Edited by

Paul Davies
and Niels Henrik
Gregersen

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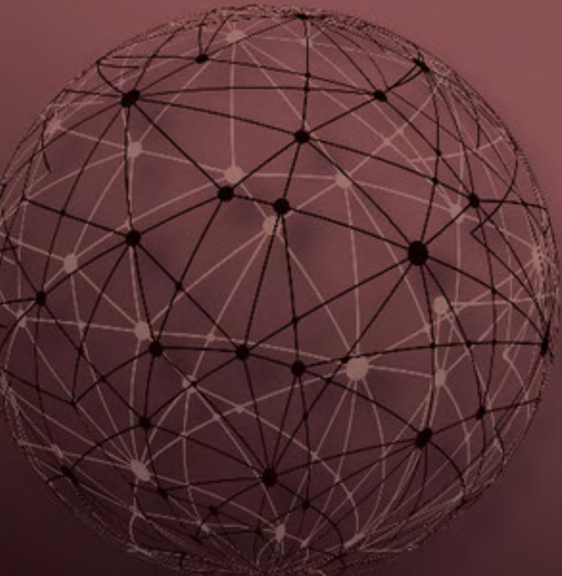

INFORMATION AND THE NATURE OF REALITY

FROM PHYSICS TO METAPHYSICS

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PAUL DAVIES (PhD London, 1970) has held university positions at Cambridge, London, Newcastle, Adelaide, and Sydney before joining Arizona State University as Professor and Director of Beyond: Center for Fundamental Concepts in Science. He has helped develop quantum field theory, and alongside his scientific work in cosmology and atomic astrophysics he has maintained interests in the origin of time asymmetry and astrobiology. He has written more than 25 books, both popular and specialist works, including *About Time* (1995), *The Fifth Miracle* (1998), *How to Build a Time Machine* (2002), *The Goldilocks Enigma* (2007) and *The Eerie Silence* (2010). He has received many awards, including the 2001 Kelvin

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ARTHUR R. PEACOCKE (1924–2006) was a biochemist and theologian from Oxford University. Having taught at Birmingham he returned to Oxford in 1959 as Professor of Physical Biochemistry. In this capacity he published more than 125 papers and three books. Later he resumed his theological interests, became ordained in 1971, and went to serve as Dean of Clare College, Cambridge University. In 1985 he became the founding director of the

He has been Director of the University's Internationales Wissenschaftsforum and is currently the Director of the Research Center for International and Interdisciplinary Theology. His method is to work through Biblical traditions as well as through contemporary philosophical, sociological, and scientific theories to address questions of contemporary culture and religion. His influential works in theology include *Creation and Reality* (1999), *What Happens in Holy Communion?* (2000), and *God the Spirit* (2004). Contributions to science and religion include *The End of the World and the Ends of God* (2000) and *Faith in the Living God* (with John Polkinghorne, 2001).

ACKNOWLEDGMENTS

This book grew out of a symposium held in the Consistorial Hall of Copenhagen University on 17–19 August 2006 under the aegis of the John Templeton Foundation and the Copenhagen University Research Priority Area on Religion in the 21st Century. The aim of the conference was to explore fundamental concepts of matter and information in current physics, biology, philosophy and theology with respect to the question of ultimate reality.

We, the editors and co-chairs, arranged the symposium 'God, Matter and Information. What is Ultimate?' in close collaboration with Dr Mary Ann Meyers, the Director of the Humble Approach Initiative under the John Templeton Foundation. The Humble Approach supports cutting-edge interdisciplinary research, insofar as it remains sensitive to disciplinary nuances, while looking for theoretical linkages and connections. Such studies are especially needed in areas of research that are central to the sciences, pertinent for a contemporary metaphysics, and yet are difficult to conceptualize and present in overview.

We are grateful to Mary Ann Meyers for her ongoing enthusiasm and expertise, and to the John Templeton Foundation for sponsoring the symposium so generously. We also want to thank the Editorial Director of Cambridge University Press, Dr Simon Capelin, for his assistance and encouragement in the publication of this book, and the anonymous peer reviewers who supported it. Lindsay Barnes and Laura Clark of the Press have set the editorial standards for this volume and worked in close collaboration with graduate student Trine-Amalie Fog Christiansen at Copenhagen University, who worked as a research assistant on this book and time and again showed her analytical skills. We owe thanks to her, and to Mikkel Christoffersen for assisting in the last phase of the production and for preparing the index.

With two exceptions, all papers grew out of the Copenhagen symposium. We asked Professor Philip Clayton to write a brief philosophical history of the concept of matter, with special emphasis on modernity, and we thank him for doing this so swiftly and well. We also wanted to include the programmatic article of the late evolutionary biologist John Maynard Smith, 'The Concept of Information in Biology' (*Philosophy of Science* 67(2), June 2000); we acknowledge the journal for giving us the permission to reprint this article as Chapter 7 of this volume.

This volume is dedicated to the memory of Arthur Peacocke who, sadly, died on 21 October 2006. Arthur Peacocke was part of the group, but because of his illness he could not attend the conference, so his paper was discussed in his absence. Chapter 12 in this volume is one of the last works from his hand. Peacocke's research in biochemistry and in the intersection of theology and science is highly regarded, and his intellectual testimony can be found in his posthumous *All That Is: A Naturalistic Faith for the 21st Century* (Fortress Press, 2007). But for many of us, Arthur was not just a great scholar, but a mentor, a fellow-inquirer, and a friend who continued to listen, explore, and ask for more. We are indeed indebted to Arthur for his personal combination of rigour and generosity.

1

Introduction: does information matter?

PAUL DAVIES AND NIELS HENRIK GREGERSEN

It is no longer a secret that inherited notions of matter and the material world have not been able to sustain the revolutionary developments of twentieth-century physics and biology. For centuries Isaac Newton's idea of matter as consisting of 'solid, massy, hard, impenetrable, and movable particles' reigned in combination with a strong view of laws of nature that were supposed to prescribe exactly, on the basis of the present physical situation, what was going to happen in the future. This complex of scientific materialism and mechanism was easily amalgamated with common-sense assumptions of solid matter as the bedrock of all reality. In the world view of classical materialism (having its heyday between 1650 and 1900), it was claimed that all physical systems are nothing but collections of inert particles slavishly complying with deterministic laws. Complex systems such as living organisms, societies, and human persons, could, according to this reductionist world view, ultimately be explained in terms of material components and their chemical interactions.

However, the emergence of thermodynamics around 1850 already began to cast doubt on the universal scope

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quantum information science, which sets as a major goal the construction of a quantum computer – a device that can process information at the quantum level, thereby achieving a spectacular increase in computational power. The secret of a quantum computer lies with the exploitation of genuine quantum phenomena that have no analogues in classical physics, such as superposition, interference, and entanglement. Quantum computation is an intensely practical programme of research, but Lloyd uses the concept of quantum information science as the basis for an entire world view, declaring that the universe as a whole is a gigantic quantum computer. In other words, nature processes quantum information whenever a physical system evolves.

