond that boundary and so in that sense no field of force beyond the body.

For on a field theory of matter, such as Faraday seems to have favoured from the late 1840s on, the forces constituting bodies are not conceived as contributing to the making of a body by being added to solid extended particles. Nor are they conceived as constituting a body by acting with intensities that diminish with increasing distances from points where their intensity is infinite, because forces of continuously varying finite intensity over space are all that constitute bodies. So with matter present wherever any such forces are present and with such forces varying continuously, there are no points in space where no matter is present. On those theories that we might call field theories of material substance, space is, then, full of matter, of continuously variable force fields.

Returning now to the historical problem of the developments separating Boyle and Faraday, we can see why complexities naturally arise in any quest for the 'origins of field theory'. Even insofar as the quest is a search for the eighteenth-century roots of Faraday's thinking, we would have to distinguish between sources for his field theories of electrical or magnetic actions and sources for his field theory of matter. And we would have to distinguish, accordingly, among the very different relations each might bear to earlier conceptions of action at a distance, both apparent and underlying action at a distance. We would have to distinguish also, therefore, among the very different relations each might have to earlier ether theories.

Heilbron (this volume) explores precedents for Faraday's field theory of electrical action. We may usefully here consider one of the Heimann–McGuire suggestions about his field theory of matter: They suggest that successive movements in thought, from Descartes through Boyle, Newton, Priestley, and Faraday, be seen as a decline for inert extension and a rise of active forces in the ontology of material substance. We have already seen something of the early steps in this progression. Boyle added solidity to Descartes' extension in marking material corpuscles off from space, whereas Newton had active forces of attraction and repulsion added to solid, atomic corpuscles that still retained their shapes and so volumes.

Newton's step was of course of great significance. In introducing these forces, he knowingly repudiated the metaphysical foundations of the mechanical philosophy. What is more, by bringing into his science of mechanics entities, attractive and repulsive forces, that fell outside the ontology of the mechanical philosophy, Newton invited a change in the very understanding of the words *mechanical* and *mechanism*. Isaac Watts acknowledged as much in asking in the next generation whether plants and animals can be formed 'by the *Mechanical Motions and Powers of Matter*', and answering:

> If by the word mechanical, we mean nothing else but those motions and powers, which proceed from the essential properties of matter considered as mere solid extended substance; then I cannot allow the proposition to be true: But if we conclude in the word mechanism, all those additional powers and motions also, which arise from the original laws of motion, which God imposed upon matter at first, such as gravitation or mutual attraction, and others of the same kind, then I allow that all things in the successive ages of the world are formed mechanically; always supposing the divine agency preserving all the atoms of matter and their motions accord-

> ing to these Laws. And it is my opinion, that all beyond this is miracle.[92]

To understand the next step, as Heimann and McGuire reconstruct it, we must appreciate why many eighteenth-century writers argued that, with these active Newtonian forces admitted to the ontology of science, the shapes of the corpuscular particles had become explanatorily otiose and their edges metaphysically embarrassing. Boscovich, most notably, urged that nothing explanatory would be lost and metaphysical coherence would be gained if the various forces were conceived as added to otherwise empty spaces – by being made to act, according to various force laws, around point-centres in those spaces – and not to tiny volumes of solid matter. Going on beyond Boscovich, Priestley and some others late in the century argued that such punctiform centres of force are themselves explanatorily redundant; they are moreover epistemologically unwelcome to an empiricist, for a point where a force acts with infinite intensity is no possible object of experience. An empiricist conception of material substance as constituted by its sensible active powers may and need admit only, they concluded, forces whose intensity varies continuously over regions of space.

Many authors, British and Continental, contributed to the emergence of such conceptions of matter, and their contributions involved arguments at many levels: theological as much as methodological, transcendental as much as empirical. Hume's scepticism about direct sensory experience of active powers had to be refuted, for example, as did charges of materialism and pantheism. The very presence of these arguments should convince one that whether or not the Heimann–McGuire analysis is correct as a whole, it is surely sound in its insistence that an impressive conceptual distance separates many late eighteenth-century natural philosophies from Newton's atoms and superadded forces.

How far those natural philosophies take us toward Faraday and so Thomson and Maxwell is, of course, another issue. That issue is one we may clarify usefully by considering the general fate of ether theories in the century separating Franklin and Maxwell.

The rise of 'mechanical' ethers

Eighteenth-century ethers. Even a cursory glance at the scientific literature indicates how radically physics changed in the period 1800 to 1840. Yet it is easier to identify this change than to characterise it accurately, and most simplistic general comparisons fall short of the mark. This situation is complicated by the differences in the historical development of the various branches of physical science. In this connection, Kuhn, among others, has suggested that the physical sciences divide into two classes that follow different developmental patterns.[93] The 'classical' sciences – astronomy, mechanics, and geometrical optics – reached a high degree of theoretical and mathematical sophistication well before the beginning of the eighteenth century. By contrast, at that time the second group, the 'Baconian' sciences, were still not governed by any strong theory, although a great deal of diverse empirical data had been collected. Among these areas were chemistry, heat theory, and electricity; physical optics does not fit very neatly into either of Kuhn's categories. During the latter half of the eighteenth century the data base of these sciences was extended considerably, and they were given explicit theoretical foundations that not only helped direct experimentation but also brought them somewhat closer to, although by no means into line with, the 'classical' sciences. It is significant that, in the period beginning around 1740, it was in these 'Baconian' sciences, rather than in the 'classical' ones, that ether theories were primarily employed. The precise relation between ethers and developments in these branches of science is, however, a question requiring further research.

Ether theories as applied to both electricity and heat were particularly fruitful, principally in respect to models (4) and (3) in the taxonomy of ethers given in a preceding section. Single and two-fluid theories of electricity were used extensively with a fair degree of success in explaining electrostatic action quantitatively, whereas the hydrodynamic model proved adequate to explaining the 'flow' of both heat and electricity. A rather late but particularly impressive example of this type of theory was Sadi Carnot's use in 1824 of the waterfall analogy in developing the theory of heat engines.[94]

In these cases ether theories not only aided conceptualisation but also provided explicit theories that made predictions and directed experimentation and the design and use of apparatus. Yet these examples should not blind us to the extensive use of ethers in nonquantitative contexts during the eighteenth century. Often ethers were proposed to explain, in a rather loose sense, some general class of phenomenon – such as cohesion or electrical attractions and repulsions – with little concern for the detailed experimental results. Moreover, a number of these less concise ether theorists were concerned primarily with biblical exegesis and the role of subtle fluids in the divine economy of nature.[95] Perhaps for these reasons ether theorising became somewhat disreputable in the eyes of some experimentalists.

Very often eighteenth-century ether theories were founded on direct analogy with the phenomena exhibited by known fluids such as water or air. Thus early vibration theories of light sought analogies between the phenomena of light and sound: Just as sound was propagated by vibrations of air particles, so light was a vibration transmitted by the ether particles. Another example is the analogy between heat and the behaviour of macroscopic fluids, which allowed heat flow to be visualised in terms of conserved particles of matter and, in this instance, enabled a small range of phenomena to be discussed quantitatively. However, it was argued that the matter of heat was invisible and yet seemed able to penetrate ordinary matter, and thus it was considered to be subtle. It also had to be weightless and able to spread from a source, and thus it was necessarily an elastic fluid. Moreover, although these largely hydrodynamic models of ethers were able to illustrate phenomena in an easily conceptualised manner, they were inadequate at explaining any but a limited range of phenomena in detail.

To take the important example of chemistry, ether theory offered an explanation of how particles might combine, but it was inadequate to explain, let alone predict, the elective combination of specific substances. Again, to cite the examples of refraction and inflection discussed by Newton, a general account could be given of how differential ether density might explain the deviation of a ray; however, this model was totally unable to deal with dispersion or diffraction patterns. No contemporary theory, it should be noted, was manifestly successful in these areas. One of the advantages of ether theory was that it offered, potentially at least, a programme by which recondite phenomena could be explained. Moreover, it seemed to provide a unified causal account of diverse types of phenomena. The writings of many early theorists make it clear that they considered speculative guesses in order, as if the object were to make somewhat plausible guesses about the underlying structure of nature.

Ether theory c. 1840. If we now examine theories of light, heat, and electricity in 1840 we find a major change. The earlier theories had by then been almost entirely replaced by high-level theories involving not direct analogies but either purely mathematical models or 'mechanical' models expressed in mathematical terms. Moreover, these deductive models provided precise predictions that were tested against experiment and that proved, at least in this respect, greatly superior to their eighteenth-century predecessors. These fields, unlike perhaps chemistry, had evolved into 'classical' physical sciences, in Kuhn's terms.

The example of physical optics will be used to illustrate this change, since it was of primary historical importance in the development of ether theories. At the turn of the century, Thomas Young advanced a vibration theory of light explicitly analogous to his theory of sound. He conceived ether as similar in structure to air but much rarer and more elastic. Just as vibrations in the air produced sound, so vibrations in this ether produced light. Young employed almost no mathematics, nor did he have a worked-out theory of wave propagation. Even his famous principle of interference was discussed simply in terms of the path difference between two rays, and he considered only the two simplest cases: when the phase difference was either 0° or 180°.[96]

If we now examine the state of the wave theory of light in the 1830s we find that men like Cauchy, Challis, Airy, and Powell were articulating the theory through mathematical models. As Buchwald (this volume) discusses in detail, many of these writers were concerned with devising 'mechanical' models of ether that could account for such complex phenomena as double refraction and dispersion.

These changes affected other branches of physics, albeit in somewhat different ways, during the period 1800–40. Largely responsible for these changes was a rather diverse group of scientists, principally French and often associated with Pierre Laplace, who greatly extended, rather than originated, a programme in scientific problem solving.[97] They conceived mechanics as the basic science to which all physical problems were to be reduced. Any problem had thus to be analysed into its simplest elements in terms of the particles and forces involved. A model would be formulated in mathematical terms, in agreement with the laws of mechanics, and from this model testable predictions could be made and compared with experiments. This method of analysis and synthesis, often involving calculus and sophisticated mathematical techniques, was used extensively and successfully in most branches of physics during the opening decades of the century, whereas previously its main area of application had been celestial mechanics. The programme as discussed so far leaves open to question the precise models employed and the further conditions imposed on them. At this level there was, of course, much disagreement. For example, while Laplace, Biot, and Malus adopted a particulate theory of light based on dynamical principles, Fresnel formulated his wave theory of light in terms of a mechanical model of ether.[98] It was indeed in the context of Fresnel's wave theory that new and exacting conceptions of ethers emerged.

'Mechanical explanation'. Before discussing further this change in ether theorising, it is necessary to clarify the concept of *mechanical explanation,* which has been the source of much confusion. In contrast to the mechanical philosophies of the seventeenth century, Newton introduced *forces;* and, in his three laws of motion, he postulated a very specific relation between the behaviour of a body – in terms of its 'quantity of matter' and its motion – and the forces acting on it. The first law states that when there is no external force acting,

the body's momentum (*mv*) will be unaffected. In the second law, a proportional relationship is specified between the impressed force and the change produced in the body's momentum, the direction of the change being in the direction of the force. Finally, when two bodies act on one another, the forces of interaction will be equal in magnitude but opposite in direction.

Of direct concern here is the insistence by nineteenth-century physicists (together with some earlier writers) that an explanatory model had to employ, or at least be consistent with, Newton's laws of motion in order for it to be mechanical. The paradigmatic example of a mechanical theory was Newton's own theory of gravitation (as distinct from his ethereal hypotheses concerning gravitational attraction). It did not employ contact action and therefore would not have counted as a mechanical explanation in Descartes' sense. Instead it involved bodies acted on by forces and behaving in accordance with the laws of motion.

This example does, moreover, illustrate further characteristics of mechanical explanation as understood in the nineteenth century.[99] Gravitational theory is very specific about the magnitude and direction of the forces acting on material bodies. It states not only that the force is attractive, acting along the line joining the bodies, but that its magnitude is given by the equation

$$F = G\frac{m_1 m_2}{d^2}$$

Mechanical explanations in general include among their premises mathematical expressions for the force vector. The example of gravitation allows us to identify other typical features of such force laws. First, they specify some property of the bodies involved – in this case their 'quantity of matter' (or masses), m_1 and m_2. (It could, of course, be their electric charges or viscosities). Second, the formula just given includes a spatio-temporal parameter – the distance (*d*) between the idealised points. Third, there is a constant – the gravitational constant (*G*). In other instances the constant(s) and variable parameters might, of course, be very different. Likewise, although some writers have suggested that only a single form of force function is permissible, there seems no reason in the present context to restrict the form of the equation. Finally, although usually implicitly, these nineteenth-century mechanical models assumed that both matter and energy were neither created nor destroyed.

The significance of mechanical ethers. The considerations just outlined specify the minimum necessary conditions of a mechanical explanation as employed in nineteenth-century physics. Since these conditions were of general applicability, they were, of course, applied to ether models. This conception of a mechanically adequate ether theory, though not unknown in the eighteenth century, allows us to draw some fairly sharp contrasts between the speculative ethers of the eighteenth century and the mechanical ethers central to certain branches of physics, particularly optics, in the nineteenth century.

In physical optics, the turning point came in about 1820 with Fresnel's version of the wave theory. In this field, as discussed in a preceding section, physicists developed *mechanical* and *mathematical* ether theories that not only explained in exact terms a number of phenomena but also made quantitative predictions that were impressively confirmed. During the next few decades a number of different ether models were proposed – one writer in 1849 counted fourteen different ether theories[100] – often with the specific intent of accounting for some of the more intractable phenomena, such as dispersion and absorption, both of which involved postulating an interaction between ether and gross matter. Yet despite these differences and the remaining problems in some parts of the theory, ether theories had to be mechanical, in the sense just discussed. Moreover, for these ether models to be of any use in the context of contemporary optical theory, they had, through their mathematical formalism, to account for at least a moderate range of optical phenomena in quantitative terms.

These requirements severely limited the range of ether theories that were scientifically worthy of consideration after about the first quarter of the century. William Rankine, for example, in 1855 distinguished the luminiferous ether from caloric and the electrical and magnetic fluids on the ground that, because the former was founded on the laws of mechanics, it was 'a probable representation of a state of things which may really exist'. By contrast, he considered that the latter fluids functioned 'merely as a convenient means of expressing the laws of phenomena', and, moreover, they often retarded the progress of science, since the unwary adopted them as true causes.[101]

One implication of the rise of mechanical ethers was that the diversity of subtle fluids disappeared from the literature, albeit more slowly from the popular press. In the eighteenth century it was frequently supposed that space was permeated by a number of noninteracting ethers, each performing a distinct function; one might account for electrical phenomena, another for heat, and a third, say, for magnetism. Although there was much conjecture that these fluids might somehow be related to one another, this situation needs to be contrasted with that of the nineteenth century, when ether theorists tended to concentrate on a single ether, which might perform a number of different functions and which was conceived in mechanical terms. The new physicists' conception of the ether lost the pictorial appeal of the early ether theories founded on commonplace analogies such as the flow of water or water waves. Instead, in order to account for polarisation, theorists suggested that ether was like some strange elastic solid, which could thus transmit transverse undulations. Furthermore, ether theory was comprehensible only to those who understood mechanics and analytical mathematics: It was no longer susceptible to direct analogical arguments but was dependent on the more abstract dynamical and mathematical theory.

A further implication of this change in ether theory concerned its domain, for instead of using it to unify diverse branches of natural philosophy, theorists initially applied the new luminiferous ether solely to optics. Even questions of photochemistry and the role of light in plant growth usually were considered outside the domain of the wave theory of light. Yet the dream of a universal ether never faded completely, and in a few areas connected with optics, and thus the luminiferous ether, some progress was made. The first of these was heat theory. Following the successes of the wave theory of light a number of writers, beginning around 1830, suggested that since radiant heat appeared to be reflected, refracted, polarised, and so on, it too was a vibration in ether (Brush, 1970). This theory, which was extended by Ampère to include heat conduction, was adopted by many scientists in preference to caloric theory.

Maxwell and post-Maxwellian ethers. Maxwell's theory of electromagnetism provided the focal point for ether theory in the latter half of the nineteenth century. The relation between electromagnetism and ether theory was, as Siegel (this volume) argues, important for Maxwell himself, since he acknowledged the need for adequate mechanical models. He came closest to achieving this aim in the early 1860s when, in his paper 'On physical lines of force', he developed a molecular vortex model. Here he considered the ether as forming closed vortex cells which are in rotation and between which are small particles functioning as idle wheels. He was able to show that the equations governing the behaviour of this mechanical model corresponded to those of electromagnetism, the rotation of the cells corresponding to the magnetic component and their translation to the electric current. Moreover, Maxwell suggested that vibrations of this ether constituted light, and he subsequently extended his theory to account for dispersion.

Since Maxwell's theory applied to both electromagnetism and optics, ether theorists were faced with the problem of constructing a model that not only would be internally consistent with mechanical principles, but also would be able to explain a wide range of electromagnetic and optical phenomena.

By 1864, Maxwell had abandoned the specific model just outlined, principally because, as Siegel (this volume) suggests, the notion of idle wheels appeared somewhat contrived and could not be translated into a specific physical particle. As Whittaker (1910) discusses in detail, Maxwell's theory led to a plethora of ether models combining rotational and translational motions of ether – one motion corresponding to the electric component, the other to the magnetic. Yet although such models did achieve considerable popularity, German physicists in particular, drawing on neo-Kantian philosophy, often propounded a very different type of ether theory. One example, which is discussed by Wise (this volume), is Helmholtz's theory of 1870 that ether is not composed of particles in motion but may be characterised by its state of polarisation, which itself is propagated through the medium.

One of the most important extensions of Maxwell's theory was Fitzgerald's 1878 account of reflection and refraction.[102] In this he drew on the ether model developed some forty years earlier by James MacCullagh, who in turn was responding to a model of Fresnel's.[103] In order to account for the polarisation of light the ether vibrations had to be transverse, not longitudinal, and therefore ether, Fresnel claimed, must be like an elastic solid. Whereas some writers criticised this conception of ether as incompatible with the free motion of the planets, MacCullagh's main criticism was that the requisite optical phenomena could not be explained by assuming ether to be both incompressible and not susceptible to distortion. What he instead proposed was an elastic solid ether that admitted distortion (Schaffner, 1972:59–68). While MacCullagh utilised this model in optics, Fitzgerald employed it in a wider domain by showing that MacCullagh's equations corresponded to those for Maxwell's theory of electromagnetism.

Stein (this volume) discusses Fitzgerald's model of ether and the responses to it from physicists, particularly Thomson, Larmor, and Lorentz, who developed further ether models. Of the complex developments of the last three decades of the century, which have been discussed by Stein and others (e.g., Whittaker, 1910; Doran, 1975), three in particular deserve attention. One of these was the renewed interest in the theory that the atoms composing material bodies were local disturbances – vortex rings – in an incompressible ether (Silliman, 1963). Helmholtz had shown that vortex rings were stable and indivisible and rebounded after collision, just as atoms were conceived to behave. Moreover, these properties of vortex rings had been demonstrated experimentally using smoke rings. This theory also had the advantage of removing one of the difficulties raised by electromagnetic field theory in that it eliminated the distinction between matter and ether by positing that matter was composed of ether.

A second development involved what some historians have considered a major departure both for ether theory and indeed for the foundations of physics (McCormmach, 1970). In place of mechanical theories of ether, Lorentz and others at about the turn of the century suggested that the ultimate reality was constituted by the electromagnetic ether and electric particles (e.g., electrons). Indeed, they contended that all the laws of nature were reducible to ether, which obeyed the electromagnetic field equations. Doran (1975) argues that this conception was by no means novel but involved an essentially Leibnizian theory of matter held by many British physicists, who conceived ether as a continuous medium to which electromagnetic properties were ascribed. As Stein (this volume) points out, however, there are some difficulties with this historical thesis.

Third, aberration experiments have been a recurrent source of empirical problems for ether theories. To take a couple of early examples, attempts were made to reconcile the observations of James Bradley, published in 1728, and those of later writers by proposing specific relationships between the earth and the ether in its neighbourhood. Young, for example, considered that ether was stationary in respect to the sun and that the earth passed through the ether without disturbing it; on the other hand, Fresnel, in responding to an experiment reported by Arago, suggested that material bodies carry with them excess ether in proportion to the square of their refractive indices (Schaffner, 1972:20–39). However, the most famous aberration experiment was that of Michelson and Morley in 1887, in which they tried to detect the expected second-order difference between the velocity of light along the line of the earth's motion and the velocity perpendicular to it. According to Fresnel's theory of partial drag, which had been revived by Lorentz in conjunction with the electromagnetic theory of light, a detectable difference was expected. However, the Michelson–Morley experiment indicated that the 'relative velocity of the earth and the ether is probably less than one sixth of the earth's orbital velocity, and certainly less than one fourth'; in other words, considerably less than predicted.[104]

One response to the Michelson–Morley experiment was to propose a new version of ether theory that would 'save the phenomena', or more exactly, save the theory. In the 1890s, Fitzgerald and Lorentz suggested the initially ad hoc hypothesis that moving bodies contract in the direction of their motion through the ether by a factor of $\sqrt{1-(v^2/c^2)}$.[105] This formula became central to Einstein's special theory of relativity and Einstein readily acknowledged his debt to Lorentz. Though Holton (1969) has argued that the Michelson–Morley experiment was not of crucial importance to the development of Einstein's theory, as has sometimes been claimed, Einstein was directly concerned with the problem of matter–ether interaction (Hirosige, 1976). His reading of Lorentz, and thus his familiarity with earlier ether theories, provides a route by which ether theory may be connected with the theoretical core of twentieth-century physics.

Epilogue: the twentieth century

There is a widely held view that ether theories suffered a dramatic and sudden demise with the rise of the special theory of relativity, since a stationary ether permeating space seems incompatible with Einstein's two postulates. In other words, after 1905 ethers became the concern of the historian rather than the physicist. To endorse this view would allow the present volume to end on an incisive note. However, conceptually rich theories, unlike the individuals who frame them, do not suddenly disappear from science but instead often survive in some modified form. This is certainly the case with ethers. Concern with ether continued after 1905, and it has been suggested by Goldberg (1970) that, particularly among British physicists, ether theorising contributed to the initial lack of interest in Einstein's theory. Most important, however, the view that ether theories did not survive 1905 is incorrect because there have been, and still are, many ether theories that, in principle, are perfectly compatible with special relativity and even general relativity. Moreover, quantum theory has led to new conceptions of ether, and not a few physicists have urged the *necessity* of some form of ether theory.

Like E. T. Whittaker, we have devoted a single volume to a survey of ether theories in the eighteenth and nineteenth centuries. As he required a second volume for the early twentieth century – and even wrote a third that has never been published – so we must suggest that to do justice to the recent and highly technical history of the topic at least one further volume would be required. Although ether theorising has continued during the present century, the rise of Einstein's theories of relativity and other developments have raised a number of new and difficult problems that, in turn, have placed further constraints on ether models. Of the many recent physicists who have been concerned with ethers we can select only two, Einstein and Dirac, to illustrate the continuing history of the subject beyond the period covered in the present volume.

Einstein, in an address delivered at the University of Leyden in 1920, stated:

> More careful reflection teaches us, however, that the special theory of relativity does not compel us to deny ether. We may assume the existence of an ether; only we must give up ascribing a definite state of motion to it, i.e. we must by abstraction take from it the

> last mechanical characteristic which Lorentz had still left it. . . [There] is a weighty argument to be adduced in favour of the ether hypothesis. To deny ether is ultimately to assume that empty space has no physical qualities whatever. The fundamental facts of mechanics do not harmonize with this view. . . According to the general theory of relativity space without ether is unthinkable; for in such space there would not only be no propagation of light, but also no possibility of existence for standards of space and time (measuring-rods and -clocks), nor therefore any space–time intervals in the physical sense.[106]

Our second example, Dirac, submitted a short but famous letter to *Nature* in 1951, which included the following:

> Physical knowledge has advanced very much since 1905, notably by the arrival of quantum mechanics, and the situation has again changed. If one examines the question in the light of present-day knowledge, one finds that the aether is no longer ruled out by relativity, and good reasons can now be advanced for postulating an aether.[107]

Notes

1 G. S. Kirk and J. E. Raven, *The Presocratic philosophers* (Cambridge, 1964), 10–14. See also W. K. C. Guthrie, *The Greeks and their gods* (London, 1950), 207–8, 263, 324; W. K. C. Guthrie, *A history of Greek philosophy* (Cambridge, 1962), 1:270–3; O. Gilbert, *Die meteorologischen Theorien des griechischen Altertums* (Leipzig, 1907), 17–65, 662–701.

2 For the texts of Anaximenes and Heraclitus and commentary, see Kirk and Raven, *The Presocratic philosophers*, 143–62, 182–215. A recent, incisive survey of pre-Socratic philosophy is given in J. Barnes, *The Presocratic philosophers*, 2 vols. (London, 1979). Valuable articles are collected in D. J. Furley and R. E. Allen (eds.), *Studies in Presocratic philosophy*, 2 vols. (London and New York, 1970, 1975); and in A. P. D. Mourelatos (ed.), *The Presocratics* (New York, 1964).

3 The historical significance of the Parmenidean impasse, clearly appreciated by Aristotle, is made a central theme in Barnes, *The Presocratic philosophers*.

4 Texts and commentary for these authors are given in Kirk and Raven, *The Presocratic philosophers*, 263–85, 320–95, 400–26. Our summary draws on Hesse (1961), 35–45.

5 For Plato on matter and the elements, see G. Vlastos, *Plato's universe* (Oxford, 1975). Important collections of articles on Plato include G. Vlastos, *Platonic studies* (Princeton, N.J., 1973); R. E. Allen (ed.), *Studies in Plato's metaphysics* (London, 1965); and G. Vlastos (ed.), *Plato: a collection of critical essays*, 2 vols. (New York, 1971). See also the article 'Plato' in *Dictionary of scientific biography*, ed. C. C. Gillespie, 15 vols. (New York, 1970–8).

6 See the comprehensive and detailed article 'Quinta essentia', by P. Moraux, in A. F. von Pauly, *Realencylopädie der classischen altertumswissenschaft*, ed. G. Wissowa, (1963), 47:1181–1263. We have been reminded (by an anonymous referee) that a clear statement of the theory of five elemental bodies, including *aither*, is to be found at 981c of the *Epinomis*, a work plausibly ascribed to Plato or a close associate. Moraux discusses whether this statement anticipates Aristotle's teaching on the five elements.

7 See F. Solmsen, *Aristotle's system of the physical world* (Ithaca, N.Y., 1960). A valuable collection of articles is J. M. E. Moravcsik (ed.), *Aristotle* (New York, 1967). See also the article, by G. E. L. Owen, D. M. Balme, and L. G. Wilson, on Aristotle in Gillespie, *Dictionary of scientific biography*.

8 Solmsen, *Aristotle's system*, 287–301; F. Solmsen, 'The vital heat, the inborn pneuma and the aether', *Journal of Hellenic Studies* 77 (1957), 119–23.

