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IBN SÎNÂ AND BURIDAN ON THE DYNAMICS OF PROJECTILE MOTION

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According to Aristotle, continuation of motion is possible only if there is continued action of a force for its maintenance. The motion of a stone or arrow after leaving the hand of a thrower or the bow therefore requires elucidation. Aristotle maintained that it was the medium, i. e., air which sustained this motion. This view was subject to much criticism in the Middle Ages both in Islam and in Europe, and the main source of inspiration of this criticism was John Philoponos, or Yaḥyâ an-Naḥwî, as he was called in the Islamic literature. But this criticism was not always of a stereotyped form. It was modified to different extents and in certain respects in the hands of different thinkers and commentators. Islamic sources are unfortunately rather silent or laconic in this respect, however.

Scientifically and from the vantage point of historical influence the most important novelty in Philoponos's idea was that it claimed that the hurled body acquires a motive power or a certain condition from the throwing agent and that this power or condition and not the ambiant medium secures the continuation of the motion. The various names given to this motive power or condition serve to give us clues as to the nature of the agent conceived in this connection. Names such as inclination, virtue, force, impetus, *mayl*, *i'timâd*, *quwwa*, etc., used by different thinkers or writers are indicative not only of the nature of this idea as conceived by them but also of their sources of inspiration or direetions of historical influence.

Of special historical importance is the fact that Philoponos conceived this motive force or inclination for violent motion impressed through the initial propulsive action as a temporary and self-weakening acquired virtue. This seemed quite natural, as the non-natural motion in question comes to an end and turns into a natural one after a while.

It was apparently for the first time in history that Ibn Sînâ conceived this impressed virtue or acquired condition as one which does not grow weaker by itself, as not a gradually self-consumed one, but as a permanent force whose effect got weakened or dissipated only as a result of external agents such as air resistance or the density of the medium through which the motion takes place in general.[1]

Now, this conception of the violent inclination is almost the opposite of that of Aristotle. For here the medium, far from exerting a propulsive action on the projectile, is the agent that opposes this motion, exactly as it does in the case of the natural motion. And moreover, self-motion means the ruin of the Aristotelian basic assumption that a body cannot sustain its violent motion without being moved by another. This is rather reminiscent of the principle of inertia, or the first law of motion of Newton, according to which a body which is not acted upon by any force will keep moving without any change of speed or direction.

Ibn Sînâ refers to this idea of his on more than one occasion. He does not specify constancy of speed and direction, but the former is perhaps not necessary. For the postulation of the continuation of a motion indefinitely may be said to entail constancy of speed in nonsophisticated thinking. Jean Buridan in the middle of the fourteenth century postulated the idea of an impressed violent virtue of the same nature as that of Ibn Sînâ which he called impetus. It too is non-self-expending or non-self-consuming. He happens also to extend this concept of impetus to rotational motion and to motion with a curvilinear trajectory. This is a drawback as far as the latter type of motion is concerned, but considering the state of knowledge in his time, we may overlook this point, and neither should we be entitled to claim for Ibn Sînâ's concept of violent inclination (*mayl qasrî*) a superiority over the notion of impetus as conceived by Buridan. Ibn Sînâ was clearly a forerunner of Buridan, and it is almost natural to think that he influenced Buridan directly or indirectly, but it would undoubtedly be desirable to find clear evidence supporting such a claim.

[1] S. Pines, "Etudes sur Awḥad al-Zamân Abû'l Barakât al-Baghdâdî", *Revue des Etudes Juives*, New Series, vol. 3, Paris 1938, pp. 3-64, vol. 4, 1938, pp. 1-33; S. Pines, "Les Précurseurs Musulmans de la Théorie de l'Impetus", *Archeion*, vol. 21, 1938, pp. 298-306; Anneliese Maier, *Zwei Grundprobleme der Scholastischen Naturphilosophie*, second edition, Rome 1951, pp. 127-141; Aydın Sayılı, "Rawish-i 'Ilmî-i Abû 'Alî Sînâ", *Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Dergisi*, vol. 12, Ankara 1954, pp. 145-152; Marshall Clagett, *The Science of Mechanics in the Middle Ages*, 1959, pp. 510-515.