Lloyd's proposal forms a natural extension of a long tradition of using the pinnacle of technology as a metaphor for the universe. In ancient Greece, surveying equipment and musical instruments were the technical wonders of the age, and the Greeks regarded the cosmos as a manifestation of geometric relationships and musical harmony. In the seventeenth century, clockwork was the most impressive technology, and Newton described a deterministic clockwork universe, with time as an infinitely precise parameter that gauged all cosmic change. In the nineteenth century the steam engine replaced clockwork as the technological icon of the age and, sure enough, Clausius, von Helmholtz, Boltzmann, and Maxwell described the universe as a gigantic entropy-generating heat engine, sliding inexorably to a cosmic heat death. Today, the quantum computer serves the corresponding role. Each metaphor has brought its own valuable insights; those deriving from the quantum computation model of the universe are only just being explored.

In the absence of a functional quantum computer, the most powerful information-processing system known is the human brain (that may change soon, as even classical computers are set to overtake the brain in terms of raw bit flips). The relationship between mind and brain is the oldest problem of philosophy, and is mirrored in the context of this volume by the information–matter dichotomy. Crucially, the brain does more than flip bits. Mental information includes the key quality of semantics; that is, human beings derive understanding of their world from sense data, and can communicate meaning to each other. The question here is what can, and what cannot, be explained merely by digital information, which is formulated in terms of bits without regard to meaning. When the foundation for information theory was laid down by Shannon, he purposely left out of the account any reference to what the information means, and dwelt solely on the transmission aspects. His theory cannot, on its own, explain the semantics and communication of higher-order entities. At most, one could say, as Deacon suggests in Chapter 8, that Shannon focused on the syntactic features of an information potential.

The foregoing properties of the mental realm are closely related to the issue of consciousness. How the brain generates conscious awareness remains a stubborn mystery, but there is a well-established school of thought that maintains it has something to do with quantum mechanics. Certainly the role of the observer in quantum mechanics is quite unlike that in classical mechanics. Moreover, if quantum mechanics really does provide the most fundamental description of nature, then at some level it must incorporate an account of consciousness and other key mental properties (for example, the emergence of semantics, the impression of free will). For many years, Henry Stapp has championed the case for understanding the mind and its observer status in a quantum context, and in Chapter 6 he sets out a well-argued case both for taking consciousness seriously (that is, not defining it away as an epiphenomenon) and for accommodating it within a quantum description of nature.

The third challenge to the inherited assumptions of matter and the material comes from evolutionary biology and the new information sciences, which have made revolutionary discoveries since the 1940s and 1950s. Placed at the interface of the physical and cultural sciences, biology plays a pivotal role in our understanding of the role of information in nature. In Chapter 7 John Maynard Smith argues that the biological sciences must be seen as informational in nature, since the sequence structure of DNA is causally related, in a systematic way, to the production of proteins. In the nineteenth century, living organisms were viewed as some sort of magic matter infused with a vital force. Today, the cell is treated as a supercomputer – an information-processing and -replicating system of extraordinary fidelity. The informational aspects of modern molecular biology are conspicuous in the way that gene sequencing and gene pathways now form the foundation for understanding not only evolutionary biology, but also cell biology and medicine. In Chapters 8 and 9 Terrence Deacon and Bernd-Olaf Küppers offer two distinct naturalistic views about how the crucial *semantic* levels of information might emerge via thermodynamical (Boltzmann) and evolutionary (Darwinian) processes. Both accounts argue that biological information is not only instructional but also has to do with ‘valued’ or ‘significant’ information, which puts the receiver in the centre of interest. Significant information, however, is always a subset of a wider set of informational states, which may be described as the underlying ‘information potential’. With this background, Deacon presents a naturalistic theory of the emergence of contextual information; that is, the capacity for reference and meaning, which he describes in terms of the notion of ‘absent realities’. This he accomplishes by combining the Shannon–Boltzmann view that information is always relative to a statistical information potential, with the Darwinian emphasis on what actually works for an organism in its pragmatic setting. In Chapter 10 Jesper Hoffmeyer then presents a biosemiotic proposal, which questions the overarching role of genetics, and rather opts for the importance of a cell-centred view. Finally, in Chapter 11, Holmes Rolston offers a natural history of the emergence of an informed concern for others. Evolution is a notoriously ‘selfish’ process, but eventually it generates systems that display altruism and exhibit concern for other beings. With the increase of sense perception and the top-down capacities of mammalian brains, an ethical dimension of nature arrives on the evolutionary scene. A cell-centred view is not necessarily a self-centred view.

It would be wrong to claim that the science-based chapters collectively amount to an accepted and coherent new view on the fundamental role of information in the material world. Many scientists continue to regard matter and energy as the primary currency of nature, and information to be a secondary, or derived concept. And it is true that we lack the informational equivalent of Newton's laws of mechanics. Indeed, we do not even possess a simple and unequivocal physical measure for information, as we have for mass and energy in terms of the units of *gram* and *joule*. Critics may therefore suspect that 'information' amounts to little more than a fashionable metaphor that we use as a shorthand for various purposes, as when we speak about information technologies, or about anything that is 'structured', or some way or another 'makes sense' to us.

The incomplete nature of information theory is exemplified by the several distinct meanings of the term 'information' used by the contributors in this volume. Quantum events as informational qubits (Lloyd), for example, have a very different character from Shannon-type digital information, or as mere patterns (Aristotelian information), and none of the foregoing can much illuminate the emergent concept of *meaningful* information (semantic information). In spite of the tentative nature of the subject, however, two reasons can be offered for giving information a central role in a scientifically informed ontology. The main point is that information makes a causal difference to our world – something that is immediately obvious when we think of human agency. But even at the quantum level, information matters. A wave function is an encapsulation of *all that is known* about a quantum system. When an observation is made, and that encapsulated knowledge changes, so does the wave function, and hence the subsequent quantum evolution of the system. Moreover, informational structures also play an undeniable causal scientific perspectives of matter and information summarized in this volume give fresh impetus to a reinterpretation of important strands of the Biblical traditions. Gregersen shows how the New Testament concept of a 'divine Logos becoming flesh' (John 1:14) has structural similarities to the ancient Stoic notion of Logos as a fundamental organizing principle of the universe, and should not prematurely be interpreted in a Platonic vein. The Johannine vision of divine Logos being coextensive with the world of matter may be sustained and further elucidated in the context of present-day concepts of matter and information, where the co-presence of order and difference is also emphasized. A typology of four types of information is presented, reaching from quantum information to meaning information. In the final essay, Welker suggests that interdisciplinary discussions (between science, philosophy, and theology) should be able to move between more general metaphysical proposals and the more specific semantic universes, which often are more attentive to the particulars. One example is Paul's distinction between the perishable 'flesh' and the possibility of specific 'bodies' being filled with divine energy. Such distinctions may also be able to catch the social dimensions of material coexistence, which are left out of account in more generalized forms of metaphysics. According to Paul, the divine Spirit may saturate the spiritual bodies of human beings and bring them into communication, when transformed in God's new creation.