9 Solmsen, 'The vital heat, the inborn pneuma and the aether'; A. L. Peck, *Aristotle: generation of animals*, rev. ed. (Cambridge, Mass., and London, 1953), app. B.

10 On Stoic physics, generally, see S. Sambursky, *Physics of the Stoics* (London, 1959); D. Hahm, *The origins of Stoic cosmology* (Columbus, Ohio, 1977); H. A. K. Hunt, *A physical interpretation of the universe: the doctrines of Zeno the Stoic* (Melbourne, 1976). This last translates a number of passages into English for the first time. On *pneuma*, see G. Verbeke, *L'Evolution de la doctrine du pneuma* (Paris, 1945).

11 Sambursky, *Physics of the Stoics*, 21–48; Hahm, *Stoic cosmology*, 157–74; Hunt, *A physical interpretation of the universe*, 17–59.

12 Nemesios, *De natura hominis*, quoted, in translation, in Sambursky, *Physics of the Stoics*, 128.

13 A. A. Long, *Hellenistic philosophy* (London, 1974), 157.

14 M. Lapidge, 'Stoic cosmology', in *The Stoics*, ed. J. M. Rist (Berkeley, Calif., 1978), 161–86.

15 See especially Plotinus, *Enneads*, I, iv, and V, i.

16 Lucretius, *De rerum natura*, V, lines 416–649.

17 Here Origen's *De principiis* (written in the third century) was an important source for later writers. For other such early sources, see Moraux's article cited in n. 6.

18 M. A. Hewson, *Giles of Rome and the medieval theory of conception* (London, 1975).

19 Our summary here follows D. Lindberg, *Theories of vision from Al-kindi to Kepler* (Chicago, 1976), 94–103.

20 F. A. Yates, *Giordano Bruno and the Hermetic tradition* (London, 1964), 1–20.

21 R. S. Westman and J. E. McGuire, *Hermeticism and the scientific revolution* (Los Angeles, 1977).

22 W. Pagel, 'Paracelsus', in Gillispie, *Dictionary of scientific biography*.

23 W. Pagel, 'Paracelsus and the neo-Platonic and gnostic tradition', *Ambix 8* (1960), 125–66; J. R. Partington, *A history of chemistry*, 4 vols. (London, 1959–70), 2:chap. 3; A. G. Debus, *The chemical philosophy: Paracelsian science and medicine in the sixteenth and seventeenth centuries*, 2 vols. (New York, 1977).

24 See, for example, M. Bonelli Righini and W. Shea (eds.), *Reason, experiment and mysticism in the scientific revolution* (New York, 1975). V. L. Bullough (ed.), *The scientific revolution* (New York, 1970), collects many such interpretations.

25 N. Kemp Smith, *New studies in the philosophy of Descartes* (London, 1952), 103–14.

26 The text of *Le monde* is in vol. 11 of R. Descartes, *Oeuvres de Descartes*, eds. C. Adam and P. Tannery, 12 vols. (Paris, 1897–1910). An English translation of some opening sections is in R. Descartes, *Descartes: selections*, ed. and trans. R. M. Eaton (New York, 1927).

27 Kemp Smith, *New studies*, 118–22.

28 *Le monde* is usually thought to have been completed by 1633. Love shows that in its treatment of subtle matter, at least, it is closer to *Principia* than to earlier writings: R. Love, 'Revisions of Descartes's matter theory in *Le monde*', *British Journal for the History of Science 8* (1975), 127–37.

29 Our summary partly follows A. Kenny, *Descartes: a study of his philosophy* (New York, 1968), 204–5.

30 *Principia philosophiae*, bk. 1, §§ 51–64. The Latin text (1644) and French translation (1647) are in vols. 8 and 9 of the Adam and Tannery edition of Descartes' works cited in n. 26. For a partial translation into English, see R. Descartes, *The philosophical works of Descartes*, trans. E. S. Haldane and G. R. T. Ross, 2 vols. (Cambridge, 1968) 1:201–303. For a recent analysis of Descartes' arguments for extension as the essence of matter see R. J. Blackwell, 'Descartes' concept of matter', in *The concept of matter in modern philosophy*, ed. E. McMullin, rev. ed. (Notre Dame, Ind., 1978), 759–75.

31 *Principia philosophiae*, bk. 2, §§ 36–45.

32 For the complexities in Descartes' conceptions of motion and force, see Westfall (1971), 56–98; A. Gabbey, 'Force and inertia in seventeenth-century dynamics', *Studies in History and Philosophy of Science 2* (1971), 1–68; P. H. J. Hoenen, 'Descartes's mechanicism', in *Descartes*, ed. W. Doney (New York, 1967), 353–68; P. Machamer, 'Causality and explanation in Descartes' natural philosophy', in *Motion and time, space and matter*, eds. P. Machamer and R. Turnbull (Columbus, Ohio, 1976), 168–99; W. E. Anderson, 'Cartesian motion', in ibid., 200–23; and even more recently, D. Clarke, 'Physics and metaphysics in Descartes' *Principles*', *Studies in History and Philosophy of Science 10* (1979), 89–112; and G. C. Hatfield, 'Force (God) in Descartes' physics', ibid., 113–40.

33 See P. J. Olscamp's introduction to R. Descartes, *Discourse on method, optics, geometry and meteorology* (Indianapolis, 1965); G. Buchdahl, *Metaphysics and philosophy of science* (London, 1969).

34 Aiton (1972), 49–57.

35 A. Sabra, *Theories of light from Descartes to Newton* (London, 1967), 46–69.

36 Kemp Smith, *New Studies*, 130–7.

37 Ibid., 105–11.

38 The complete text of this essay is reprinted in M. B. Hall, *Robert Boyle on natural philosophy: an essay with selections from his writings* (Bloomington, Ind., 1965), from R. Boyle, *The works of the Honourable Robert Boyle*, ed. T. Birch, 2nd ed., 6 vols. (London, 1772), 4:68–78.

39 See §§ 3–5 of Boyle's essay.

40 R. Boyle, 'About an attempt to examine the motions and sensibility of the Cartesian Materia Subtilis, or the Aether, with a pair of bellows, made of a bladder, in the exhausted receiver', reprinted in Hall, *Robert Boyle on natural philosophy*, 358–63, from Boyle, *Works*, 3:250–2.

41 Boyle, in Hall, *Robert Boyle on natural philosophy*, 198, 209. It is thus an error to think that mechanical philosophers were distinctive in not admitting active principles.

42 For such an attempt, see P. Rattansi, 'Newton's alchemical studies', in *Science, medicine and society in the Renaissance: essays to honor Walter Pagel*, ed. A. G. Debus, 2 vols. (New York, 1972), 1:167–82; P. Rattansi, 'Some evaluations of reason in sixteenth and seventeenth-century natural philosophy', in *Changing perspectives in the history of science: essays in honour of Joseph Needham*, eds. M. Teich and R. Young (London, 1972), 148–66.

43 For the text (with translation) of 'De gravitatione', see A. R. Hall and M. B. Hall (eds. and trans.) *Unpublished scientific papers of Isaac Newton* (Cambridge, 1962), 89–156.

44 W. Gilbert, *On the magnet, magnetick bodies also, and on the great magnet the earth: a new physiology, demonstrated by many arguments & experiments* (London, 1900), 209–10.

45 E. J. Dijksterhuis, *The mechanization of the world picture*, trans. C. Dikshoorn (Oxford, 1961), 313.

46 Descartes, *Principia philosophiae*, bk. 4, §§ 133–180. Cf. J. F. Scott, *The scientific work of René Descartes* (London, 1952), 188–92.

47 Our summary follows that in J. Passmore's article on More in *Encyclopedia of philosophy*, ed. P. Edwards, 8 vols. (New York and London, 1967), 5:387–9.

48 R. Cudworth, *The true intellectual system of the universe: wherein all the reason and philosophy of altruism is confuted, and its impossibility demonstrated*, 3 vols. (London, 1845), 3:231–2.

49 H. Power, *Experimental philosophy in three books: containing new experiments microscopical, mercurial, magnetical* (London, 1664), 71–2, 152–61. Cf. Rattansi, 'Newton's alchemical studies'.

50 Cudworth, *True intellectual system*, 1:249.

51 I. Newton, 'An hypothesis explaining the properties of light', in T. Birch, *The history of the Royal Society of London* 4 vols. (London, 1756–7), 3:247–305; I. Newton to R. Boyle, in R. Boyle, *The works of the Honourable Robert Boyle*, ed. T. Birch, 5 vols. (London, 1744), 1:70–3. P. 74 of this work contains a letter from Newton to Oldenburg concerning ether. These texts are reprinted in facsimile in *Isaac Newton's papers and letters on natural philosophy*, ed. I. B. Cohen (Cambridge, Mass., 1958).

52 See, in particular, Aiton (1969); Guerlac (1967); Hall and Hall (1967); Hawes (1968*b*); McGuire (1968); McMullin (1978); Rosenfeld (1969). Only after completion of this introduction did the editors become aware of Corson (1974), which contains a detailed discussion of the chronological development of Newton's ideas about ethers drawing on both published and manuscript documents. Corson's interpretations are generally though not invariably in accord with those suggested here.

53 I. Newton, 'De aere et aethere', in Hall and Hall, *Unpublished scientific papers of Isaac Newton*, 227.

54 I. Newton, *Optice* (London, 1706), 344. The translation is that of the *Opticks*, 4th ed. (London, 1730; reprinted, New York, 1952), 401.

55 For example, Newton 'An hypothesis', 253; Newton to Boyle, 71.

56 'An hypothesis', 249.

57 Cotes's preface and the 'General scholium' added to the 2nd (1713) ed. of the *Principia*. See also query 31 of the *Opticks*.

58 Newton, *Opticks*, 2nd ed. (London, 1717), 326. See also McGuire (1970).

59 'An hypothesis', 255. See also Newton to Boyle, 70.

60 *Opticks* (1717), 292–313. See R. H. Stuewer, 'A critical analysis of Newton's work on diffraction', *Isis 61* (1970), 188–205.

61 *Opticks* (1717), 324–6. However, Howard Stein has drawn to our attention a passage in the *Principia* (bk. 3, prop. 6, cor. 2) where Newton states that ether itself is subject to gravitational attraction. There remains the problem of how these passages can be reconciled.

62 *Opticks* (1717), 327.

63 'An hypothesis', 250–1.

64 *Opticks* (1717), 323–4.

65 'An hypothesis', 252–5; *Opticks* (1717), 328.

66 Some of Newton's accounts of ether, especially in manuscripts he did not publish,

even raise the question whether, after all, ether is mechanical in the sense of conforming to his own laws of motion, his own science of mechanics. At least once – in a passage quoted by Heimann (this volume) in his n. 17 – Newton seems to describe ether as lacking resistance and so without inertia, and as not acting, therefore, in accord with his laws of mechanics. But how is inertia to be avoided in an ether presumably formed from particles of the same matter as air? If the particles had negligible volume, then, perhaps, the medium would have no measurable inertia. But could God still be conceived as endowing such particles with attractive or repulsive forces and, if so, with what consequences for the medium as a whole and for the bodies floating in it? As McMullin (1978) implies, in discussing such texts, a unified and coherent interpretation of all Newton's ether theorising, published and unpublished, still eludes even recent scholarship.

67 On Boerhaave's career see G. A. Lindeboom, *Hermann Boerhaave: the man and his work* (London, 1968). For the chemistry, H. Metzger, *Newton, Stahl, Boerhaave et le doctrine chimique* (Paris, 1930), remains indispensable.

68 Lindeboom, *Hermann Boerhaave,* 179 ff.

69 Love (1974); H. Boerhaave, *A new method of chemistry,* trans. P. Shaw and E. Chambers (London, 1727), 220–38.

70 Love (1974); Boerhaave, *A new method of chemistry,* trans. P. Shaw, 2 vols. (London, 1741), 1:386–7, 397.

71 Boerhaave, *A new method* (1727), 222, 233.

72 On Robinson and his career, see Schofield (1970).

73 Fox (1971). H. Guerlac gives a bibliography in his article on Lavoisier in Gillespie, *Dictionary of scientific bibliography.* This article is reprinted, with minor changes, as H. Guerlac, *Antoine-Laurent Lavoisier, chemist and revolutionary* (New York, 1975).

74 For example, E. Mach, *The principles of physical optics,* trans. J. S. Anderson and A. F. A. Young (London, 1926).

75 *Opticks* (1717), 324–5.

76 For example, I. B. Cohen (ed. and intro.), *Benjamin Franklin's experiments: a new edition of Franklin's experiments and observations on electricity* (Cambridge, Mass., 1941), 302; Cohen (1956); D. H. D. Roller, 'The development of the concept of electric charge: electricity from the Greeks to Coulomb', in *Harvard case histories in experimental science,* eds. J. B. Conant and L. K. Nash, 2 vols. (Cambridge, Mass., 1957), 2:541–639.

77 Cohen, *Benjamin Franklin's experiments;* Cohen (1956); D. Roller, 'The early development of concepts of temperature and heat: the rise and decline of the caloric theory', in Conant and Nash, *Harvard case histories,* 1:117–214.

78 Sabra, *Theories of light from Descartes to Newton;* A. Fresnel, *Oeuvres complètes d'Augustin Fresnel, publiées par Henri de Sénarmont, Emile Verdet et Léonor Fresnel,* 3 vols. (Paris, 1866–70).

79 D. Gooding, 'Conceptual and experimental bases of Faraday's denial of electrostatic action at a distance', *Studies in History and Philosophy of Science 9* (1978), 117–49; R. Hare, 'A letter to Professor Faraday, on certain theoretical opinions', *American Journal of Science and Arts 38* (1840), 1–11, and *41* (1841), 1–14. Faraday replied in ibid. *39* (1840), 108–20.

80 D. Hartley, *Observations on man, his frame, his duty, and his expectations* (London, 1749); J. Priestley, *Hartley's theory of the human mind, on the principle of association of ideas: with essays relating to the subject of it* (London, 1775).

81 R. Boscovich, *Theoria philosophiae naturalis,* 2nd ed. (Venice, 1763); W. Herschel, *The scientific papers of Sir William Herschel,* ed. J. L. E. Dreyer, 2 vols. (London, 1912); J. Priestley, *The history and present state of discoveries relating to vision, light and colours* (London, 1772); Schofield (1970), 235–76; R. McCormmach, 'Henry Cavendish: a study of rational empiricism in eighteenth-century natural philosophy', *Isis 60* (1969), 293–306.

82 T. Reid, *Essays on the intellectual powers of man* (Edinburgh, 1785), esp. essay 1, chap. 3, and essay 2, chap. 3. See also Laudan (1970).

83 H. Martineau (ed.), *The positive philosophy of Auguste Comte,* 2 vols. (London, 1853), 1:225. Cf. W. R. Grove 'On the correlation of physical forces', *Literary Gazette, and Journal of Belles Lettres* (1844), 25.

84 F. Engels, *Herrn Eugen Dührings Umwälzung der Wissenschaft* (Stuttgart, 1921).

85 Lord Salisbury, 'Presidential address', *Report of the sixty-fourth meeting of the British Association for the Advancement of Science* (London, 1894), 8.

86 W. Ostwald, *Vorlesungen über Naturphilosophie* (Leipsig, 1902). See also E. Hiebert, 'The energetics controversy and the new thermodynamics', in *Perspectives in the history of science and technology,* ed. D. H. D. Roller (Norman, Okla., 1971), 67–86.

87 H. Poincaré, *Science and hypothesis* (London, 1905), 211.

88 Goldfarb (1977). Cf. Fox (1979).

89 See R. E. Schofield, 'Joseph Priestley, natural philosopher', *Ambix 14* (1967), 1–15; and the criticism of that article in J. G. McEvoy, 'Joseph Priestley, natural philosopher: some comments on Professor Schofield's views', *Ambix 15* (1968), 115–21. See further J. G. McEvoy and J. E. McGuire, 'God and nature: Priestley's way of rational dissent', *Historical Studies in Physical Sciences 6* (1975), 325–404; J. G. McEvoy, 'Joseph Priestley, "aerial philosopher" ', *Ambix 25* (1978), 1–55, 93–116, 153–75, and *26* (1979), 16–38.

90 McGuire (1974). This article draws in turn on Heimann and McGuire (1971), Heimann (1971), and Heimann (1970). See also J. E. McGuire and P. Heimann, 'The rejection of Newton's concept of matter in the eighteenth century', in McMullin, *The concept of matter in modern philosophy.*

91 On the historical and conceptual complexities surrounding the notion of field, see Stein (1970); Tonnelat (1959).

92 I. Watts, *The works of Isaac Watts,* eds. D. Jennings and P. Doddridge, 6 vols. (London, 1753), V, 594.

93 T. S. Kuhn, 'Mathematical versus empirical traditions in the development of physical science', *Journal of Interdisciplinary History 7* (1976), 1–31; reprinted in T. S. Kuhn, *The essential tension* (Chicago, 1979).

94 S. Carnot, *Reflexions sur la puissance motrice du feu et sur les machines propres a développer cette puissance* (Paris, 1824).

95 For example, John Hutchinson, Samuel Pike, and William Jones of Nayland. See Heimann (1973); Heimann and McGuire (1971); the forthcoming dissertation by Chris Wilde of Cambridge University.

96 See, principally, T. Young, 'On the theory of light and colours', *Philosophical Transactions 92* (1802), 12–48; T. Young, *A course of lectures on natural philosophy and the mechanical arts,* 2 vols. (London, 1802), 1:457–71.

97 R. Fox, 'The rise and fall of Laplacian physics', *Historical Studies in the Physical Sciences 4* (1974), 89–136.

98 E. Frankel, 'The search for a corpuscular theory of double refraction: Malus, La Place and the prize competition of 1808', *Centaurus 18* (1974), 223–45; Buchwald (this volume).

99 E. Nagel, *The structure of science: problems in the logic of scientific explanation* (London, 1961), 153–202.

100 R. Moon, *Fresnel and his followers: a criticism, to which are appended outlines of theories of diffraction and transversal vibration* (Cambridge, 1849), ix.

101 W. Rankine, 'Outlines of the science of energetics', *Proceedings of the Royal Philosophical Society of Glasgow 3* (1855), 381–99.

102 G. F. Fitzgerald, 'On the electromagnetic theory of the reflection and refraction of light', *Philosophical Transactions 170* (1880), 691–711. See Schaffner (1972), 204–7.

103 J. MacCullagh, 'An essay towards a dynamical theory of crystalline reflexion and refraction', and other related papers reprinted in J. MacCullagh, *The collected works of James MacCullagh*, eds. J. H. Jollett and S. Haughton (Dublin, 1880).

104 A. A. Michelson and E. W. Morley, 'On the relative motion of the earth and the luminiferous ether', *Philosophical Magazine 24* (1887), 449–63.

105 Several papers on this subject have been reprinted in vol. 4 of H. A. Lorentz, *Collected papers*, 9 vols. (The Hague, 1935–9).

106 A. Einstein, 'Ether and relativity', in *Sidelights on relativity* trans. G. B. Jeffery and W. Perrett (London, 1922).

107 P. A. M. Dirac, 'Is there an aether?' *Nature 168* (1951), 906–7.

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Ether and imponderables

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The physics of active, ethereal imponderable fluids represented the main current of speculation among British natural philosophers in the second half of the eighteenth century. These 'fluids' were envisaged as being composed of particles that mutually repelled each other, this property being referred to as 'elasticity'. The 'elastic fluids' were conceived as being 'subtle' (being able to penetrate the empty spaces between the particles of ordinary matter in bodies), as being weightless (or at least with no measurable weight), and as being attracted by the particles of ordinary matter. Frequently postulated to explain the phenomena of electricity, magnetism, optics, heat, and chemistry, the operations of the repellent particles of the imponderable fluids were thus traced to interparticulate forces of attraction and repulsion. These characteristic features of the imponderable fluids suggest that their articulation was influenced by Newton's concept of ether, postulated as a 'subtle', 'elastic', particulate substance in the queries appended to the second English edition of the *Opticks* (1717), and by Newton's theory of interparticulate forces of attraction and repulsion, especially as explicated in query 31 of the 1717 *Opticks* (Cohen, 1956; Schofield, 1970; Heimann and McGuire, 1971; Heimann, 1973).

The extent to which the theory of ethereal substances proposed by eighteenth-century British natural philosophers can be analysed in relation to Newtonian categories has, however, been questioned (Home, 1977*a*). The theory of imponderable fluids may seem to echo the Cartesian doctrine of the all-pervading subtle ether that, though in decline in cosmology (Aiton, 1972:244–56), provided the model for the fluid theories of fire and magnetism advanced by Daniel Bernoulli and Euler in the 1740s. Nevertheless, there are important differences between the Cartesian and Newtonian ethers. The Cartesian ether was a plenum; its operations arose from the contact action of its component particles. By contrast, the Newtonian ether was composed of particles that were separated by void space and that acted on gross bodies by means of their repulsive forces. The 'Newtonian' character of the elastic fluids postulated by British natural philosophers was explicit, and cannot be regarded as a Newtonian veneer disguising an essentially Cartesian vortex model. Nevertheless, the development of the imponderable fluid theories cannot be ascribed solely to the influence of the ether concept, though in attempting to clarify the diverse conceptual origins of the imponderable fluid theories this chapter emphasises the primary importance of the Newtonian concept of ether. An analysis of the development of Continental imponderable fluid theories would show different patterns of thought, with 'Newtonian' concepts exercising a less dominant influence; and although understanding imponderable fluid theories in eighteenth-century British natural philosophy in relation to Newton's theory of ether does not completely characterise their intellectual provenance, that theory does provide an illuminating context for historical analysis.

Newton's ether theory aroused little interest until the 1740s, and a central aim of this chapter is to analyse the reasons for its adoption at that time and to clarify the manner in which the concept of ether provided the paradigm for the imponderable fluid theories. Further, the incorporation of Boerhaave's 'fire' in theories of an ethereal 'electrical fire' and of Stahl's 'phlogiston' (the chemical principle of inflammability) as a modification of ether led to a broadening and transformation of the theory of ether. By the end of the century attempts were made to formulate a unified theory of ether, reducing the diversity of phenomena to the modifications of a single ethereal active substance. This chapter attempts, then, to clarify how Newton's theory of ether was transformed into the concept of an inherently active substance, a theory of nature that contradicted Newton's own doctrine of the intrinsic passivity of material entities, all activity being for him ultimately grounded in divine agency. For these later theorists, active powers were held to be intrinsic to some or even all material substances, and ether functioned as the source of the activity of nature. The transformation of Newton's theory of ether was associated with a blurring of the distinction between the categories of activity and passivity in Newton's natural philosophy, and a rejection of its theological implications.[1]

However, despite the dominance of the theory of ethereal fluids in late eighteenth-century British natural philosophy, alternative conceptual schemes continued to be canvassed. The speculative and qualitative cast of the theory of imponderable fluids was unacceptable to those natural philosophers interested in a mathematical theory of nature, to whom Newton's *Principia* (1687), with its stress on the role of the forces quantitatively determining natural phenomena, appeared a more appropriate paradigm for physical theory. The Scottish natural philosophers Robison and Playfair opposed the supposition of interstitial particles of ether to explain gravity and of imponderable 'ethers' to account for the phenomena of electricity and heat (Cantor, 1971; Olson, 1975:157–224). Cavendish attempted to develop Newton's theory of the unity of matter and the Newtonian programme of the quantification of the interparticulate forces; for Cavendish, the fluids of light, electricity, and phlogiston were ponderable, and heat was regarded as the motion of the particles of ordinary matter. Ether played no role in his theory of nature, and he rejected the supposition of imponderable fluids and anomalous forms of matter.[2]

The disjunction between the theory of imponderable fluids and the quantitative theory of interparticulate forces as alternative programmes for physical explanation does illuminate the aims of some eighteenth-century British natural philosophers. However, it has been argued by Schofield that there was a fundamental opposition in eighteenth-century British natural philosophy between (1) any theory of atoms and interparticulate forces and (2) any theory of an ether or of imponderable fluids. On Schofield's account, although these two lines of theorising both derived from Newton's natural philosophy, they employed quite distinct principles of physical explanation.[3] This interpretation imposes a distorting analytic framework, simplifying Newton's natural philosophy and the complexities of eighteenth-century interpretations of Newton's theory of nature. In Newton's natural philosophy the mode of action of ether was grounded on the agency of repulsive forces; and eighteenth-century ether theorists stressed the role of the repulsive forces associated with the ethereal imponderable fluids, arguing that there was a balance in nature between the attractive force associated with ordinary matter and the repulsive force of the ethereal fluids. To make a contrast between force and ether concepts the analytic framework for the interpretation of eighteenth-century British natural philosophy is to ignore the relation between Newton's ether and his concept of 'active principles', natural agents that he held to be distinct from the 'passive' principles that characterised the properties of matter. In this chapter it is argued that the status of ether as an active principle was fundamental to the development of theories of active, ethereal imponderable fluids. In place of a disjunction between 'force' and 'ether' concepts, it is suggested that a more appropriate analytic framework for characterising the 'Newtonian' origins of British imponderable fluid theories is to be found in the relations among the Newtonian concepts of forces, active principles, and ether. For Newton's speculations were ambiguous, and these categorial complexities were reflected in the conceptual structures of eighteenth-century ether theories, in which 'Newtonian' concepts of force, active principles, and ether were conflated in the theory of inherently active ethereal imponderables endowed with repulsive forces (Heimann and McGuire, 1971).

Newton's ether theory: the published sources

Newton provided several sources from which eighteenth-century natural philosophers could learn of his ether theory. His first published discussion of ether was his introduction of a subtle and elastic ether in the queries to the 1717 *Opticks* to explain optical reflection and refraction and to provide a causal explanation for gravity.[4] But his earliest speculations on ether, introduced in his 'Hypothesis explaining the properties of light' written in 1675 (though not published until 1757)[5] and in a letter to Oldenburg of 1676 correcting this paper (published in 1744),[6] placed these optical speculations in the context of a cosmology based on the circulation and transformation of ethereal spirits. Newton qualified this ethereal cosmology in a letter to Boyle written in 1679 (though not published until 1744),[7] where he expressed the possibility of an explanation of gravity in terms of the differential densities and sizes of ether particles. The problems of interpreting Newton's theory of ether derive both from the different emphases of these discussions and from the ambiguity of Newton's arguments.

