Article

The Roots of the Western Concept of the "Laws of Nature": From the Greeks to Newton

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This article traces the historical origins of the traditional Western idea of the laws of nature, from the classical period and its biblical roots to the early modern period (Newton). The laws of nature, in this view, are regularities built and sustained by God into the natural world. They are secondary causes, sustained by the ordained power of God. The focus is upon developments in the Middle Ages, especially scientists influenced by Arabic learning and Aristotelian science. I conclude that the division between primary and secondary causes, and between God's ordained and absolute power, is still important for today's religion and science dialogue.

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Hegel taught us that the history of an idea is an important part of understanding the nature of that concept. The first example of this kind of historical explanation, of course, comes not from Hegel but from Aristotle, whose *Metaphysics* (book A) is a historical *tour de force* of the concept of cause. In this article, my purpose is to lay out the historical developments of the idea of "laws of nature" in Western culture, from the earliest sources to the early modern period. I will demonstrate that there has been a common, dominant understanding of the laws of nature in the West, rooted in biblical theism. At the same time, this notion of a law of nature has been understood and developed in diverse ways by particular thinkers from the past. There is a unity of general understanding, and a diversity in the details of how this is worked out.

In this paper,[1] I will outline this unity and diversity and will argue that there is a "traditional" Western idea of the laws of nature. The general idea that a law of nature is a physical regularity built by God into the very fabric of the universe, by means of which (along with other things) he conserves the physical universe in existence throughout time.

As with many of the root ideas of Western culture, the notion of a "law of nature" can be traced back to both Greco-Roman culture and to biblical religion. The notion of a law of nature (Latin: *lex* or *regula naturae*; Greek: *nomos physeos*) has two sources in the classical period: Hellenistic natural philosophy, especially Stoicism; and the Christian patristic tradition.[2] In the Christian case, the God of the Bible is understood as Lawgiver (among other things), but also as Creator. Patristic authors such as Augustine and Basil of Caesarea used the term "laws of nature," and understood these as coming from God the Creator.[3] This was particularly true in those works of the patristic period that sought to harmonize the teachings of the Bible with the then-current science or natural philosophy.[4] For both Augustine and Basil, the natural world operated according to regularities ordained by the divine Creator and Lawgiver.[5] Basil taught, for example, that the various types of fish are assigned to their own watery habitats by "a law of nature."[6] Augustine, too, stated that "the ordinary course of nature in the whole of creation has certain natural laws."[7]

Turning from Christian to pagan sources for Stoic philosophy as well as Roman culture in general, law was an important

Alan G. Padgett, *a Methodist theologian and pastor, is a professor of systematic theology at Luther Seminary in Saint Paul, MN, where he teaches courses in theology and science. A member of ASA, Alan holds advanced academic degrees from Drew University (M.Div.) and the University of Oxford (D.Phil.). After studying natural science, he converted to Christianity and entered the ministry. The author or editor of seven books and numerous articles in philosophy and theology, his most recent work is* Science and the Study of God: A Mutuality Model for Theology and Science *(Eerdmans, 2003). Alan can be reached by email: apadgett@luthersem.edu.*

cultural and religious concept (although arguably not as central as *torah* to Judaism). For the Stoics, God or Zeus is universal Reason (*logos*), the principle of order or law that is immanent in all things and gives structure to both the cosmos and human societies. As early as the third century BC, Cleanthes in his famous *Hymn to Zeus* could write of Zeus as "Universal Nature, piloting all things according to Law."[8] To the classical mind, the heavens seemed particularly good examples of natural bodies obeying the laws of nature. Indeed, the very word "astronomy" indicates this: the law (*nomos*) of the stars (*astros*).

In two other poems about nature influenced by Stoic thought, we also find poetic expression of the "laws of nature." In the famous *De Rerum Natura*, the Epicurean natural philosopher and poet Lucretius (ca. 99 BC–51 AD) tells us that he wished to "teach in my poem how all things are bound to abide in that law by which they were made."[9] Also during the first century AD, the last of the Roman didactic poets, Marcus Manilius, spoke of the laws of nature. Like Lucretius, his poem *Astronomica* is a natural philosophy, but with a specific focus on the heavens. Unlike the Epicurean philosopher, Manilius was more willing to speak of God (in a Stoic sense) as the source of the laws of nature, e.g., "For when God brought the whole universe under law …," or in a more poetic vein, the planets "perform the dances of their orbits which nature's law diversifies."[10]

While poets and patristic writers, therefore, could use the term "law of nature" and mean thereby a principle of order governing natural bodies given by Nature or God, there was no developed conception of a law of nature in the classical period. Natural philosophy tended to be either Platonic or Aristotelian (or something of both), neither one of which gave any centrality to law of nature as we know of it in modern science.[11] We are wrong to think, however, that the bare concept of a "law of nature" cannot be found in the classical period.

In the Middle Ages, the notion of a law of nature, especially the relationship between God and the world, was given further philosophical development by Christian thinkers. To take an early example, Peter Damian (eleventh century) is best remembered for his discussion of divine omnipotence. In that context, he discussed the laws of nature. Damian argued that the Almighty Creator was not limited by them, but rather was their author and sustainer. He specifically taught that God's absolute power rules over the laws of nature, and that the divine will conserves the laws of nature in being.[12] This philosophical position was later developed into medieval *voluntarism*, which has a long history.[13] As opposed to both Aristotelian and Platonic natural philosophy, voluntarism insisted that the structures of Nature were not deduced by logical necessity from first principles, nor were they fixed and eternal. For voluntarist natural philosophers, the order of nature stems from the will of almighty God, who is free to do things differently. God chose to create the laws of nature in this way, and he could have chosen differently. The laws of nature are not logically necessary, according to voluntarism, nor are they eternal. This belief meant that the structure of Nature was contingent. Logic alone would not discover them; we would have to look and see.