It is of great interest in this juncture that Galileo adhered to a theory of the self-expending type of the *virtus impressa* at the beginning of his career, in his Pisan period, and that he later abandoned this view in favor of the permanent type of impetus propounded by Buridan. It was with the help of this new mental and intellectual orientation that Galileo achieved his monumental work in the field of the science of mechanics, notwithstanding Koyré's persistent effort to establish the contrary thesis.[2]

Ibn Sînâ speaks of his idea of impressed force or virtue, or violent impulse, on more than one occasion.[3] The following passage quoted from the Physics part of his Kitâb ash-Shifâ is of interest on various accounts :

"Another proof for the impossibility of vacuum is that we observe ob-jects which move by nature in differing directions and which also differ in their speed and sluggishness, and this dissimilarity arises either from a condition intrinsic to the moving body or is due to a circumstance residing in the distance traversed. The diversity of speed and sluggishness that arises from a circumstance inherent in the moving body is sometimes due to differences in the force of its inclination. For the heavier body will be swifter in its descent and the lighter body in its ascent either because of its greater force or because of its larger bulk, and the opposite of these is the case as for the cause of its slowness. And sometimes these arise from the differences of shape. For instance, if the moving body has the shape of a square and moves with its surface to the front it will be different from the body which has the shape of a cone and moves with its tip foremost or the square plane figure that moves with an angular inclination to its trajectory. For the square body will have to displace a greater amount of material with which it comes into initial contact, whereas the cone is not in a similar situation. Thus, in every case the cause of celerity is the ability of the body to forcefully displace whatever tries to resist or hinder it and to cleave a path for itself with telling effect. In other words, the body which is able to do this is speedier and the one not so equal to it is more sluggish. And in vacuum such a state of affairs does not materialize. But we shall not dwell on this point, for it is not of advantage to our purpose... Now let us

[2] Ernest A. Moody, "Galileo and Avempace", *Journal of the History of Ideas*, vol. 12. 1951, pp. 394-396, 410-412, 412.

[3] See, above, p. 141-142, note 1.

assert that if a body moves in a vacuum inevitably one of the two following circumstances will occur. It will either traverse the empty space in a time or without spending any time. But it is impossible that this traversal should take no time. For it will neces-sarily traverse part of the distance before traversing the whole of it. This will therefore of necessity take place in time, and this time must needs have a ratio with the time of motion in non-empty space..."[4]

This passage seems to suggest the probability that Buridan was familiar with the physics part of Ibn Sînâ's Kitâb ash-Shifâ. For he speaks of pointed objects moving with their pointed end to the front or vice versa, and this example seems to occur rarely in the literature on this subject, but he says this won't make any appreciable difference in the speed of objects hurled into the air and uses it to refute the Aristotelian idea of the propulsive action of the air in the violent motion of the projectile.[5]

Again, this passage seems to indicate that Ibn Bâjja (Avempace) was perhaps influenced by Ibn Sînâ and it corroborates the conclusion to be drawn from the passages from Albertus Magnus quoted below indicating that Ibn Sînâ and his Kitâb ash-Shifâ were one of the major sources of inspiration for European thinkers in the field of dynamics. For the argument that geometrical distance or dimension alone should be deemed as a major factor imposing the necessity of the passage of time in motion through

[4] Ibn Sînâ, *Kitâb ash-Shifâ*, Tehran lithographic edition, 1886, vol. 1, p. 59; Persian translation of the Physics part of the Kitâb ash-Shifâ by Muḥammad 'Alî Furûghî, Tehran 1319 Hsh. (1940), pp. 208-209. This passage is from the eighth chapter of the second discourse (*maqâla*) of section *(fan)* 1 of the Physics part of the Kitâb ash-Shifâ.

This chapter (ch. 8) is among the parts of the Kitâb ash-Shifâ that are known with certainty to have been translated into Latin. Another passage from this chapter, one that is relevant to Ibn Sînâ's conviction that the violent impetus or inclination of the projectile is non-evanescent, has been made available in French translation by S. Pines ("Etudes sur Awḥad al-Zamân ...", pp. 54-56. This is from Kitâb ash-Shifâ, Tehran lith. ed., vol. 1, p. 61. See also, Marshall Clagett, *op. cit.*, p. 513 and note 13, p. 514 and note 20).

Ibn Sînâ speaks of the violent *mayl* on various occasions in other parts of his Kitâb ash-Shifâ also (See, Tehran ed., e. g., vol. 2, pp. 458, 605). I shall refer here only to those passages that, as far as I could ascertain, are of a nature to contribute to the specific points or views propounded in this paper.