Newton's ether was thus most familiar to the eighteenth-century natural philosophers in the account given in the 1717 *Opticks*, which introduced the physical model of ether as composed of mutually repelling particles. The most extended account of the mode of action of ether was given in query 21, where Newton argued that

> the exceeding smallness of its Particles may contribute to the greatness of the force by which those Particles may recede from one another, and thereby make that Medium exceedingly more rare and elastick than Air, and by consequence exceedingly less able to resist the motions of Projectiles, and exceedingly more able to press upon gross Bodies, by endeavouring to expand it self.[8]

In suggesting this model to explain the agency of gravity, Newton was not invoking the Cartesian concept of pressing or impact of contiguous particles constituting a plenum. In the *General scholium* to the second edition of *Principia* (1713) he had argued that gravity 'must proceed from a cause that penetrates to the very centres of the sun and planets' and that 'operates not according to the quantity of the surfaces of the particles upon which it acts (as mechanical causes are accustomed)'.[9] In referring to the 'pressing' of the ether, Newton was not suggesting the Cartesian impact model; nor was he envisaging a fluid medium acting by hydrostatic pressure. As he pointed out in query 28, at any point in a fluid the pressure acts equally in all directions, whereas 'Gravity tends downwards';[10] hence fluid pressure is irreconcilable with the directionality of gravity. Though Newton's ether has sometimes been viewed as providing some form of contact-action explanation of gravity, Newton's own statements emphasised the irreducibility of gravity to 'mechanical' or contact-action theories.[11]

Newton apparently envisaged ether acting by a differential density arising from the repulsive forces exerted by the minute particles of ether, while the great 'elastick force' of the ether, its tendency to 'expand it self', enabled it to 'press upon gross Bodies' and to cause planets to approach or recede. Arguing analogically, in query 21, Newton claimed that just as the small size of light corpuscles implied forces of great intensity in relation to size, the particles of ether, which were 'exceedingly smaller than those of Air, or even than those of Light', were endowed with the strongest forces with respect to their sizes. Ether was composed of 'Particles which endeavour to recede from one another', its agency manifested through the differential density of the ethereal 'medium'.[12] So Newton's gravitational ether did not act by contact action; its particles were separated by void space and acted on one another by their repulsive forces. It has been argued that in attempting to reduce the force of gravity to the repulsive forces of the ether particles, Newton's ether embodied the problem of action at a distance that it purported to explain (McGuire, 1968:187; Westfall, 1971:395). In questioning the intelligibility of ether as an explanation of gravity this interpretation ignores an important characteristic of the ether, its status as a Newtonian active principle.

Newton distinguished between gravity and those physical properties – hardness, extension, inertia – that he held to be intrinsic to the nature of matter. As he emphasised in a famous statement to Bentley (published in 1756), gravity was not to be considered as 'innate, inherent and essential to Matter'.[13] In query 31 of the 1717 *Opticks*, Newton contrasted passive principles such as *vis inertiae* (force of inertia) and the 'passive Laws of Motion as naturally result from that Force' with 'active Principles, such as that of Gravity'.[14] In Newton's natural philosophy active principles were agents that were not reducible to the passive principles of matter. As a putative explanation of gravity the ether of the 1717 *Opticks* was, by implication, an active principle establishing the intelligibility of the phenomenon of gravity (Heimann and McGuire, 1971:240–5). This interpretation is in consonance with the theological function of ether. One likely motive for Newton's inclusion of ether in the 1717 *Opticks* was to refute Leibniz's criticism of Newton's concept of gravity as a 'miracle', an 'occult quality' and a 'fiction'.[15] Arguing for a contact-action or 'mechanical' explanation of gravity, Leibniz expounded his views at length in his correspondence with Clarke in 1715–16. Newton conceived active principles as manifest in certain 'general Laws of Nature'. Regarded as the manifestation of God's lawful, causal agency in nature, they functioned as the cause of motion and gravity.[16] Rejecting the reducibility of gravity to a contact-action model, Newton conceived the ether of the 1717 *Opticks* as an active principle communicating God's causal agency and as a physical model (though not a contact-action model) establishing the intelligibility of the distance force of gravity.

This interpretation of ether as an active principle implies that ether had an ambiguous conceptual status in Newton's natural philosophy. Composed of particles of matter, ether would ostensibly appear to fall under the category of passive principles. However, Newton's manuscript references to ether between 1706 and 1717 show that he sought to distinguish between the passivity and inertia of *ordinary* matter and the active properties of ether.[17] Despite these reflections on the anomalous nature of ether particles, Newton did not characterise their properties in a systematic way, and his only published hints about these issues were in his discussion of the 'greatness' of the 'elastick force' of ether, and its implied status as an active principle. Nevertheless the conceptual status of ether as an active principle was to exercise considerable influence on the development of the imponderable fluid theories. In Newton's natural philosophy active principles were distinct from the passive properties of matter, and their activity was dependent on God's causal agency; but the ambiguous conceptual status of Newton's ether as both an active and a material principle led many eighteenth-century theorists to interpret ether as a substance endowed with inherent activity, conflating the active – passive dualism of Newton's natural philosophy.

In query 31 of the 1717 *Opticks*, Newton linked active principles with the 'great and violent' processes of chemistry, questioning the reducibility of chemistry to the 'passive Laws of Motion'.[18] Taking ether as an active principle, some eighteenth-century chemists assimilated 'fire' and 'phlogiston' to ether and emphasised the irreducibly chemical properties of ether. The association between ether and chemical active principles was heightened by the publication of Newton's 'Hypothesis on light' and his letter to Oldenburg, where the operations of ether were linked to chemical processes, and where ether served the same function as active principles in maintaining the activity of nature. Newton suggested that 'the whole frame of nature may be nothing but aether condensed by a fermental principle'. He supposed that nature

> may be nothing but various Contextures of some certaine aethereall Spirits or vapours condens'd as it were by precipitation, much after the manner that vapours are condensed into water or exhalations into grosser Substances and after condensation wrought into various formes, at first by the immediate hand of the Creator, and ever since by the power of Nature . . . Thus perhaps may all things be originated from aether.

Newton added that 'nature is a perpetuall circulatory [the word *circulatory* was omitted from the published version] worker'; by the chemical transformation of ethereal spirits and by 'nature making a circulation', the activity of the cosmos was conserved.[19] In stressing that ether was an underlying first principle from which all things originated, in supposing that the activity of the cosmos was conserved by the circulation of ethereal spirits, in arguing for the generation of all things from ether, and in relating the operations of ether to chemical processes, Newton echoed seventeenth-century alchemical and neo-Platonist writers.[20] In a manner analogous to his disjunction between active principles and the passive principles of matter, this chemical, active ethereal cosmology lay outside the framework of the 'passive Laws of Motion'.[21]

The emergence of imponderable fluid theories

Newton's ether theory aroused little interest among natural philosophers until the 1740s. A contemporary assessment of the ether hypothesis of the 1717 *Opticks* as 'something new in the latest edition of his *Opticks* which has surprised his physical and theological disciples'[22] hinted at the reason for this lack of interest. Newton's discussion of the mode of action of ether in query 21 was far from clear, and Newtonian natural philosophers had been schooled to be wary of contact-action or 'mechanical' explanations of gravity. Natural philosophers such as John Keill and theologians like Clarke had taken up the cudgels in public defence of Newton's theory of the attractive force of gravity and his theological argument in explicating gravity as the effect of the divine will. Ether appeared to have a questionable status in this 'Newtonian' world view. Indeed, the review of the Latin edition of the 1717 *Opticks* in the *Acta eruditorum* regarded Newton's introduction of ether as providing a contact-action explanation of gravity, reflecting Leibnizian criticisms of the 'occult' nature of attractive forces.[23] In England, Robert Greene claimed, in his *Philosophy of the expansive and contractive forces* (1727), that Newton had proposed ether in the 1717 *Opticks* in response to the criticisms of Newton's theories of atoms, the void, and the passivity of material entities in Greene's *Principles of natural philosophy* (1712) (Heimann and McGuire, 1971:255–61). Despite these responses, Henry Pemberton, who had edited the third edition of *Principia* (1726) for Newton, mentioned Newton's 'subtle and elastic substance diffused through the universe' in his *View of Sir Isaac Newton's philosophy* (1728).[24] Nevertheless, until the 1740s, Newtonian popularisers avoided ether in favour of Newton's theory of short-range interparticulate forces as developed in the queries to the *Opticks* (Schofield, 1970:19–62; Thackray, 1970:8–82).

The new interest in Newton's theory of ether among British natural philosophers was related to the burgeoning enthusiasm for electrical studies. As Benjamin Martin noted in his *Philosophia Britannica* (1747), though Newton had discussed ether 'he seem'd not at all delighted with the thought, nor ever laid any stress upon it'; by contrast, contemporary theorists 'are arriv'd at great dexterity since Sir Isaac's time . . . [and] can now almost prove the existence of this aether by the phenomena of electricity'.[25] Four important developments in the period 1717–46 fostered this shift in opinion: an increasing stress on the role of repulsive forces and on the balance in nature between attractive and repulsive forces; the impact of Boerhaave's concept of 'fire'; the publication of Newton's early letters to Boyle and Oldenburg on ether, and of Bryan Robinson's *Dissertation on the aether of Sir Isaac Newton* (1743); and the interest in electrical effluvia (Cohen, 1956:205–362; Heimann, 1973:10–17). These four points will be discussed in turn.

The early Newtonians focused on the description of attractive forces, which was consonant with the gravitational paradigm for the theory of interparticulate forces, but in his *Vegetable staticks* (1727), Stephen Hales developed the implications of Newtonian repulsive forces. Hales was concerned to discuss the production of gases in chemical and biological processes and, following Newton, to explicate the properties of gases in terms of repulsive forces. In the *Opticks*, Newton had associated the 'repelling Power' of particles with the gaseous state: A 'true permanent Air' contained 'particles receding from one another with the greatest Force'. Moreover, Newton had argued that '*Aether* (like our Air) may contain Particles which endeavour to recede from one another', the 'elastick force' of the ether being traced to the 'exceeding smallness of its Particles' and hence the 'greatness of the force by which those particles may recede from one another'.[26] Hales considered that chemical processes were maintained by the production and absorption of gases by chemical substances, which he supposed brought about by attractive and repulsive forces. Associating 'air' with the alkali principle, he interpreted the interaction between acidic and alkaline substances in terms of the interaction of opposing forces. In expounding a theory of 'air' based on the Newtonian concept of repulsive forces, Hales developed the implications of Newton's theory of ether, postulating that the order of nature was dependent on a balance between attractive and repulsive forces. Nature would become 'one inactive cohering lump' if matter were 'only endued with a strongly attracting power'; so intermingled with 'attracting matter' there was 'a due proportion of strongly repelling elastic particles [air], which might enliven the whole mass, by the incessant action between them and the attracting particles'.[27]

Hales envisaged a fundamental balance of nature, a balance between attractive and repulsive forces. Associating attractive and repulsive forces with different material entities, an attracting matter and an 'elastic', ethereal repelling matter, he considered nature as inherently active, its activity maintained by the 'incessant action' of attractive and repulsive forces. Hales's two-substance theory of attractive ordinary matter and repulsive 'air' was to exercise considerable influence on the development of Benjamin Franklin's theory of electricity in the 1740s, which posited a dualism of ordinary matter and a repulsive, ethereal electric 'fluid'; the concept of a balance of powers between attractive matter and ethereal repelling 'fluids' was to be a characteristic feature of the theory of unified ethereal substances developed by James Hutton in the 1790s; and Hales's arguments were to have a significant influence on the development of the imponderable fluid theories.

Boerhaave's concept of 'fire', the theoretical kernel of his *Elementa chemiae* (1732; translated into English by Dallowe in 1735 and Peter Shaw in 1741), was a major influence on the development of Franklin's theory of electricity. For Boerhaave, fire was a physical instrument, the cause of chemical change and 'the instrumental cause of all motion', being 'the great changer of all things in the universe, while itself remaining unchanged'.[28] Boerhaave's 'active element' of fire was not an elastic fluid, and there is no evidence that Boerhaave's formulation of the concept owed anything to Newton's ether. Nevertheless, ether and fire did have some properties in common. Boerhaave stressed the 'excessive minuteness' of the particles of fire, and emphasised that fire was a space-pervading substance that was immutable and not subject to the laws of gravity. Fire had the 'property of penetrating all solid and fluid bodies'; it 'exists always and everywhere'. Fire maintained the activity of the universe, for through the agency of the 'active element' of fire the 'whole universe might continue in perpetual motion'.[29] These outward similarities between Boerhaave's space-pervading substance of fire and Newton's ether led natural philosophers to conflate the two concepts.

This affinity to Newton's speculations was emphasised in Shaw's footnote commentary to his translation. Shaw implied a relation between Boerhaave's quasi-material fire and Newton's active principles; as a substance possessing inherent activity, the source of the activity of nature, fire was interpreted as being analogous to Newton's ether, itself an active principle maintaining the activity of nature. The conflation of ether–fire as an inherently active substance was fostered by the ambiguous conceptual status of Newton's ether as both an active principle and a material substance. The dualism between ether–fire and ordinary matter posited by British natural philosophers in the 1740s can be traced to Boerhaave's view that fire 'has a power of expanding everything else', counteracting the contractive power of 'the remaining bodies which have a virtue implanted in them, whereby they constantly resist this separation of their elements'. Thus there were 'two principles' in nature, 'one of expansion, the other of attraction',[30] a dualism analogous to Hales's theory of attractive and repelling substances, which was explicitly linked to the Newtonian dualism between ordinary matter and ether. By the 1740s natural philosophers had developed dualistic theories in which '*elementary fire*' was considered to be an ethereal substance 'endowed with active Powers distinct from those of other Matter'.[31]

The publication of a systematic treatise on Newton's ether, Bryan Robinson's *Dissertation on the aether of Sir Isaac Newton* (1732), and the publication of Newton's letters to Oldenburg and Boyle in 1744 and of Robinson's pamphlet *Sir Isaac Newton's account of the ether* (1745), which included a reprint of the letter to Boyle and of extracts from the ether queries of the 1717 *Opticks*, brought Newton's theory of ether to the attention of natural philosophers. In his *Dissertation on the aether*, Robinson emphasised that Newton had considered ether to be composed of particles acting on each other at a distance by their repulsive forces. Although his quantitative treatment of optics, gravitation, and capillarity in terms of the sizes and forces of ether particles was not echoed in the writings of the imponderable fluid theorists, his espousal of the Newtonian ether had a considerable impact on the work of the electrical theorists of the 1740s. Benjamin Wilson's identification of ether with an electrical substance in his *Essay towards an explication of the phenomena of electricity deduced from the aether of Sir Isaac Newton* (1746) was made with an explicit acknowledgment to Robinson.

The interest in electrical studies in the late 1740s can be linked to the new concern with Newton's ether; it was supposed that investigations in electricity would enable natural philosophers to 'discover the nature of that subtile elastic and etherial medium, which Sir Isaac Newton queries on, at the end of his *Opticks*'.[32] Boerhaave's ethereal fire, Hales's dualism of ordinary matter surrounded by repelling ethereal air, and Newton's theory of the ethereal elastic fluid were to help shape the hypotheses of the electrical theorists, notably the work of Benjamin Franklin. Franklin had read the work of Hales, Boerhaave, and Wilson, as well as Newton's *Opticks*, and his theory of the electrical fluid brought the concept of material electrical 'effluvia', which electrical theorists had employed as an explanation of electrical phenomena, within the framework of the Newtonian concept of ether. The focus of Franklin's theory of electricity was to seek an explanation for the charging and discharging of bodies, especially the Leyden jar, a device capable of delivering electric shocks, which had been discovered shortly before he began his researches in 1747 (Cohen, 1956:285–478; Home, 1972). In Franklin's influential theory electrification was represented by the permeation of the electrical fluid through the interstitial pores of the electrified body. Franklin considered this 'electrical matter' to consist of 'particles [which were] extremely subtile', differing from 'common matter in this, that the parts of the latter mutually attract, those of the former mutually repel each other'. In Franklin's theory, 'though the particles of electrical matter do repel each other, they are strongly attracted by all other matter', by ordinary matter, that is; and he argued that surplus 'electrical matter' was held in place around electrified bodies as an 'electrical atmosphere' by an attraction between the particles of these bodies and those of the electric fluid.[33] In explicating a theory of electrification, Franklin posited a dualism of ordinary matter and the electric fluid, developing Hales's dualistic theory for the explanation of electrical phenomena. Boerhaave's influence can be seen in his reference to the electrical fluid as an 'electrical fire'. The electrical fluid was conceived as analogous to Newton's ether, being composed of mutually repelling particles. The electrical matter was envisaged as an electrical ether, and Franklin suggested that fire, ether, and electricity were 'different modifications of the same thing',[34] though he ultimately distinguished between the properties of fire and those of the electric fluid (Schofield, 1970:172).

Franklin was concerned to explain electrification rather than to formulate a systematic theory of nature, but his ideas illustrate the impact of the Newtonian ether, and the associated theories of Hales and Boerhaave, on the electrical imponderable fluid theories of the 1740s. A systematic treatment of the identification of Newton's ether with a repelling, active, material substance that was applied to explain a diversity of phenomena can be seen in Gowin Knight's *Attempt to demonstrate, that all the phaenomena in nature may be explained by two simple active principles, attraction and repulsion* (1748). Knight claimed that the activity of nature required the supposition of 'some Active Principle or Principles capable of producing and continuing Motion in the Universe', these active principles being the forces of attraction and repulsion.[35] Knight associated the forces or active principles with two different material entities, and he argued that 'attraction and repulsion cannot both, at the same time, belong to the same individual substance, being contraries', concluding that 'there are in Nature two kinds of Matter, one attracting the other repelling'. Echoing Hales's dualistic theory, Knight held that the repellent ethereal matter clustered around the particles of attracting matter, and argued that the phenomena of light and magnetism could be reduced to the motions of the repellent matter. Light was explained as the propagation of a vibrational tremor along a chain of mutually repellent particles, and magnetism (Knight's major interest) was explained as a 'circulation of the repellent fluid' between magnetic poles.[36]

Although Knight's treatise illustrates the transformation of the Newtonian concepts of force, active principles, ether, and matter in the 1740s, he was careful to emphasise that the active principles of attraction and repulsion were not inherent in material substances but were themselves the manifestation of divine activity in nature. However, the further development of the imponderable fluid theories led some natural philosophers to the enunciation of a theory of nature in which matter was endowed with inherent activity. The transformation of the Newtonian dualism between active and passive principles into a dualism of ordinary attracting matter and an active, ethereal repelling substance, and the conflation of ether–fire as an inherently active substance, led to the conflation of the dualism between active and material or passive principles that was a seminal feature of Newton's natural philosophy. Ether functioned as an inherently active substance endowed with repulsive force, and ordinary matter was considered as possessing an inherent attractive force. This theory contradicted Newton's concept of the intrinsic passivity of material entities; activity was subsumed in the inherent powers of material substances. These arguments were fully articulated in James Hutton's theory of nature in the 1790s, but although many natural philosophers did not explicitly formulate the philosophical and theological implications of this position, an early statement of this argument in Cadwallader Colden's *Principles of action in matter* (1751) illustrates the conceptual transformation associated with the interpretation of ether as an inherently active substance. Asserting that it was 'unphilosophical' to ascribe activity to divine agency, Colden claimed that motion was inherent in matter: Motion 'exists in something, which has in itself the power of moving'. All material substances, including ordinary matter, were regarded as 'acting principles', as being endowed with inherent activity. Ether was a 'species of matter', an acting principle maintaining the activity of nature.[37]

The interpretation of ether as an inherently active substance threatened the theological foundations of Newton's philosophy of nature. For Newton ether was an active principle, a manifestation of God's causal agency in nature. Newton's view of ether was maintained by Colin Maclaurin in his *Account of Sir Isaac Newton's philosophical discoveries* (1748), which echoed Newton's voluntarist theology in pointing out that if gravity were 'produced by a rare and elastic *aethereal medium*', then 'the whole efficacy of this medium must be resolved into his power and will, who is the supreme cause', for God is 'the source of all efficacy'. Maclaurin's interpretation of the theological status of ether was being called into question by the emergent view of ether as an inherently active substance endowed with repulsive force. This theory of nature was sustained by the view that the phenomena of nature could be reduced to the interaction of two material principles, attractive and repulsive, and that the diversity of phenomena could be explained in terms of a single ethereal substance: The 'terms *Fire, Electricity, electrical Aether, aetherial Spirit*' were 'synonymous'.[38] This interpretation of ether was to be fundamental to the development of the unified theory of ether in the second half of the eighteenth century.

Chemistry and the development of unified ether theories

In query 31 of the 1717 *Opticks,* Newton provided hints about his theory of chemistry. Despite his appeal to a programme of chemical explanation in terms of a quantified science of interparticulate forces (Thackray, 1970:18–42), he associated chemical phenomena with the operation of active principles, questioning the reducibility of chemistry to 'passive Laws of Motion'. The chemical connotations of ether and active principles were heightened by the strongly chemical ethereal speculations in Newton's 'Hypothesis explaining the properties of light' and his letter to Oldenburg. The revival of ether in the 1740s and the development of a dualistic natural philosophy of ordinary matter and ethereal fluids led some British chemists to invoke ether for the explanation of chemical processes, the chemical resonances of ether being strengthened by the assimilation of Boerhaave's concept of fire to the ether concept. The chemical theories that employed ether, and that were enunciated from the late 1740s on, proposed a dualism between ordinary matter and the irreducibly chemical properties of ether, with fire and phlogiston being assimilated to ether.[39] This expansion of the ether concept led to the emergence of unified ether theories in which the diversity of phenomena were reduced to the operations of an ethereal substance.

Peter Shaw's translations of Stahl's *Philosophical principles of universal chemistry* (1730) and of Boerhaave's *New method of chemistry* (1741) made an important contribution to these developments. Shaw followed Stahl in questioning the reducibility of chemistry to the mechanical philosophy, claiming, in his *Chemical lectures* (1734), that 'genuine chemistry' preferred to leave to 'other philosophers the sublimer disquisitions of primary corpuscles or atoms' and urging that chemistry should avoid such 'metaphysical speculations'.[40] In commenting in his edition of Boerhaave's treatise on Boerhaave's assertion that chemical change 'is effected by means of motion alone', Shaw questioned the reducibility of chemical phenomena to the motion of corpuscles, pointing out that the 'common laws of sensible masses . . . will not reach to those more remote, intestine motions of the component particles'. Shaw claimed that 'besides the common laws of sensible masses, the minute parts they are composed of seem subject to some others, which have as yet been but lately taken notice of, and are yet more than guessed at'. He was here referring to the 'new mechanics' that Newton had based on the power of 'attraction', a quantified science of interparticulate forces 'not reducible to any of those in the great world'. Nevertheless, Shaw questioned the applicability even of this 'sublimer mechanics' to chemistry, going on to quote almost verbatim from Newton's remarks on active principles in query 31, and arguing that active principles were the fundamental agents in nature: 'The author of nature has added to bodies certain active principles to be the sources of motion'. For Shaw the ultimate principles in nature were irreducibly chemical, to be found in the study of the chemical role of active principles rather than in the motion of corpuscles:

> [It is] by means of chemistry that Sir *Isaac Newton* has made a great part of his surprising discoveries in natural philosophy; and that curious set of queries, which we find at the end of his optics, are almost wholly chemical. Indeed chemistry, in its extent, is scarce less than the whole of natural philosophy.[41]

These arguments helped to shape the chemical doctrines advanced by William Cullen in his chemical lectures at Glasgow in the late 1740s. Cullen was concerned to pinpoint the sources of chemical change, and he followed Newton and Hales in arguing that there were 'two great principles, the attractive & repulsive,' which were 'the source of motion and change'. In emphasising the importance of the theory of elective attractions, Cullen followed Newton's own stress on the quantification of interparticulate forces, but the influence of Hales, Boerhaave, and Shaw is apparent in Cullen's stress on repulsion, on the expansive force of fire as the source of repulsion, and hence on the irreducibility of chemistry to universal forces of attraction and repulsion. In Cullen's view 'fire pervades all bodies and keeps their parts asunder', and hence 'attraction & fire were to be considered as the primary causes of motion'. He associated fire with electricity and ether, reflecting contemporary work in natural philosophy: 'Fire [is] an elastic fluid . . . [we know there is] an aether in bodies from the reflexion &c of light, from electricity. The same with fire & present everywhere'. Cullen developed the dualistic theory of ordinary matter and ether to incorporate the chemical role of ether. Lecturing in 1757–8, he argued that 'there are only two elements, one of them gravitating matter, the other a subtile aether', going on to note that according to this hypothesis, 'its [*sic*] probable that light and all other phaenomena of Fire depend upon this Subtile Aether in all Bodies'. Cullen explained the crucial chemical phenomenon of combustion by supposing 'that inflammable bodies are of such a particular texture as to recover these particles of Aether' as 'phlogiston'.[42] Cullen's introduction of Stahl's principle of inflammability, phlogiston, to denote the chemical manifestation of ether broadened the conceptual framework of the theory of ethereal substances.

These ideas were further developed in the Edinburgh lectures of Cullen's student Joseph Black. In appealing to the theory of ether, Black was concerned to explain the combustion of chemical substances, ether serving to justify the intelligibility of the phlogiston concept. In a lecture in 1768, Black declared:

> Sir Isaac Newton is of the opinion that there is in nature a certain fluid of exceeding elasticity subtility and density, that pervades all nature, the different modifications of which produce the phenomena of Electricity, magnetism and Gravity and the cohesion of the smaller parts of bodies to each other . . . I am therefore of the opinion that this is the inflammable principle. [Talbot, 1967: ch. 13, 42]

Phlogiston was thus a 'modification' of ether, its supposition justified by appeal to the Newtonian pedigree. In a lecture delivered in the 1780s, Black argued that the principle of inflammability, 'phlogiston' or 'subtle aether', was a 'subtile & active fluid', and he affirmed the dualistic theory of nature in denying that this ether or phlogiston was a 'gravitating substance'; rather, 'this matter is exempted from the laws of gravitation'.[43] Questioning the unity of matter, Black stressed the chemical connotations of ether and the disjunction between chemical principles and the laws of ordinary matter. In Black's view, 'heat may be considered in nature as the great principle of chemical movement and life', and he supposed that phlogiston was a manifestation of heat: 'Heat or light are the principles of inflammability'.[44] In Black's theory of nature chemical and thermal phenomena were closely associated, and heat, light, and phlogiston were imponderable substances, modifications of ether and distinct from ordinary matter; chemical and ethereal principles were not reducible to the passive laws of ordinary matter.

Black's lectures expanded the theory of ether to include chemical, optical, and thermal phenomena, providing hints towards the formulation of a unified ether theory. The chemical role of ether, in its 'modifications' as heat, light, and phlogiston, was emphasised in several works published in the 1770s, often reflecting Black's influence.[45] In his *Philosophical inquiry into the causes of animal heat* (1778) the Edinburgh-educated physician P. D. Leslie followed Black in arguing that 'phlogiston is fire and light, or a certain subtile elastic fluid, upon the modifications of which the phenomena of heat and light depend'. This ethereal substance 'is the chief cause and principle of activity in the universe' and is 'exempted from the common laws of gravitation'. Leslie explicitly identified phlogiston with the '*Newtonian* ether, the electrical *aura, materia subtilis,* fire and light'.[46] Similar ideas were proposed by Bryan Higgins in his *Philosophical essay concerning light* (1776). Higgins supposed that light, phlogiston, fire, and electricity were different modifications of ether: 'Fire is not considered as a homogeneal body different from light and phlogiston; and I am unwilling to admit the Electric Fluid as an element different from these'.[47]

The phlogiston concept thus played a central role in eighteenth-century British natural philosophy. However, many chemists considered phlogiston an ordinary chemical substance rather than an ethereal imponderable. British chemists who adopted this interpretation included Kirwan, Cavendish, and – for a time – Priestley, all of whom equated phlogiston with some form of 'inflammable air [hydrogen]'. Nevertheless the view of phlogiston as an ethereal active substance represents an important British chemical tradition: Phlogiston was identified with or viewed as a 'modification' of fire, light, electricity, and ether.[48] This unified ether theory stressed the unity and activity of nature; avoiding a superfluity of diverse imponderable fluids, these theorists reduced the operations of nature to a dualism of gravitative matter and ether.