In the Middle Ages, the notion of a law of nature, especially the relationship between God and the world, was given further philosophical development among Christian thinkers.

This history of medieval natural philosophy reaches a high watermark with the re-introduction of Aristotle, and of Arabic learning based upon Greco-Roman and Hindu cultures (especially medicine and mathematics). In 1159, John of Salisbury could lament the lack of geometrical and astronomical science in Europe, as compared to Islamic countries.[14] Soon, however, the learning of the Arabs and Greeks was translated into Latin and became the backbone of the new University liberal arts curricula, especially at Paris and Oxford. This literature helped to create a separate faculty of philosophy, with an interest in natural philosophy and metaphysics as distinct from theology.

The gift of the Muslim philosophers to late medieval natural philosophy was their mathematics, based upon Greek and Hindu sources, that included several significant developments. The new mathematical learning could be used to describe the natural world, as especially the field of optics was making clear. This mathematical approach to metaphysics was upheld within a Christianized Platonic and Pythagorean tradition. The final combination of mathematics (Platonic-Pythagorean), observation and experience (Aristotelian) and voluntarism (biblical-theological) provided the vital philosophical milieu in which early modern science could develop.[15] Of course, this generalization is too simple. These philosophical currents did not exist in pure forms, nor was their combination a simple matter. Rather, they represent perspectives and trajectories of medieval thought found in various manifestations in the actual works of medieval philosophers.

Medieval natural science was based principally upon commentaries on Aristotle's natural philosophical books. As Edward Grant points out: "The translation of Greco-Arabic science, within which Aristotle's natural books formed the core, laid the foundation for the continuous development of science to the present."[16] As astronomy and natural philosophy became based upon Aristotle's works, there developed an important distinction between astronomy and natural philosophy. This can be illustrated by Simplicius (sixth century), a late Neo-platonic commentator on Aristotle's *Physics*, whose work was translated into Latin by Grosseteste. Simplicius gives a very clear distinction (citing many authorities from the Aristotelian tradition) between astronomy, which is focused particularly on the stars and planets—their shape, size, and distances—and natural philosophy or physics. He writes:

> Astronomy does not seek to pronounce on any of these [substantial] questions, but reveals the ordered nature of the phenomena in the heavens (*taxin ton ouranion kosmon*) … [S]ince astronomy touches on the study of quantity, magnitude, and quality of their shapes, it understandably has recourse to arithmetic and geometry.[17]

The powerful combination of a mathematical and geometrical approach, combined with the work of natural philosophy, provides the historical background for early modern science.

Copernicus, then, is an astronomer in this Aristotelian sense. Natural philosophy, on the other hand, examines the substance of the heavens and its most basic elements and properties. For this reason, the astronomer "must get his basic principles from the natural scientist (*physikes*)." Galileo, then, is no astronomer in this sense of the term, but rather a natural philosopher. This distinction is typical of Aristotelian science. The powerful combination of a mathematical and geometrical approach, combined with the work of natural philosophy, provides the historical background for early modern science.

The term "first principles" (*principia* in Latin) becomes the common word for things we might call the laws of nature. Aristotle did not use these words in our modern sense, as we have seen. As natural science becomes based upon his work, many natural philosophers begin to use the word "first principles" or just principles of natural philosophy. One is reminded immediately of Descartes' *Principles of Philosophy*, or Newton's *Principia* in this regard, where the word *principia* in the title means something like the rules or laws of nature. The terms *lex naturae* in Latin gradually became associated with moral law, as, for example, in Aquinas. But the use of these words for the laws of nature did not fully die out, as we shall see.

These generalizations need concrete investigation, which we cannot fully develop here. We can only briefly illustrate these points by examining the work of select medieval natural philosophers. While the stage of history was set for the powerful combination of voluntarism, empiricism, and a mathematical approach to natural philosophy, it was made in fits and starts. Part of this combination can be found, in early form, in the work of Robert Grosseteste (ca. 1170–1253), who was a natural philosopher, theologian, Bishop of Lincoln and the one of the first Chancellors of the University of Oxford.[18]

Early in his career, Grosseteste was interested in natural philosophy and mathematics, rather than the more typical scholastic methods which dominated Paris. Such natural philosophy was available through new translations from Arabic learning and a few other medieval sources. Grosseteste was an influential teacher at Oxford on these subjects. Until about 1225, he worked mostly on science and mathematics, producing an important commentary (the first in Latin that we know of) on Aristotle's *Posterior Analytics*. His interest in theology led him to the study of Greek, and he became one of the best Greek scholars in the West at that time. His theological work combines both biblical studies and natural philosophy, one example of which is his own *Hexaemeron*. Grosseteste lectured on theology to the Franciscans at Oxford and published a number of biblical-theological works. For all of his intellectual career, he was interested in the nature of light. In *De luce*, he developed a metaphysics of light as the first form of "prime matter" and the basic stuff of the human soul.[19]

While at Oxford, Grosseteste introduced the new Aristotelian philosophy as mediated by Arabic commentators. For our purposes, he represents the very early combination of interest in mathematics with natural philosophy, typical of Platonic-Pythagorean influence. R. W. Southern has placed Grosseteste in a twelfth-century tradition of English medieval science, which was distinct from the methods and aims of the great scholastic thinkers of the day in Paris or Bologna. But Grosseteste makes a decisive break with even these humble predecessors in the breadth of his learning and in the scope of his interests, as well as in his consistent emphasis on observation as a foundation for natural science (à la Aristotle). With his mathematical interests and his theistic and voluntarist world view, Grosseteste was an important contributor to medieval science.