[5] René Dugas, *Histoire de la Mécanique*, Neuchatel 1950, p. 49. Giovanni Battista Benedetti, more than two centuries after Buridan, also speaks of the shape of objects, and he says that the shape will have hıfluence on speed. See, Alexandre Koyré, *Etudes Galiléennes*, Paris 1939, p. 48.

empty space is a well-known argument of European thinkers following Ibn Bâjja.

After his exposition of Aristotle's argument against motion in the void, Albertus Magnus says, as quoted by Moody :

"Against him, both Avicenna and Avempace object, drawing from it three inconveniences. The first is, that a medium which resists a motion is not a natural medium. ... The second ..., that if the motion which is in a medium that does not resist the movement of what is borne through it, is in an indivisible time, it follows that the motion of the heavenly bodies is instantaneous. ... A third difficulty is this : while the proportion of a motion is as of two causes, from one primarily and from the other secondarily, it follows from what has been said, that one motion is not proportional to another motion except according to what is secondary and accidental in the motion".

Moody continues, "The assumption on which Avempace's arguments are based, Albert points out, is that the primary and essential cause of the differences in speeds of the motions of heavy and light bodies, is the differences in the power or perfection of their movers — in this case, of their substantial forms or intrinsic 'natures'. The truly natural medium, therefore, is held to be one in which the power and perfection of these natures is fully realized in movement; and such a medium will not be one in which the motion is retarded by resistant matter, but it will be a pure empty space. Thus the essential effect and measure of motive power, for Avempace, is the time of traversal of a given distance of empty space. The pushing aside of such material body as may be contained within that distance, is not the natural or essential effect and measure of the motive power, but is secondary and accidental."

Moody then makes the following quotation from Albertus Magnus again:

"Since then this comparison of movers would stili remain, even if a separate vacuum were posited, it seems that it would be according to this comparison that there would be a proportion of a faster and slower motion in the void, if the latter were supposed. Hence it was inconvenient to say that there would be no proportion of motion to motion, in speed or slowness, except by reason of the density and rarity of the medium. ... These are the objections stated by the two philosophers, Avicenna and Avempace, against the position of Aristotle, whom we follow."[6]

This latter quotation is reminiscent of the passage of Ibn Sînâ given above, but as Albertus Magnus does not reproduce statements verbatim it would be difficult to make exact determinations.

The influence exerted by Islam upon Western Europe, during the late Middle Ages, in the field of Aristotelian dynamics is generally known to have come through translations of Aristotelian works from the Arabic and translations from Ibn Rushd, or Averroes, in particular. This latter work brought European thinkers into contact also with the ideas of Ibn Bâjja who exerted a powerful influence upon Europe in this respect. In his commentary on Aristotle's Physics, Ibn Rushd included a rather substantial disquisition on Ibn Bâjja's criticism of Aristotle's dynamics in his otherwise lost work, and this was a source of inspiration for European thinkers up to the time of Galileo. Another path of transfer of ideas from Islam to Europe in this field is deemed by some to have come from Al-Bitrûjî who was quite well known in Western Europe and who touched upon the subject of dynamics in his astronomical work. He was influenced by Ibn Bâjja through Ibn Ṭufayl, and, like Ibn Bâjja, he too supported the idea of a *virtus impressa* which would undergo, of its own accord, a gradual decay due to its unnatural character.[7] Ibn Rushd was the source that made available to Europe the ideas of Ibn Bâjja advocating the law that velocity is determined by the arithmetic difference between the magnitudes of the motive force and the resistance offered by the corporeal medium in which the motion takes place, whereas Aristotle had propounded the law according to which velocity would be equal to the ratio of force to resistance. Ibn Rushd's passage in question contains no mention of Ibn Bâjja's views concerning the motion of the projectile. It has been proposed that the idea of an evanescent *virtus impressa*, or impressed force, was transferred from Islam to Europe by Al-Bitrûjî. This path of transmission has been proposed by Duhem.

[6] Ernest A. Moody, "Galileo and Avempace", *Journal of the History of Ideas*, vol. 12, 1951, pp. 376-377.

[7] Moody, "Galileo and Avempace", pp. 184-186, 192-193, 391. See also, below, p. 152 and note 22.

Ibn Sînâ's name should be added to this list, and his name would undoubtedly occupy a place of honor in it. Moreover, none of these except Ibn Sînâ could have influenced Buridan in the strategic move he made in departing both from the Aristotelian, or the Averroist, views, as well as from the ideas of Ibn Bâjja, making him blaze the trail that was destined to lead to the monumental achievement of Galileo. He had a precursor in Ibn Sînâ in the idea of a permanent impressed virtue and he very likely was influenced by him.