The systematic *Dissertations on different subjects in natural philosophy* (1792) by Black's associate James Hutton provided a full statement of this unified ether theory, with an emphasis on its philosophical and theological implications. Hutton supposed a dualism of gravitational (attractive) matter and the 'emanation of [repelling] matter from the sun';[49] these two kinds of matter maintained the operations of nature, 'the opposite powers . . . continually balancing one another, or alternately prevailing'. If the gravitational matter were to prevail then 'gravitation would soon bring all the matter of this machine [the universe] to rest, and would lock up every body in a state of the most absolute inactivity'. The emanation of matter from the sun was thus a 'necessary cause of vital motion', for 'without the influence of the sun this world would remain an useless mass of inert matter'. This solar substance was envisaged as an active principle embracing all the imponderable fluids: 'Light, heat and electricity appear to be three different modifications of the same matter'.[50] In explicating this theory of the unified ether or solar substance, Hutton appealed to a wide variety of phenomena. He was especially concerned to explain the interrelationships among heat, light, electricity, and chemistry. The relationship between light and heat, the association of a loss of heat with the emission of light, was explained by arguing that light and heat were different 'modifications' of the repulsive solar substance. Phosphorescence was explained by the claim that light is 'arrested and detained in a certain modification' within bodies forming a 'phlogistic substance'; this matter may be emitted from its connection with a body and 'resume its former character of light'. The phlogiston theory thus implied 'the union of the matter of light and heat with some of the chemical substances of bodies' to form a 'phlogistic substance'. Combustion involved the loss of light and heat and the decomposition of phlogistic substances.[51] Hutton regarded electricity as related to light and thought heat a modification of the solar substance, and he claimed that heat and light would affect the conduction of electricity by bodies. Biological and chemical processes were also connected in Hutton's scheme, and he contended that 'plants compose phlogistic matter in growing', for there was no evidence for decay without renewal: 'There would also appear to be in the system of this globe, a reproductive power, by which the constitution of this world, necessarily decaying, is renewed'.[52] Nature was thus conceived as a system of processes and transformations, different modifications of the ethereal solar substance serving as sources for the regeneration of nature.

In Hutton's system light emanated from the sun and was contained in bodies as phlogiston, an idea probably acquired from Black and Macquer;[53] and the operations of nature were maintained by the circulation and conservation of phlogiston. Hutton's conception of nature has analogies with Newton's theory of the 1670s, in which ether was an underlying principle maintaining the activity of nature by its circulation, though Hutton's theory reflected the transformation in the Newtonian concepts of ether and active principles in the eighteenth century. Hutton rejected Newton's dichotomy between active principles and passive matter. Rejecting Newton's atomism and theory of the passivity of material entities, Hutton distinguished between the phenomenal manifestations of substances, which he termed 'body', and the underlying substratum, or 'matter'. This substratum was defined in terms of its intrinsic activity: 'Matter may thus be considered as acting powers'.[54] In Hutton's dualistic theory the ethereal solar substance functioned as an inherently active substance endowed with repulsive force, balancing the inherent attractive force of gravitative matter. On the theological level this conception of nature contrasted with Newton's stress on divine sustenance by means of active principles, for activity was subsumed in the acting powers constituting material substances. Nature was thus a self-regenerating system of active powers, its self-sufficiency maintained by the inherent activity of material substances.

Ether functioned as an active substance immanent in the fabric of nature, conserving and recruiting activity by its transformations and circulation: 'Nature is a perpetual circulatory worker'.

Hutton's emphasis on the role of phlogiston suggests that he considered chemical principles applicable to the powers that characterised the invisible realm of matter. Devoid of solidity, extension, and inertia, Huttonian matter could not be characterised by the passive laws of motion.[55] As John Playfair expressed it, in Hutton's system 'the chemist . . . is flattered more than anyone else with the hopes of discovering in what the essence of matter consists; and Nature, while she keeps the astronomer and mechanician at a great distance, seems to admit him to a more familiar converse, and to a more intimate acquaintance with her secrets'.[56] Hutton thus suggested a cosmology determined by irreducibly chemical principles.

Adam Walker's textbook *A system of familiar philosophy* (1799) provided a full exposition of the unified ether theory. Walker asserted the identity of fire, light, electricity, and phlogiston as 'modifications of one and the same principle', the ethereal repelling substance. The operations of nature were determined by a 'balance' of the two 'powers' of attraction and repulsion, which were 'opposing or antagonistic principles . . . in a state of unceasing warfare'. Electricity was the 'genuine principle of light and fire', and the emanation of the 'ethereal matter' of electricity from the sun activated the universe, for electricity was 'the soul of the material world'.[57]

The stress on the unity of natural phenomena thus led to enunciations of a dualistic world view, in which the transformations of an ethereal, active repellent substance balanced the attractive power of gravitating matter, providing a coherent scheme for the systematisation of a diversity of phenomena and the interactions between natural agents. In his *Mathematical and philosophical dictionary* (1795–6), a reliable guide to contemporary attitudes, Charles Hutton reported that 'there was such a strong affinity between the elements of fire, light and electricity, that we may not only assert their identity upon the most probable grounds, but lay it down as a position against which at present no argument of any weight has an existence'.[58]

The influence of unified ether theories

Between 1798 and 1806 there were several new developments in British natural philosophy that initiated the decline of the imponderable fluid theories. In 1798, Rumford rejected the imponderable fluid theory of heat, arguing that the theory could not explain the generation of heat by friction. The invention of the battery and the discovery of electrolysis in 1800 led to Humphry Davy's theory of electrochemistry; in a full statement of his theory in 1806, Davy explained electricity by the forces of chemical affinity, abandoning the theory of the electric fluid. Thomas Young's advocacy of an undulatory theory of light in papers written between 1799 and 1804 led him to reject the concept of light as an ethereal elastic fluid analogous to fire, as well as Newton's 'emission' theory of light as the projection of 'rays' of discrete corpuscles.[59] Although these developments illustrate the decline of imponderable fluid theories in the early nineteenth century, the conceptions of nature explicated by Rumford, Davy, and Young demonstrate the continued influence of the theory of unified ethereal substances on the development of natural philosophy.

The impact of the unified ether on the ideas of Rumford, Young, and Davy can be seen by a brief survey of their theories of nature. Rumford rejected the theory of heat as an imponderable fluid in favour of a theory in which the effects of heat were held to be the result of the interaction between the motion of the particles of ordinary matter and the vibrations of an ambient ethereal medium. Supposing a dualism of ordinary matter and ether, he asserted that the vibrations of the 'atmospheres composed of aether' surrounding the particles of ordinary matter were communicated to the surrounding ether and finally to other particles of ordinary matter.[60] This theory of the transmission of heat was reminiscent of Gowin Knight's account of the propagation of light based on a dualistic theory of matter and ether. Rumford echoed concepts characteristic of eighteenth-century ether theories in maintaining that '*motion* is an essential quality of matter'; matter was inherently active and hence 'rest is nowhere to be found in the universe'.[61]

The theory of ethereal atmospheres was also adopted by Young in his early discussions of the mode of action of ether. He supposed a universal ethereal substance that 'may possibly be the ground work of all the phenomena of nature', speculating that 'light, heat, cohesion and repulsion' may 'depend on some modification of the actions of the medium [the ether]', which was 'connected with the electric fluid'. Although he abandoned this programme of a unified natural philosophy grounded on the concept of ether, probably because he could not satisfactorily explain cohesion and repulsion through the theory of ethereal atmospheres, the theory of the unified ether shaped the development of Young's natural philosophy, and the concept of a luminiferous ether as the vehicle of light and radiant heat became the central feature of his theory of optics (Cantor, 1970).

In an early essay, Davy argued that 'the electric fluid is probably light in a condensed state . . . its chemical activity upon bodies is similar to that of light'; he claimed that 'the different species [of matter] are continually changing into each other'. Davy referred to James Hutton, and this commitment to the unity and interconversion of natural powers was characteristic of Hutton's unified ether theory. This conception of nature was of fundamental importance for Davy's formulation of his electrical theory of chemical affinity. Davy argued that the electrical and chemical powers were so interconnected that it was likely that the electrical and chemical forces were 'identical'. Although he abandoned the theory of the electric fluid, his emphasis on the unity of natural powers echoed the unified ether theory. Davy continued to maintain a dualistic natural philosophy in which an 'etherial matter' endowed with repulsive force was conceived as the '*antagonist* power to the attraction of cohesion',[62] a concept characteristic of the unified ether theory.

Davy's theory of nature exemplifies the manner in which the unified ether theory continued to shape the commitments of natural philosophers, even though the supposition of imponderable fluids – to explain the phenomena of heat, repulsion, and electricity – was increasingly being called into question. The unified ether theory emphasised the balance of forces, the unity and interconversion of natural phenomena, and the self-sufficiency of nature, contending that the activity of nature was maintained by forces of attraction and repulsion. These ideas, ultimately divorced from imponderable fluid theories, had a continued and significant influence on the development of British natural philosophy in the nineteenth century. The concepts of the balance of forces and the self-sufficiency of nature were developed by Faraday and Joule in the 1830s and 1840s into the theory of the convertibility and indestructibility of natural powers, one of the strands that, transformed, became explicated as the 'conservation of energy' by about 1850.[63] The theory of the unified ether thus had an enduring impact on the history of natural philosophy.

Notes

1 Heimann (1973); P. M. Heimann, 'Voluntarism and immanence: conceptions of nature in eighteenth-century thought', *Journal of the History of Ideas 39* (1978), 271–83.

2 R. McCormmach, 'John Michell and Henry Cavendish: weighing the stars', *British Journal for the History of Science 4* (1968), 150; R. McCormmach, 'Henry Cavendish: a study of rational empiricism in eighteenth-century natural philosophy', *Isis 60* (1969), 293–306.

3 Schofield (1970), 15, asserts a rigid dichotomy between 'mechanists' who sought 'the causation for all phenomena of nature . . . [in] the primary particles of an indifferentiable matter . . . and the forces of attraction and repulsion between them', and 'materialists' who believed that 'the causes of phenomena inhere in unique substances'. These categories are derived from a distinction between force and ether theories in Newton's natural philosophy. Cf. P. M. Heimann, 'Newtonian natural philosophy and the scientific revolution', *History of Science 11* (1973), 1–7.

4 I. Newton, *Opticks; or, a treatise on the reflections, refractions, inflections and colours of light*, 4th ed., 1730 (reprinted, London, 1952), 347–70.

5 I. Newton, 'An hypothesis explaining the properties of light', in T. Birch, *The history of the Royal Society at London*, 4 vols. (London, 1756–7), 3:247–305; reprinted in *Isaac Newton's papers and letters on natural philosophy*, ed. I. B. Cohen (Cambridge, 1958), 177–235; text in I. Newton, *The Correspondence of Isaac Newton*, ed. H. W. Turnbull, J. F. Scott, A. R. Hall, and L. Tilling, 7 vols. (Cambridge, 1959–77), 1:362–86.

6 Newton to Oldenburg, 25 Jan. 1675/6, in R. Boyle, *The Works of the Honourable Robert Boyle*, ed. T. Birch, 5 vols. (London, 1744), 1:74; reprinted in Cohen, *Papers and letters*, 254. See Newton, *Correspondence*, 1:413–14.

7 Newton to Boyle, 28 Feb. 1678/9, in Boyle, *Works*, 1:70–3; reprinted in Cohen, *Papers and letters*, 250–3; text in Newton, *Correspondence*, 2:288–95. See also I. Newton, 'De aere et aethere', in *Unpublished scientific papers of Isaac Newton*, eds. A. R. Hall and M. B. Hall (Cambridge, 1962), 214–20. On the date of this manuscript of the 1670s cf. Hall and Hall, *Unpublished papers*, 187; Westfall (1971), 373, 409–10.

8 Newton, *Opticks*, 352.

9 I. Newton, *Mathematical principles of natural philosophy*, trans. A. Motte, rev. F. Cajori (London, 1934), 546. Hereafter *Principia*. On Newton's rejection of Cartesian vortices see Whiteside (1964, 1970).

10 Newton, *Opticks*, 362. On Newton's concept of pressure see A. E. Shapiro, 'Light, pressure and rectilinear propagation: Descartes' celestial optics and Newton's hydrostatics', *Studies in History and Philosophy of Science 5* (1974), 273–6.

11 A classic statement of the interpretation of Newton's ether as a 'mechanical' medium is in Maxwell's 1878 article 'Ether', in J. C. Maxwell, *The Scientific Papers of James Clerk Maxwell*, 2 vols. (Cambridge, 1890), 1:763–75. Commentators who adopt this interpretation take different attitudes to the significance of the ether. Rosenfeld (1965) views Newton's 'mechanical' ether as his preferred position; whereas Hall and Hall (1967) view the 'mechanical' ether as unimportant in Newton's natural philosophy, as it contradicts the methodology of *Principia*. Both these accounts begin from a mistaken premise: that Newton's ether was a quasi-Cartesian 'mechanical' medium.

12 Newton, *Opticks*, 351–2. Cf. Bechler (1974).

13 *Four letters from Sir Isaac Newton to Doctor Bentley containing some arguments in proof of a Deity* (London, 1756), 25; reprinted in Cohen, *Papers and letters*, 302.

14 Newton, *Opticks*, 401.

15 Draft letter from Newton to the editor of *Memoirs of Literature* (written some time after 5 May 1712) in reply to a letter of Leibniz's, in Newton, *Correspondence*, 5:298–300.

16 Newton, *Opticks*, 401. Cf. McGuire (1968), 187–208.

17 In drafts he referred to a 'subtile Aether or Aetherial elastic spirit' (quoted in Guerlac [1967], 48); this was reflected in his allusion to a 'subtle spirit' in the *General Scholium* to the 2nd ed. of *Principia* (1713). This was qualified as an 'electric and elastic' spirit in a marginal note in Newton's own copy of *Principia* and in Motte's 1729 English translation. See Newton, *Principia*, 547. On Newton's use of the phrase 'electric and elastic' see A. R. Hall and M. B. Hall, 'Newton's electric spirit: four oddities', *Isis 50* (1959), 473–6; A. Koyré and I. B. Cohen, 'Newton's "electric and elastic spirit" ', *Isis 51* (1960), 337. In a draft reply to Leibniz (see n. 15), Newton argued that gravity could be explained 'by a power seated in a substance in wch bodies move & flote without resistance & wch has therefore no *vis inertiae* but acts by other laws than those that are mechanical'. Newton, *Correspondence*, 5:300.

18 Newton, *Opticks*, 380, 401. Cf. McGuire (1968), 164–74.

19 Newton, *Correspondence*, 1:364–6.

20 B. J. T. Dobbs, *The foundations of Newton's alchemy or 'the hunting of the Greene Lyon'* (Cambridge, 1975), 204–6. The tentative suggestion by Walker (1972) that Newton's ether is to be identified with the neo-Platonic *spiritus mundi* is mistaken. Cf. McGuire (1977), 107–9.

21 Newton, *Opticks*, 401. Cf. McGuire (1967), 85; Heimann (1973), 8–10.

22 Quoted in R. Kargon, *Atomism in England from Hariot to Newton* (Oxford, 1966), 138.

23 *Acta eruditorum* (1720), 185–8.

24 R. Greene, *The principles of the philosophy of the expansive and contractive forces; or, an inquiry into the principles of the modern philosophy: that is, into the several chief rational sciences, which are extant* (Cambridge, 1727), 1–2; H. Pemberton, *A view of Sir Isaac Newton's philosophy* (London, 1728), 377. See also B. Worster, *A compendious and methodical account of the principles of natural philosophy*, 2nd ed. (London, 1730), 28.

25 B. Martin, *Philosophia Britannica; or, a new and comprehensive system of the Newtonian philosophy*, 2 vols. (Reading, 1747), quoted in Thackray (1970), 135.

26 Newton, *Opticks*, 351, 352, 396.

27 S. Hales, *Vegetable staticks; or, an account of some statical experiments on the sap in vegetables* (London, 1727), 178.

28 [H. Boerhaave] *A new method of chemistry: including the history, theory and practice of the art: translated from the original Latin of Dr. Boerhaave's Elementa chemiae*, trans. P. Shaw, 2 vols. (London, 1741), 1:220, 236.

29 Ibid., 1:208, 223, 359, 362.

30 Ibid., 246–7.

31 J. Rowning, *A compendious system of natural philosophy* (London, 1737–43), iii.

32 Peter Collinson to Cadwallader Colden, March 1745, quoted in Cohen (1956), 435.

33 I. B. Cohen (ed.), *Benjamin Franklin's experiments* (Cambridge, Mass., 1941), 213–14.

34 Ibid., 233, 210.

35 G. Knight, *An attempt to demonstrate, that all the phaenomena in nature may be explained by two simple active principles, attraction and repulsion* (London, 1754), 4–5.

36 Ibid., 10, 66–7. Home (1977*a*), 262, considers Knight a Cartesian. This view fails to acknowledge the distinctive Newtonian framework of Knight's theory: cf. Heimann and McGuire, (1971), 296–9.

37 C. Colden, *The principles of action in matter, the gravitation of bodies and the motion of the planets explained from those principles* (London, 1751), 27, 28, 73. Cf. Schofield (1970), 130–3; Heimann and McGuire (1971), 303.

38 C. Maclaurin, *An account of Sir Isaac Newton's philosophical discoveries* (London, 1748), 381–9. See Heimann, 'Voluntarism and immanence', 275; R. Lovett, *The subtil medium prov'd* (London, 1756), n.p., preface.

39 Heimann (1973). For a survey of eighteenth-century chemical writings on this topic see Ziemacki's discussion (1974) of phlogiston and ethereal agents in eighteenth-century British chemistry. This work supplements the study of 'Newtonian' chemistry by Thackray (1970), who ignores the development of imponderable fluid theories in chemistry.

40 P. Shaw, *Chemical lectures publickly read at London* (London, 1734), 146.

41 Boerhaave, *Chemistry*, 155–7, 173.

42 A. L. Donovan, *Philosophical chemistry in the Scottish Englightenment: the doctrines of William Cullen and Joseph Black* (Edinburgh, 1975), 141–51.

43 Quoted in D. McKie, 'On some Ms. copies of Black's chemical lectures', *Annals of Science 21* (1965), 223.

44 Quoted, respectively, in Donovan, *Philosophical chemistry*, 229, and in T. Cochrane, *Notes from Doctor Black's lectures on chemistry 1767/8*, ed. D. McKie (Wilmslow, Cheshire, 1966), 83. On Black and theories of heat, see D. McKie and N. H. de V. Heathcote, *The discovery of specific and latent heats* (London, 1935); Fox (1971), 6–67; Donovan, *Philosophical chemistry*, 222–77; Talbot (1967).

45 J. R. Partington and D. McKie, 'Historical studies in the phlogiston theory: III, Light and heat in combustion', *Annals of Science 3* (1938), 338–71.

46 P. D. Leslie, *A philosophical inquiry into the causes of animal heat: with incidental observations on several physiological and chymical questions connected with the subject* (London, 1778), 104, 119, 124.

47 B. Higgins, *A philosophical essay concerning light* (London, 1776), 13.

48 Ziemacki (1974) distinguishes between theories in which phlogiston was considered to be a universal active medium and theories in which phlogiston was identified with an ordinary ponderable substance. A parallel development occurred in France in the 1760s: Rouelle, Macquer, and Venel equated phlogiston, Stahl's inflammable principle, with Boerhaave's fire, thus transforming both concepts. For Boerhaave fire was a physical instrument, the source of chemical change while itself remaining unchanged; for Stahl phlogiston was one of the chemical 'principles' that formed the basis of chemical substances. In identifying Stahl's phlogiston with Boerhaave's fire, Rouelle emphasised that fire was a chemical constituent of bodies, like phlogiston. See M. Fichman, 'French Stahlism and chemical studies of air, 1750–1770', *Ambix 18* (1971), 94–122; H. Metzger, *Newton, Stahl, Boerhaave et la doctrine chimique* (Paris, 1930), 209–45; R. Rappaport, 'Rouelle and Stahl – the phlogistic revolution in France', *Chymia 7* (1961), 73–102; Love (1974).

49 J. Hutton, *Dissertations on different subjects in natural philosophy* (Edinburgh, 1792), 246. On Hutton's natural philosophy cf. Heimann and McGuire (1971), 281–95.

50 Hutton, *Dissertations*, 263, 505.

51 Ibid., 175, 517, 519.

52 Ibid., 214, 218.

53 McKie, 'Black's chemical lectures', 215; P. J. Macquer, *Dictionnaire de chymie*, 2nd ed. 4 vols. (Paris, 1778), 3:144.

54 Hutton, *Dissertations*, 501.

55 Ibid., 257. See Heimann (1973), 19–21, on Hutton's theory of chemistry.

56 J. Playfair, 'Biographical account of James Hutton', in J. Playfair, *The works of John Playfair*, 4 vols. (Edinburgh, 1822), 4:83.

57 A. Walker, *A system of familiar philosophy*, rev. ed., 2 vols. (London, 1802), 1:6, 14, 18, and 2:1, 74.

58 C. Hutton, *A mathematical and philosophical dictionary*, 2 vols. (London, 1795–6), 1:473.

59 Fox (1971), 99–103; P. M. Heimann, 'Conversion of forces and the conservation of energy', *Centaurus 18* (1974), 152–3; Cantor (1970).

60 B. Rumford, *The complete works of Count Rumford*, 4 vols. (Boston, 1870–5), 2:172.

61 Ibid., 2:104. Goldfarb (1977) argues convincingly that Rumford's work has been wrongly interpreted as a precursor of the kinetic theory of heat, and stresses the role of the ether in Rumford's natural philosophy. However, in pointing to Boerhaave as Rumford's probable source, Goldfarb ignores the tradition of natural philosophy discussed in the present chapter. Another possible source of Rumford's ether is Lambert's *Pyrometrie* (Berlin, 1779), sections of which Rumford translated for Fourier. See Fox (1979).

62 H. Davy, *Collected works of Humphry Davy*, 9 vols. (London 1839), 2:28, 35; 4:44, 56, and 5:40.

63 Heimann, 'Conversion of forces', 147–61.

2

Ether and the science of chemistry: 1740–1790

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The Scottish cultural context

Ether poses methodological problems for the historian of eighteenth-century science. The subtle fluid appeared in a proliferating variety of guises and performed in a bewildering number of roles, so that the most effective tactic seems to be to define a fairly narrow perspective and write ether's history from that point of view. Thus it becomes possible to write isolated sectors of the subject, in case studies that examine ether's role with regard to theoretical developments within a particular science; to epistemology, methodology, and theology; or to natural philosophy in general. This technique tends to reduce a Protean subject to manageable units of analysis, and has that to recommend it. However, its logic has problematic implications in the long run, for it will tend only to produce a cumulative display of ether's profusion, doubtless with numerous roles and functions added to those already instanced. It would be perfectly possible, for example, to write of ether's association with moral theory in the eighteenth century, or even to write its political history.[1] Simply to provide a coherent summary of existing work would be a formidable enough task. To hope that all these essentially analytical perspectives, reflecting as they do the interests and skills of many diverse specialists, may one day prove susceptible of unifying synthetic interpretation is pious in the extreme.

Caught between the Scylla of analytic possibility and the Charybdis of plausible synthetic explanation, ether's history urgently requires a canvass of alternative modes of approach. One such approach that begins to avoid the current dilemma is to examine in detail the uses ether was put to, and the pressures that shaped its cognitive development, within a particular cultural context. Immediately, the historian is thereby freed to see ether not in narrow vertical slices (methodology, epistemology, theory . . .), but in relation to its position within a culture-specific, overall cognitive structure. The isolated slices now appear as organically related parts of a cultural system. Further, if the social dimensions of that system be capably laid out, then ether can be seen as responsive not merely to narrowly conceived cognitive inputs, such as limitations of experimental technique or ideas of what could pass as a legitimate theory, but also to the larger economic and ideological forces that moved and shaped the culture. This approach thus gives full and integrated play to ether's multifarious nature while connecting it with those factors generally recognized by historians as responsible for the formation of the world in which men, even scientists, perceive, think, and act.

The arena chosen for this novel pursuit of ether is the mid-eighteenth-century culture of the High Enlightenment, in particular its Scottish manifestation. Two things render this choice appropriate. The social bases of the culture have recently been explored with a degree of success; so there is a reasonably solid body of opinion from which to work.[2] Also, ether was on the rise in this period, partly within medical science and physics, partly within certain epistemological writings, but above all in chemistry, which by 1755 had become a leading sector in scientific culture in its experimental success, growth in theory, institutional development, and social patronage.[3] Ether's place in the socially and cognitively expanding science of chemistry therefore offers the most likely scene of successful investigation. Further, the direction that studies of Lavoisier and the chemical revolution in France have now taken reveal the central place of ethereal concepts in the origin and continued prosecution of Lavoisier's chemical theory.[4] This material will provide the opportunity to close with an examination of French chemistry, in order to determine whether French chemistry's use of ether can be compared with the Scottish, and seen as an extension of it.

Eighteenth-century Scotland's most committed ethereal scientist was the chemist and physiologist William Cullen. Ether featured strongly in his expositions of the theoretical bases of both disciplines, and in the case of chemistry it did so from the time he first started teaching the subject at the University of Glasgow in 1747.[5] During his time as a teacher and practitioner of chemistry at Glasgow, then at the University of Edinburgh from 1756 to 1766, Cullen continued to deploy, and significantly to develop, the concept of ether. But Cullen was not Scotland's first etherealist. George Martine, whose critical experimental investigations of current opinion regarding rates of heating and cooling were to prove important for Joseph Black, had given sympathetic mention to Newton's ether in *An examination of the Newtonian argument for the emptiness of space and of the resistance of subtile fluids*, published in 1740. So too had Colin Maclaurin, in *An account of Sir Isaac Newton's philosophical discoveries*, posthumously published in 1748.

