scientific and cultural center in Prague after 1620. The Prague edition of the tables remained almost unnoticed, and only a few copies were saved; probably the only complete copy is kept, together with the handwritten "instruction," in the library at Danzig. Thus, Bürgi's greatest discovery had no apparent influence on the development of science.

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LUBOŠ NOVÝ

BURIDAN, JEAN (*b.* Béthune, France, *ca.* 1295; *d.* Paris, France, *ca.* 1358), *philosophy, logic, physics.*

Although Jean Buridan was the most distinguished and influential teacher of natural philosophy at the University of Paris in the fourteenth century, little is known of his personal life. He was born in the diocese of Arras, and went as a young cleric to study at the University of Paris, where he was first enrolled as a student in the College of Cardinal Lemoine and later became a member of the College of Navarre. It is probable that he obtained his master of arts degree soon after 1320, since a document dated 2 February 1328 mentions him as rector of the university in that year. Other documents, relating to benefices whose revenues provided his financial support and bearing the dates 1329, 1330, 1342, and 1348, describe him as a "very distinguished man," as a "celebrated philosopher," and as "lecturing at Paris on the books of natural, metaphysical, and moral philosophy." Two passages in his own writings indicate that at some date prior to 1334 he made a visit to the papal court at Avignon and, on the way, climbed Mt. Ventoux in order to make some meteorological observations.

In 1340 Buridan was rector of the university for a second time, and in that year he signed a statute of the faculty of arts which censured certain masters for the practice of construing texts in a literal sense rather than in accordance with the intentions of the authors, warning that this practice gave rise to "intolerable errors not only in philosophy but with respect to Sacred Scripture." One of the articles of censure bears on a statement known to have been made by Nicolaus of Autrecourt, whose skeptical views on causal inferences were attacked by Buridan in his own writings. The last documentary mention of Buridan occurs in a statute dated 12 July 1358, where his name appears as witness to an agreement between the Picard and English nations of the university. It is not unlikely that he fell victim to the Black Plague, which in 1358 took the lives of many of those who had managed to survive its first outbreak in 1349.

Buridan was a secular cleric rather than a member of a religious order, and he remained on the faculty of arts to the end of his life without, apparently, seeking to obtain a degree in theology. In his lifetime he was held in high esteem by his colleagues, students, and ecclesiastical superiors; and for nearly two centuries after his death his teachings in natural philosophy and logic were of paramount influence in the universities of northern and eastern Europe. A document in the archives of the University of Cologne, dated 24 December 1425, speaks of the preceding century as "the age of Buridan," and when George Lockert, in 1516, edited one of Buridan's works, he stated that Buridan still ruled the study of physics at Paris. In later centuries, the story of the ass who starved to death because he could not choose between two equally desirable bundles of hay was attributed to Buridan, and another story, presumably legendary but perpetuated by the poet François Villon, related that Buridan had been involved in scandalous relations with the wife of Philip V of France and had, by the king's order, been tied in a sack and thrown into the Seine.

The extant writings of Buridan consist of the lectures he gave on subjects in the curriculum of the faculty of arts at Paris. In the fourteenth century this curriculum was based largely on study of the treatises of Aristotle, along with the *Summulae logicales* of Peter of Spain and other medieval textbooks of grammar, mathematics, and astronomy. Buridan composed his own textbook of logic, *Summula de dialectica,* as a "modern" revision and amplification of the text of Peter of Spain; he also wrote two treatises on advanced topics of logic, entitled *Consequentiae* and *Sophismata,* which are among the most interesting contributions to late medieval logic. All of his other works are in the form of commentaries and of critical books of *Questions* on the principal treatises of the Aristotelian corpus. The literal commentaries are extant only in the unpublished manuscript versions, but the books of *Questions* on Aristotle's *Physics, Metaphysics, De anima, Parva naturalia, Nicomachean ethics,* and *Politics* were published, along with Buridan's writings in logic, after the invention of the printing press.

The only modern edition of a work by Buridan is that of his *Questions* on Aristotle's *De caelo et mundo,* previously unedited, which appeared in 1942. Most of the printed editions represent the lectures Buridan gave during the last part of his teaching career, although earlier versions are to be found among the unpublished manuscript materials. Until a critical study of the manuscripts is made, however, there is no sure way of determining any order of composition for Buridan's works, nor of tracing the development of his thought over the thirty-odd years of his academic career.