Our hope is that the selection of essays presented in this volume will open a new chapter in the dialogue between the sciences, philosophy, and theology.

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PART I

HISTORY

2

From matter to materialism . . . and (almost) back

ERNAN McMULLIN

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The matter concept has had an extraordinarily complex history, dating back to the earliest days of the sort of reflective thought that came to be called 'philosophy'. History here, as elsewhere, offers a valuable means of understanding the present, so it is with history that I will be concerned – history necessarily compressed into simplified outline.

This story, like that of Caesar's Gaul, falls readily into three parts. First is the gradual emergence in early Greek thought of a factor indispensable to the discussion of the changing world and the progressive elaboration of that factor (or, more exactly, cluster of factors) as philosophic reflection deepened and divided. Second is the radical shift that occurred in the seventeenth century as the concept of matter took on new meanings, gave its name to the emerging philosophy of materialism and yielded place to a derivative concept, mass, in the fast-developing new science of mechanics. Third is the further transformation of the concept in the twentieth century in the light of the dramatic changes brought about by the three radically new

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ordinarily fully realized in the individual member of the species.

Aristotle began from the logic of change-sentences (McMullin, 1965). In contrast to Parmenides, who attempted to generate paradox by construing change as a movement from non-Being to Being, Aristotle saw such sentences as triadic: a subject (a leaf, say), a predicate (brown), and a lack, to begin with, of that predicate (non-brown). This allowed him to point out that the original lack cannot be regarded as non-Being; it conveys something real, namely the capacity or potentiality to become brown, a distinctive fact about the leaf. The 'matter' of the change is that which remains throughout – but it also, crucially, is the bearer of potentiality. Green leaves, though not brown, have the distinctive potentiality to turn brown at some point. This is something real about leaves, a potentiality that is crucial to our understanding of what leaves are. This important moral is one that may be drawn from every sentence that denotes a change.

The world for Aristotle was made up of substances, unities that exist in their own right as living things do. What if one of these ceases to be? What occurs is a change, not a replacement, so something must remain the same. The matter of such a change cannot have properties of any kind, he argued, for if it does, it must itself be a substance – which would mean that the change itself in that case would not be a truly substantial one. (This is his main objection to the various sorts of underlying 'stuff' postulated by his Ionian predecessors.) This led him to introduce first, or 'prime', matter, something that lacks all properties of its own and functions only to ensure the continuity, and hence the reality, of substantial change.

Aristotle himself had little to say about prime matter, but his successors invested much effort in attempting to clarify this controversial notion.

What stands out in this story is that matter, as the one who introduced the term understood it, is not distinguished by any particular property. In the case of ordinary (non-substantial) change, the 'matter' ('second' matter, as it came to be called) is just the subject of the change, whatever its properties happen to be (a leaf, for instance). Where the change is substantial, the matter is necessarily property-less, not a constituent in the ordinary sense but something that came to be described as a metaphysical principle (McMullin, 1965, pp. 173–212). But whether it possesses formal properties or not, matter was seen by Aristotle first and foremost as the bearer of potentiality.

There were other features of the matter concept that came in for fuller treatment in the later medieval tradition. One was individuation (Bobik, 1965). Aristotle's substances had form and matter as co-principles or aspects, each requiring the other in order to constitute an existent thing. Form obviously could not individuate; it could be instantiated indefinitely many times. So individuation would have to come from the side of matter, and prime matter at that. But how? Prime matter was supposed to be indeterminate. Individuation clearly had something to do with location in space and time. After much discussion, it was decided that these properties belonging to the Aristotelian category of quantity would have to be part, at least, of the thing that designated something as an individual: '*materia signata quantitate*', as the phrase went. It was not at all clear that this new role attributed to matter was compatible with the earlier account of substantial change, although individuation clearly was involved in the ensuring of continuity of a body through such change.

What should be noted, however, is the introduction at this point of the notion of a 'quantity of matter' (Weisheipl, 1965). That would bear fruit in a different context – in the study, for example, of the phenomena of rarefaction and condensation, taken to be straightforward examples of substantial change of one element (water, say) into another ('air', or vapour). There are clearly quantitative constraints on such a change; the quantity of some 'stuff' otherwise indeterminate must be conserved. Richard Swineshead suggested, on intuitive grounds, that the quantity of this stuff, the quantity of matter, should be proportionate to the volume as well as to the density of the body concerned: the definition that Newton would later adopt as his own.

Parallel to this but in the very different context of motion, Jean Buridan postulated an 'impetus' in the case of moving bodies that is conserved in unimpeded motion and is a measure of resistance to change of motion. He too made it proportionate to the body's quantity of matter. The quantification of matter in this context was obviously a major step towards the mechanics of a later age. The issue of conservation had pointed Aristotle to the concept of matter in the first place, but now it was leading in a very different direction, one he had surely not anticipated.

One other development owed more to Plato than to Aristotle. From the beginning, Christian theologians favoured the strong dualism of body and soul that characterized the neo-Platonic tradition. This dualism was also described as being between 'matter' and 'spirit', thus leading to another rather different sense of the term matter – namely as a generic term that describes any item in the physical world. To be 'material' in this sense is simply to belong to the physical world, the contrast here also often described as being between the corruptible and the incorruptible. The operation of the human intellect was taken to be of a 'non-material' sort, incapable of being reduced to 'material' categories; indeed (as Aquinas and others held), ultimately independent of the operation of the brain. Defining mind in terms of the immaterial or the non-material would leave behind the issue of how the boundaries of 'material' action were to be drawn. No one at that earlier time could have guessed how difficult that would later become.

2.2 Phase two: transformation

The seventeenth century marked a transformation in the concept of matter; one in which the burgeoning science of mechanics played the principal role. With the shift of focus from the world of living things to the more generic topic of bodies in motion came the rejection of the Aristotelian category of substance that had depended so much on the organism as paradigm. And with the disappearance of substantial form came the removal of the barrier to regarding change as involving 'stuff' with specific properties. In this reversal, Descartes played an important part (Blackwell, 1978). Convinced that the world should be fully intelligible to the human mind, and convinced further that the intelligibility of geometry furnished the model he needed, he equated the stuff of which the world was made – its 'matter' – with extension. Reducing the matter of bodies to their extension, a combination of their volume and their shape, would make the world fully amenable to the methods of geometry. The science of motion could then be rendered entirely mathematical, with the help of two intuitive principles: conservation of motion; and restriction of action between bodies to contact only.