More importantly for this analysis, another sector of intellectual culture was already proving significantly favourable to ethereal conceptions, in ways both direct and indirect. This was the investigation of human nature and cognition put forward by David Hume in *A treatise of human nature* (1739) and *An enquiry concerning human understanding* (1748), and by Adam Smith in *The principles which lead and direct philosophical enquiries, illustrated by the history of astronomy*. This last was not published until 1795, after Smith's death, but it was first composed and written in the 1750s,[6] and was arguably a development of material presented in his professorial lectures at Glasgow, where he was accustomed to discuss the 'general powers of the human mind'.[7]

In his treatment of human nature and knowledge, Hume made no major and direct use of ether in the manner of David Hartley,[8] though he did make occasional use of an active spirit hypothesis.[9] Indeed, Hume generally was by no means averse to hypotheses, a matter that appears to create a difficulty when juxtaposed with his strictures on the impossibility of knowing 'the ultimate springs and principles' of natural phenomena,[10] and with the Newtonian severity of many of his methodological prescriptions.[11] James Noxon suggests part of the solution to this awkward juxtaposition, commenting that Hume did not 'distinguish in so many words between groundless speculative hypotheses and verifiable working hypotheses. The distinction is, however, implicit in his usage'.[12]

This reconciliatory point can be extended by emphasising the psychologising elements in Hume's analysis of causation. Although this analysis reduced necessary connection, philosophically considered, to constant conjunction, Hume stressed the determining power of associative patterns of belief in producing the idea of necessity,[13] and elsewhere insisted on the status of psychological necessity attained by such beliefs. Without the regular patterns of causal belief induced by association, perceptual and imaginative coherence and stability would be lost, and life would become, so to speak, phenomenally unliveable.[14] Coupled with Hume's own occasional use of an active spirit hypothesis and Noxon's argument, these psychologising elements warrant the conclusion that Hume's methodology and epistemology by no means ruled out ethereal speculation.

This is still some distance from the claim that Hume might actually have encouraged such speculation. However, there is evidence suggesting just such encouragement. Hume's critical opposition to the participation of religious and theological tenets in the rational discourse of moral and natural philosophy is well known. With regard to natural philosophy, aspects of this opposition were formulated some time before the classic assault on divine teleology in nature contained in the *Dialogues concerning natural religion.* In particular, he had attacked the argument of Cartesian occasionalism for the supreme deity 'as the immediate cause of every alteration in matter'.[15] For Hume this was an exercise in tautology. He had shown that we have no philosophically intelligible idea of causal power; thus the referral of such power to the deity was a further retreat into unintelligibility.[16] Nor did Hume confine his attack to Cartesian occasionalism. In *An enquiry,* the Newtonian variant received similar treatment, though Newton himself was exempted for, from this essay's point of view, the most significant of reasons. Newton, not intending 'to rob second causes of all force or energy', on the contrary 'had recourse to an etherial active fluid to explain his universal attraction; though he was so cautious and modest to allow, that it was a mere hypothesis, not to be insisted on, without more experiments'.[17] Ethereal speculation was seen by Hume as legitimate, a secular and therefore a preferable alternative to any reliance on a realm of divine causation in nature.

Hume's philosophical analysis of natural science was continued by his intellectual colleague and friend Adam Smith. In the spirit of 'the true old Humean philosophy',[18] Smith developed less an epistemology of science than a psychology of theory invention. He located the motivations of the scientific enquirer in two human passions, surprise and wonder, the former produced by an unexpected occurrence, the latter either by a singular novel object or by a succession of familiar objects in unfamiliar sequence.[19] These passions were functions of a more fundamental psychological mechanism, the association of ideas, and occurred when the expectations created by association about the regular behaviour of the external world were frustrated.[20] The way in which the imagination then grappled with these frustrations constituted the central concern of philosophical enquiry, philosophy being defined as 'the science of the connecting principles of nature . . . it represents the invisible chains which bind together all these disjointed appearances'.[21] Faced with these intervals in its expectations, the imagination literally pictures something to unite the disjointed appearances, thus enabling the passage of thought to resume a 'smooth, natural and easy' course.[22] The supposition of this linking chain of intermediate and imperceptible events succeeding each other 'in a train similar to that in which the imagination is accustomed to move'[23] is the only recourse open to the imagination in such circumstances. Smith offered here a psychologising account of causal inference, revealing both its analogical strategy and its necessary use of imperceptibles. The main example he used to illustrate the process was ethereal,[24] and he clearly regarded such speculative hypotheses as a naturally determined, integral, and central part of scientific enquiry. He was clear, too, in his denial that the imagination's 'invisible chains' had any native ontological status; they were associative chains, the product of mind, a point emphasised with direct reference to the Newtonian system of universal gravitation.[25]

Hume's analysis of causation and induction had tended to move science into a world of custom and belief, properly controlled by accurate experience and reflection. The net effect of Smith's work was to confirm this move, and extend it, as overtly as possible, into the province of passion and imagination. As regards ether, their treatment allows the proposition that classical empiricism not only need not have frowned upon ether, but indeed could generate powerful arguments in its favour.

The salience of this proposition lies not only in the interest and force of the arguments themselves, and hence in the likelihood of their influence. The arguments were part of a general cognitive field, a large philosophical endeavour which at that time was assuming considerable cultural and educational importance. One significant feature of this cognitive field's structure concerned the relation of epistemology and psychology, the science of human nature, to natural science. Hume had stated this programmatically in the introduction to *A treatise,* claiming that '*Mathematics, Natural Philosophy* and *Natural Religion,* are in some measure dependent upon the science of MAN; since they lie under the cognizance of men, and are judged of by their powers and faculties'.[26] The relation of the science of man to natural science was therefore one of priority. Natural science was the client, awaiting the benefits and strictures delivered by its patron. This structural relation gained a general acceptance in Scottish culture, evidenced not only in the work of individuals such as Hume or Reid, but also in its embodiment in university curricula.[27]

From its basic engagement with questions of human nature and cognition, the philosophy of Hume and Smith moved to moral theory, politics, and economics.[28] There are of course very significant differences between the conclusions that each of them reached, but certain crucial aspects of their work possessed a unifying similarity. Moral theory, for example, was approached from the point of view of psychological naturalism and of social determinism. Moral judgement and action originated in human sentiment and tended to conform to shared, communal norms. Economic theory, developed particularly by Smith, focused upon and attempted to reduce to systematic understanding those forces, such as division of labour, responsible for economic expansion and the creation of wealth.

Hume's and Smith's understanding of these topics cannot easily be separated from their earlier investigations. Hume had originally intended his science of man to provide foundations for what followed. Smith, though less overt in his intentions, is now coming to be understood as one whose philosophy of cognition and morals bears strongly upon his better-known work in economic theory.[29] Setting aside the issue of how far they managed to fulfil intentions to construct methodologically and substantively coherent intellectual systems, this is simply to say that there is adequate warrant for treating their work not as sequences of separate and distinct investigations, but as unified enterprises whose parts potentially possess manifold connective relations. Apparently restricted, technical discussions of the psychological origin and epistemological standing of scientific knowledge cannot with safety be isolated from systems of thought whose foundations they supported.

Broadly speaking, Hume and Smith were tackling a series of issues raised in acute form by the commercial growth of their nation, and the impact of that growth upon politics, social development, and human conduct – the problems of a modernity long sought by the Scots and now being achieved, not without anxiety about the implications of the achievement. Indeed, the relevance of their work was considerable, and this in turn depended upon perception of their modes of analysis and substantive doctrines as relevant to the ideological needs of the rising generation of Scotland's landed and professional elite.[30] Elite interest and participation in the philosophical culture provided by Hume and Smith can be persuasively documented through the elite's membership in and activities within societies such as the Philosophical and Select Societies of Edinburgh,[31] groups whose programmes and concerns directly reflected some of the philosophers' central preoccupations,[32] and whose avowed central aim was to improve Scottish life by stimulating progress in knowledge, agriculture, and manufacture.[33]

The substantial social relations of Scottish philosophy can, then, be adequately demonstrated. It is possible now to begin to inquire how this cultural complex affected ether. One aspect of this is already visible, for Hume's antioccasionalist support of ether may be taken directly as an expression of the modernising secularisation of culture whose main spokesman he was, and for which he incurred the considerable hostility of some elements in the Church of Scotland.[34] The question now to be posed is whether ether can be seen as having continued to respond to the shift towards secularisation, and also to those other features of philosophical culture so far instanced: the cognitive priority of epistemology, moral determinism, and economic advance.

As earlier suggested, the rising chemical science of William Cullen is the best site on which to examine expectation of ether's sensitivity to the concerns outlined. Expectation is heightened immediately by comprehension of Cullen's involvement with the culture of his day. As a university teacher he

played an important role in the establishment and expansion of modern scientific education so earnestly desired by the Scots.[35] He was also a zealous improver, undertaking work in the technology of agriculture and manufacture. His playing the improvement card was important in the advancement of his career, because it gained for him the patronage of Lord Kames and the Duke of Argyle.[36] It established him ideologically as a patriotic citizen actively concerned with the promotion of his community's material prosperity. Cullen was also a prominent member of the Philosophical and Select Societies, contributing papers on chemical theory and on the steps to be taken to improve the teaching and practice of his science.[37] His adopted roles as reforming educator and civically minded scientist show therefore the considerable strength of his involvement with contemporary culture, through the fostering of modernity.

There are also strong circumstantial indications that certain of his intellectual loyalties were to Hume and Smith. He was a colleague of Smith's at Glasgow. This of course need not indicate intellectual loyalty; indeed, it may cynically provoke the opposite assumption. However, their joint sympathy for the mind and person of David Hume was revealed when Smith moved from the chair of logic to that of moral philosophy. Hume was a candidate for the vacated chair, and both Smith and Cullen wanted him as a colleague at Glasgow.[38] Although his candidacy failed, defeated by the church, Hume expressed copious thanks to Cullen for his support and friendship.[39] This occasion of Hume's attempt to enter academia lends credence to the view that Cullen should be seen as philosophically allied to Hume and Smith, particularly when one considers that Cullen's commitment was maintained in the face of by no means negligible clerical hostility.

That commitment was clearly expressed in Cullen's efforts to redesign the philosophical basis of chemical science. He accepted first of all the priority of epistemological analysis. He told his students:

> Logic is a very necessary part of introductory learning. By Logic I mean the analysis of the human mind, such as may be found in Mr. Locke's excellent treatise of the understanding. This is not only necessary in chemistry, but also in every other science where there is danger of error. I cannot but lament that students of medicine in the university are not obliged to go thro certain preparatory branches of learning.[40]

Accepting the cognitive priority of 'Logic', what precise form should it take? Locke was adduced as the *type* of thing Cullen recommended, but the exact form revealed a fundamentally Humean connection. 'In recommending this Study of Logic, we would, if we could venture, recommend it in a particular form. Not an obstinate disbelief in every *thing* and every *fact*, but that kind of Scepticism which the poet calls "The slow consenting Academic Doubt" '.[41] Cullen surely had his friend, the arch-sceptic of the age, in mind. Further discrimination is necessary here, however. Cullen was recalling Hume not at the end of book 1 of *A treatise*, teetering rhetorically on the brink of the abyss,[42] but in the essay 'Of the academical or sceptical philosophy', which concludes *An enquiry*. There academic scepticism is supported as a moderating corrective against Cartesian scepticism, held to be '*antecedent* to all study and philosophy',[43] and against thoroughgoing Pyrrhonism, which teaches men 'the absolute fallaciousness of their mental faculties, or their unfitness to reach any fixed determination in all those curious subjects of speculation, about which they are commonly employed.'[44] Cullen used the mitigated scepticism advocated by Hume to warn against acceptance of the 'concurrent testimony of a great number of authors . . . all facts which are said to be universal, are also to be suspected. General principles . . . [are] always to be received with diffidence'.[45] It was also used to point to our liability 'to mistakes in assigning causes for Phenomena'.[46] Cullen's sceptical mode of empirical epistemology exhibited congruence with Hume's. Now Hume's sceptical empiricism, in its methodological expression of temperate inductivism, has been seen to have coexisted with a psychologising stress on theory and hypotheses, a position developed by Smith. Cullen's congruence followed. The general principles mentioned by Cullen, though to be received with diffidence, were also 'certainly very necessary'.[47] Cullen's general attitude to speculative theory was positive. In his history of chemistry he emphasised the science's appeal to the liberal and speculative mind,[48] and later said, with reference to fire:

> You must in this and other subjects indulge me in giving much Theory. For tho' no body would recommend a wantonness of theory less than myself; yet I must be an advocate for its utility under proper restriction. It is a most powerful means of exciting us to experiments, and consequently the knowledge of facts.[49]

Theorising was empirically and heuristically justified, existing in subtle balance with its sceptical control. The stress on psychological satisfaction seen in Cullen's assertion that chemistry could gratify the liberal and speculative mind was also used in his extended discussion of causation in chemistry: 'But when several phenomena are referred to one common cause, we are satisfied'.[50] This recalls Smith's judgement of the satisfying effect brought about by the unifying power of a hypothesis.[51] Two further Smithian points emerge. First, with reference to Cullen's willingness to reason analogically in matters of theory, he can be seen adverting to the 'atmosphere of excited electricity which determines bodies once got within its sphere of attraction' when introducing his theory of chemical attraction by ether.[52] Second, although spending much time on this and other ether-based speculations, he insisted, like Smith, on their conjectural rather than ontological status.[53] Altogether then, Cullen's philosophical chemistry can be described as conforming with some precision to the work of Hume and Smith. The conformity may be seen in the general feature of epistemology's cognitive priority. It is seen, too, in Hume's, Smith's, and Cullen's substantive descriptions of scepticism's relationship to theory, the psychological aspect of speculation, and speculation's analogical derivation and conjectural status.

A plausible account of the intellectual coherence of Hume, Smith, and Cullen has now been established, and can lead into a demonstration of ether's relation to those expressions of modernity, secularization, political economy, and moral theory. It might be expected that the analytical task of showing the chemical ether's relation to cultural modernity is far more difficult and intricate than the effort of relating its supposedly closer cognitive connections of epistemology and method. This is not the case. The relationship to modernity is relatively immediate and easy to see. It is very directly illustrated in the case of secularization. Cullen was a secular as well as a sceptical and speculative chemist. In this he is to be contrasted, along with Hume, with the rest of his own and the preceding generation of Scottish philosophers and scientists. Thinkers such as Robert Wallace, Francis Hutcheson, Alexander Monro, Andrew Plummer, and Colin Maclaurin, all of them professors of science or philosophy at Glasgow or Edinburgh, embraced forms of reasoning that utilised First and Final Causes. Cullen explicitly rejected such reasoning. He was not a chemical theist, but that of course was natural enough, in that chemistry, constantly concerned with the *artificial* manipulation of bodies, allowed little opportunity for natural theological exposition in the manner of astronomy upon the *naturally* existing structure of the heavens, or of anatomy and optics upon the structure of the eye.[54] He had adequate opportunity, however, to introduce First Causes and the activity of God, as his predecessor Plummer had done with regard to chemical attraction.[55] But Cullen was no chemical occasionalist, and explicitly and curtly forbade such thinking in chemistry. 'Some say this attraction is the immediate act of the Creator. But this way of reasoning would soon put a stop to philosophical enquiries'.[56] In place of God as effective causal agent, Cullen put ether:

> Throughout all nature there seems to be an elastic repellent fluid, which is the cause of the phenomena we observe in nature; more particularly, of the various states of aggregation in different bodies . . . The attractive and repellant powers are constantly acting in op-

> position to each other, and yet perhaps depend on the very same Aether acting by different circumstances.[57]

Ether now stood where once God stood in the structure of causation, as the immediate source of all active power. The pattern of Cullen's argument again remarkably evokes Hume, in the latter's invocation of Newton's ether in his sally against the occasionalists. Thus ether was used to develop its secularising potential, in chemistry as in epistemology, and the expression is perfectly direct.

Its connection from Cullen's chemistry to the economic basis of the culture and the perception of that base in political economy is less direct, but still strikingly close. Cullen did not construct arguments to show that ether promoted good theory that could then be applied to technological improvement. The relationship here is more subtle and more interesting and has to do with Cullen's conception of chemistry as 'philosophical' and with the precise socioeconomic status of the philosophical chemist. 'Philosophical chemistry' has to be defined very closely in this context, according to the exact construction placed upon it by Cullen. It did not mean epistemological discussion, nor did it necessarily mean systematisation. He described it as 'knowledge of those facts which must lead us to the knowledge of Causes, or the [philo]sophical part of Science'.[58] In other words philosophical chemistry was a science that gave causal explanations. The definition was comparable to Smith's description of philosophy as the 'science of the connecting principles of nature . . . representing the invisible chains which bind together all these disjointed appearances'.[59] Given that Cullen came to locate all chemical causality in ether, his ability to expound an ethereal chemistry was quite central to the image of philosophical chemistry he wished to purvey. That image was not only conceived in cognitive terms, however. It had important socioeconomic dimensions. As has been seen, Cullen believed in the 'liberal' appeal of chemistry – indeed, equated liberality with speculation: 'Or if more liberal still he aims at speculation . . .'[60] Chemistry as a liberal study was here contrasted with the traditional image of the 'chymists'; in Adam Smith's evocative phrase, 'those only who live about the furnace'.[61] Many years later, Cullen's achievement as a chemist was appraised by a successor in the Glasgow lectureship both as establishing philosophical chemistry and as 'taking chemistry out of the hands of the artists, the metallurgists and pharmacists, and exhibiting it as a liberal science, fit for the study of gentlemen'.[62] The liberal science, then, contrasted with chemistry as 'art', as practical technique and trade. The liberality was attained by rendering the science philosophical, an intellectual subject appropriate for attention from members of a leisured, gentlemanly elite who were not going to prosecute the practical side of the subject vocationally. The difference was essentially one of the labour process involved. In philosophical chemistry the labour was intellectual, meant to produce knowledge; in 'chymistry' it was technical and practical, meant to produce material goods. The different labour processes were attached, of course, to widely separate social categories. Yet Cullen, it has to be remembered, was an improver, and by no means wished for a separation of knowledge and practice. The image he sought was one that preserved the usefulness of knowledge while acknowledging the gulf between labour processes and between social categories. The terms of his perception here take us straight to the heartland of commercial expansion as it was then becoming to be understood in terms of the division of labour:

> It is the merchant that must inform us what arts there is a demand for and it is the merchant who must inform us of the marketable quality of manufactures . . . the merchant of more liberal education & extensive views must excite and direct the slow toiling industry of the artificer.[63]

It was the colleague of Adam Smith who spoke. The philosophical chemist concerned to improve technology did not set up his process and proceed to manufacture. He waited to be informed by the educated merchant about materially profitable objects of improvement, and he left to the merchant the stimulation and direction of the practical labourer. The labour process as it affected chemistry is divided in three parts. The labourer's task is directly productive, the merchant's directive and judgemental, and the philosopher's intellectual, to lend the aid of his special knowledge. In sociological terms, the division of labour adduced by Cullen mapped a social hierarchy with the philosophical improver now introduced at the top. Ether's relation to the economic base and to current analytic perceptions of it is now apparent. Because it was the substantive theoretical foundation of chemistry, and hence central to the science's new philosophical image, it was amalgamated, via the process of the division of labour, with the new economic role and social status of the philosophical chemist.

The final area of expectation, that of moral understanding, fails of any illustration in Cullen's chemistry, but is amply fulfilled in Cullen's medicine. This takes the argument beyond the strict bounds of this chapter while pursuing the trail of Cullen's thought. Fortunately, brief argument only is needed, as ether's role is once again obvious and direct. Hume's and Smith's description of moral conduct as originating in natural feeling rather than rational assessment, and their emphasis on its social function, could quite justifiably lead to their arguments' being seen as expressions of determinism, and this was in part the cause of the deeply disturbed reactions of some contemporaries, particularly those of the first generation of commonsense philosophers: Reid, Gregory, and Beattie.[64] Common sense was equally disturbed by another contemporary deterministic account of human nature, David Hartley's materialistic analysis, which relied upon the association of ideas and the nervous ether.[65] Cullen's theoretical medicine, like his chemistry, was dominated by ether, which underlay his concept of life and of disease, so it is hardly surprising to find commonsense opposition to Cullen in this sphere.[66] Although the terms of commonsense opposition to Hume, Smith, and Cullen had methodological expression, the radical concern was very much the preservation of active morality;[67] so in the field of morals the ether's materialistic associations raised implications of determinism for those contemporary moralists who sought to preserve a concept of morality based on active will.

Ether now stands fully displayed in the totality of its cognitive and cultural relations. Its modalities were those essential features of mid-eighteenth-century Scottish philosophical modernity, secularisation and determinism. Its mediation was the intensification of the division of labour, as that process created the new role of philosophical chemist. The analysis can fittingly end with the thought that Cullen himself might well have approved its spirit. With a sophistication regrettably rare among later chemical historians he commented in his history of chemistry on the subject's connection with the 'political and religious state of nations'.[68]

Ether theories of the Scottish chemists

Cullen's chemistry was of course far more than the impression embedded upon it by its cultural matrix. The matrix undoubtedly stimulated the appearance and shaped the acceptance and use of the science's central theory, but the theory also had to function as a theory. To achieve a complete portrait, it is necessary to turn now from ether's external relations and examine its domestic history.

The sources initially drawn upon by Cullen for his chemical ether appear to have been obvious ones in Newton's writings and in Bryan Robinson's accounts of Newton's ether. These, said Cullen, formed the 'most plausible scheme of chemical philosophy and will at least check the false theories of the corpuscularians'.[69] Robinson's speculations, and his aims, would seem to have been important for Cullen. In much of Robinson's work, the intention was to define ethereal activity in ways that made it more amenable to quantitative analysis, by reducing its species of action to more or less simple formulae, thus: 'If R. denote the Rarefaction of a Body by Heat, H the degree of Heat in the Body, and C the Strength of the Cohesion of its Parts; then, setting aside all external Compression, R will be as H/C'.[70] Such formulations might be dismissed as vacuous, a mere playing with letters that offered little real hope of assigning genuine quantitative parameters under experimental conditions. Yet the consistency of Robinson's attempt cannot be gainsaid, nor can the influence of its general desire for a quantified ethereal science. Indeed, the latter, it will be suggested, is of special importance in reaching an appreciation of Cullen's chemistry.

Some details of Robinson's notions concerning the interaction of heat and ordinary matter also deserve mention, bearing as they do a strong resemblance to the early stages of Cullen's thoughts on the same subject. For Robinson, heat was a vibratory motion of particles of ordinary matter, caused by vibrations of ether within ordinary bodies. After relating temperature to condensation of ether in the pulses of these vibrations, and describing how rarefaction of ordinary matter begins as its particles retreat from more to less dense pulsations, Robinson went on to reveal how this process terminated in fluidity:

> If the degree of Heat in a solid Body, to which the Expansive Force of the *Aether* between the Parts of Body is Proportional, be equal to the Force wherewith the Parts of the Body cohere; that Body, setting aside external Compression, will become fluid, and its Parts, by yielding to a Force impressed, be rendered capable of moving easily amongst themselves.[71]

An equilibrium of ether's elastic, expansive force and the cohesive force binding particles of ordinary matter causes fluidity. By the same token, once the degree of heat exceeds the cohesive force, a body's particles will recede from one another, attaining an aeriform state.[72]

Robinson held that ether's power was nonmechanical, was the power of '*Spirit*', and that ordinary matter was inert.[73] Accordingly, he could not treat his force of cohesion as a property of ordinary matter. Dismissing cohesion as an effect of ether's gravitational action, he maintained instead that cohesion was an effect of light united with ordinary particles. This union caused increased density in the immediately neighbouring ether. No reasons for this were specified, but the effect of the increased ether density 'when the particles touch, [is to] press them on the sides opposite to the place of contact, and by that pressure make the particles to cohere with force'.[74]

As will be seen, Cullen by no means produced a straightforward rehearsal of Robinson's ideas when he came to develop his own theories of ether–matter interaction. However, once alerted by Cullen's recommendation of Robinson's works, it is reasonable to assume that features found there, particularly the impulse to quantification, the account of the states of matter, and the language of ether density, did inform Cullen's theoretical chemistry.

Out of these sources, Cullen developed two major theories – of chemical reactivity and the states of matter – which were applied to a variety of chemical problems. He also used ether for his theoretical understanding of fire, a topic to which he devoted much space. Underpinning and prompting these theoretical enquiries was a programme of experimentation.

A point requiring initial emphasis is that Cullen's thoughts on such matters underwent considerable development, as might be expected, between the late 1740s and early 1760s. Overall, this development was one that enhanced the role of ether in his chemistry. In the late 1740s, he explained chemical attraction by the relative balance of two sets of forces, the attraction of cohesion between particles of ordinary matter, and the repelling forces of the particulate ether. Given that different bodies contain different densities of ether:

> If the density of the one is not so much greater than that of the other as to overcome the attraction of its parts, the aether in each upon their approach will repel each other. If the density is greater, they will be attracted and join each other.[75]

As Robinson might have expressed it: Taking $A1$ and $R1$ to denote the attractive cohesion of the first body and the repelling ether contained in it, and $A2$ and $R2$ for the same in the second body, then attraction will occur either when $R1 > A2$, or when $R2 > A1$.

This same conception of the relative balance of attractive and repelling forces dependent on the relative density ratios of ordinary and ether particles was used in the account of matter's three states. Bodies whose cohesive attractions were greater than the repelling forces of contained ether were solid. When the two sets of forces were equal, bodies were fluid; they became elastic when the ether's repulsion was greater than the body's cohesive attraction.[76] The similarity of this scheme to Robinson's is obvious; but equally notable was Cullen's choice not to follow up Robinson's opaque speculations on the relation of light particles, ether density, and cohesion. Cohesion was treated as something distinct from, and acting in opposition to, ethereal repulsion.

At this early stage of ethereal speculation, Cullen faced one very considerable theoretical puzzle, and that was to account for the selective or preferential nature of chemical attraction. It was going to depend, obviously enough, on the relativities of ether's combination with chemically differing bodies,[77] but he was not able initially to offer a theoretical explanation of this. His own concept of philosophical chemistry as causal explanation coupled with his definition of the objects of chemical study as the particular qualities of bodies made the subject of election particularly pressing, and so far the general theory of reactivity was unable to cope with this most obvious feature of chemical particularity.

Cullen made progress with this puzzle by the early 1760s, if not before. An important stage in the sequence was a series of experiments he undertook in the first half of the 1750s, about which he read reports to the Glasgow Literary Society under the title 'On the generation of heat and cold by mixture'.[78] The experiments showed the opposite thermal effects of different chemical reactions. The crucial example was Glauber's salt, which in its deliquescent state with water generated heat, but in its crystalline state with water generated cold. As Cullen remarked, the chemical materials in each case were the same: the water and the acid and alkali composing the neutral salt; yet the thermal effect was opposite. He thought this could be explained by the different states of aggregation of the two forms of the salt, and the consequent different types of reaction they entered into with water: 'When a deliquescent salt is added to water, a part of this is united with it by way of mixture [i.e., combination], but when a crystalline salt is added to the same, it is united with it by solution only'.[79] The general law he formulated from his experimentation, despite the awkward counter-example of acids with volatile alkali, was that 'every mixture generates heat, and that every solution generates cold'.[80]

Cullen's explanation of this notable general phenomenon, to be found in his lectures, was in terms that related ether to state of aggregation. In mixture, condensation took place, releasing ether (identified with the matter of fire) and raising temperature. In solution, rarefaction occurred, absorbing ether and lowering temperature.[81] From this experimentation, then, Cullen was coming to see thermal effect as an empirical key to the discrimination of ether's particular union with bodies, and in a way that made conversions of state acutely important.