Buridan made significant and original contributions to logic and physics, but as a philosopher of science he was historically important in two respects. First, he vindicated natural philosophy as a respectable study in its own right. Second, he defined the objectives and methodology of scientific enterprise in a manner that warranted its autonomy with respect to dogmatic theology and metaphysics; this achievement was intimately connected with the fourteenth-century movement known as nominalism and with the controversies precipitated at the universities of Oxford and Paris by the doctrines associated with William of Ockham. Buridan's own philosophical position was thoroughly nominalistic, and indeed very similar to that of Jean de Mirecourt, a theologian of Paris whose teachings were condemned in 1347 by the chancellor of the university and the faculty of theology. Buridan himself was able to escape the charges of theological skepticism that were directed against his fellow nominalists of the theological faculty. He owed his good fortune in part, no doubt, to his prudence and diplomacy. Primarily, however, he could ward off criticism for the fundamental reason that he employed the logical and epistemological doctrines of nominalism in a methodological, rather than a metaphysical, way in formulating the character and the evidential foundations of natural philosophy.

The formal logic presented in Buridan's *Summula de dialectica* is closely related, in topical structure and terminology, to the so-called terminist logic of the thirteenth century, represented by the textbooks of William of Sherwood and Peter of Spain. Although it presupposes the nominalist thesis that general terms are signs of individuals, and not of common natures existing in individuals, it does not exhibit any strong evidence of direct influence by the logical writings of Ockham; it may well have been developed independently of such influence on the basis of the modern logic (*logica moderna*) already well established in the arts faculties of Oxford and Paris. The doctrine of the supposition of terms, basic to this logic, is used in defining the functions of logical operators or syncategorematic signs in determining the truth conditions of categorical propositions of various forms and in formulating the laws of syllogistic inference, both assertoric and modal. Treatises on topical arguments, fallacies, and the demonstrative syllogism conclude the work.

Buridan's *Sophismata,* designed to constitute a ninth part of the *Summula,* apparently was written much later in his life, for it contains criticisms of the theory of propositional meanings, or *complexe significabilia,* which Gregory of Rimini introduced in 1344. This work presents a fully developed analysis of meaning and truth which corresponds closely to that of Ockham's *Summa logicae.* It goes beyond the work of Ockham, however, in presenting original and highly advanced treatments of the problem of the nonsubstitutivity of terms occurring in intensional contexts and the problem of self-referential propositions represented by the Liar paradox. Buridan's treatment of these problems exhibits a level of logical insight and skill not equaled until very recent times. His treatise *Consequentiae,* which develops the whole theory of inference on the basis of propositional logic, marks another high point of medieval logic, the significance of which has been appreciated only in the twentieth century.

Buridan's philosophy of science is formulated in his *Questions* on the *Metaphysics,* and is applied to the concepts and problems of natural science in his *Questions* on the *Physics.* The Aristotelian definition of science as knowledge of universal and necessary conclusions by demonstration from necessary, evident, indemonstrable premises is accepted. A sharp distinction is made, however, between premises in which the necessity is determined by logical criteria or by stipulated meaning of the terms, and those in which evidence rests on empirical confirmation and which are called necessary in a conditional sense, or "on the supposition of the common course of nature." Only in the latter sense do the principles of the natural sciences have evidence and necessity.

> These principles are not immediately evident; indeed we may be in doubt concerning them for a long time.

> But they are called principles because they are indemonstrable, and cannot be deduced from other premises nor be proved by any formal procedure; but they are accepted because they have been observed to be true in many instances and to be false in none.[1]

The significance of this theory of scientific evidence lies in its rejection of the thesis, held by most of the scholastic commentators on Aristotle, that the principles of physics are established by metaphysics and that they are necessary in the sense that their contradictories are logically or metaphysically impossible. This metaphysical interpretation of Aristotelian physics led Bishop Étienne Tempier and the faculty of theology at Paris to condemn, in 1277, doctrines taught by members of the arts faculty as truths necessary to philosophy, although contradictory to dogmas of the Christian faith. By construing the principles of the sciences of nature as inductive generalizations whose evidence is conditional on the hypothesis of the common course of nature, Buridan was able to concede the absolute possibility of supernatural interference with the natural causal order, and yet to exclude such supernatural cases as irrelevant to the purposes and methodological procedures of the scientific enterprise. Nicolaus of Autrecourt, demanding that scientific principles have absolute necessity and certainty, had argued that a science of nature based on causal laws established by inductive generalization had no evidence whatsoever, since it could not be known in any given instance whether or not God was producing an effect without a natural cause. Buridan refers to Nicolaus' position in these words:

> 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 of the kind described above.[2]

The conception of scientific enterprise formulated by Buridan as a means of justifying its pursuit within the framework of the Christian doctrine of divine omnipotence is the conception within which science has operated since the late seventeenth century. To make science compatible with Christian dogma, Buridan had to break its traditional ties with metaphysics and define its principles methodologically, in terms of their value in "saving the phenomena." He still encountered some theological difficulties in applying this method within the domain of physics, as did Galileo three centuries later; but after the time of Buridan, natural philosophy had its own legitimacy and ceased to be either only a handmaiden of theology or a mere exposition of the doctrines of Aristotle.

The *Questions* composed by Buridan on problems raised in Aristotle's *Physics* and *De caelo et mundo* exhibit his application of these criteria of scientific method and evidence to the critical evaluation of Aristotle's theories and arguments and to the diverse interpretations of them offered by Greek, Moslem, and Christian scholastic commentators. The general scheme and conceptual framework of analysis, within which Aristotle's physics and cosmology are formulated, is accepted by Buridan as the working hypothesis, so to speak, of natural philosophy. But the scheme is not sacrosanct, and Buridan not infrequently entertains alternative assumptions as being not only logically possible but also possibly preferable in accounting for the observed phenomena. While the authority of Aristotle had often been challenged on the ground that his positions contradicted Christian doctrine, it had come, in Buridan's time, to be challenged on grounds of inadequacy as a scientific account of observed facts. Buridan's major significance in the historical development of physics arises from just such a challenge with respect to Aristotle's dynamic theory of local motion and from his proposal of an alternative dynamics which came to be known as the impetus theory.

An obvious weakness of Aristotle's dynamics is its inability to account for projectile motions, such as the upward motion of a stone thrown into the air after it has left the hand of the thrower. According to the assumptions of Aristotelian physics, such a motion, being violent and contrary to the natural movement of the stone toward the earth, required an external moving cause continuously in contact with it. Since the only body in contact with it is the air, Aristotle supposed that in some way the air pushes or pulls such a body upward. This feeble explanation drew criticism in antiquity and from medieval Moslem commentators and gave rise to a theory that the violent action of the thrower impresses on the stone a temporary disposition, of a qualitative sort, which causes it to move for a short time in the direction contrary to its nature. This disposition was called an impressed virtue (*virtus impressa*), and it was held to be self-expending and quickly used up because of its separation from its source. Franciscus de Marchia, a Franciscan theologian who taught at Paris around 1322, gave a full presentation of this theory, and it is likely that Buridan was influenced by it.

In treating of the problem of projectile motion in his *Questions* on Aristotle's *Physics* (VIII, question 12), Buridan expounded Aristotle's theory of propulsion by the air and rejected it with arguments similar to those that Marchia had used. His own solution was in some respects like that of Marchia, but in one crucial point it was strikingly different. The tendency of the projectile to continue moving in the direction in which it is propelled, which Buridan calls *impetus* rather than *virtus impressa,* is described as a permanent power of motion, which would continue unchanged if it were not opposed by the gravity of the projectile and the resistance of the air. "This impetus," he says in another discussion given in his *Questions* on the *Metaphysics,* "would endure forever [ad infinitum] if it were not diminished and corrupted by an opposed resistance or by something tending to an opposed motion."[3]

The suggestion given here of the inertial principle fundamental to modern mechanics is striking, as are some further uses that Buridan makes of the impetus concept in explaining the accelerated velocity of free fall, the vibration of plucked strings, the bouncing of balls, and the everlasting rotational movements ascribed to the celestial spheres by Greek astronomy. Buridan defines impetus in a quantitative manner, as a function of the "quantity of matter" of the body and of the velocity of its motion; thus, he seems to conceive of impetus as equivalent to what in classical mechanics is called momentum, defined as the product of mass and velocity. In treating the action of gravity in the case of freely falling bodies, Buridan construes this action as one imparting successive increments of impetus to the body during its fall.