Even as he translated and interpreted Aristotle, Grosseteste placed Aristotelian natural philosophy in a broader Christian and Neo-platonic world view. In addition to a theistic basis, which was ultimately voluntarist, he was committed to a natural philosophy based upon mathematics. This emphasis derived from Platonic and Pythagorean traditions, as mediated to him through Patristic authors like Augustine. A mathematical natural philosophy is demonstrated in a number of his works, particularly works on astronomy, light, and in his treatise on geometry, *De Lineis, Angulis et Figuris*. He defends his mathematical approach to natural philosophy in the latter book, stating:

> There is an immense usefulness in the consideration of lines, angles and figures, because without them natural philosophy cannot be understood. They are applicable in the universe as a whole and in its parts, without restriction, and their validity extends to related properties, such as circular and rectilinear motion …[20]

Notice that Grosseteste wants to use geometry, which was long a key tool of astronomers, within natural philosophy. This is a decisive step in the history of Western science, although Grosseteste was not alone in making it. As John McEvoy notes in his careful exposition of Grosseteste's thought: "We can discover [in his works] an originality and an importance which in the long run did have a bearing on science, in so far as science came into being in dependence upon certain metaphysical beliefs."[21]

Grosseteste developed an experimental scientific method for the investigation of contingent, physical truths, which for him was part of the divine order and natural law. He understood the law of nature, stemming from the Word of God, to include the spiritual, moral, and physical ordering of creation. This is clear from his *Hexaemeron*, which like Basil's was a commentary on the first days of creation, as well as from his discussion of natural law in *De cessatione legalium*.[22] Like Basil, Ambrose, and Augustine, Grosseteste was concerned with the combination of biblical, metaphysical, and scientific thought in his theological works. But unlike them, he was doggedly interested in scientific explanations for natural phenomena when writing his natural philosophy. This is clear in his commentary on the *Posterior Analytics*, which is free of the spiritual allegorizing of the natural world typical of medieval natural histories. In his biblical commentaries, however, Grosseteste did engage fully in allegorical and symbolic speculation upon both the biblical text and natural phenomena.

Medieval thinkers had a more unified understanding of God, nature, and humanity than we do today. Both nature and Scripture alike were filled with spiritual lessons. And like others of his day, Grosseteste used the term "laws of nature" to refer to the spiritual and moral laws of God. But he also saw the term "laws of nature" as referring to physical regularities. In *Hexaemeron*, he writes: "Since the origin of nature is the word of God, it is God's right to give a law to nature (*legem dare naturae*), since he gave it its origin."[23]

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The direct legacy of Grosseteste was not great in his own time. His only real theological heir was John Wycliffe, a century later. The theological tradition of his age (as represented, for example, by the great English theologian and philosopher John Duns Scotus) went decidedly into scholastic methods. He did have some important followers in science, however, such as Roger Bacon and John Pecham. Grosseteste was convinced that natural philosophy could only progress under geometrical analysis, but did not carry this forward very far. He was no great experimenter, yet his methods and examples provided a stimulus for later scientific developments.

The importance of Grosseteste, then, is not in his excellence as a scientist, but in his setting forth a new method, metaphysics, and epistemology for the discovery of physical reality. For example, in his most important work on scientific method (his commentary on the *Posterior Analytics*), he makes this remarkable comment:

> *Sollertia* ("insight," Greek *anchinoia*) is the penetrating power in virtue of which the mind's eye does not rest on the outer surface of an object, but penetrates to something below the visual image. For instance, when the mind's eye falls on a colored surface, it does not rest there, but descends to the physical structure of which the color is an effect. It then penetrates this structure until it detects the elemental qualities of which the structure is itself an effect.[24]

Such a method was quite distinct from that of Scholastic natural philosophy, based as it was upon textual analysis rather than physical observation. Grosseteste's mathematical and empirical approach to natural philosophy was to bear fruit in a few followers who would continue the development of medieval natural philosophy. When combined with Scholastic philosophical methods, Grosseteste's mathematical and observational methods would bear more fruit.

One of the most famous followers of Grosseteste was Roger Bacon (ca. 1220–1292). Bacon was a Franciscan philosopher and scientist who studied and taught at Oxford and Paris.[25] He was even more accomplished than Grosseteste (whom he admired) in the areas of Greek and Arabic natural philosophy, mathematics, and optics. Bacon pressed even further for the application of mathematics to natural philosophy. He declared: "Nothing of supreme moment can be known in them [the sciences] without mathematics."[26]

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Bacon was a true experimental scientist, one of the very first in Europe. This becomes clear in his major scientific work, *Opus Maius*.[27] He applied his immense experimental and mathematical learning to the science of light, continuing the interests of Grosseteste. Bacon also was interested in the reform of education and was quite critical of the Scholastic methods. He proposed that education should be scientific and mathematical and, even more importantly, based upon the study of original languages. These were, he argued, more valuable to theological research than the traditional medieval subjects.[28] These can be recognized as the fundamental studies that Grosseteste practiced in theology (languages) and natural philosophy (observation and geometry).[29]

Bacon was one of the earliest masters to lecture directly on Aristotle at Paris, and did so for many years. He never seems to have "advanced" to theological studies, as many other medieval thinkers did. While modern historians of science find Bacon fascinating and significant, his own contemporaries misunderstood him, and his own Order eventually condemned him. He seems to have been imprisoned for two years around 1277.