His biographer informs us that he went on to compile tables of these thermal effects; so the experimental prosecution continued.[82] So too did the theoretical development. The shift his theory now underwent was a major one, of ontological proportions. Instead of dealing in two causal parameters, the attractions of ordinary matter and the repulsions of ether, he located all activity in ether, leaving ordinary matter inert. The change is vividly seen in the theory of states of matter, now conceived by way of the relative density of ether internal and external to a body. It was solid when the external ether was greater than the internal, fluid when external and internal were equal, elastic when the internal was greater than the external.[83] The theory of attraction naturally underwent a similar shift. Employing the analogy of contemporary electrical theory, Cullen imagined that

> every body is surrounded by its own proper atmosphere of this fluid, which grows more dense as it recedes from the surface. This is analogous to the atmosphere of excited electricity which determines bodies once got within the sphere of its attraction to the surface of the electric body. It is to be observed, that bodies thus in contact with the excited body, remain, some longer, some a shorter time in contact with that body, until they have got an atmosphere of their own: then they are repelled till meeting with some other matter, they discharge their atmosphere, and are attracted and repelled as before.[84]

Attraction was now explained by the density gradient of an external ether atmosphere rather than by the relative densities of internal ether and ordinary matter. Cullen immediately applied the further detail of the electrical analogy to an additional elucidation of his distinction between mixture and solution. In mixture, bodies brought into contact have one common atmosphere, whereas in solution solute and solvent retain their own atmospheres and can thereby act separately upon other bodies.[85] How is it, though, that ether atmospheres determine bodies to a position where they have a common atmosphere and form a new chemical body? The most likely effect of the approach of two bodies each surrounded by ether is surely a repulsion, not an attraction. Cullen asked his audience to grant

> one postulatum, to viz [*sic*] that inert matter, in a certain contiguity of its parts, has a power to diminish the repelling power of the countervening aether betwixt its particles. This admitted, the attractive power may be the effect of repulsion, when two bodies are in such a close contiguity as to diminish the power of the intervening ether betwixt its particles.[86]

Ether between particles was perhaps being imagined as squeezed out or pushed aside by their contiguous approach. If not, if Cullen was thinking of some other power of inert matter, then the contradiction in terms showed the new ontology failing to sustain the theoretical exposition.

Moreover, the crucial issue of election remained. Cullen evidently believed that he had made some progress here, though his treatment was scattered and brief. When talking of the operations of chemistry, such as decomposition and combination, he asserted that combination depends on attraction, and attraction upon fluidity.[87] Shortly after, he claimed that 'fluidity is the only means of giving that contiguity which is necessary for the Attraction of Cohesion', but he then immediately canvassed electrical (i.e., ethereal) attraction as an *alternative* cause to fluidity.[88] Finally, having settled for the ether atmosphere variant just described, he nonetheless went on to add that 'the *elective* depends upon Fluidity'.[89] Clearly there was a pronounced degree of confusion as the crucial topic was approached. The most consistent gloss to be given Cullen's thought here would accept his insistence that contiguity was essential for a combination to take place, with the new particulate configuration possessing a single atmosphere. Fluidity might then be seen as enabling contiguity, because fluid particles, in the equally balanced distribution of their internal and external ether, were more easily determinable into contiguity by an approaching ether atmosphere.

Cullen himself did not face these acute problems of ether interface and balance; so, strictly from the evidence, the impression of confusion over election must stand. The new chemical ontology of ether, with its Smithian promise of unity and simplicity, broke down precisely where it needed to succeed. A final point should be made, however, which explains Cullen's desire to link fluidity and election. This desire related to the experimental side of his programme. If fluidity could have been established as the cause of election, then a potential route to a thoroughly quantified chemical science of elective attraction was opened up, by temperature measurement of the thermal effects of chemical reactions. Cullen's goal was therefore a large and ambitious one, and his means to it decidedly innovative. His degree of success in its pursuit is ultimately to be evaluated against the stature of his enterprise and the originality of the theoretical and experimental programme.

Cullen's reformulation of chemical theory in ethereal terms had a profound impact upon the direction and content of chemical science in the decades that followed. The work of Joseph Black, William Irvine, and Adair Crawford, to name only the better known of the Scottish chemical succession, was predominantly taken up with the question of heat in relation to the states of matter and change of state. However, the relationship of this later work to Cullen's cannot be assessed straightforwardly as a direct extension of Cullenian chemistry. Both Black and Crawford entered reservations about the ethereal concept of heat, and Irvine made some notable modifications to Black's doctrines of latent heat and heat capacity. Clearly then, there are problems in seeing Scottish chemistry simply as an extended working through of Cullen's basic ideas on ether–matter interaction.

Indeed, is there any point at all in maintaining Cullen's significance when faced with what seems to be a denial of his most fundamental concept by his most illustrious pupil, Joseph Black? Some historians, accepting Black's published views on the 'materialist' (i.e., ethereal) theory of heat, have wished to see his work as independent of any theoretical commitment on the nature of heat.[90] Others, however, wish to claim that Black was indeed a materialist, adhering to a notion of heat as subtle, self-repelling matter capable of entering into combination with matter by attraction, in a 'chemical' fashion.[91] This dilemma is capable of resolution. The answer to the question of Black's views on the nature of heat depends upon the timing of his utterances and the precise context of their composition. Once this is realised, it is possible to reassert the strong sense in which Black was Cullen's pupil.

The evidence for Black's theoretical neutrality concerning heat comes from the very end of his career, in John Robison's edition of Black's chemical lectures, where Black is made to say that the chemical theory 'will please the imagination, but does not advance knowledge. I therefore avoid such speculations . . .'[92] The avoidance, however, may be taken to be Robison's rather than Black's, for Robison had an avowed detestation of material fluid theories, and granted himself the most substantial editorial licence.[93] In fact, even in Robison's edition of the lectures, Black did not 'avoid such speculations', devoting space to a discussion of his pupil William Cleghorn's theory of heat,[94] a theory that, as Arthur Donovan has noticed, bore a strong resemblance to Cullen's first theory of the states of matter.[95] It is also possible to find Black considering heat as subtle matter in earlier sets of notes taken by students.[96] But the strongest evidence for seeing Black as a Cullenian etherealist comes not from any of his lectures, but from his notebooks, in the record of observations and queries that he followed in his formulation of the principle of latent heat. Some of these observations bore immediately upon Cullen's experiments on thermal effect in chemical reactions, particularly those where absorption and release of heat appeared as a consequence of change of state.[97] Others noted the necessity of heat for elasticity, and beyond that indicated an implicitly chemical conception of heat: 'Nitrous ether boils *in vacuo*, and grows vastly cold. Is not the cold produced merely by the evaporation of the elastic parts; or does it emit air, which requires heat for its elastic appearance?'[98] Elsewhere in his notebooks, Black argued that

> heat may be considered in nature as the great principle of chemical movement and life . . . we must consider it not as an accident in bodies, but as a separate and specific existence, not less so than light or electric matter; and though agreeing with these in some of its effects, in its nature possibly different from either.[99]

Although these notes contain no unambiguous formulation of heat as subtle matter, Black, like Cullen, considered heat as the cause of elasticity, as the fundamental active agent in chemical phenomena, and as comparable in some of its aspects to the matter of electricity. These features of Black's early work on heat surely indicate the large extent of his indebtedness to Cullen's ethereal chemistry at the moment of his most profound insight into the nature of heat's interaction with matter. Neither his later methodological caution in front of his students, at a period when commonsense philosophy's anti-ether and antihypothetical sentiments were gaining ground, nor Robison's editorial bias ought therefore to be allowed to obscure the close intellectual relationship of Cullen and Black before 1757.

Cullen, it should be emphasised, not only provided Black with interesting data and a general theoretical framework. His work provided the precise point of entry and exact form of problem that issued in Black's discovery of latency. Black's earliest notebook queries, before 1752, were on 'the nature of cooling mixtures, and the cold produced by liquefaction'.[100] The first entries quoted by Robison were on the reverse phenomenon, the heat released on state conversion from fluid to solid.[101] Black was concerned in the first instance not with the broad question of change of state, but with the narrower topic of fluidity, a point confirmed in Black's own reminiscences;[102] and fluidity, it may be recalled, lay at the obscure centre of Cullen's beliefs about elective attraction. Black may then have been initially engaged with the Cullenian problem of reactivity, but certainly not with the formulation of a general theory of change of state.

However that may have been in the early and mid-1750s, the development of Black's work on heat, and of the work of his pupils and successors, led Scottish chemistry away from Cullen's problem. He initiated a chemistry of ether–matter interaction that was of the highest importance for the origin of Black's work, but its extension involved the loss of at least one of his most cherished goals, the quantification of elective attraction. Black, Irvine, and Crawford became far more interested in the definition of and solution of problems to do with change of state, heat capacity, and animal heat. After Black's well-known discovery of latency and capacity, the most significant innovation in the Scottish chemists' study of heat was made by William Irvine. Irvine attempted an elegant and unifying reformulation of Black's principles by theorising that latent heat was a function of heat capacity: specifically, that the absorption and release of that heat necessary for change of state was the result of an enlargement or diminution of a body's capacity for heat.[103] Irvine's reformulation of Black's work had strong chemical implications that were made explicit in Adair Crawford's study of animal heat. Crawford held that air entering the lungs contained heat. Blood, returning from the body's extremities impregnated with phlogiston, was robbed of this phlogiston by the air, whose attraction for it was stronger. As this transference took place, the air emitted its heat, which was absorbed by the blood. The blood was able to absorb the heat because its capacity for heat had been enlarged by its loss of phlogiston.[104] In Crawford's work, capacity had become the key concept to understanding the absorption and emission of heat in animal chemistry. Further, Crawford was at pains to distance himself from what was by then the traditional way of conceptualising reactivity and heat. Attraction was only a metaphor,[105] heat not being capable of combining with matter chemically.[106] This point was made with reference to Lavoisier, who saw the heat evolved in combustion as the result of chemical decomposition. According to Crawford, this heat was the result of a change in capacity.[107] Irvine's idea of capacity was then the pivotal move in this final distancing of Scottish chemistry from its Cullenian origins.

Lavoisier as ether theorist

The foregoing description of Scottish chemical theory and its applications reveals a striking correspondence between certain of its aspects and important features of Lavoisier's chemistry as it developed after the mid-1760s. Recent studies persuasively advance the view, first, that his focus on gases, seen most famously in the case of oxygen, derived from a standing interest in the theory of the elastic state, which he early came to regard as the effect of the combination of ordinary matter with caloric ether, the matter of fire.[108] Second, they show that within his continued study of heat, prosecuted with Laplace, there was a notable effort to relate caloric ether to the understanding of chemical attraction.[109] This concordance of Scottish and French chemistry is highly significant for the history of ether. It shows in general terms the very considerable dominance that the concept achieved in chemistry in the science's most crucial formative years. More particularly, it illustrates the notable degree of unanimity imposed within the science by an overarching theory that allowed rigorous experimental prosecution.

An initial point to make before exploring this topic in more detail is that the Scots were not, so to put it, responsible for Lavoisier. They did not stimulate Lavoisier's interest in the elastic state, and the impact of their work when it reached Paris, though not negligible, was not radical.[110] The topic under discussion is therefore not a sequential development moving from Edinburgh to Paris. It is rather a question of outlining the way in which an analogous development created a similar conceptual set that therefore serves the historian to characterise the science in the broadest terms possible.

The fundamental reinterpretation wrought by Lavoisier scholars in the past decade has in turn evoked an interestingly problematic picture. Although the stages of his work on heat and elastic state theory have been brought clearly to light, and his attack on calcination and combustion thereby set in a novel context, the developmental process has not been characterised. The poles of that process can be seen in the following question: How did the geochemist of the 1760s with an interest in the German Eller's two-element theory of matter become the decidedly Newtonian caloric theorist of the 1780s? Though this question cannot be adequately answered within the confines of this chapter, it does focus clearly on the direction of Lavoisier's development. He came increasingly to employ the terminology of particles and attractive and repulsive forces, terminology that allows comparison with the Scots. The terminology of his comments on Eller's theory of the elements allows no such comparison.[111]

The overall process by which Lavoisier came to hold these views can be briefly summarised as follows. His quest for a theory of elastic state, achieved in some measure by 1772, focused his attention on the calcination of metals, because this phenomenon involved weight gain. Previously, Lavoisier had believed metals to lose air during calcination, because they afterwards no longer effervesced with acids.[112] The discovery of oxygen gave him the opportunity to formulate a new theory of acidity, which directed him to the chemical affinities of the oxygen principle.[113] The partnership with Laplace in the study of heat provided him with a theoretical terminology of particles, force structure, and balance from which he was able to manufacture a theory that enlarged and integrated his ideas on states of matter and chemical attraction.[114]

It is the latter stage that bears comparison with the Scots. By 1772, Lavoisier had firmly concluded that 'air is a particular fluid combined with the matter of fire',[115] but it was not until later, under Laplace's influence, that he overtly adopted terminology indicating that expansibility and elasticity were conceived in terms of a structure of forces. That he did adopt such terms by the early 1780s is seen in his discussion of the affinities of the oxygen principle, where he claimed that he had had this aim in view since the beginning of his work on oxygen and had been gathering materials for it for several years.[116] He offered some penetrating criticisms of the defects of contemporary affinity tables. They dealt only with simple affinities, whereas the chemist is normally encountering at least double or triple affinities. They did not take account of water's attraction in reactions performed the wet way. They ignored the crucial variables of degree of saturation and temperature.[117] This last point is especially relevant when the Scottish comparison is borne in mind. Lavoisier argued that all bodies are immersed in an all-penetrating igneous fluid that acts contrary to the force of attraction maintaining their aggregation. Their solid, liquid, or aeriform state is a consequence of the relative balances of the two sets of forces. The degree of heat in bodies must then affect the degree to which they are, or are not, combinable, because that degree of heat determines the relative firmness of each body's particulate union. Solid bodies such as lead and tin do not combine because the attraction between them is insufficient to overcome the attraction binding the particles of the separate substances. Once, however, the action of heat weakens the strength of their aggregation, the attractive force between them can operate, and a combination take place.[118] Lavoisier, very much under the sway of Laplace on this question of affinity, believed that this scheme held out great hopes for the progress of chemistry. It was not altogether chimerical to envisage a time when the chemist would precalculate the results of reactions, as the geometer now did for the motions of celestial bodies.[119] The fact that attraction varied with temperature offered the mode of measurement; according to Laplace, the balance of caloric and cohesion furnished a precise means for comparing chemical affinities.[120]

As the caloric ether assumed an ever-increasing role for Lavoisier, his theoretical chemistry came particularly to resemble the early version of William Cullen's. Their views on the states of matter had no significant differences, and on chemical attraction and its integration with states of matter the difference was slight. More generally, Lavoisier's chemical theory of heat can be closely compared with those of Black and Cleghorn. Certain discriminations require emphasis, however, particularly with regard to Cullen. Although both came to see temperature measurement as the key to understanding elective attraction, and to consider it an avenue for fundamental advance of their science, Cullen went on to abandon the attraction of cohesion for a unicausal chemical ether, whereas Lavoisier continued to think in dualistic terms of attractive cohesion and repelling caloric. Cullen, moreover, favoured ether density concepts that did not appear in Lavoisier, and his view of matter's liquid state did not incorporate the factor of external air pressure, as Lavoisier's did.

Yet despite these distinctions, the historian can surely have no doubt about ether's significance for the development of chemistry. It was so fundamental that the massive and transforming innovations brought about by Cullen and Lavoisier simply cannot be imagined without it. Although ether does not give one all there is to know about chemistry in this period, its position was central enough to propose the conclusion: no ether, no new chemistry.

Acknowledgments

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Notes

1 Study of ether's role in moral theory might begin with David Hartley's *Observations on man, his frame, his duty, and his expectations*, 2 vols. (London, 1749). Its role in political ideology can be examined in the Revolutionary and Napoleonic periods. See J. B. Morrell, 'Professors Robison and Playfair, and the Theophobia Gallica: natural philosophy, religion and politics in Edinburgh, 1789–1815', *Notes and Records of the Royal Society of London 26* (1971), 43–63.

2 N. T. Phillipson, 'Culture and society in the 18th century province: the case of Edinburgh and the Scottish Enlightenment', in *The university in society: studies in the history of higher education*, ed. L. Stone, 2 vols. (Princeton 1974), 2:407–48.

3 J. R. R. Christie, 'The rise and fall of Scottish science', in *The emergence of science in Western Europe*, ed. M. P. Crosland (London, 1975), 119–20.

4 Fox (1971); J. B. Gough, 'Nouvelle contribution à l'étude de l'évolution des idées de Lavoisier sur la nature de l'air et sur la calcination des métaux', *Archives Internationales d'Histoire des Sciences 22* (1969), 267–75; H. Guerlac, 'Chemistry as a branch of physics: Laplace's collaboration with Lavoisier', *Historical Studies in the Physical Sciences 7* (1976), 193–276; R. J. Morris, 'Lavoisier on fire and air: the memoir of July 1772', *Isis 60* (1969), 374–80; R. Siegfried, 'Lavoisier's view of the gaseous state and its early application to pneumatic chemistry', ibid. *63* (1972), 59–72.

5 Cullen's chemistry lectures for 1748–9 show an already well-developed understanding of ether's uses for chemical theory. W. Cullen, Royal College of Physicians of Edinburgh (hereafter RCPE), MS C15.

6 It was certainly composed before the return of Halley's comet, which Smith referred to in the future tense. A. Smith, 'The principles which lead and direct philosophical enquiries, illustrated by the history of astronomy', in A. Smith, *The early writings of Adam Smith*, ed. J. R. Lindgren (New York, 1967), 106.

7 John Millar, quoted in *Lectures on rhetoric and belles lettres, delivered in the University of Glasgow by Adam Smith: reported by a student in 1762–3*, ed. J. M. Lothian (London, 1963), xvi.

8 Hartley, *Observations*, passim.

9 D. Hume, *A treatise of human nature*, in D. Hume, *Philosophical works of David Hume*, 4 vols. (Edinburgh, 1826), 1:88.

10 D. Hume, *Enquiries concerning the human understanding and concerning the principles of morals*, ed. L. A. Selby-Bigge, 2nd ed. (Oxford, 1902), 30.

11 Hume, *Treatise*, 8–10.

12 J. Noxon, *Hume's philosophical development* (Oxford, 1973), 91.

13 Hume, *Treatise*, 220.

14 D. Hume, *An abstract of a treatise of human nature*, eds. J. M. Keynes and P. Sraffa (Hamden, Conn., 1965), 32.

15 Hume, *Treatise*, 212.

16 Ibid.

17 Hume, *Enquiries*, 73.

18 The phrase is John Millar's. D. D. Raphael, 'The true old Humean philosophy and its influence on Adam Smith', in *David Hume: bicentenary papers*, ed. G. P. Morice (Edinburgh, 1977), 25.

19 Smith, *Early writings*, 32–9.

20 Ibid. 39–40.

21 Ibid., 45.

22 Ibid., 40.

23 Ibid., 40–1.

24 Ibid., 39, 41.

25 Ibid., 108.

26 Hume, *Treatise*, 'Introduction', 7.

27 This point is discussed by G. E. Davie, *The democratic intellect: Scotland and her universities in the nineteenth century* (Edinburgh, 1961), 3–25; and by Olson. (1975), chap. 1.

28 A not untypical sequence for Scottish intellectuals of this period; compare this sequence with the careers of Thomas Reid and Dugald Stewart.

29 See J. R. Lindgren's excellent monograph, *The social philosophy of Adam Smith* (The Hague, 1973).

30 N. T. Phillipson, 'Towards a definition of the Scottish Enlightenment', in *City and society in the eighteenth century*, eds. P. Fritz and D. Williams (Toronto, 1973), 140–3.

31 R. Emerson, 'The social composition of enlightened Scotland: the Select Society of Edinburgh, 1754–1764', *Studies on Voltaire and the Eighteenth Century 114* (1973), 291–329.

32 Phillipson, 'Towards a definition', 139; Christie, 'Rise and fall of Scottish science', 118.

33 J. R. R. Christie, 'The origins and development of the Scottish scientific community, 1680–1760', *History of Science 12* (1974), 140.

34 E. C. Mossner, *The Life of David Hume* (Austin, Tex., 1954), 156–61.

35 J. Thomson, *An account of the life, letters and writings of William Cullen, M.D.*, 2 vols. (Edinburgh, 1859), 1:40–5.

36 Christie, 'Rise and fall of Scottish science', 120.

37 W. Cullen, 'An essay towards ascertaining the different species of salts', published by L. Dobbin, 'A Cullen chemical manuscript of 1753', *Annals of Science 1* (1936), 138–56; W. Cullen, 'Of the cold produced by evaporating fluids, and of some other means of producing cold', *Essays and Observations, Physical and Literary* 2 (1756), 145–56.

38 Thomson, *Cullen*, 606.

39 Ibid., 72–3.

40 W. Cullen, RCPE, MS C10 (chemistry lectures of the early 1760s), 27.

41 Ibid.

42 Hume, *Treatise*, 340.

43 Hume, *Enquiries*, 149.

44 Ibid., 150.

45 Cullen, RCPE, MS C10, 30.

46 Ibid.

47 Ibid.

48 Ibid., MS C11 (history of chemistry), 3.

49 Ibid., MS C10, 26.

50 Ibid., MS C15, 1, 79.

51 Smith, *Early writings*, 45.

52 Cullen, RCPE, MS C10, 83.

53 Ibid., MS C15, 1, 79.

54 I owe this point to Dr. Nicholas Fisher of the University of Aberdeen.

55 A. Plummer, 'Experiments on neutral salts, compounded of different acid liquors, and alcaline salts, fixt and volatile', *Essays and Observations, Physical and Literary 1* (1754), 337.

56 Cullen, RCPE, MS C10, 68.

57 Ibid., 83.

58 Ibid., 22–3.

59 Smith, *Early writings*, 45.

60 Cullen, RCPE, MS C11, 3.

61 Smith, *Early writings*, 46.

62 J. Robison (ed.), *Lectures on the elements of chemistry, by Joseph Black, M.D.*, 2 vols. (Edinburgh, 1803), vol. 1, Preface, xxii.

63 W. Cullen, Glasgow University Library, Cullen MSS, no. 7.

64 Phillipson, 'Towards a definition', 144–6.

65 Hartley, *Observations*, passim.

66 Cullen's opponent was John Gregory, an early member of the Aberdeen Philosophical Society and latterly a professorial colleague of Cullen's at Edinburgh.

67 Olson (1975), 28–31.

68 Cullen, RCPE, MS C11, 1.

69 Ibid., MS C10, 87.

70 B. Robinson, *A dissertation on Sir Isaac Newton's aether* (Dublin, 1743), 95.

71 Ibid., 96–8.

72 Ibid., 100.

73 Ibid., 122.

74 Ibid., 114–16.

75 Cullen, RCPE, MS C15, 1:132.

76 Ibid., 130–1.

77 Ibid., 57.

78 Thomson, *Cullen*, 580–3.

79 Ibid., 581.

80 Ibid., 583.

81 Ibid., 53.

82 Ibid., 52.

83 Cullen, RCPE, MS C10, 112–13.

84 Ibid., 83.

85 Ibid., 84.

86 Ibid., 86–7.

87 Ibid., 68–9.

88 Ibid., 69.

89 Ibid., 84.

90 E. g., D. McKie and N. H. de V. Heathcote, *The discovery of specific and latent heats* (London, 1935), 27–8.

91 E. g., Schofield (1970), 185–90.

92 Robison, *Lectures*, 1:193.

93 See Robison's editorial correspondence, in *Partners in science: letters of James Watt and Joseph Black*, eds. E. Robinson and D. McKie (London, 1970), 320–77.

94 Robison, *Lectures*, 34.

95 A. Donovan, *Philosophical chemistry in the Scottish Enlightenment* (Edinburgh, 1975), chap. 9, n. 62, p. 308.

96 J. Black, Edinburgh University Library, MS Dc. 3 11, 4.

97 Robison, *Lectures*, 1:525–6.

98 Ibid.

99 A. Ferguson, 'Minutes of the life and character of Joseph Black, M.D.', *Transactions of the Royal Society of Edinbrugh 5* (1805), 108.

100 Robison, *Lectures*, 1:xxiii.

101 Ibid., 525.

102 Ibid., 156.

103 W. Irvine, *Essays, chiefly on chemical subjects* (London, 1805), 88.

104 A. Crawford, *Experiments and observations on animal heat, and the inflammation of*

combustible bodies, being an attempt to resolve these phenomena into a general law of nature, 2nd ed. (London, 1788), 361–2.

105 Ibid., 363.
106 Ibid.
107 Ibid., 372.
108 See n. 4.
109 Guerlac, 'Chemistry as a branch of physics', 270–3.
110 Fox (1971), 29.
111 Siegfried, 'Lavoisier's view of the gaseous state', 61.
112 Ibid., 69.
113 Guerlac, 'Chemistry as a branch of physics', 270.
114 Ibid., 271.
115 Ibid.
116 A. Lavoisier, 'Mémoire sur l'affinité du principe oxygine', in A. Lavoisier, *Oeuvres de Lavoisier*, 6 vols. (Paris, 1862–93), 2:546.
117 Ibid., 547–8.
118 Ibid., 547.
119 Ibid., 550–1.
120 'Mémoire sur la chaleur', in Lavoisier, *Oeuvres de Lavoisier*, 2:317. Guerlac attributes authorship to Laplace.

3

Ether and physiology

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Ethers have often been invoked to explain how matter, considered to be inert, could be endowed with motion. This problem was nowhere more acute than in the study of life; living things are self-moving, and the matter of living bodies was consequently held to be either innately mobile or moved by a special principle of life. Moreover, living things were seen not only as self-mobile, but as purposeful in their motions. Consideration of these problems highlighted two important questions that recurred throughout the history of physiology: What is the *source* of motion in the body? and what *controls* it? The theme of this chapter is that an examination of these questions will illuminate the role of subtle fluids in physiology.

Answers involving subtle fluids had been offered to these questions since antiquity. Purposeful, voluntary motions were universally held to arise from the rational soul of man, but this soul was also widely held to be immaterial and immortal, differing on both counts from the body. How then could the immaterial soul create motion in matter? One answer was to postulate a fluid so subtle that it somehow partook of the immateriality of the soul and of the materiality of the body. This answer took two rather different forms in the Galenic and Aristotelian traditions, both of which were subsequently of importance in the West.