> It must be imagined that a heavy body acquires from its primary mover, namely from its gravity, not merely motion, but also, with that motion, a certain impetus such as is able to move that body along with the natural constant gravity. And because the impetus is acquired commensurately with motion, it follows that the faster the motion, the greater and stronger is the impetus. Thus the heavy body is moved initially only by its natural gravity, and hence slowly; but it is then moved by that same gravity as well as by the impetus already acquired, and thus it is . . . continuously accelerated to the end.[4]

The effect of a force, such as gravity, is thus conceived of as a production of successive increments of impetus, or of velocity in the mass acted upon, throughout the fall. It is a short step from this to the modern definition of force as that which changes the velocity of the body acted upon, implying the correlative principle that a body in uniform motion is under the action of no force. Buridan does not quite take this step, since he retains the Aristotelian assumption that a constant cause must produce a constant effect, and ascribes the increase in velocity to the addition of impetus as an added cause acting along with the gravity.

Yet his theory obviously requires a distinction between impetus as a "conserving cause" of motion and gravity as a "producing cause" of the motion conserved by the impetus; his failure to draw the consequence of this distinction was perhaps because he did not attempt a mathematical analysis involving the concept of instantaneous velocities added continuously with time. Whether Buridan construed the acceleration as uniform with respect to time elapsed, or with respect to distance traversed, is not clear. He probably regarded the two functions as equivalent, a view that, however impossible from a mathematical point of view, was retained into the seventeenth century, when Descartes and Galileo (in his letter to Sarpi of 1604) sought to prove that velocity increases in proportion to time elapsed from the premise that velocity increases in direct proportion to distance of fall.

Buridan's concept of impetus is further distinguished from the modern inertial concept by the fact that he construes rotational motion at uniform angular velocity as due to a rotational impetus analogous to the rectilinear impetus involved in projectile motion. Galileo did likewise, and was in this respect nearer to Buridan than to Newton. But Buridan makes a striking use of his impetus concept, in its rotational sense, by arguing that since the celestial spheres posited by the astronomers encounter no external resistance to the rotational movements and have no internal tendency toward a place of rest (such as heavy and light bodies have), their uniform rotational motions are purely inertial and require no causes acting on them to maintain their motions. There is, therefore, no need to posit immaterial intelligences as unmoved movers of the heavenly spheres, in the manner that Aristotle and his commentators supposed. "For it could be said that God, in creating the world, set each celestial orb in motion . . . and, in setting them in motion, he gave them an impetus capable of keeping them in motion without there being any need of his moving them any more."[5] It was in this way, Buridan adds, that God rested on the seventh day and committed the motions of the bodies he had created to those bodies themselves.

It is clear that Buridan's impetus theory marked a significant step toward the dynamics of Galileo and Newton, and an important stage in the gradual dissolution of Aristotelian physics and cosmology. Buridan did not, however, exploit the potentially revolutionary implications of his analysis of projectile motion and gravitational acceleration, or generalize his impetus theory into a theory of universal inertial mechanics. Thus, in discussing the argument of Aristotle against the possibility of motion in a void, Buridan accepted the principle that the velocity of a natural motion in a corporeal medium is determined by the ratio of the motive force to the resisting force of the medium, so that if there were no resisting medium, the motion would be instantaneous. This is scarcely consistent with the analysis of gravitational acceleration as finite increments of impetus given to the falling body by its gravity, and Buridan made no effort to harmonize these two different approaches within a common theory.

In a question bearing on the *De caelo et mundo,* Buridan asks whether it can be proved that the earth is at rest, with the celestial spheres rotating around it, as Aristotle supposed. He states that many people of his time held it to be probable that the earth rotates on its own axis once a day and that the stellar sphere is at rest. And he adds that it is "indisputably true that if the facts were as this theory supposes, everything in the heavens would appear to us just as it now appears."[6] In support of the hypothesis, he invokes the principle that it is better to account for the observed phenomena by fewer assumptions or by the simplest theory, and argues that since the earth is a small body and the outer sphere is a very large one, it is more reasonable to attribute the rotation to the earth than to suppose the enormously faster rotation of the much larger sphere. After giving this and other arguments in favor of the theory of diurnal rotation of the earth, Buridan makes it quite clear that they cannot be refuted by any of the traditional arguments purporting to prove that the earth is at rest. He says that for his part he chooses to hold that the earth is at rest and the heavens in motion; and he offers, as a "persuasion" for this view, the argument that a projectile thrown straight upward from the earth's surface will fall back to the same spot from which it was thrown.