Bacon could use the term "natural law," as most medieval thinkers did, i.e., to refer to the moral law of God.[30] But he also, like Grosseteste, could use the term to describe the mathematical order of the natural world, which, of course, also comes from God the Creator. For example, he held the principle that "nature works more effectively in a straight line than a curve" to be one of the laws or rules of nature.[31] He notes in passing that all corporeal bodies are also material bodies (rather than spiritual) and so "they must obey the laws of material and corporeal things."[32]

For Bacon, the laws of nature (or the rules, principles, or truths of nature) were often mathematical and imposed upon creation by an almighty Creator.[33] They could, however, just as well be metaphysical. For example, he held that there was, "by divine ordination and a universal law of nature" (*lege nature*), a limit to what spiritual and celestial substances could bring about.[34] The rules or laws of nature, though ordained by God, could be discovered through careful observation, analysis, and mathematical formulation. An example of this would be Book II of his work on force and agency, *De multiplicatione specierum*, which is devoted to the geometric analysis of the subject.[35] After explaining some of the geometry of refraction, he writes: "This refraction occurs according to the law (*lege*) that governs passage from the subtler to the denser substance."[36] So Bacon used the terms "law" and "law of nature" to refer to the natural order, often mathematical, which the divine Ruler created into the world.

In Bacon, we find the flowering of the methods advocated by Grosseteste. Unfortunately, Bacon found almost no followers, and his work lay in obscurity until the seventeenth century rediscovered him. But his example demonstrates the power of late medieval natural philosophy to generate scientific inquiry of a mathematical kind.

Less well known in our day, but more respected than Bacon in their own day, was a group of mathematical philosophers associated with Merton College, Oxford, who continued the emphasis on mathematical and logical analysis of physical problems.[37] Known as the "Merton School" or the "Oxford Calculators," these logicians were influenced by Grosseteste, and to some extent by Bacon. Grosseteste and Bacon were hardly the only voices in this tradition; Gerard of Brussels wrote an important *Book on Motion*, utilizing mathematical analysis of kinematics.[38] But the Merton School carried this analysis to new heights of excellence. They had a large influence (within a narrow range of topic) upon later Continental natural philosophy and early modern scientists like Galileo who studied motion.

The most influential man in this group in his own day and nation was doubtless Thomas Bradwardine (ca. 1295–1349), who became Archbishop of Canterbury and was known as the *doctor profundus*.[39] In medieval science, his greatest contribution was his *Tractatus de proportionibus* (1328), which was studied by scientists into the seventeenth century. H. L. Crosby, the translator of this work into English, declares that it is "the first [scientific work] to announce a general law of physics whose expression calls for anything more than the most rudimentary mathematics."[40] Bradwardine was just as distinguished a theologian, and entered into the debate concerning voluntarism with his treatise *De causa dei* (1344).[41] Bradwardine, following Augustine, denied free will in a libertarian sense to human beings. However, he did insist upon the full freedom of God's will over all creation, including the laws of nature. Because of God's absolute power, he can do things that are contrary to the laws of nature.

Bradwardine and the Merton school had a long history of influence within the narrow topic of kinematics.

There was a common medieval distinction between God's absolute power (*potentia absolutis*) and God's ordained or disposing power (*potentia ordinatus*).[42] In terms of the geometry of motion, for example, Aristotelian natural philosophy would argue that all motion must of necessity be upward, downward, or circular, that is, away from the center, toward the center, or around the center. But if this is so, God cannot move the world. Bradwardine denied this, allowing that God can do this because of his absolute omnipotence.[43] At that time, science, following Aristotle, thought a vacuum was impossible. Bradwardine denied this in God's case (but not in the normal course of nature). He wrote:

> Indeed, by means of His absolute power, God could make a void anywhere that he truly wishes, inside or outside the world.[44]

While Bradwardine analyzed the laws of nature in terms of geometry and mathematics, like Grosseteste he insisted that God was the source of these laws, and was not himself bound by them.[45]

The determinism of Bradwardine should give us caution in using the term "voluntarism." In this article, we are talking about the freedom of the divine will, something most medieval theologians and scientists (like Bradwardine) would simply assume. This we are calling "voluntarism." There is also a voluntarism of the human will, which Bradwardine argued against. This issue does not enter into our topic. So our argument is that *divine* (not human) voluntarism was historically effective in helping to develop the traditional Western notion of a law of nature.

Bradwardine and the Merton school had a long history of influence within the narrow topic of kinematics. Jean Buridan, one of the most distinguished natural philosophers at Paris in the fourteenth century, was influenced by their works and, in general, by the Oxford "school" of natural philosophy in the thirteenth and fourteenth centuries (which would include Grosseteste). Buridan (ca. 1292–1358) was one of the most prestigious intellectuals in Europe in his day and continued to develop medieval natural science. Like Bacon, Buridan flourished wholly in the Arts faculty (philosophy), not taking the normal route of continuing "upward" to theological studies.[46] As the work of these two scholars illustrates (and more could be added to their number), the conceptual division between the disciplines of theology and natural science began during this time, especially after the social impact of the condemnation of certain Aristotelian philosophical teachings in Paris in 1277.[47] Buridan wrote, for example, that "in natural philosophy we ought to accept actions and dependencies as if they always proceed in a natural way."[48]

The distinction between natural science and theology is not, as is sometimes thought, a product of the Renaissance (which, of course, did much to enlarge the division!). Buridan in particular made significant headway in setting forth scientific methodology that was distinct from theological methods and conclusions. We should note, however, that Buridan was devoutly Christian, and his natural philosophy was framed within a Christian world view. For example, after the quotation given above, Buridan went on to state: "Nevertheless God is the cause of this world." He argued in the same question that the motion of the heavens, and other effects, depend upon God as their First Cause.