However, there were some obvious barriers in the way of such a reductive picture of matter. First, the property of impenetrability would have to be smuggled in: extensions as such cannot collide! Second, and more serious, the lack of anything corresponding to density would make the construction of a plausible mechanics very difficult, if not impossible. Bodies of different densities obviously have different mechanical properties. Third, as matter and extension are the same, there is no empty space. How then are bodies to move? Descartes displayed extraordinary ingenuity in an effort to get around these and other difficulties, but it eventually became clear that a matter with only the single property of extension could not furnish the basis for an adequate mechanics.

The incentive for such a reduction remained, however, although now more realistically moderated to admit a handful of properties besides shape and volume: impenetrability, mobility, inertia, and perhaps density. There was a way of getting round admitting this last property: if one adopted the corpuscular model of matter, density could be explained in terms of degree of packing of corpuscles (assumed to be of uniform density) in an otherwise empty space. These properties were often defined as the 'primary' qualities of matter, in contrast to the 'secondary' ones. 'Primary' here could mean objective rather than subjective qualities, understanding the latter as dependent in one way or another on a perceiver. Or it could refer to the

the bounds of the mechanical philosophy as it had been understood up to that time. It appeared to pose an unwelcome decision: either to treat it as action at a distance (generally regarded as unacceptable) or as mediated by something across intervening space. Newton himself had showed that this latter could not be a medium possessing inertial mass. But what other alternative was there? Over the years following the publication of the *Principia*, he tried out a variety of ideas, among them an 'elastic spirit' and an 'immaterial' medium (McMullin, 1978b, pp. 75–109). The reductivist concept of matter of the mechanical philosophers was clearly coming under strain at this point.[1]

Furthermore, matter itself seemed to occupy an ever-smaller part of Newton's universe. How were the particles of which light appeared to be composed able to traverse transparent media of considerable thickness? If they struck material corpuscles, they would surely be halted or at least diminished. Transparency could be explained only by postulating that the material corpuscles or atoms occupied merely a tiny part of the transparent body. And if this were so, might it not be the case in non-transparent bodies too? In the opinion of Samuel Clarke, Newton's disciple, the new mechanics entailed the view that matter is 'the most inconsiderable part' of the universe; the immaterial forces that in effect filled space were what really counted. Joseph Priestley would later write that according to the 'Newtonian philosophy' all the solid matter in the solar

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[1] Leibniz was an important contributor to this discussion; see Chapter 3 by Philip Clayton in this volume.

system 'might be contained within a nutshell' (Thackray, 1968).

Roger Boscovich carried this thought to its logical conclusion, dismissing solid extended matter entirely and replacing it with point-centres of force. Besides the long-range gravitational force of attraction, he postulated a short-range force of repulsion that would constitute something like an extended atom around each point-centre. This 'atom' would not have a well-defined surface but the force of repulsion would make penetration more and more difficult, and in the end physically impossible, as the centre was approached.

Before this, potentiality had always been associated with an actuality of some sort. But Boscovich's atoms were not actual; they were themselves potential only, specifying what would happen if . . . If what? Could a potentiality trigger another potentiality? Clearly, a new sort of status was being attached to potentiality here, a kind of shadowy materiality. Others, like Kant in his early writings, would take up the challenge offered by this apparent paradox, noting that it at least avoided the more familiar paradoxes associated with infinite divisibility (Holden, 2006). However, the stubborn actuality of the world of ordinary experience made it difficult to countenance so radical a move.

And this sort of challenge would steadily strengthen as the eighteenth and nineteenth centuries progressed. Static electricity could apparently be stored. Ought it, therefore, to qualify as 'material'? The successes of the wave theory of light suggested an intervening medium of some sort . . . but what sort? Newton had shown that such a medium could not be inertial. But in that case, how could it be material? What was now to count as 'matter'?

It was from electromagnetic, not gravitational, theory that a resolution would ultimately emerge (McMullin, 2002). The successful portrayal of electromagnetism in field terms convinced Maxwell that the field had to be regarded as something more than a convenient calculational device. It had to designate a reality of a new sort, defined by the energy it carried, although understood as pure potentiality. In the earlier days of Newtonian mechanics, energy and momentum only gradually came to be recognized as significant quantities in their own right, mass retaining its dominant role. For a time, it was not clear which of the two, energy or momentum, would prove to have the all-important property of being conserved through change. Finally, that role was bestowed on energy. And with the advent of the field concept, energy did indeed appear to be emerging as a reality in its own right. But how was it to be related to matter? An entirely unexpected answer to that question was soon to make its appearance.

2.3 Phase three: dematerialization?

The physics of the twentieth century led the human imagination into domains stranger and stranger, domains as remote as could be from the comfortably familiar matter of yesteryear. In that respect, the shift might be described as a progressive dematerialization, each stage corresponding to one of the three great advances that physics made in the course of the new century.[2]

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[2] I am particularly grateful to Gerald Jones and William Stoeger S.J. for their unstinting help in illuminating some of the more technical issues discussed in this section, and to Paul Davies for a valuable correction.

2.3.1 *Relativity*

The special theory of relativity ('special' because it deals only with the special case of uniform motion) came as the first warning shock of a radically new era in physics. Its farthest-reaching consequence was assuredly the mass–energy equivalence described in Einstein's famous equation: $E = mc^2$. It implies that rest mass can be transformed into radiation, and vice versa. In a process in which mass is lost (as with certain kinds of fission or fusion at the atomic level), the mass deficit is made up by the release of energy in the form of (massless) radiation as well as the kinetic energy of the final-state particles (if any) involved. Conversely, energy can be transformed into mass in the process of pair creation when the energy available is high enough to transform into the rest masses of the two particles. A gamma-ray (high-energy) photon can create an electron–positron pair if it strikes a nucleus that absorbs the photon's momentum; two such photons in collision in the presence of an electrical charge likewise can create a pair of particles if their joint energies are high enough to supply the two rest masses needed.

This is a startling demotion of matter as the sole carrier of the 'reality' label. Something without mass is, by the Newtonian definition at least, something without any quantity of matter. Massless radiation would not, then, qualify as matter. The Einstein equivalence equation has, in effect, begun the 'dematerialization' of physical reality. The only way in which the world can still be described as the 'material' world, or the term materialism can preserve its original significance, is to redefine 'matter'. But how? Materialism, if one wants to retain the term, seems to have unexpectedly become a much more open doctrine.

In his general theory of relativity, Einstein went on to consider the more complicated case of accelerated motion, and hence of force. Here, the mass–energy equivalence has a further consequence. Whereas in the past mass was the sole measure of gravitational agency, both active and passive, that role is now transferred to mass–energy. In the Einstein field equations, the stress-energy tensor on the right-hand side describes the sources of the gravitational field, and these now include energy, both kinetic and potential, as well as rest mass. These can be summed together with the aid of the equivalence. So a photon, for example, despite having zero rest mass, will exert gravitational force in virtue of its kinetic energy. And a tightly wound watch will contribute slightly more to gravity in virtue of its potential energy than one that has run down.