A passage wherein Ibn Sînâ dwells at some length on the nature of violent motion of the projectile runs as follows :

"If the violent motion of the projectile is due to a force (or potentiality) (*quwwa*) which is in the moving body it should certainly not disappear or decay or deteriorate. For when a force resides in a body it will either endure or it will disappear. But if it endures the motion will continue forever, and in case it disappears or weakens it will either disappear or weaken due to a cause or do so by itself. We shall consider the case of total dissipation and the case of weakening will also become clear thereby. Now, it is impossible that it should dissappear or disintegrate by itself, for the coming into being of a thing for which annihilation or nonexistence is befitting is impossible in the first place. If, however, its annihilation is due to a cause, this cause is either within the moving body or outside of it. If it was in the moving body, while at the beginning of the motion it was nonexistent in deed and was perhaps suppressed and later it became predominent, then the existence of another cause is required in order that such be the case, and this sequence of causes will go on indefinitely and without coming to an end. But if the cause be outside of the moving body or be in the body but its engenderer be outside, then, of necessity, the producer of the effect is either in contact with the moving body or is apart from it. In case it has to contact the moving body, the cause must be a material body that meets the moving body, and such cannot be the case in empty space, and violent motion will therefore neither disappear in empty space nor come to a stop. And in case the cause does not act through contact but is apart from the moving body, then why has it not produced its effect at the beginning? In this way, the judgment concerning such a case becomes similar to that of the cause which resides in the moving body itself. The truth thus is that the succession of resistances is what gradually brings about the dissipation of the impressed violent virtue and causes its annihilation. But this is impossible unless the motion does not take place in absolute void."[8]

If void existed, therefore, motion would last indefinitely in it. Ibn Sînâ seizes upon this idea, which is irreconcilable with Aristotelian convictions, and uses this ideal but unrealizable condition also as an argument in favor of the Aristotelian thesis of the nonexistence and impossibility of the void. For, the existence of a permanent violent inclination or *qasrî mayl* would otherwise lead to the possibility of motion continuing indefinitely. This idea too is seen to have been adopted identically by Buridan.

Ibn Sînâ can have influenced Europe in general and Buridan in particular, in the field of dynamics, through various works of his, but through his Kitâb ash-Shifâ in particular. I shall limit myself here to considering the possible influence he exerted through his Kitâb ash-Shifâ on Buridan.

The translation of this important work into Latin was made in several stages. The first two discourses (*maqâla*) of the first part, i. e., first *fan* of the Physics (Samâ' aṭ-Ṭabî'î) and the beginnings of discourse 3 (containing each 15, 13, and 14 chapters respectively) were translated already by the Toledo group of translators, presumably shortly after 1150 A. D. This translation is anonymous; it may have been made by Dominique Gundissalinus with or without collaboration of some other person. Additional translations from the Physics were made by a certain Johannes Gundissalinus and a collaborator roughly around the year 1275. Concerning these latter translations D'Alverny writes :

"They completed the third book *[maqâla]* of the Physics with the ex-ception of its last three chapters, but they did not translate the fourth section *[maqâla]* of the Arabic text. They undoubtedly had at their disposal a deficient manuscript, for the 'explicit' indicates that they thought they had completed their task. On the other hand, they have set up a Book *[maqâla]* III and a Book IV with the six first chapters of the third section *[maqâla]* as described by P. Anawati on the basis of the Tehran lithographic edition and

[8] *Kitâb ash-Shifâ*, Tehran lith. ed., vol. 1, p. 61 (*Physics, fan 1*, *maqâla* 2, chapter 8); Furûghî translation, p. 214.

a manuscript of the Azhar University,[9] and it is possible that their copy of the manuscript had a division of this type."[10]