Buridan was famous as a logician, natural philosopher, and commentator on Aristotle. He was twice elected rector of the University of Paris. As a commentator and scientist, he knew of the work of Grosseteste (especially his commentary on the *Prior Analytics*), and may have known something of Bacon, who also lectured for many years in Paris on Aristotle. But unlike Grosseteste, who was a realist and much influenced by Platonic thought, Buridan was a nominalist.

Buridan's philosophy of science was much influenced by a philosophical movement whose most brilliant defender was William of Ockham. Nominalists held that universal properties are mere words (*nomen* in Latin) rather than real things, as Platonic philosophers (realists) argued. This debate was centuries old, but in the fourteenth century, it became particularly acute. There developed, following Ockham, a kind of skeptical nominalist epistemology, which undercut any knowledge of the real causes of things. This would also undercut any natural theology, as indeed Ockham argued. To his credit, Buridan, though a nominalist, argued against such skeptical conclusions in the realm of natural philosophy.[49] True science, according to Aristotle, was deductive. Buridan accepted this, but noted that such demonstrative knowledge was limited in scope. There are principles that are only conditionally necessary (that is, physically necessary if God does not change his action) and cannot be known with logical rigor (*certitudine*),[50] but they indeed can be known. He wrote:

> These principles are not immediately evident; indeed we may doubt concerning them for a long time. But they are called principles because they are indemonstrable, and cannot be deducted from other premises nor proved by any formal procedure; they are accepted because they have been observed to be true in many instances and to be false in none.[51]

Examples of what we can know physically are the modes of being, such as height, width, and depth, which are natural and distinct. These can be known through geometry and arithmetic.[52] Buridan followed the typical late medieval practice of using "law of nature" to refer to the moral law, not to the "principles" of natural philosophy nor the natural "modes" of physical objects. But for Buridan, these principles and modes (or properties) are not known through logic alone, but by experience and analysis.

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So against the extreme form of skeptical nominalism (as personified by his opponent Nicholas of Autrecourt), Buridan insisted that we can know the natural causes of physical phenomena, what we might call the laws of nature.

> It has hereby been shown that very evil things are being said by certain ones who seek to undermine the natural and moral sciences because absolute evidence is not possessed by most of their principles and conclusions, it being supernaturally possible for them to be rendered false. For in these sciences absolutely unconditional evidence is not required, and it is enough if we have conditional or hypothetical evidence.[53]

Against skeptical nominalist theology and philosophy, Buridan accepted the less-than-logically-pure principles of natural science as being sufficient for its aim, i.e., to discover the principles of natural philosophy and the mathematical properties of physical things.

Buridan was not simply a logician and metaphysician. He was a distinguished medieval scientist as well, whose major contributions come in commentaries on Aristotle's *Physics* and *On the Heavens*. Perhaps his most important scientific discovery was his impetus theory of local motion.[54] He could use this theory to talk about God's relationship to the principles of natural science. Impetus (his special term for inertial force) also comes from God. Buridan wrote:

> God, when He created the world, moved each of the celestial orbs as He pleased, and in moving them He impressed in them impetuses which moved them without his having to move them any more except by the method of general influence whereby he concurs as a co-agent in all things which take place.[55]

God was not only the "prime mover," but the source of the principles of natural order and motion (First Cause), which Buridan studied in a scientific (as well as metaphysical) manner.

This distinction which Buridan develops between natural philosophy and theology is an important one, even for our own day. By his absolute power, God can do anything that is logically impossible, including creating matter from nothing or moving the entire universe. But such miracles are not the subject of natural science. Instead, natural science investigates the ordinary activity of God, by which he sustains the universe, his "method of general influence." A sixteenth-century, collaborative Jesuit scientific commentary on Aristotle from Coimbra, Portugal, notes that God conserves the universe throughout time (*in perpetuum durare*) in the common and ordinary concourse (*communi et ordinario concursu*) of nature.[56]

This, I think, is a key distinction, even for our own day. Natural science investigates the common and well-ordered (*ordinatus*) activity of God, his ordained power by which he conserves the world. That is the reason miracles are not part of natural philosophy, as far as first principles are concerned. In our own time, we would say that the natural sciences aim to explain the activity of God in sustaining the physical universe through his ordained power, including matter, energy, and the laws of nature. Buridan, and the late medieval tradition with him, accepted miracles, which God does by means of his absolute power, but did not use them to explain physical phenomena within the domain of natural philosophy.

In his reflections upon God as the source of the laws of nature, Oresme allowed that God could create many worlds by his infinite power. … Laws of place and motion would apply to any world created by God …

The mathematical tradition of natural philosophy was carried on by a number of Buridan's students and followers, including Nicole Oresme (ca. 1320–1382). He was a theologian, scientist, and philosopher of wide-ranging interests.[57] Unlike Bacon and Buridan, Oresme became a theologian, as well as a mathematician and natural philosopher. He was also a more extreme nominalist than either of them, and his speculations in natural philosophy were just that—speculations. He was not as famous as Buridan, whom he knew and whose works he studied. Nevertheless Oresme's work in natural philosophy and mathematics was significant, especially in Paris. A tutor and friend of Charles V, the king of France, Oresme was commanded to translate some of Aristotle's texts into French for the further edification of the nobility. As well as works on ethics and politics, Oresme completed a translation and commentary on Aristotle's *On the Heavens*, which is the first important scientific work in the French language and Oresme's last publication. This book, which was quite influential in its own way, is an early example of the use of a clock metaphor to discuss the regular motions of the physical universe.[58]

With respect to his views on the laws of nature, Oresme used the term "law of nature" always in the sense of the moral law or natural law.[59] When writing about what we now call the laws of nature, he consistently used "principles" of nature. While Oresme accepted the general idea of the laws or principles of nature from earlier philosophers, he extended the idea to speculation about other possible worlds. In his reflections upon God as the source of the laws of nature, Oresme allowed that God could create many worlds by his infinite power. God is not only creator, but governor of any and all worlds that could possibly exist. So if God made another world, it would have physical principles or laws of nature (in this case, of place and motion toward a center) the same as our world does. Oresme wrote: "If God [in His infinite power] created another world like our own, the earth and the other elements of this other world would be present there just as they are in our own world"[60] Laws of place and motion would apply to any world created by God, he argued. "[I]f several worlds existed, no one of them would be outside Him nor outside His power."[61] This universal character of the laws of nature will have great influence on Descartes and other scientific minds in the early modern period.