When Newton defined mass as 'the quantity of matter' for the purposes of his mechanics, he had in mind its inertial and gravitational roles. These roles had by now been enlarged by the two theories of relativity, and mass–energy had taken the place of mass alone in relativistic mechanics.[3] However, rest mass and energy, although physically convertible into one another, still retain their separate identities: rest mass is not a form of energy, and

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[3] It should be noted that in all of this, 'mass' is to be understood as 'rest mass.' An alternative, less popular, usage would redefine 'mass' in relativistic terms to include kinetic and potential energy as well as rest mass. According to this definition, photons would have 'mass' ('relativistic' mass) and the gravitating entity would once again be 'mass' only, but now in an altered sense: one that obscures the still fundamental difference between rest mass and energy.

According to the majority interpretation of the new theory – the so-called 'Copenhagen' interpretation – electrons do not even possess sharp positions or momenta prior to measurement. (A minority view – the 'Bohm' interpretation – still not definitively set aside, would deny this.) They would not, then, qualify as matter, were the classical seventeenth-century type of definition to be maintained. Roughly speaking, electrons seem to travel as waves but to interact as particles.

Even worse, the quantum uncertainty principle applies not only to the position–momentum pair but also to energy–time. It follows that the energy state of the electromagnetic vacuum fluctuates around the zero value, the maximum amount of such a fluctuation in energy being correlated to the maximum time it may persist. (Strictly speaking, what the uncertainty principle entails, as Heisenberg envisaged it, is only that such a fluctuation, were it to occur, could not be observed, not that such fluctuations actually occur. But no matter . . .) The fluctuation is then represented as a 'particle' (a photon) of a certain energy. Since, according to the uncertainty principle, it cannot be observed, it has come to be called a 'virtual' particle. The energy added by its sudden appearance would violate conservation of energy were it to be real, but being only virtual, it is granted a (convenient!) exemption from the conservation requirement.

Although virtual particles cannot, in principle, be observed, the net effect of the quantum energy fluctuations in the vacuum *has* been observed, it is claimed; its magnitude was in fact predicted in advance (the Casimir effect). The effect is tiny, requiring a very demanding level of accuracy in a complex experimental arrangement. This has encouraged the conclusion that the virtual particles (in this case, virtual photons, supposedly infinite in number) are nonetheless 'real' in the sense that 'their indirect effects are measurable' (Krauss, 1989, p. 35). 'No doubt remains that virtual particles are really there' (Barrow and Silk, 1993, pp. 65–66). Whether this constitutes an adequate test of 'reality' is disputed. Others insist that in-principle observability is the ineliminable criterion of what counts as a 'real' particle. At this point, the distinction between 'real' and 'virtual' evidently begins to thin out.

'Virtual' particles make an appearance also in a different quantum context. In order to calculate the interactions between (real) particles in quantum field theory, Feynman introduced a simplified diagrammatic method of estimating the relevant probabilities. The forces involved are represented as the exchange of virtual particles between the real particles, carrying the momentum from one to the other that affects their individual motions. This is then said to resolve the difficulty posed by the apparent action at a distance implicit in Newton's notion of gravitational force. Exchange of momentum via the action of virtual particles that travel from one body to the other at last provides an explanation of gravitational action, so it is claimed, and allows one to dispense with the troublesome notion of force entirely. (Whether this really is an improvement in terms of explanation is not entirely obvious.)

Among physicists themselves, there is an evident division as to the status that should be accorded to this sort of 'virtual' entity (Davies, 2006, p. 74). For example: 'Virtual particles are a language invented by physicists in order to talk about processes in terms of Feynman diagrams . . . Particle physicists talk about [decay] processes as if the [virtual] particles exchanged . . . are actually there, but they are really only part of a quantum probability calculation . . . they cannot be observed' (SLAC, 2006). Yet the metaphor of particle exchange has clearly taken hold in ways that suggest that, for the average physicist, it is something more than a convenient calculational device.

2.3.3 Cosmology

Moving finally to the fast-growing science of cosmology, it too has cast up matter-related surprises of late. After the big-bang theory of cosmic origins received crucial confirmation in the 1960s, the question of the fate of the universe – continuing expansion or eventual contraction – soon became a focus of attention. It turned out that the balance between the two options was an extremely delicate one: the cosmic mass–energy density today had to be in the neighbourhood of a specific ('critical') intermediate value for runaway expansion or rapid collapse to have been avoided, that is, for the universe to be the long-lived one that it evidently is. (Another way of putting it is that the ratio of the actual value to the critical value, symbolized by the Greek letter omega (ω), had to be not too far from unity, ensuring an approximately 'flat' space–time.) The problem was that for this to be the case, the density would have had to be poised close to the critical value, to a fantastic degree of precision, before the cosmic expansion began, because the effect of the expansion would have been to magnify very rapidly any initial deviation from the critical value. This set off the first round in a celebrated debate about what came to be called 'fine tuning' (McMullin, 2008).

In 1981, Alan Guth proposed an ingenious modification of the big-bang theory that involved a gigantic cosmic inflation in the first fraction of a second of the expansion. Over time, the idea proved to have far-reaching consequences, the first of these being a solution of the critical density problem: the inflation would inevitably push the cosmic curvature towards flatness and hence the mass–energy density towards the critical value.[4] To the extent that the theory of inflation is confirmed, the search for an answer to the cosmic curvature question is answered: it is very close to flat.[5] But that now leaves a rather different question: assuming that the ratio of the actual mass–energy density to the critical value is, in fact, very close to unity, where is that amount of mass–energy to come from?

The trouble is that the 'baryonic matter' of which stars and planets (and ourselves) are made does not come even close to bringing the cosmic mass–energy density up to the critical value; its contribution appears to be no more than perhaps 4% of the desired amount. (What is now routinely called 'matter' here includes radiation and the kinetic and potential energies of all known particles, conforming to the revised definition of 'matter' proposed above.) Enter a new sort of matter: called 'dark' originally because it does not interact with the radiation that is the normal indication of matter's presence, but now rather more because its

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[4] In that regard, the repulsive 'gravity' of inflation has the opposite effect to that of the attractive gravity involved in gradually slowing the motions consequent to the original 'big bang'.

[5] Recent measurements of small anisotropies in the cosmic microwave background by the Wilkinson Microwave Anisotropy Probe (WMAP) satellite offer strong confirmation for this important claim.

nature is not at all understood despite the most intensive investigation.

As early as the 1930s it was noted that the motions of galaxies within galactic clusters was more rapid than the amounts of conventional gravitating matter could explain. Many suggestions were forthcoming, among them the possibility that Newton's equations might have to be modified in order to apply over such enormous distances. But the theory that eventually gained wide acceptance was that the galaxies were surrounded by vast clouds of something or other that betrays its presence by a single property only: it exerts gravitational attraction. It is believed to have rest mass. More recently, its effects have been identified in several other contexts: gravitational lensing, and the temperature of the X-ray-emitting gases in galactic clusters, for example.