For Galen, the 'animal spirit' was the agent of the rational soul, occupying the brain and nerves and communicating between the will and the voluntary muscles. The 'animal' or 'nervous' spirit remained the physicians' traditional subtle matter of physiology until at least the beginning of the eighteenth century, and was indispensable in explaining body–mind interaction in voluntary motions. The problem of interaction did not necessarily arise in the case of the involuntary actions, whether 'vital' or 'natural', for these did not involve the immaterial soul, but resulted from a 'faculty' or simply from 'nature'.[1]

Galen confessed that the term *faculty* was often used in ignorance of true causes, and the analogy he employed to illustrate the action of a faculty included the attraction exerted between similars: the motion of oil towards the wick of a lamp and the suction of air into bellows. Because there was no problem of interaction, Galen was not obliged to use subtle fluids to explain these motions, and his 'vital spirit' was a physiological agent of respiration, not motion. In no case did Galen face the question how the motion arose or how a very small motion of the barely material spirit in the nerves could produce great muscular power. His physiology was founded on the innate powers of living matter.[2]

By contrast, Aristotle in both his physiology and his physics drew a sharp distinction between the mover and the moved: Everything that moved was moved by something else and the ultimate source of motion was an unmoved mover. In animals the unmoved mover was the soul, and Aristotle here used the analogy of a mechanical puppet set in motion by pulling the strings. Because the unmoved mover was immaterial, Aristotle was faced with a problem of interaction when explaining the origin and control of bodily motion. He answered the problem by invoking a spirit (*pneuma*, the word used also by Galen) that mediated between the mover and the moved by supplying a force of expansion and contraction that, in his analogy, moved the strings of the puppet.[3]

The innate (not respired) spirit provided Aristotle with a physical answer to the question of the source of motion. However, in solving the second problem – the control of motion – Aristotle made the explanation psychological. The unmoved mover was the soul's perception of an external Good or Evil, and this aroused the motion of appetition. This in turn excited the motion of the animal in pursuing the Good or avoiding the Evil. The *rational* appetite was concerned with voluntary motion, but animals were compelled to act involuntarily by simple perception and appetition. Since the nonrational sentient soul of animals was a form of matter, the living creature carried with it its own causes of motion, but this living matter was not essentially mobile. It was the *pneuma* that in this way imposed motion upon matter that also carried the soul (*psyche*) from generation to generation and was responsible for the inception and development of the new individual. This *pneuma* was an active subtle fluid far removed from the elements of the mundane world but related to the ether of the heavens.

Subtle fluids in pre-Newtonian physiology

This common stock of traditional ideas provided the basis for a number of different seventeenth-century answers to the questions of biological

motion. The generation of animals was an irreducibly biological problem, and one for which subtle fluids continued to provide an answer. Harvey used Aristotle's notion of a quintessence, and similar ideas were used in the eighteenth century by Stephen Hales, Hermann Boerhaave, and Linnaeus. However, in the period between Harvey and Hales, science passed through a corpuscularian revolution: Matter was now believed to consist of particles, whether part of a universal plenum or atoms traversing a void. The doctrine of corpuscularity asserted that ultimate reality lay in particles and motion: What then of spirits, which had traditionally bridged the gap between materiality and immateriality?

Descartes banished them. The nervous spirits became, in accordance with the doctrine of a universal plenum, passive particles acting mechanically, subtle only in their smallness. Moreover, according to the Cartesian world picture the immaterial soul, which was a different category of existence from matter, nevertheless could produce voluntary motions in the body. The break with traditional ideas was decisive and lay at the root of much Continental (and particularly French) physiology in the later seventeenth and eighteenth centuries. However, in England physiology was already strongly influenced by Harvey, whose work could be seen as developing Aristotelian biology in a very effective way, with the result that Aristotelian and other traditional concepts did not suffer a sudden eclipse; certainly, corpuscularity forced a compromise with the old ideas, although only a few writers embraced Cartesian ideas. Thus the term *spirit* retained some suggestion of innate mobility and nonparticulate subtlety, and the word sometimes carried its theological connotations into physiology. For example, Francis Glisson[4] argued that spirits (demons and angels) were essentially alive, whereas the matter of man's body was 'accidentally' alive insofar as his rational, spiritual soul imposed spiritual life upon it. The growth of animals and plants was attributed to the action of a plastic force, the *archeus* of the 'chemists' (Van Helmont and others), which was a development of the primeval life of matter and which Glisson identified with the Hippocratic healing power of nature; the *archeus* was at least partly spiritual in nature. The notion of the Great Chain of Being also provided a reason for supposing the existence of spiritual forces at work in the physical world, and George Cheyne, early in the eighteenth century, held that there was, above man in the chain, *'an active, self-motive, self-Determining Principle'* that supplied motion to the inert matter of the universe.[5] Robert Whytt of Edinburgh believed in a similar chain of 'intelligences' above man, and he also believed that the inert matter of the body was moved by an extended but immaterial soul which, like that of Glisson and later animists, was to be identified with the Hippocratic healing force of nature (French, 1969). A contrast to the situation in Britain was provided by the Continental mechanists (before about 1740) who, under the influence of Descartes, could not believe that a soul or spirit could directly move matter (except in the case of voluntary motion). Thus, Friedrich Hoffmann of Halle[6] believed in a chain of spiritual entities but was obliged to accept ether to account for animal motions. His theory is discussed in the section of this chapter entitled 'Cartesian subtle matter'.

The absence of a Cartesian physiological revolution in Britain meant the survival not only of active spirits, but also of the soul to which they were closely related. A number of late seventeenth-century writers tried to dress up more or less traditional ideas in corpuscular clothing; thus, Thomas Willis retained a lower *anima*, controlling the grosser physiological activities, in addition to a rational *animus*. The *anima* was akin to fire, located in the blood, and found also in animals; and the *animus* was like light and was distributed through the brain and nerves. Willis also claimed that the blood was the source of the spirits, whence they were 'alembicated' by the heat of the body. These spirits were particulate but *active*, and were more closely related to the chemical spirits of the Oxford physiologists who had been working on respiration than to the mechanical spirits of Descartes. For Willis muscular motion was the result of the effervescent meeting of different kinds of spirit. However, Willis's scheme was entirely qualitative, and the activity of the spirits and the two souls – the lower of which was material – combined to obscure the questions of the origin and control of motion.[7]

Other English physiologists of the later seventeenth century reacted against Cartesian and corpuscular mechanism and developed their subject along Harveian or even Aristotelian lines. Thus, Glisson strongly objected to the view that matter was inert, claiming that to a certain extent all matter was alive and capable of motion, an idea fundamental to the problems of the origin and control of bodily motion. All matter, he argued, had 'primeval life' that possessed the fundamental properties of perception, appetition, and motion.[8] We have already seen that each of these, *perceptio, appetitus*, and *motus*, was a faculty of the Aristotelian soul, study of which was a regular part of the university course in Glisson's time. The idea was, moreover, elaborated in moral philosophy, through the problems of volition and appetition, in the school pneumatology of the early eighteenth century[9] and in didactic texts on natural law of the same period.[10] The argument common to all was that *perceptio* perceived Good or Evil, *appetitus* generated a desire to follow the first or avoid the second, and *motus* was the subsequent action. *Perceptio* was unconscious (except in the case of man's rational faculty), and *appetitus* and *motus* were involuntary; that is, they operated in the area that Descartes had

relegated to machinery, and the notion of 'unconscious perception' remained for that reason problematic for the Continental mechanists.

Yet the idea of unconscious perception was used by the arch-mechanist of traditional historical interpretation, G. A. Borelli, who employed it precisely because he saw and tackled the problems of physiological motion that we are now considering. Since he and others used it we must begin to change our minds about what is meant by the traditional term *mechanist*. We must first distinguish between French and Italian ideas of mechanism in the late seventeenth century. Borelli's mechanism was inspired by the mathematical success of the physical science of his compatriot Galileo rather than by the beast–machine of French physiology after Descartes. Borelli successfully treated the gross movements of animals by considering their parts as levers and pulleys, but his theory was inadequate to explain the beating of the heart, the most notable of all the involuntary motions.[11] He argued that the heartbeat began when the presence of blood acted as an unpleasant stimulus to the embryonic ventricle: The stimulus was perceived as Evil by the soul, the *appetitus* of which desired to avoid the stimulus, and the *motus* of which initiated the first contraction of the ventricle to expel the offending blood. The returning blood caused the cycle to be repeated and the motion became in a sense habitual. To express its reliance on the soul, Borelli called this motion 'animastic'; we might call it 'tissue animism'.

Subtle matter in eighteenth-century physiology

There were several different kinds of subtle matter used in medical theory in this period to solve the problems of motion: first, the two surviving classical accounts described in the opening section of this chapter, which provided different models of imposed and innate motion (animal generation by subtle matter can be included in this group); second, electricity; third, heat considered as a fluid and the closely related ideas of 'light' and 'fire' as fluids; fourth, Cartesian subtle matter; and fifth, the Newtonian ether.

In taking these categories in turn we find that the first, traditional accounts of subtle matter, must include the dispute about the existence of nervous spirits. A subtle matter flowing down from the brain through the nerves was an answer to the problem of the control of motion, but there was some scepticism about the supposed cavity of the nerves. Normal aqueous fluids were too gross[12] to have the necessary features of subtlety and rapidity of motion, but, on the other hand, little else could be observed in nerves. As a result it was often assumed that the nerve juice was a mixture consisting of a coarse, passive, and nutritive part and a subtle, active part comparable to the macrocosmic ethers of the various theories of the time. Thus, G. D. Santorini held that the nerve juice contained an active ether composed of very small particles with great rapidity of motion.[13] In this way the nerve juice was said to be analogous to semen, in which the glutinous matter was contrasted to the active ethereal subtle fluid that was responsible for generation. The same parallel, between the action of ether in the nerves and that in animal generation, was made by Hoffmann[14] and was almost certainly a revival of the classical idea in an attempt to establish a comprehensive biological theory; many others made similar attempts.[15]

Electricity was often regarded as a fluid after the Leyden jar became well known, and it was undeniably active and subtle. Benjamin Franklin and others considered the electrical fluid particulate and able to lie quiescent in bodies as a lurking vital fire. By the middle of the century it was realised that electricity could stimulate muscular contraction, and it was not long before electricity was used in Edinburgh to treat a palsy by the administration of some six hundred severe shocks in three days (French, 1969:47). Haller stimulated the nerve of a muscle with electricity and obtained a contraction but with characteristic caution did not identify electricity with the subtle matter of the nerves. Even when electric fish were examined in detail and the copious supply of nerves to the electric organs of the torpedo were noted, there was no general agreement that the active agent of the nerves was electricity.

In posing again our questions about the control and origin of physiological motion, we can see that electricity regarded as a fluid had the qualities of subtlety and rapidity necessary for the control of muscular motion, if not for its source. Again, the motion of the heart can be seen as a critical case, because it was distant from the powers of the soul, and because it was a motion that could only with difficulty be reduced to mechanism. These factors encouraged the German worker Staehelin[16] to suggest that the nerve fluid was electrical in nature and that it reached the heart discontinuously, each drop stimulating the muscle of the heart to contract, while relaxation occurred as the fluid left the heart and entered the blood. But as we have seen, Staehelin's views were exceptional. The real problem was whether the stimuli of various kinds (including electricity) aroused the innate powers of the muscle, or whether they called into action a separate principle of motion. In the later part of the century, Felix Fontana and Luigi Galvani proposed that this principle was to be identified with the electrical fluid itself (Ritterbush, 1964:50, 51), but broadly speaking, eighteenth-century physiologists did not consider the body an electrical machine. The old problem of muscular motion, the problem of the source of physiological motion, continued to be discussed in its own terms. If there was a common notion of biological electricity, it was that

organisms collected and concentrated the dispersed electrical fluid as a principle of vitality.

The notion of fire as a subtle fluid played a very much larger part in eighteenth-century physiological speculation. Fire had been the most active and subtle of the four elements of the Greeks, second only to the ether of the heavens, and the word came to express a number of different ideas: electrical fire; the corpuscular and chemically active fire of late seventeenth-century physiology; the subtle fluid of heat, caloric; and the principle of combustion, phlogiston. It is not always possible to distinguish sharply among these ideas, and they have in common the notion that heat was active and could move matter, for example, that of muscles. Often these ideas became intermixed: For example, if heat, as a secondary quality, was simply the result of particles in motion, then perhaps the particles involved were simply those of an elementary matter of fire; if heat was a fluid, could it not flow about the body, its particles, like those of light, moving with great speed in the nerves? What is quite clear is that the general acceptance of corpuscularity during the later seventeenth century greatly lessened the differences among fires, spirits, auras, ethers, heat, and light of an earlier age. All these terms, in a new corpuscular guise, were used in physiology to explain the action of the nerves, from Willis and his contemporaries in the 1680s to John Tabor and his contemporaries in the second decade of the eighteenth century.[17] Tabor located the soul within the brain and held, like Willis, that it radiated itself to the nerves and sense organs like light. In both cases the soul seems to have been conceived as subtle matter, the material *anima* of seventeenth-century binary animism.

Tabor's animism was perhaps a reaction against the growing influence of Boerhaave, whose mechanistic physiology was part of a medical scheme that was to become paramount before the middle of the century. Boerhaave gave an important role to 'fire' both in his chemistry and his physiology, and this drew attention to the problems of animal heat and motion. Most of the roles attributed to fire in animal motion were qualitative, but heat, particularly when conceived as a fluid, could also have its quantitative aspects. The intensity of the body's heat had traditional medical importance in judging the degree of fever, but now, in the eighteenth century, those who thought of heat as a fluid could also discuss its volume. Joseph Black's quantitative work on heat was known to William Cullen, who, as a medical man, was aware that biological heat was a special case, because of its 'innate' nature and association with life. Cullen would also have known of the seventeenth-century idea that respiration and combustion were very similar, both consuming air and generating heat, and he claimed that the production of animal heat by respiration was governed by the activity of an ethereal fluid in the nerves.

Cullen's notion of an ethereal nerve fluid was soon extended. Interest in the subject of animal heat, whether or not fluid, was high in Edinburgh in the 1770s, as shown by the large number of student dissertations on the topic. One student incautiously identified Cullen's ethereal nerve fluid with Newton's universal ether *and* with the electrical fluid. The student was rebuked at surprising length by William Smellie in the first *Encyclopaedia Britannica.*[18] The search for nonmechanical explanations of life led also to John Hunter's view of life as 'animal fire', freed from food as the result of respiration. This material basis of life was diffused through the body, upon which it imposed its motion. Possibly, Hunter thought of respiration in terms of a transfer of phlogiston, which is certainly what Priestley had in mind when explaining the relationships among respiration, combustion, and the vital activities of plants. Priestley also held that phlogiston was the cause of muscular motion. Another way of explaining muscular motion by fire-related subtle fluids was that employed by Buffon, who supposed that at a fundamental and universal level there were two kinds of matter, a *matière vive* and *matière brute. Matière vive* was essentially active, responsible for the phenomena of light and heat, and composing the ultimate 'organic molecules' that formed living bodies; it corresponded to the Newtonian force of repulsion. *Matière brute* was inert and passive, and corresponded to Newtonian attraction.[19] So here the Newtonian repulsive force – the hint is probably taken from Newton's idea that fermentative actions supply motion to the world – is made an innate property of a certain kind of matter, which becomes as active and as subtle as ether. An alternative was to emphasise the material activity of Newton's ether, and Buffon's countryman Lamarck assumed that an elementary, ubiquitous, and ethereal 'fire' produced sensible heat when activated, excited the motions of animals and plants, and was the source of motion in the macrocosmic world.[20]

Cartesian subtle matter

Another answer to the problems of the control and origin of motion that were allied to the problem of dualism could be found within Descartes' own system. Of the different grades of original matter described by Descartes, the finest could, with one change, serve the purposes of other subtle fluids: It was necessary only to attribute activity to it, and the Cartesian tradition in physiology on the Continent could be extended into the period when British physiology was dominated by Newtonian mechanism in the form of the hydraulic-machine model put forward by Archibald Pitcairne at the beginning of the eighteenth century. Thus, without departing very far from the Cartesian tradition, Johannes Gottsched, discussing muscular motion in 1694, denied

appetite and will in the natural motions of animals and claimed that all involuntary motions were due to the activity of an ether, which he also called *aer* and *aura*,[21] universal and innately active. In the body it moved the particles of blood in a fermentative motion and was distilled from the blood to form the active part of a dual-nature nerve juice characteristic of the time.

Gottsched explained muscular motion by the assumption that ether in the muscle fibre expanded with heat across the width of the fibre, thus reducing its length. This is a minor variant of older ideas about the inflation of muscles, and Gottsched employed the usual seventeenth-century speculative microgeometry of muscle structure to explain contraction. His explanation did not meet the criticism that muscles were known to decrease rather than increase in volume in contraction. Moreover, his explanation was 'kinematic' in failing to relate the quantity of motion in the ether to that in the muscle. Yet it is clear that Gottsched did face the problem of the quantity of motion in the body; although he did not entirely distinguish between the various quantitative aspects of motion such as the force, the distance moved, the velocity, and the amount of moving matter, yet he had a general notion that the muscles somehow produce a great deal 'more' motion than they get from the nerves. Indeed, as he observed, it was the common view that there was some mechanical contrivance in the muscles that multiplied the inflowing *virtus* of the nerves. Aristotle had said that motion resulted from the moving force overcoming the resistance, so that, for example, a man might fail to move a boat beached in sand. Yet, armed with a lever, he would perhaps succeed; it appeared that the lever was multiplying the moving force. Indeed, some seventeenth-century physiologists thought that muscles acted as levers or pulleys in this way, multiplying the force of the nervous spirits. Gottsched held that the microgeometry of the muscle could *not* multiply forces, and also that the force developed by the muscle was actually greater than appeared during its motion because of the disadvantageous position of the insertion of the muscle into the bone in relation to the position of the fulcrum and weight. It was obvious to him that the additional force of the muscle was derived from a separate principle, ether.

So Cartesian subtle matter could also be used to explain the motion of an inertly material Cartesian body. Those physiological writers who had not perceived the quantitative problem of the origin of motion in the body remained kinematic in outlook and felt no necessity to invoke ethereal explanations. The Spaniard Martin Martinez, writing in 1723 on the motion of the heart,[22] considered that a very small force or motion (*vis* or *commotio*) of the nerves could raise great weights by the machinery of the muscle, analogous to multiple pulleys. It followed that there was no need of an active principle, and Martinez denied spirits of all sorts.

Another reason for denying spirits and subtle fluids was the belief that the immaterial soul could directly produce motion in matter, and that no problem of dualistic control or origin of motion existed. George Ernst Stahl began to put forward such arguments through his students' dissertations as early as 1685:[23] Spirits were either material or immaterial, not both, and so might be acted upon either by the body or by the soul. But to rely on spirits as an intermediary between the material and immaterial was simply to put the problem of dualism one stage further back. It was preferable, he argued, to say that the immaterial soul acted upon matter by means of motion; motion implied direction, and direction, purpose; since no mere machine was purposeful, the soul regained its traditional importance in physiology.

Opposition to Stahl's theory came from his own university, Halle, in the person of Hoffmann, whose beliefs have been hinted at earlier in this chapter. Hoffmann devoted a separate tract to the subject, and from it we can see that he was fundamentally a Cartesian mechanist, but held a number of ideas from different sources that somewhat complicate his system. Spirits, including those above man in the Chain of Being, were essentially active and, being immaterial, were unable to move matter, except for the mind of man in creating voluntary motion; matter was essentially inert except for the simple motion of the particles of fluids. However, this motion was too simple to account for life, which Hoffmann explained by invoking an ether to impose motion on the not-quite-inert matter of the body. Life was no more than the sum of these imposed motions and was 'mechanical'. Ether itself seems to have been derived by Hoffmann partly from the work of the English respiratory physiologists of the previous century.[24]

Newtonian ether

The effect of Newtonianism on English physiology was to introduce in an acute form the problems of physiological motion that form the basis of our discussion and that had partly been obscured by seventeenth-century chemical physiology and innate Glissonian powers of matter. Newtonianism posed the question that the Cartesians had faced: If matter is inert, and the bodily machine is material, what moves the machine? The Newtonians thought about motion in general in quantitative terms, and when thinking about animal motion in particular, did much to make physiology a quantitative, 'dynamic' science. In general, they believed that there was a constant loss of motion in the universe in collisions between moving bodies, and that there had to be sources of new motion like ether, gravity, and elasticity; in the particular case of animal motion, they could also use an explanation that Newton had suggested in query 31 to the *Opticks* (1717) in which these general sources of motion were discussed, that is, the fermentative motion that supplied movement to the heart and blood.

The early Newtonians, like Archibald Pitcairne, considered the body a hydraulic machine, no doubt in Newtonianising the seventeenth-century tradition of work on the circulating fluids and glandular secretion, but at the same time there was an alternative tradition, dating back at least as far as Glisson, of examining the solid parts, particularly the muscles and nerves. Glisson's notion of the innate mobility of muscle is generally held to have influenced Haller's important work on the *vis insita* or irritability, and between the two men much effort had gone into attempts to establish a microgeometry of muscle structure and, alternatively, the structure of the ultimate fibre. Clearly, the solid parts were more gross than the moving fluids of the body, and where ether was used as an explanation of motion it was normally thought to act upon the solids. It was partly for this reason that Pitcairne did not employ ether as an explanation, and partly for the reason that his Newtonianism was derived from the *Principia* and not from the *Opticks*. Once more the question was faced, but more acutely than in the physical sciences: Was matter essentially passive or active?

The English and Scottish answer in the Newtonian period was generally that the inertness of matter required an external moving force. This view fitted well the prevailing natural theology, and Andrew Baxter in 1733 relied heavily on physiological evidence to assert the immateriality of the soul and the existence of God. Ether itself, he claimed, was material and therefore inert, and had no role in physiology, because all motion was derived directly from God. 'Let us look into any book of anatomy, or natural philosophy . . . and we shall not find that the particular instances alledged are intended to shew whence the origin of motion is; or that *fine machinery may be a power to itself*'.[25]

Similar arguments are found in Browne Langrish's book on muscular motion, published in the same year as Baxter's.[26] Like other post-Pitcairne medical men, Langrish drew more heavily on the *Opticks* and its queries than on the *Principia,* and he added to Pitcairne's hydraulic model a discussion of the solid fibres. Even in the hydraulic machine, Langrish was aware of some of the dynamic problems of motion: 'In all hydraulic Engines there is an absolute Necessity for a perpetual supply of the moving force'. The ultimate origin of motion seems to have been, for Langrish, outside the realms of physics and physiology, and probably he thought, like Baxter, that the ultimate mover was God: The 'principal agent' of motion was too subtle ever to be demonstrated mathematically, and it was only the physical manifestation of motion that was performed 'mechanically'.

So we cannot expect a physiological answer to the problem of the origin of motion from Langrish, despite the fact that he was aware of the problem, and his description of muscular action is consequently kinematic in following only the pathways taken by motion in the body, and not its quantity. Taking his hint from the *Opticks* and the Newtonians, Langrish asserted that the constituent particles of matter were polarised like magnets and that attraction depended on unlike poles facing one another. Crystallisation, chemical changes, and muscular motion were to be explained on this basis. The control of muscular motion by the nerves was explained by the nervous spirits' somehow adjusting the polarity of the particles of the muscle so as to achieve a greater or lesser attraction. This was the 'mechanism' of muscle action, yet, despite his claim that the resultant force of a machine could never be greater than that put into it, Langrish saw no discrepancy between the amount of motion exercised by the nervous spirits in rotating or otherwise adjusting the polarity of the muscle particles and the amount of motion developed by the contracting muscle. He consistently referred to the *qualities* of attraction and repulsion, and did not grasp Newton's concept of the 'quantity of matter' or its relationship to attractive forces.

Ether would have been an excellent answer to Langrish's unanswered problem of the hydraulic engine without a moving force, but he was prevented from using an ethereal explanation for two reasons. First, he disagreed with the well-known account recently published by Robinson (discussed later in this section) which accounted for muscular motion by an ethereal vibration of the nerves and muscular membranes, which were said to swell across their width and so contract along their length. Second, he was influenced by Glisson's nonmechanical account of muscular contraction without inflowing spirits and increased volume. By the time Langrish gave the Croonean lectures[27] in 1747 he probably felt that to use the term *ether* in relation to muscular motion no longer implied belief in Robinson's particular use of the idea, nor in an influx of Cartesian spirits. Moreover, he now felt free to use the term *ether* to describe the nervous spirits that imposed motion on matter.

One point in Langrish's criticism of Robinson illuminates very well the problems faced by British physiologists in attempting to cope with Continental mechanism. Langrish thought that the ganglia existed in order to prevent bodily vibrations from disturbing the nervous spirits that might otherwise produce false sensations or motions. Attention was given to the ganglia at the time because of a dilemma in physiology: If the nerves were indeed unbranched in their passage to and from the brain, then the soul must perceive

everything that happens in the body. This agreed acceptably with the traditional faculties of the soul, but most Continental physiologists by then believed that the soul had the single faculty of conscious rationality. But it was clear that the soul was not conscious of the natural motions of the body (such as peristalsis of the intestines), and although Descartes had relegated these to machinery, it was felt in Britain that they involved some kind of vital activity. There was therefore a search for a vital centre outside the brain that organised nonconscious physiological motion. Perhaps the ganglia on the vagus and sympathetic nerves were such centres? Perhaps they were where the nerves branched? Perhaps they acted as filters to prevent voluntary commands from reaching the vital organs and sensations from moving in the reverse direction? The search for an extracranial organising centre played a significant part in the formulation of notions about autonomic functions of the sympathetic system and about the transmission of reflex actions across the spinal cord.

Bryan Robinson's *Treatise,*[28] although principally concerned with the hydraulics of the body–machine, borrowed from the *Opticks* the notion of ether vibrating in the solid nerves. Conducted to the muscles, this vibration caused a swelling in the membranes, which in turn contracted the fibres. The advantages of such a scheme in physiology were simply that there was no need to postulate invisibly small cavities in the nerves, and that the subtlety of ether accounted for soul–body interaction, that is, the control of voluntary motion. This problem was more obvious at the time than that concerned with the source and quantity of motion. Robinson's solution was employed by Richard Mead in his introduction to William Cowper's book on muscles[29] and by George Thomson in his treatise on bones.[30] Neither of these contributions went beyond Newton's discussion in the *Opticks;* medical men in general had but slight acquaintance with the *Principia* and the laws of motion, and for the greater part their physiology remained kinematic.

The most elaborate use of an explanation of nervous action resting on ethereal vibrations was that employed by David Hartley,[31] who related sensations in the soul to vibrations, analogous to those of heat and maintained by a Newtonian ether, in the medullary parts of the brain. The scheme provided a mechanical basis for associationalist psychology, but Hartley was anxious to declare that mental events themselves were not mechanical, and he made the pious declaration that his system could not be used to prove the materiality of the soul. He was left with the problem of interaction between body and soul, as Descartes had been, but, using Newton's principle of limited explanation, he professed himself unconcerned whether the problem was soluble in any of the ways in which the post-Cartesian philosophers had solved it. Nevertheless, he allowed himself to speculate that there might be an 'infinitesimal elementary body' transmitting the medullary changes to the soul. In physiological terms the idea was not very novel, for ether simply replaced the traditional nervous spirits. This modernisation of earlier ideas may have been the route by which Battie[32] arrived at a theory similar to Hartley's and which explained how 'pressure' was transmitted along the particles of the nerves to the brain, causing sensations in the soul.