This argument does not seem consistent with Buridan's own impetus theory, unless he had in mind a point made later by his pupil Albert of Saxony, who held that the lateral impetus shared by the projectile with that of the surface of the rotating earth would be insufficient to carry it over the greater arc which it would have to traverse, when projected outward from the earth's surface, in order to fall back at the same spot. Not only Albert of Saxony, but also another pupil of Buridan's, Nicole Oresme, took over this discussion of the earth's rotation; Oresme concluded that it is impossible to prove either side of the question, since the motion is purely relative. Oresme said that he accepted the view that the earth is at rest, but only because this seemed to be assumed by the Bible. It is of interest to note that when Copernicus was a student at Cracow, Buridan's works in physics were required reading in the curriculum of that university.

While rejecting the theory of the diurnal rotation of the earth, Buridan says that the earth is not immobile at the center of the world, and proves it as follows: Because the dry land protruding from the ocean is mostly on one side of the earth, the center of volume of the earth does not coincide with its center of gravity. The earth, however, is the center of the world in the sense that its center of gravity is equidistant from the inner surface of the celestial spheres. But this center of gravity is continuously altered by the erosion of the dry land, which slowly gets washed into the sea; and consequently the whole mass of the earth slowly shifts from the wet side to the dry side in order to keep its center of gravity at the center of the universe.

Buridan's significance in the history of science lies more in the questions he raised than in the answers he gave to them, although in some cases his answers opened up new theoretical possibilities that were undoubtedly influential in the rise of modern mechanics in the seventeenth century. The impetus theory was taken over by Buridan's pupils and was made known throughout central Europe, although in a degenerate form that fused it with the older theory of a self-expending *virtus impressa* and introduced a number of confusions and errors that Buridan himself had avoided. It was in this degenerate form that it was conveyed to Galileo by his teacher Buonamici, so that Galileo had to take the step that Buridan had taken three centuries earlier when he discarded Marchia's theory of the self-expending impressed force in favor of impetus as an enduring condition only changed or diminished by opposed forces. Buridan's application of the impetus concept to the analysis of free fall, although retained and made known by Albert of Saxony, was forgotten by most of the later teachers of physics, even when they retained the concept in dealing with projectile motion.

Even when Buridan's specific contributions to physical problems were forgotten, however, the influence of his conception of scientific evidence and method remained operative; and it may be said that the idea of mechanics, in the modern sense, became established in early modern times through the work of Buridan and of his contemporaries. In particular, Buridan may be credited with eliminating explanations in terms of final causes from the domain of physics, which he does very explicitly in his *Questions* on the *Physics* (II, questions 7 and 13) and in his *Questions* on the *De caelo et mundo* (II, question 8). The mechanistic conception of nature, construed as a methodological assumption more than as a metaphysical thesis, emerged in the fourteenth century as a natural development from Buridan's philosophy of science. He was not an experimental scientist or a mathematical physicist; but as a philosopher of science he did much to clear the way for, and to point the way to, the development of modern science in these directions.

NOTES

1. *Qu. in Metaph.* II, Qu. 2 (1518), fol. 9*v*.
2. *Ibid.*, Qu. 1 (1518), fol. 9*r*.
3. *Ibid.* (1518), fol. 73*r*.
4. *Qu. De caelo et mundo* (1942), 180.
5. *Qu. in Phys.* VIII, Qu. 12, fol. 121*r*.
6. *Qu. De caelo et mundo* II, Qu. 22 (1942), 227.

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ERNEST A. MOODY

BURLEY, WALTER (*b.* England, *ca.* 1275; *d. ca.* 1345?), *logic, natural philosophy.*

A colophon to the final version of Burley's commentary on the *Logica vetus* that is dated 1337 stipulates that the work was composed in its author's sixty-second year, a factor which places Burley's birth about 1275, possibly in one of the two towns named Burley in Yorkshire. Although almost nothing is known of his youth, it seems most reasonable to presume that Burley began his studies at Oxford sometime during the last decade of the thirteenth century, for two works dated 1301 and 1302 already