Nevertheless, despite extended efforts, the composition of dark matter still defies identification. For one thing, the relative cosmic abundances of the lightest elements, calculable on both theoretical and observational grounds, would strongly suggest that dark matter cannot consist of the protons and neutrons that normally make up baryonic matter (Greene, 2004, pp. 432–435). The contribution of dark matter to the cosmic mass–energy density has been estimated by its gravitational effects. However, at around 22%, its contribution was still not enough to bring the total even close to the critical value at which theorists insist it should lie.

Fortunately, another potential contributor has recently made its appearance. Evidence from one type of supernova seems to indicate that the cosmic expansion postulated by the big bang, instead of steadily decelerating up property of negative pressure,[9] let alone one with an energy density that is both unexpectedly tiny as well as possessing a quite precise value,[10] it is fortunate that when the contribution to the cosmic energy total is computed, it turns out to be just sufficient to bring the cosmic energy density to the desired critical value, closing the worrisome gap, and thus affording precious support for the vacuum-energy hypothesis. This would make dark energy by far the main contributor to the energy density of the universe: recent estimates give it approximately 74% of the whole.

The topic of dark energy is quite obviously a work in progress. There are too many unsolved issues, and there is too much dependence on observational evidence not yet within practical reach, to allow confident conclusions to be drawn. It is one thing to say that dark energy, if it existed, could account for several key cosmic features. But it is another thing entirely to explain its origins, to find a place for it in the complex web of contemporary cosmological theory. Still, even at this early stage of what may turn out to be a very long story, it is clear that the consequences

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[9] Although 'negative pressure' sounds counterintuitive, Roger Boscovich and others among Newton's successors speculated about the consequences of introducing gravitational systems that would be partially self-repulsive, i.e. exert 'negative pressure'.

[10] Indeed, the task of finding a theoretical ground for it is so difficult that it has led physicists such as Max Tegmark and Steven Weinberg to postulate a 'multiverse' in order to make it unnecessary to find such a ground (Carr, 2009). The precision of the required value of the vacuum energy density raises once again the issue of cosmic 'fine tuning' that has given rise to so much controversy inside and outside recent cosmology (McMullin, 2008).

for the notion of what our universe is ultimately made are likely to be far-reaching.

2.4 Conclusions

2.4.1 One

The long and complicated history of the matter concept sketched here tells of a continuing effort to find the best ways to penetrate beyond the information given us by our senses to describe how things are and how they came to be. These ways have led far from the simplicities that inspired the hopes of the original inquiry. Aristotle saw matter as, among other things, the reservoir of potentiality. That role has now become the dominant one.

The fields postulated by relativity theory at the scale of the large and of quantum theory at the level of the small are designators of potentiality, of dispositions, of 'what-would-happen-if'. Energy itself is in a real sense an expression of potentiality. It almost seems that it is to the potential, rather than the actual, that reality should be attributed at the most fundamental level. Yet can there be potentialities without the actual? The potentialities here are not indefinite: they are quantified in various ways depending on the kind of field in question. Going from Aristotelian matter to the materialism of the early modern period involved a move from an indefinite potential, constrained eventually only in terms of quantity, to spatially extended, and indisputably actual, hard massy particles. From these particles to the 'matter' of present-day physics could be described as a move back again to potentiality, although no longer indefinite.

2.4.2 *Two*

We have seen that one can go either way with the decision as to whether to limit the scope of the term 'matter' to rest mass, or to extend it to mass–energy so as to include energies related in one way or another to mass. Would that extension alone be enough to secure for matter its traditional role as a generic term for the 'stuff' of physical reality? The present status of dark energy is too uncertain to allow a confident answer. Is dark energy mass-related? It is if the Einstein equivalence holds for it. And its crucial gravitational role would seem to imply that it does. But does that mean that it could be transformed into something possessing rest mass? We have no idea. At any rate, when cosmologists speak of the cosmic 'mass density', it is significant they make it constitute only around a third of the whole, including in it only baryonic and dark matter (see, for example, Peebles and Ratra, 2003). It does not include dark energy.

Also, the implications of the term 'vacuum' ought not to be forgotten: it presumably means that the relevant space is 'empty'. Empty of what? Presumably of rest mass. To all appearances, dark energy as a property of the vacuum would have been present in the 'vacuum' even if there had never been any rest mass at all. That would seem to suggest that it is not, in fact, mass-related. In any event, it appears rather strained to qualify it as 'matter'. If that protean term is to be used at all in the cosmic context, it is best to say that the universe consists of matter *and* energy. And if one has to have a generic term to apply to the universe as a whole, then 'energy', rather than 'mass–energy', would seem (for the moment, at least) to be the proper one. The density term at the cosmic level would then simply be 'energy density'.

2.4.3 Three

What, then, of 'materialism'? Ought that label to be replaced with 'energeticism'? More important than the choice of label, what of the reductionist project that was synonymous with the older materialism? One of the most significant shifts that marked the Scientific Revolution as indeed a 'revolution' was the turn to underlying physical structure as the means of explaining the properties of macroscopic bodies. The further assumption was that the components of the explanatory structure – corpuscles, ethers, and the like – could be fully and finally described in terms of primary qualities themselves familiar from everyday experience. This form of explanation could, then, plausibly be described as 'reducing' the whole to its parts.

Gravity posed a problem, as we saw; no place could be found for it in the categories of the reductive 'mechanical philosophy' of the day. Attributing gravity to matter meant inferring from matter's behaviour in an ensemble to a potential possessed even when the material body was considered on its own. Gravitational mass and inertial mass describe what *would* happen if the body in question were to act gravitationally upon, or be acted upon by, another body. These behaviours are elicited only in the presence of a larger whole. Fields of the kind that define contemporary physics are likewise holistic in nature. They exist throughout an extended region and the field values at any point depend on the values across the field generally.

Inferring from the behaviour of a whole to a quality of its parts expressed only when they are acting as parts of that whole is just the opposite of reduction, understood as explaining the behaviour of a whole in terms of the properties of its parts when these parts are considered in isolation (McMullin, 1972). The former inference might be better described as explaining the parts in terms of the whole. The whole in such a case might still be said to be nothing more in ontological terms than a collection of its parts, but only on condition that the 'parts' are defined in equally ontological terms by the role they play in the whole. Reductionism and holism point in different ways.

2.4.4 *Four*

The strong forms of mind–body (or soul–body) dualism of the past posited a sharp ontological divide between the immaterial and the material, where the former often tended to be defined simply as the negation of the latter. That brisk way of approaching the distinction is no longer adequate. The boundaries of 'material' potentiality, the outer limits of the forms that can emerge in the most complex wholes that energy can sustain, are nowadays not so easily set down. Quantum entanglement and particle creation ought to warn us that further surprises are almost certainly still in store.