Western natural science continued its basis upon the natural books of Aristotle, through a gradual transition until the end of the seventeenth century and Isaac Newton (1642–1727). Since space is limited here, I will focus on Newton as one example for all of early modern science.

Newton opens the Preface to his famous *Mathematical Principles of Natural Philosophy* with the statement: "The moderns … have undertaken to reduce the phenomena of nature to mathematical laws."[62] The Axioms at the beginning of the work are entitled *Axiomata, sive Leges Motu*. Newton used the word "principle" for gravity or for law of nature. "[T]hey [material particles] are moved by certain active Principles, such as is that of Gravity … These Principles I consider … general Laws of Nature."[63] And God is the source of the laws of nature. Newton's God is the absolute Lord of the universe. "He rules all things, not as the world soul but as the lord of all, the Pantokrator."[64]

In his work on optics, Newton notes that "God is able … to vary the Laws of Nature and make Worlds of several sorts in several Parts of the Universe."[65] Against Descartes, Newton returns to the traditional theory of God's absolute power, which is able to alter the laws of nature at will. The basic theological concepts in Newton's natural philosophy were already part of his scientific inheritance from the past. In fact, in a recent work on Newton, Ted Davis and John Henry have clarified some of the confusing things Newton wrote concerning God and gravity, by utilizing the distinction between God's ordained and absolute power.[66] But Newton's brilliant transformation of natural philosophy soon overturned the larger Aristotelian paradigm in which these concepts were developed.

Copernicus, Galileo, Kepler, Descartes, Newton, and the other great early scientists were both arguing against, but also using and continuing in some respects, the late medieval and renaissance tradition of natural science. One area where there is continuity is the notion of the laws of nature, and the role of God in natural philosophy. But after Newton, the decisive break with the past is too great, and this tradition gradually becomes less marked in the writings of natural scientists. Nevertheless, the Christian tradition of natural philosophy handed on a distinctively theistic notion of the laws of nature, that is, as stemming from the ordained power of God by which he concurs with the normal course of nature. This view is so common throughout the history of Western science before 1700 that we should call it the traditional Western view. A law of nature, in this view, is a physical regularity built by God into the very fabric of the universe by means of which (along with other things) he conserves the physical universe in existence throughout time.

I believe that a return to this traditional concept of a law of nature, grounded in the ordained power of God, could help solve several contemporary issues and confusions in the philosophy of science and in the ongoing dialogue between religion and science. The purpose of this essay, however, has been primarily historical. I have sought simply to demonstrate that, in the midst of diversity, there was a common Western conception of "law of nature" based upon belief in the ordained power of God. ✯

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Notes

[1] Research funding for this article was provided by the John Templeton Foundation, through the Oxford Templeton Seminars in Science and Christianity (1999–2001).

[2] For secondary literature on this topic see, G. Frey, "Naturgesetz," *Historisches Wörterbuch der Philosophie*, 6:528–31; Jane Ruby, "The Origins of Scientific Law," *Journal of the History of Ideas* 47 (1986): 341–59; J. R. Milton, "The Origin and Development of the Concept of the 'Laws of Nature,'" *European Journal of Sociology* 22 (1981): 173–95; F. Oakley, "The Rise of the Concept 'Laws of Nature,'" *Church History* 30 (1961): 433–57; E. Zilsel, "The Genesis of the Concept of Physical Law," *Philosophical Review* 51 (1942): 245–79.

[3] There are even earlier Jewish and Christian authors, such as Philo, who use the idea. See Christoper Kaiser, *Creational Theology and the History of Physical Science* (Leiden: E. J. Brill, 1997), 35–6.

[4] In particular, these would be Augustine's *Literal Commentary on Genesis* and Basil's *Hexaemeron* (*On the Six Days of Creation*) as well as the Latin version of the *Hexaemeron* from the pen of Ambrose.

[5] See Basil, *Hexaemeron*, vii.3–5 and viii.4; English translation in *Nicene and Post-Nicene Fathers, Second Series* (Oxford: J. Parker, 1895), 8:91–3, 97. For the Greek text, see J. P. Migne, ed., *Patrologiae Graeca* 29: 156–8. Augustine, *The Literal Meaning of Genesis* 2, trans. J. H. Taylor (New York: Paulist Press, 1983), 41. See the Latin text of *De Genesi ad litteram*, ed. J. Zycha in *Corpus Scriptorum Ecclesiasticorum Latinorum* 28/1 (1894; reprint, New York: Johnson Reprint, 1970).

[6] *Hexaemeron*, vii.3 (p. 92).

[7] *De Gen.*, ix.17 (*Literal Meaning*, 2:92).

[8] Line 2 of the Greek text, for which see Gilbert Murray, et al., eds., *The Oxford Book of Greek Verse* (Oxford: Clarendon Press, 1931), #483. There are several English translations, including the rather good one in F. H. Sandbach, *The Stoics*, 2d ed. (Indianapolis: Hackett, 1994), 110–1.

[9] Lucretius, *De Rerum Natura*, ed. M. F. Smith (LCL; Cambridge, MA: Harvard, 1924), 5:58. See also 2:714 and 719 for his use of the term law of nature.