Continental ethers in the period after Newton

The use of Newtonian ethers in physiology outside Newton's own circle of English and Scottish followers was much more limited, and it is not clear whether the ethereal fluids employed by eighteenth-century French and German writers were primarily Newtonian in inspiration. For example, F. Quesnai, writing in the 1740s,[33] gave ether a central role in his physiological scheme, but it was only partly Newtonian, for he drew freely from Descartes and the ancients. His ether was universal and particulate, penetrating gross bodies by way of their pores. It was the only active form of matter, was akin to fire, and was particularly concerned with the production of heat and cold and with the transmission of light. Its action was entirely by contact and was less in dense bodies because of their greater porosity. Physical properties like weight and elasticity depended upon the activity of the ether. Quesnai's description of the action of ether within the body makes it clear that he began to appreciate the quantitative problems of motion: The body was essentially inert, and even though it could produce subtle humours (the chemical spirits of the previous century), they were ultimately derived from food and were thus likewise passive; their motion was imposed from without, by ether. So great was the contrast with the essentially active ether that ether was conceived by Quesnai as a principle of life. This 'vital principle' resided chiefly in the nerves of the major part of the nerve juice (the minor and coarser part, like that described by Santorini, was nutritive) and so was ideally placed to control the motions of the body.

As the sole active form of matter, this vital principle also generated the motion of the body, but the life it gave to the body in this way was *mechanical* life. The idea of mechanical life was more comprehensible on the Continent (we have seen that it was used by Hoffmann) than it was in Britain, where the term *mechanism* suggested something that excluded life. The idea of mechanical life had arisen from Descartes' contention that animals were purely mechanical. This view was somewhat modified by the later mechanists, who, like Hoffmann, claimed that the parts of the animal machine may move with their own innate, if low-level, powers. Such a view made possible the unique biological properties conceived by such 'mechanists' as Haller, and we shall see below that a form of vitalism arose from such ideas. In a further modification of the original idea the term *mechanism* became interchangeable with *organic necessity*, an idea that stated that the motions of animals were not free but bound by necessity to the structure of the organic parts: This was not to deny that those parts may be alive in a fairly traditional and nonmechanistic way.[34]

Just as British physiological writers had difficulty with the notion of 'mechanical life', so their Continental counterparts found the concept of 'unconscious sensation' incomprehensible. We have seen that from Glisson onwards there survived a notion that the lower physiological activities were governed in some nonrational and perhaps automatic way by the soul, but on the Continent, so completely had Descartes banished the lower activities of the soul that 'soul' was equated with 'mind' or consciousness: It cannot be the soul that constructs the body or controls its every action, for we are not conscious of it doing so. Yet again the question arises: If the body is a machine, what moves the parts? Quesnai recognised this 'dynamic' problem, and tried to answer it. He saw that the problem arose because of the adoption of mechanism: 'On oublie la puissance motrice & directrice, qui est precisement l'Ame Vegetative'.[35] The very mechanism of the body emphasised to Quesnai that a moving force was needed, and this he found in his ethereal vital principle. Yet the problem of dynamics still remained, for the vital principle in the nerves had still to transmit enough motion to the muscles to explain the great force the muscles could produce. He was unable to suppose that such a great force could be channelled down the narrow passageway of the nerves and was obliged to conclude that the force of the muscles was derived from the activity of ether in the blood they contain. The source of motion, then, was localised ether, and its control was partly by nervous transmission by means of ether and partly by the organic necessity of the structure of the parts. Ultimately this organic necessity was referable to God, who had constructed the machine. The result was a series of nonpsychic biological properties very similar to those described by Haller. Although failing to provide an adequate dynamic answer to his problems, Quesnai had at least separated out the two questions of the source (and quantity) of motion and of its control, which had always been confused in kinematic physiology.

Animism, mechanism, and dynamic physiology

The question of the inertness or innate activity of matter was central not only to those who used ether as an explanation, but also to two groups long opposed in the traditional historical interpretation, the 'animists' and the 'mechanists'. These two groups will appear in a new light if we examine them in relation to the physiological problems that made the use of ether desirable: the problems of the origin, quantity, and control of motion.

It is characteristic of all mechanistic arguments that the body alone produced and guided its motions. Paradoxically, by following this article of faith, the mechanists to a greater or lesser extent abandoned the doctrine that matter is inert, for example, by postulating God-given natural forces that inhered uniquely in biological matter and that were responsible for motion and other activities. This was a qualitative notion, defended on a priori grounds, and it was the animists who developed a quantitative and penetrating attack on this position by showing that, however complex, biological matter remained essentially inert. The converse paradox was that for animists the body was a true machine, and could only be moved by an external force, the soul.

An early mechanist position, transferring some Newtonian physics into a Cartesian view of the body, is seen in the graduation thesis of J. Bajollet, 1735.[36] The body was conceived as a hydraulic machine, with its motions dependent on the arrangement and physical properties of its parts. There were no spirits and no chemical explanations. Each physiological motion was no more than the generation of momentum ('actual force') in proportion to the moving cause, and the result of action was 'impression' determined by the quantity of the resisting 'virtual force'. 'Function' was not a guided action and had no purpose. The result of two actions of equal but opposite momentum was either static equilibrium or constant motion about the point of equilibrium, that is, libration, which was the key to this severely reductionist physiology. 'The life of man', wrote Bajollet, 'is nothing other than a libration of the principle organs, or the heart and vessels with blood'. The valves of the heart turned this libration into a circuit of blood, and the continued balance of the librating forces represented health. Libration made the human machine move with perpetual motion: 'It is true that in the human machine there is this difference (from other machines) that it needs no restitution of weights or elasticity, at least at the sensible level, so that throughout life it is a specimen of perpetual motion'. 'Weights or elasticity' referred to the devices driving the clockwork, Bajollet's frequently used analogy, but nowhere in his dissertation is there any reference to forces being lost through friction; increased resistance of the smaller vessels in inflammation was simply a cause of an increased pulse in a system where the effects of opposing momenta alternately became causes. The whole system of alternations was so complex as to be quite outside the powers of mathematics to describe, and Bajollet's scheme remained as qualitative as it was intended to be quantitative in principle by reducing physiology to physics.

All of these points were to be bitterly disputed by the animists: the lack of quantitative reasoning; the omission, in a reductionist programme, of any explanation of the control of motions and purpose; the naive assumption of perpetual motion; and above all the refusal to acknowledge the need of a constant supply of a moving force.

The reaction against this extreme reduction, or identification of biology with physics, was soon seen, in Montpellier and elsewhere. Physiology was, after all, the study of man, and man was compounded of body and soul. Some signs of this reaction are seen in the 1738 thesis of N. Cambray.[37] The effects of the soul in the body were emphasised, including morbid changes not restricted to the voluntary organs. Unlike any machine, the soul could recognise Good and Evil, and this recognition became again a principle of motion. Cambray, like many others who followed him, consciously tried to place his own reasoning in the long tradition of European scholarship from which Cartesian and Newtonian mechanists (in physiology) were felt to have broken away.

It is probable that Cambray's thesis was inspired by Sauvages, who in the 1730s began to teach an animist doctrine in Montpellier, probably having been influenced by Stahl. Likewise, the results of Sauvages' teaching appeared in several other dissertations by his students.[38] The Stahlian position was modified in two ways: First, Sauvages was more interested in medical applications of animism, and second, the Stahlian soul was pushed towards the idea of Hippocratic 'nature' or its healing power. This medical interest forms a link among several groups of ideas we have already met; Sauvages said that all diseases were the body's attempt to reject intrusive morbific matter. This was a cardinal point in the war against the mechanists: no mechanical system could recognise morbific matter (indeed, no mechanical system could become 'ill'); and perception and reaction were closely related to the non-conscious perception, appetite, and motion, the pursuit of Good and the flight from Evil, that we have met in the neo-scholasticism of Glisson, the habituation theory of Borelli, and the general educational framework of the later seventeenth century. These issues were also closely involved with the stimulus and response theory, which in the hands of both Descartes and Bellini[39] was mechanical, automatic, but nevertheless purposeful in avoiding damage to the fabric of the body.

The same sets of ideas were reinforced in the new format in which the academic ideas of the eighteenth century were presented. We can see natural, unconscious appetite as a cause of animal motions in Hutcheson's pneumatology, which was taught in the Glasgow arts course; we may see something similar in another 'new' eighteenth-century subject, the law of nature and nations, and Otto's 1738 text on the subject used the same language as the physiologists: Moral actions were free, but other actions of the body and of the world at large were *mechanical*. The very inertness of matter, said Otto, removed any arbitrariness in the actions imposed on it, which were consciously determined, not free. The actions of the body were determined by the mechanical structure (i.e., organic necessity) of the solids and liquids, and death was a cessation of motions (i.e., the end of mechanical life). Yet it is clear that biological behaviour, lying between the moral actions of the rational soul and the necessary action of the mechanical body, did not fit any more neatly into enlightened treatises on natural law than it did into Cartesian mechanism. Once more, what moves, and what guides, the mechanism? Otto spoke of a force created originally alongside all matter (*vim omni materiae concreatam*) and inherent in it: He used the term *vis insita,* and in most respects this force acted as that later described by Haller. 'Nature', then, was this motive force guided by the structure of the body's solids and fluids. This was nature in the sense that Sauvages used it to recall the Hippocratic healing power, and it was nature in precisely the sense used by Galen at the opening of *Natural faculties:* an inherent, living force, not part of a soul, that determined the lower physiological activities.

Nature in this sense filled the gap in mechanical dualism, a gap that was obvious to those with experience of the biological world and that was being filled by other theorists with ether. To return to Sauvages,[40] we can see that it was Newtonian physics that caused his dissatisfaction with the mechanical account of the body. The most important point is that he rejected the notion of the body as a perpetual motion machine. To change the position or motion of a body, force was required; in any actual machine, part of the moving force was consumed in overcoming resistance, and only what remained produced useful work: No result was greater than its cause, no motions were multiplied. His model of a machine was the pulley, which mechanists like Martinez had held multiplied motions, but in which Sauvages balanced his equation of motion by distinguishing between force and velocity, so that $FC = PV$, where F is the force (weight) applied to the pulley, C is the velocity of the part it is applied to, P the suspended weight, and V the velocity at which it moves. From Newton, Sauvages accepted that motion was lost in collision (friction in the case of the circulating fluids) and that there must be a constant generation of new motion. The problem of dynamic physiology was squarely put by Sauvages, who said that in any actual hydraulic machine the ratio of ingoing to outgoing forces after loss by friction was 27:4. This made it quite impossible that the product of such a machine, that is, the animal spirits of the mechanists, should retain enough force to account on their own for muscular motion, including the beat of the heart, which in the traditional mechanist scheme was the source of all motions in the body, including that by which the animal spirits themselves were separated from the blood. As remarked previously, the heart was the critical case in these disputes for this reason, and the post-Harveian work on the circulation of the force of the heart by Borelli, Keill, Hales, Jurin, and others was closely and mathematically examined by the animists to prove the existence of a mover external to the hydraulic machine of the body.

Sauvages also denied 'libration' in the form of 'perfect elasticity'; again, he demonstrated the loss of motion in quantitative terms by measuring the decreasing distance of rebound in a bouncing ball, which he explained by assuming that motion was lost through internal friction and dissipated as sound and vibration of impact. The result of all this was to show that a pure hydraulic machine, conceived on Pitcairne's lines, needed a constant supply of a moving force. This was supplied by the essentially living and mobile soul, and there are suggestions in this dissertation that Sauvages conceived this force as being supplied along the nerves by the animal spirits travelling at nearly the speed of light, much as ether had been envisaged. However, as for the critical case of the still-beating isolated heart, Sauvages thought that the soul or vital principle might be distributed through the body and its principal organs. He had not clearly separated the rational *animus* from a nonconscious *anima* on traditional lines, and he stated that the joint principle was the chief characteristic of motion, whether physical or intellectual. This physical motion was direct horsepower, the ultimate answer to the problem of dynamic physiology. He consciously reintroduced one of the traditional faculties of the soul, but paradoxically his proof of the power of the soul made the body into a true hydraulic machine that he discussed quantitatively, whereas the mechanists to whom he was opposed avoided mathematical demonstrations. In line with this argument and opposed to that of Stahl, Sauvages said that the soul was bound by strict laws established by the Creator. He used an analogy between the soul and a clavichordist who may play what he pleases but is obliged to express himself according to the accepted scales. The analogy went further and explained how the player may play perfectly without directly attending to the motions of each finger, and even while his mind is occupied by another matter. Unconscious, vital actions were thus explained without involving the conscious rationality of the soul. Here the soul had prescribed laws for itself to enable these vital actions to proceed in the best manner without its perpetual attention. The 'best manner' was originally rational and wise, but became automatic through habit, and also involved the pursuit of Good and the flight from Evil. In medical terms this was the expulsion of morbid matter in disease, or in actions like coughing, which were voluntary (i.e., soul-directed) but automatic (i.e., habituated) upon the stimulus of particles entering the trachea. Finally, the musical analogy was extended to explain how the vibrations in the nerves of the brain were related to mental events: Such vibrations were 'isochronous' with the action of the *anima*. Although the substrate for these vibrations is not discussed, it is not difficult to see these ideas as a parallel to ethereal, Hartleyian psychology.

Vitalism and the disappearance of ether

In the animism of the eighteenth century the problems of the origin, quantity, and control of motion were squarely faced, and this constituted a major distinction between the animists and the mechanists. Against this background ether had an important role as a source of imposed motion and as a means of communication between body and soul.

The animist–mechanist dispute was not resolved but was transformed into a conflict between various forms of vitalism. In general vitalism avoided the most controversial features of animism and mechanism, particularly the unconscious perception, physiological activity, and even rationality of the immortal and immaterial soul. This was incomprehensible to those whose background was the Continental Cartesian[41] tradition that equated soul with the conscious mind. Most animists avoided the difficulty of unconscious sensation and rationality by attributing strict laws of union to the body–soul duality. Bound by these laws and sometimes located within the tissues, the soul was to a certain extent reduced to a vital force.

Vitalism also avoided the reductionism of the mechanists, a feature that the animists had successfully attacked, mathematically showing the weakness of the mechanical model. Avoiding the worst of both systems, vitalism also combined their best: that is to say, the features with the greatest explanatory value at the time. This came about partly as a result of experimental work, in which the problems of motion we have been discussing were conceived as the very important questions of irritability and sensibility. Experiments exploring the reaction of parts of the body to stimuli invariably involved the nerves, muscles, spinal cord, and brain, and although the competing animists and mechanists believed themselves to differ on fundamental grounds, their experimental results were similar. What emerged was the idea of biological properties, that is, qualities (principally of sensation and motion) that were unique to living systems and not to be derived from a mechanical model.

Hall[42] suggests that these explanations of life fall into three categories in which life was considered as immanent, inhering in a simple form in all matter; emergent, arising through the complexity and organisation of matter; or superadded to matter by a vital principle. In the first two of these categories our problems of motion were again obscured, and, as we have seen before, in such circumstances ether could play no explanatory role. But where motion and life were thought to be imposed the notion of subtle active fluids could again be of use.

Perhaps the most important concept of the later part of the eighteenth century was Haller's notion of *vis insita:* the innate ability of the muscle to contract. We cannot fit this into any of Hall's three categories because of Haller's studious avoidance of speculative explanations. The *vis insita* was a natural, God-given force, indefinitely greater than the stimulus that provoked it (as a small spark may explode any amount of gunpowder), and it did not necessarily arise from the complexity of the parts or reside in the ultimate particles of matter. Haller's limited explanation did not encourage a quantitative approach to the problems of motion, but it did enable him to dismiss all theories of subtle matter as fashionable and rash speculations.[43] This reliance on Newton's principle of limited explanation can be compared to the attack on hypothetical ethereal explanations made by Thomas Reid towards the end of the century.[44]

Only when discussing the motion of the heart did Haller imply that motion may depend upon complexity of structure (the unique branching of the muscle fibres of the heart), in which case the *vis insita* of the heart would be emergent. The difficulty with emergence was to decide at what stage of increasing complexity the nonliving becomes living, and one answer to this was to assume that at all stages matter had some form of life; that is, to posit the notion of immanence. Later writers like Maupertuis, writing in the middle of the eighteenth century, seemed to recall the doctrine of Glisson in claiming that the particles of matter have some form of 'desire, aversion and memory'.[45]

Although ether played no part in the immanent and emergent forms of vitalistic theory, it could be used where motion and life were considered to be imposed upon matter. This form of vitalism differed from animism in that the ultimate principle of life was no longer the immortal soul of Christian tradition, but some separate vital principle, and ether was less an agent of communication and more a vital principle itself. Again, it was the stubborn idea that matter, or at least some matter, was inert and passive that called upon a separate principle to explain life and motion. The *matière vive et brute* of Buffon is an example we have already met, and later in the century, Buffon's compatriot Bergier attacked d'Holbach's system of nature and defended theology on the basis of motion imposed upon inert matter.[46]

Much of what has now been said on vitalism can be illustrated by reference to the Montpellier followers of Sauvages. Theophile de Bordeu emphasised the biological properties of sensibility and irritability, of which each organ had its own kind, and which together constituted a principle of life quite distinct from the rational soul. Bordeu's student thesis also reveals his familiarity with the ideas of Glisson.[47] The views of Bordeu's successors at Montpellier had considerable influence in France. Menuret de Chambaud and Henri Fauquet published the new physiology in the *Encyclopédie*, and the 'organicism' of Bordeu is held to have been a model for Bichat's 'organic sensibility', one of the five fundamental vital forces described by him. P. J. Barthez adopted a Newtonian concept of the inertness of matter, and the vital principle to which he appealed as an answer to the problem of motion in the body was developed from Bordeu's account. In places, Barthez implied that the vital principle was a subtle fluid, but he always denied that it acted as an intermediary between body and soul.

Notes

1 See the opening chapters of Galen, *On the natural faculties*, trans. A. J. Brock (London, 1916).

2 A useful summary of Galen's physiology is given by M. T. May in her translation of Galen's *On the usefulness of the parts of the body*, 2 vols. (Ithaca, N.Y., 1968), 1:44–64.

3 *De motu animalium*, 701b (see also *De anima*, 432a), in Aristotle, *The works of Aristotle*, trans. J. A. Smith and W. D. Ross, 12 vols. (Oxford, 1908–52).

4 F. Glisson, *Tractatus de natura substantiae energetica* (London, 1672), 186 ff.

5 G. Cheyne, *An essay of health and long life*, 8th ed. (London, 1734), 144–55.

6 See his account of the differences between his system and that of Stahl: F. Hoffmann, *Opera omnia physico-medica* (Geneva, 1748–9), and *Supplementum pars secunda* (Geneva, 1749), separately paginated.

7 T. Willis, *The remaining medical works*, trans. S. P.[ordage] (London, 1681), 88.

8 Glisson, *Tractatus*, the *ad lectorem* and passim.

9 For example, F. Hutcheson, *Synopsis metaphysicae, ontologiam et pneumatologiam complectens*, 4th ed. (Glasgow, 1756).

10 For example, M. H. Otto, *Elementa juris naturae et gentium* (Halle, 1738).

11 J. A. Borelli, *De motu animalium*, 2nd ed. (Leiden, 1685), pt. 2, 109.

12 But see A. Stuart, 'Experiments to prove the existence of fluid in the nerves', *Philosophical Transactions 37* (1731–2), 324.

13 G. D. Santorini, *Opuscula medica* (pt. 2: *de nutritione animalium*), (Rotterdam, 1719), 117.

14 Hoffmann, *Opera* (the fifty-eighth and fifty-ninth 'difference'), 25.

15 A number of authors are listed by A. von Haller, *Elementa physiologiae corporis humani*, 8 vols. (Lausanne, 1756–66), 4:378.

16 Reported by Haller, *Elementa physiologiae*, 1:500, 501.

17 J. Tabor, *Exercitationes medicae* (London, 1724), 301.

18 See the article 'Aether', in *Encyclopaedia Britannica*, 3 vols. (Edinburgh, 1771). The Edinburgh student attacked in this article was G. R. Brown. Mendelsohn (1964), 111.

19 T. S. Hall, *Ideas of life and matter*, 2 vols. (Chicago, 1969), 2:116–7, 8–9.

20 J. Hodge, 'Lamarck's science of living bodies', *British Journal for the History of Science 5* (1971), 323–52.

21 J. Gottsched, *Dissertatio de motu musculorum* (Köningsberg, 1694), 383.

22 M. Martinez, *Observatio rara de corde in monstroso infantulo, ubi obiter, et novo de motu cordis, et sanguinis agitur* (Madrid, 1723).

23 G. E. Stahl (praeses), *Dissertatio physiologico-medica de sanguificatione in corpore semel formato* (Halle, 1704). This dissertation was disputed in April 1684.

24 It is unlikely that the Newtonian Langrish derived his idea of ether from Hoffmann, as Schofield (1970), 194, suggests.

25 A. Baxter, *An enquiry into the nature of the human soul*, 3rd ed., 2 vols. (London, 1745), 1:147.

26 B. Langrish, *A new essay on muscular motion: founded on experiments, observations, and the Newtonian philosophy* (London, 1735).

27 Royal Society of London, *Philosophical transactions from their commencement in 1665 to the year 1800, abridged by . . . C. Hutton, G. Shaw and R. Pearson*, 18 vols. (London, 1809), 10 (pt. 2):1199.

28 B. Robinson, *A treatise on the animal oeconomy* (Dublin, 1732).

29 W. Cowper, *Myotomia reformata* (London, 1724), lxiii.

30 G. Thomson, *The anatomy of the human bones* (London, 1735).

31 D. Hartley, *Observations on man, his frame, his duty and expectations*, 2 vols. (London, 1749), 1:511.

32 W. Battie, *A treatise on madness* (London, 1758), 25.

33 F. Quesnai, *Essai physique sur l'oeconomie animale*, 2nd ed., 3 vols. (Paris, 1747).

34 See Otto, *Elementa juris*, 10, 64, 92–7.

35 Quesnai, *Essai*, 3:120.

36 J. Bajollet, *Vitae ac mortis animalium conspectus medico-mechanicus* (Montpellier, 1735).

37 N. Cambray, *Dissertatio de vita corporis humani* (Montpellier, 1738). Cambray is recorded as the author, there being no professor as praeses.

38 Sauvages speaks of these dissertations as expressions of his own ideas. See R. K. French, 'Sauvages, Whytt and the motion of the heart: aspects of eighteenth century animism', *Clio Medica 7* (1972), 35–54.

39 R. Descartes, *Treatise of man*, trans. T. S. Hall (Cambridge, Mass., 1972), 35; L. Bellini, *De urinis, de sanguis missione et de febribus* (Frankfurt, 1698) (see *De sanguis missione*, 165: *De stimulis*).

40 The most complete statement of Sauvages' physiology is his *Physiologiae elementa* (Amsterdam, 1755). A terse essay is appended to his translation of Stephen Hales's *Haemastaticks*, in which he reveals his debt to the Newtonians. See E. [Etienne, i.e., Stephen] Hales, *Haemastatique, ou la statique des animaux* (Geneva, 1745).

41 The Cartesian tradition continued strong in France until challenged by Sauvages and his followers. The influence of Stahl was greatest in Germany, and was taken up with modification in Britain. The Low Countries retained the modified mechanism of Boerhaave, and the influence of the Italian mechanists prevented wide adoption of animism in Italy. See Haller, *Elementa physiologiae*, 1:bk. 4, and 4:bk. 2.

42 Hall, *Ideas of life and matter*, 2:pt. 5.

43 Haller, *Elementa physiologiae*, 8:378.

44 For Haller's work on irritability (and sensibility), which has received much attention from the historians, see his *A dissertation on the sensibility and irritability of the parts of animals* (London, 1755; reprinted with an introduction by O. Temkin, Baltimore, 1936). A more detailed discussion is given in Haller's *Elementa physiologiae*, 1:459–505, on the motion of the heart, and 4:514–63, on the contraction of muscles. The ultimate divine origin of the biological property of irritability is set out in the small tract *Ad Roberti Whyttii nuperum scriptum apologia* (Roche, 1764). Thomas Reid, the Scottish commonsense philosopher, wrote an unpublished paper

on muscular motion towards the end of his life (he died in 1796): '*Animal Spirits* . . . and vibrations in an elastick Ether which pervades all Bodies are all Hypotheses, and like all other hypotheses in Philosophy, labour under two defects. First they suppose the Existence of certain things of whose existence we have no Evidence, and Secondly when they are supposed to exist they do not account for the phenomena they are brought to explain . . . [Nervous transmission and muscular contractions cannot] be accounted for by any laws of Mechanism we know. It is something beyond Mechanism and of a superior Nature'. Transcript in the possession of Mr. G. Davidson of the Medical School, University of Aberdeen. See also T. Reid, *Essays on the powers of the human mind,* 3 vols. (Edinburgh, 1819), 1:121–38.

45 Hall, *Ideas of life and matter,* 2:25.

46 N. S. Bergier, *Examen du materialisme,* 2 vols. (Paris, 1772), 1:11.

47 I am indebted for this information to Dr. Elizabeth Haigh, who allowed me access to the typescript of her forthcoming book on French vitalism.

4

The theological significance of ethers

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During the period covered by this volume, the discussion of ether theories was not limited solely to assessing their explanatory power but also covered their more general functions. In particular, many writers employed ether theories to help solve theological problems, and in this way ethers bridged scientific and theological contexts. The major problem that lay behind the theses discussed herein concerned the relationships between God and the physical universe and between mind (or spirit) and matter. Although comparatively few of those who subscribed to ether theories discussed their theological significance explicitly, the concept of ether was employed throughout the eighteenth and nineteenth centuries in the solution of this classic enigma of dualism.

For convenience the general problem of dualism will be subdivided. Five particular but related problem areas can be identified for which ethers were important, and these will be discussed in turn and illustrated with examples derived principally from British writers. The first section of this chapter concerns the role of ethers in natural theology, and the second explores their cosmological functions; ethers were sometimes related to the ultimate structure of matter and were equated with the protoplast. Third, ethers were employed to account for all motion and activity in the universe, thereby provoking theological responses ranging from assertions that ethers had biblical roots to claims that the role of God was being challenged by atheists who tried to account for all motion by a mechanical fluid. A related problem is discussed in the fourth section, which concerns the role of ethers as intermediaries either between God and the physical universe or, analogically, between mind and matter. Finally, the diverse relations between ether and spirit are analysed.

These five problem areas were widely recognised during the eighteenth and nineteenth centuries, and yet only a small proportion of writers utilised ethe-