At the same time, it should not be supposed either that these scientific developments point to a straightforward reductionist solution of the mind–body problem that has for long proved so teasing to philosophers of mind. Herbert Feigl long ago warned against drawing this inference, attractive though it may seem to some (Feigl, 1962). The

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3

Unsolved dilemmas: the concept of matter in the history of philosophy and in contemporary physics

PHILIP CLAYTON

By the end of the modern period, a particular world view had become firmly entrenched in the public understanding. Unlike most philosophical positions, which are sharply distinguished from scientific theories, this world view was widely seen as a direct implication of science, and even as the *sine qua non* for all scientific activity. For shorthand, let's call this view "materialism."

Materialism consisted of five central theses:

(1) Matter is the fundamental constituent of the natural world.
(2) Forces act on matter.
(3) The fundamental material particles or "atoms" – together with the fundamental physical forces, whatever they turn out to be – determine the motion of all objects in nature. Thus materialism entails determinism.
(4) All more complex objects that we encounter in the natural world are aggregates of these fundamental

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particles, and their motions and behaviors can ultimately be understood in terms of the fundamental physical forces acting on them. Nothing exists that is not the product of these same particles and forces. In particular, there are no uniquely biological forces (vitalism or "entelechies"), no conscious forces (dualism), and no divine forces (what came to be known as supernaturalism). Thus materialism implied the exclusion of dualism,[1] downward causation (Bøgh Andersen et al., 2000), and divine activity.[2]

(5) Materialism is an *ontological* position, as it specifies what kinds of things do and do not exist. But it can also become a thesis concerning what may and may not count as a scientific explanation. When combined with a commitment to scientific reduction, for example, it entails that all scientific explanations should ultimately be reducible to the explanations of fundamental physics. Any other science, say biology or psychology, is incomplete until we uncover the laws that link its phenomena with physics. In its reductionist form – which historically has been its most typical form – materialism thus excludes interpretations of science that allow for "top-down" causation, also known as "strong emergence."[3] Materialists may be divided on

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[1] The classic materialist view of consciousness is expressed in Crick (1994).

[2] The challenge to divine action is well spelled out in a series of books, *Scientific Perspectives on Divine Action*, edited by R. J. Russell, and published by the Vatican Observatory Press. See especially the summary volume in the series by R. J. Russell, N. Murphy, and W. Stoeger (2008).

[3] The distinction between "strong" emergence, which affirms real causal activity at levels of organization higher than physics, and "weak"

> whether, and if so how soon, these reductions will actually be accomplished. Still, it is an entailment of materialism in most of its modern forms that an omniscient knower would be able to reduce all higher-order phenomena to the locations and momentums of fundamental particles.

In the following pages I argue that we have both philosophical and scientific reasons to doubt the adequacy of this widely accepted doctrine of materialism. In the history of Western philosophy, as we will see, it has turned out to be notoriously difficult to formulate a viable concept of matter. And physics in the twentieth century has produced weighty reasons to think that some of the core tenets of materialism were mistaken. These results, when combined with the new theories of information, complexity, and emergence summarized elsewhere in this volume, point toward alternative accounts of the natural world that deserve careful attention and critical evaluation.

3.1 The concept of matter in the history of philosophy

A strange dynamic emerges when one begins to study the history of the concept of matter in Western philosophy. It appears that, each time the greatest systematic philosophers have attempted to define it, it has receded again and again from their grasp. The very philosophers who claim to offer a resolution of the conceptual problems

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emergence, which denies this, goes back to Bedau (1997, pp. 375–399). For more detail on these concepts, see Clayton (2004).

and a synthesis of opposing schools – Plato, Aristotle, Thomas Aquinas, Descartes, Leibniz, Hegel, Whitehead – repeatedly fail to supply a substantive concept of matter, leaving the reader each time merely with lack, or *privatio*: nothing instead of something. When one adds the recurring paradoxes that arise within philosophical theories of matter to the developments in physics sketched in the following section, one begins to wonder whether there is something fundamentally flawed in the idea of a world built up out of matter.

Although the description just given applies to a whole series of philosophers in the West, it fits the philosophy of Plato with particular accuracy. Plato inherited a rich tradition of natural philosophy developed during the pre-Socratic period. Numerous philosophers had developed divergent accounts of what could be the *archē*, or ultimate principle, which for many amounted to an account of the nature and properties of matter. Thus for Thales all was ultimately water; for Empedocles it was the four elements of earth, air, fire, and water; for Parmenides, the *logos*, or reason; and for Heraclitus, the principle of change itself ("you can never step into the same river twice"). Plato realized that this diversity of incompatible positions confronted philosophy with a series of dilemmas: Is everything part of a single unity, or does "the many" represent the ultimate truth? Is change real, or is it illusory? What unifies the diversity of appearances? As is well known, Plato found his solution in the doctrine of the "Forms." What is ultimately real is the *eidos*: the idea of a thing. These ideas exist in a purely intellectual realm and serve as the patterns or exemplars after which all existing things are modeled. This object is a tree because it participates

> forms emerge in matter – living beings come to be . . . It follows that the account of structures existing in the material world cannot be given within the framework of Aristotle's sole theory of matter, and so must involve additional explanatory postulates. (Freudenthal, 1995, p. 2)

In fact, the problem is worse. In Aristotle's system, whenever some thing is differentiated from other things – whenever it is *this* rather than *that* – it is distinguished thanks to its form. Pure matter, then, must be purely undifferentiated stuff. Matter is the *hypokeimenon* (ὑποκείμενον), that which lies beneath (cf. the Latin *subjectum*); it is what takes on all the properties of the thing without itself having any intrinsic properties. But if it has no form and properties of its own, it cannot be directly grasped by reason. Matter as *hypokeimenon* stands closer to the idea of *khôra* ("receptacle") in Plato's *Timaeus* (1965) – the container or space in which something else takes place.[5] Matter is that unknown which, when combined with form, produces this or that specific object. But taken by itself it is completely unknown, mysterious. Matter is that which forever eludes the grasp of the philosopher. (Perhaps this embarrassing consequence of Aristotle's philosophy has something to do with the fact that, when experimental natural science started to emerge in the early modern period, it found itself forced to break free from the strictures of Aristotelian natural philosophy and to begin again on a different basis.)

Predictably, during the many centuries dominated by Platonism, the same difficulties arose that we noted above.

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[5] This is also the sense in which Jacques Derrida uses the term in his famous little book on khôra. See Derrida (1995a).