[10] Manilius, *Astronomica*, ed. G. P. Goold (LCL; Cambridge, MA: Harvard, 1977), 2:475 and 1:670–1.

[11] Aristotle uses the bare form of words "law" of nature in only one place, in the opening of *On the Heavens* (*De Caelo*, 268A, 14). Interestingly the context is, again, that of astronomy. However, his meaning here is quite different from our interests in this paper.

[12] For the Latin text, see Pierre Damien, *Lettre sur la toute-puissance divine*, ed. A. Cantin (SC 191; Paris: Ed. Du Cerf, 1972), §13, 448–50, which also has an excellent introduction to Damian. For an English translation, see letter 119 in the Fathers of the Church edition of his *Letters*, trans. O. J. Blum, 5 vols. (Washington, DC: Catholic University of America Press, 1989–1999).

[13] For a discussion of medieval voluntarism, see N. Kretzmann, A. Kenny and J. Pinborg, eds., *The Cambridge History of Later Medieval Philosophy* (Cambridge: Cambridge University Press, 1982), 537–9, 638–40; and William Wallace, "The Philosophical Setting of Medieval Science," in *Science in the Middle Ages*, ed. David Lindberg (Chicago: University of Chicago Press, 1978).

[14] John of Salisbury, *Metalogicon*, IV.6, trans. D. D. McGarry (Berkeley: University of California Press, 1962), 212.

[15] See Edward Grant, *The Foundations of Modern Science in the Middle Ages* (Cambridge: Cambridge University Press, 1996). Pierre Duhem and A. C. Crombie are particularly remembered for advocating this thesis, among twentieth century historians of science. See Duhem, *Le systém du monde*, 10 vols. (Paris: Hermann, 1913–1959) and Crombie, *Medieval and Early Modern Science*, 2 vols. (New York: Anchor Books, 1959).

[16] Edward Grant, *Planets, Stars, and Orbs: The Medieval Cosmos, 1200–1687* (Cambridge: Cambridge University Press, 1996), 13.

[17] Simplicius, *On Aristotle Physics* 2, trans. Barrie Fleet (London: Duckworth, 1997), 47 (on Aristotle, *Physics*, 193b23). Greek text in *Symplicii In Aristotelis Physicorum*, ed. H. Diels, 2 vols. (Berlin: Reimer, 1882), 2:291.

[18] Southern argues that he was not confirmed as Chancellor by the Bishop (p. xxx). For more on Grosseteste, see A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science, 1100–1700*, 2d. ed. (Oxford: Oxford University Press, 1962), John McEvoy, *The Philosophy of Robert Grosseteste* (Oxford: Oxford University Press, 1982); and R. W. Southern, *Robert Grosseteste*, 2d ed. (Oxford: Oxford University Press, 1992).

[19] Robert Grosseteste, *On Light*, trans. C. C. Riedl (Milwaukee: Marquette University Press, 1942).

[20] Cited from McEvoy, 168; for the original text, see Ludwig Baur, ed., *Die philosophischen Werke des Robert Grosseteste*, BGPM 9 (Munster: Aschendorff, 1912), 59; for a modern English translation, see E. Grant, ed., *A Source Book in Medieval Science* (Cambridge, MA: Harvard University Press, 1974), 384–8.

[21] McEnvoy, 169.

[22] Robert Grosseteste, *Hexaemeron*, ed. R. C. Dales and S. Gieben (London: British Academy, 1982); English translation, *On the Six Days of Creation*, by C. F. J. Martin (London: British Academy, 1996). This text will be cited by section number, which is uniform in both the Latin and English editions.

Natural law is used in the moral sense in Robert Grosseteste, *De Cessatione Legalium*, ed. R. C. Dales and E. B. King (London: British Academy, 1986), I.v.2,6, I.vi.8.

23Grosseteste, *Hexaemeron*, 3.iii.5.

24Cited from Southern, 168; original text in Robert Grosseteste, *Commentarius in Posteriorum Analyticorum Libros*, ed. P. Rossi (Florence: L. S. Olschki, 1981), 281.

25For the life and work of Bacon, see A. C. Crombie and J. D. North, *Dictionary of Scientific Biography*, s.v. "Bacon, Roger"; T. Crowley, *Roger Bacon* (Louvain: *Ed. Institute Superior de Philosophie*, 1950); Stewart Easton, *Roger Bacon and his Search for a Universal Science* (New York: Columbia University Press, 1952); and the first chapter of *Roger Bacon and the Sciences*, ed. J. Hackett (Leiden: Brill, 1997).

26*Opus Maius*, part IV, d. 1, chap. 3 (p. 127, Burke ed.)

27Roger Bacon, *The "Opus Maius" of Roger Bacon*, ed. J. H. Bridges, 3 vols. (London: Williams & Norgate, 1879–1900); and in English, *The Opus Majus of Roger Bacon*, trans. R. B. Burke, 2 vols. (1928; reprint, New York: Russell & Russell, 1962). Part V is given a modern critical edition and translation by David Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages* (Oxford: Oxford University Press, 1996).

28*Opus Maius*, parts III and IV.

29Crombie and North, 377f.

30*Opus Maius*, part II, chap. 2 (pp. 37–8, Burke ed.).

31*Opus Maius*, part IV, d.3, chap. 1 (p. 139, Burke ed.)

32*Opus Maius*, part V, part 1, d 6, chap. 4 (p. 87, Lindberg ed.)

33For example, "Just as the wisdom of God is provided for the ordering (regimen) of the universe, so too is this science of vision—powerfully, usefully, and by its agreeable beauty" (*Opus Maius*, part V, d. 3, chap. 3; p. 330, Lindberg ed.). At one point Bacon even uses the word *canon* for a law of nature (*Opus Maius*, part V, part 3, d. 2, chap. 4, pp. 310, 316, Lindberg ed.).