Plato's great disciple, Augustine, faithfully passed the Platonic view of matter into the tradition of Christian philosophy, where it remained dominant in the West for the next 1000 years. Both matter and evil represented a privation of being or goodness (*privatio boni*) rather than positive principles in their own right. Even Plotinus, the great mystical philosopher who sought to synthesize Plato and Aristotle in the third century, continued the tradition of locating essential reality at, or above, the level of intellect. For him, as for the Gnostic religious philosophies of the Hellenistic period, matter was that from which one must flee in order to experience salvation or liberation – or knowledge. A similar idealist strain continued to dominate through the long history of Neo-Platonism in the West.[6]

Aristotle's old problem was repeated in the work of Thomas Aquinas in the thirteenth century. In contrast to the Platonic theologians, Aquinas sought to affirm the empirical world and to take seriously the creation of a material world by God. Following Aristotle, he viewed objects as a combination of form and matter. At first it looked as though Aquinas was able to offer a more adequate theory of matter than Aristotle because his theology allowed for the possibility that God created the matter of the universe *ex nihilo*. One might expect that the creation of the world by God would lend matter a more solid existence and assure its ontological status.

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[6] This is masterfully demonstrated in the work of Werner Beierwaltes, for example Beierwaltes (1972, 1985) and Beierwaltes, von Balthasar, and Haas (1974).

However, Aquinas, later baptized as "the theologian" of the Catholic Church, failed to solve the conundrum of matter. Since God, the ultimate definer of Being (*esse ipsum*), is pure Spirit, not embodied in or dependent upon matter in any way, the relation of matter to God as its ultimate source remains a dilemma. How could God create something essentially different from himself? (The relation of God to evil remains equally puzzling, again suggesting the parallel that we noted in Augustine: matter ≈ evil.) The problem is reiterated in Aquinas's anthropology: the essence of the human person is the soul, which is each person's "form" or essence. If the person is to be complete, his or her soul must be reunited with the body after death. Yet the nature of this matter, which is somehow supposed to be necessary for full existence, remains unthought. To the extent that Aquinas's theology came to supply a normative framework for much of subsequent Christian theology, especially in the Roman Catholic tradition, his inadequate answer to the problem of matter continues to influence Western thinkers to the present day.

René Descartes, the so-called "father of modern philosophy" in the West, at first seemed to make progress on this ancient dilemma. In his *Meditations* of 1640 (Descartes, 1968–1969), he insisted that there are two ultimate kinds of substance: *res cogitans*, or "thought," and *res extensa*, or "matter." As the text proceeds, however, it gradually becomes clear that, although Descartes has guaranteed matter a clear ontological status, its role remains subordinate to thought. The essence of the person is the mind or consciousness, which stands in an absolute contrast to the body. Thus Descartes writes in the *Discourse*, “I knew I was a substance the whole essence of which is to think, and that for its existence there is no need of any place, nor does it depend on any material thing, so that this ‘me’, that is to say the soul . . . is entirely distinct from the body” (ibid., p. 101). Or, in his most pithy expression, “I exist and am not a body; otherwise, doubting of my body I should at the same time doubt myself” (ibid., p. 319).

Descartes could never solve the problem of the interaction of mind and body because he had defined them at the outset as two diametrically opposed substances with no common ground.[7] Faced with this sort of ultimate dichotomy, all that remains is to center one’s philosophical system on the one or the other. Descartes, still deeply influenced by the disembodied God of Western theism, made the (for him) obvious choice and placed all value upon the side of mind, will, and rationality.

Gottfried Wilhelm Leibniz represents a particularly interesting instance. His metaphysical theories were

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[7] Thus Julius Weinberg writes, “It can be shown that Descartes has two different arguments for the distinction of mind and body. (1) It is possible, i.e. involves no contradiction, to think that I, as thinking, exist and that nothing extended exists, and since the existence, power, and veracity of God assures me that God can bring about whatever I can conceive, it is therefore possible that I exist without a body. Hence, body and mind are really distinct. (2) The essence or attribute of nature which is thought (*cogitatio*) is logically incompatible with that of extension. Hence these attributes cannot belong to one substance but only to two” (Weinberg, 1977, p. 71). Weinberg adds, “Descartes’ interest in the proof of a real distinction between mind and body is, at least, twofold. On the one hand, it forms the basis of a proof of the immortality of the soul . . . On the other hand, Cartesian dualism opens the way to a purely physical or even mechanical account of the physiology of the human body and, indeed, a purely physical account of the natural world” (Weinberg, 1977, p. 72).

highly influential, and through his disciples Wolff and Baumgarten remained dominant in European thought until the time of Kant. Leibniz was deeply intrigued by the development of mechanistic physics in the seventeenth century and contributed to its development in a major way through the invention of the differential calculus. His philosophy of infinitely divisible particles would, he believed, provide a metaphysical platform for unifying this new physics with the Western metaphysical tradition, and with Christian theology in particular. This meant, however, that Leibniz had to show how the resulting universe could be created and ruled by God, could be purposive and meaningful, and could be compatible with the perfect goodness of its omnipotent Creator. With this goal in mind, he defined the existence of individual atoms or "monads" as *purely mental* sources of activity:

> The Monad, of which we will speak here, is nothing else than a simple substance, which goes to make up composites; by simple, we mean without parts . . . There is nothing besides perceptions and their changes to be found in the simple substances. And it is in these alone that all the internal activities of the simple substance can consist. (Leibniz, 1992, pp. 67, 70)

In his lengthy correspondences, Leibniz tried to work out an adequate theory of matter. Taken all together, he argues, the "simple substances" produce the behaviors in the world that physicists study. But individually, each one is as we are: a center of intellectual activity, will, and understanding. Cells and electrons may possess much less understanding than we humans do, but they are mental agents nonetheless. Further, each monad is "windowless," which means that it does not actually perceive its and fragile" (Friedmann, 1962, p. 245f). Throughout the correspondences Leibniz continues to speak as if there is matter, and hence motion and empirical perception. He does well to do so, as a thoroughgoing idealism would make it more difficult (to put it mildly) to individuate the mental substances that are the building blocks of his metaphysics. But matter is at best a by-product of the mental substances, and at worst an illusory category incompatible with what is at root an idealist system. Thus, it appears, the first major metaphysical system written after the dawn of modern physics turns out to be a form of unmitigated idealism. Matter, it seems, is merely an appearance, an illusion foisted upon us by an inaccurate comprehension of the world around us.

Nineteenth-century German philosopher Georg Wilhelm Friedrich Hegel claimed to offer the great philosophical synthesis of all knowledge and of all previous philosophies. He believed that the dichotomy between mind and matter, like all previous dichotomies, was something he could leave behind. In Hegel's writings, one does indeed find numerous attempts to incorporate the results of the natural science of his day. Unfortunately, however, in the development of Hegel's system the concept of mind or spirit (*Geist*) dominates yet again. Although one may not perceive it fully until the end of history, the force that moves all things and propels history forward is Absolute Spirit, not matter. *The Phenomenology of Spirit* (1807) chronicles the history of "Spirit coming to itself"; the history of Spirit, it turns out, provides the ultimate explanation and the ultimate moving force for all that is. If there is a material aspect of the Absolute, it remains strangely silent in Hegel's work. In the end, matter does not play