34*De multiplicatione specierum*, I.6, ed. David Lindberg in *Roger Bacon's Philosophy of Nature* (Oxford: Oxford University Press, 1983), 84. See also pp. 85, 87 and IV.1, p. 209 for his use of "law of nature."

35Op. cit., 91–177.

36Op. cit., II.4, p. 127.

37See Christopher Lewis, *The Merton School and Kinematics in Late Sixteenth and Early Seventeenth Century Italy* (Padua: Antnore, 1980); Edith Sylla, "The Oxford Calculators," in *The Cambridge History of Later Medieval Philosophy*, 540–63; and M. Clagett, *The Science of Mechanics in the Middle Ages* (Madison, WI: University of Wisconsin Press, 1959), 199–239.

38See Grant, *Source Book*, 234–7 and Clagett, 185–95.

39For his life, see John E. Murdock, "Bradwardine, Thomas," *Dictionary of Scientific Biography* 2:390–6; Gordon Leff, *Bradwardine and the Pelagians* (Cambridge: Cambridge University Press, 1957); and Edith Dolnikowski, *Thomas of Bradwardine* (Leiden: Brill, 1995).

40See H. L. Crosby, *Thomas of Bradwardine* (Madison, WI: University of Wisconsin Press, 1955) which contains an English translation of the work.

41See Leff, *Bradwardine* and Grant, *Source Book*, 555–60.

42See, e.g., William of Ockham, *Quodlibetal Questions*, IV, q.1, trans. A. J. Freddoso and F. E. Kelley, 2 vols. (New Haven: Yale University Press, 1991), 491–2. See further, William J. Courtenay, *Covenant and Causality in Medieval Thought* (London: Variorum, 1984).

43*De causa Dei*, Bk. I, chap. 5; in Grant, *Source Book*, 557, 560.

44Ibid.

45See, e.g., the doxology at the conclusion of his *Tractatus de proportionibus*, p. 140 (Crosby ed.).

46On Buridan, see E. A. Moody, *Dictionary of Scientific Biography*, s.v. "Buridan, Jean"; Alessandro Ghisalberti, *Giovanni Buridano dalla Metafisica alla Fisica* (Milan: Vita e Pensiero, 1975); and Benoit Patar, ed., *Ioannis Buridani Expositio et Quaestiones in Aristotelis De Caelo* (Louvain: Peeters, 1996).

47For more on the condemnations of 1277, see E. Grant, "The Condemnation of 1277, God's Absolute Power, and Physical Thought in the Late Middle Ages," *Viator* 10 (1979): 211–44, reprinted in his *Studies in Medieval Science and Natural Philosophy* (London: Variorum, 1981); see also David Lindberg, *The Beginnings of Western Science* (Chicago: University of Chicago, 1992), 234–44.

48*Quest. de caelo*, book 2, q.9 (p. 423f., Patar ed.).

49See, e.g., Joannis Buridanus, *In Metaphysicen Aristotelis* (Lyon, 1518), II, q. 1, fol. 8.

50Ibid.

51Cited from Moody, 604; original text, *In Metaph.*, II, q.2, fol. 9v.

52See *Quest. de Caelo*, I, q. 2 (p. 234, Patar ed.).

53Cited from Moody, 605; original text in *Quest. Meta.* II, q. 1, fol. 9r.

54Clagett, *Science*, 505–30 for discussion and a brief translation.

55Cited from Clagett, 536; original text, *Questiones super octo physicorum libros Aristotelis*, VII, q. 12 (Paris, 1509), fol. 121r.

56Conimbricenses [College of Arts at Coimbra], *Commentarii Collegii Conimbricenses S. J. in quatuor libros De Coelo* (Lyon, 1598), book 1, chap. 2, q. 1, art. 2. Also in Grant, *Planets*, 77n.

57On Oresme, see Marshall Clagett, *Dictionary of Scientific Biography*, s.v. "Orseme, Nicole"; ——, *Nicole Oresme and the Geometry of Qualities and Motions* (Madison, WI: University of Wisconsin Press, 1968), G. W. Coopland, *Nicole Oresme and the Astrologers* (Liverpool: Liverpool University Press, 1952), and E. Grant, *Nicole Oresme and the Kinematics of Circular Motion* (Madison, WI: University of Wisconsin Press, 1971).

58Oresme, *Le Livre du ciel et du monde*, ed. A. D. Menut and A. J. Denomy (Madison, WI: University of Wisconsin Press, 1968), 70d–71a, 73d.

59*De configurationibus qualitatum et motuum*, II.38 (in Clagett, *Nicole Oreme*, 381).

60Grant, *Source Book*, 551, from *Livre de Ceil*, bk. I, chap. 24.

61Grant, *Source Book*, 552, from *Livre de Ceil*, I.24.

62Issac Newton, *Principia*, trans. I. B. Cohen and A. Whitman (Berkeley: University of California Press, 1999), 381.

63Issac Newton, *Optikcs*, 4th ed. (1730; reprint, London: Bell, 1931), 401.

64General Scholium to the *Principia*, 940.

65*Opticks*, 405.

66John Henry, "'Pray do not Ascribe that Notion to Me': God and Newton's Gravity," in *The Books of Nature and Scripture*, ed. J. Force and R. H. Popkin (Boston: Kluwer, 1994), 123–48; Edward Davis, "Newton's Rejection of the 'Newtonian Worldview,'" *Science and Christian Belief* 3 (1991): 103–17, reprinted from *Fides et Historia* 22 (1990): 6–20.