In discourse (*maqâla*) 4, chapter 12, of the second book (*fan*) (As-Samâʿ aṭ-Ṭabî'î) of the Physics (At-Tabî'îyât) part of the Kitâb ash-Shifâ, Ibn Sînâ says, "Natural objects have inclinations such as gravity and levity. The heavy bodies are those that have an inclination to move downwards, while the light bodies have an inclination to move upwards. And the greater their inclination, the less they lend themselves to violent motion and the slower their unnatural motions. Indeed, moving a huge stone of great weight or its traction are not like moving or pulling a little stone of small weight. Likewise, making a small amount of air flow through water is not like making a great amount of air pass through water. It is true that small objects such as mustard seed, hay, and wood chips when hurled will not penetrate into the air like heavier objects. But the cause thereof is not that heavy objects lend themselves more readily to projection or traction, this is rather because such objects, in certain cases, due to their smallness, do not receive from the projecting agent a motive force sufficient to sustain their motion, and when this force is adequate they are capable to clear a path for themselves through the ambiant air, but despite this their acquired force will rapidly wear away and cease to exist. ..."[11]

And in chapter 14 of the same discourse or *maqâla* Ibn Sînâ speaks of the divergent views concerning the projectile motion, comparing them with one another, criticizing them, and stating his preferences. He writes, e. g., "How can one say that the air that has returned to the back of the projected object has accumulated in such a fashion that it drives what is in front of it; and why should such a body of air, when it has come together, move forward and also move the body which is behind it? And how can one say that the motive agent engenders a force (or an inclination) in the moving body? Such a force has to be either natural (ṭabîʿî) or spiritual (or psychic) (*nafsânî*), or accidental (*ʿaraḍî*), and it is none of these. For you assert that

[9] G. C. Anawati, *Essai de Bibliographie Avicennienne*, Cairo 1950, pp. 44-45.

[10] M. T. D'Alverni, "Avicenna Latinus", *Archives d'Histoire Doctrinale et Littéraire du Moyen Age*, year 36, 1961, Paris 1962, pp. 285-287.

[11] *Kitâb ash-Shifâ*, Tehran lith. ed., vol. 1, p. 149 (*Physics*, *fan 1*, *maqâla* 4, chapter 12); Furûghî tr., p. 506.

an upwards motive power is in the substance of fire and is a form, and if such a motion occurs in the stone it would be accidental. How then could one nature be both accident and form ? ... But as to my own preferences, as a result of my investigations, I have come to decide that the truest view is that the moving body receives a force and inclination from the motive agent. Indeed, this inclination becomes descernible when one wants to stop by force a body moving with natural motion, or, a body moving with a violent motion, as well. In the course of such an attempt one feels a resistance (or opposition) which may be intense or weak. ..."[12]

Again, toward the end of chapter 15, *maqâla* 4, of the second book *(fan)* of the Physics part of the Kitâb ash-Shifâ, Ibn Sînâ writes :

"The case of a motive force pushing a body is the same as that of traction. As to the hurling force, it sometimes happens that it produces a greater effect in a heavier body than in a less ponderous one. It will act, e. g., with greater strength in the body twice as heavy than in the body having half the weight. This ratio will not persist, however. For the celerity and sluggishness of the projectile will not remain the same near the two extremities of its trajectory, but in the parts near the end the speed is smaller, and according to some, it reaches its maximum in the middle part."[13]

Buridan conceived of impetus quantitatively also. For he pointed out that if a heavy body and a light body were hurled with the same speed, the heavier body's motion would last longer and would have a longer trajectory, indicating that impetus increased with weight or quantity of matter. He also noted that the greater the initial velocity of projection the greater the duration and distance of flight. Thus he considered impetus as a virtue or inclination proportional to weight times velocity. Thus, his conception of impetus comes very close to the momentum of Newtonian mechanics. This quantity was called both impetus and momentum by Galileo.

It is of interest that Ibn Sînâ refers to the idea of impetus as something increasing with weight, but in one case he feels the need of rejecting it,

[12] *Kitâb, ash-Shifâ*, Tehran lith. ed., vol. 1, p. 154 (*Physics, fan 1, maqâla* 4, chapter 14); Furûghî tr., pp. 524-525; A. Sayılı, "Rawish-i 'Ilmî-i Abû 'Alî Sînâ", p. 149.

[13] *Kilâb ash-Shifâ*, Tehran ed., vol. 1, p. 158 (Physics, fan 1, maqâla 4, chapter 15); Furûghî tr., p. 534.

while in another case he accepts it but does not cling to it firmly. In other words, in this matter, Ibn Sînâ vacillated between the two alternatives. For, as seen in the third passage quoted from him last he accepts the view of the increase of imparted impetus with increased weight, qualifying his assertion only by saying that the speed does not remain the same along the trajectory. It seems, moreover, likely from his phraseology that the reason he hesitates and rejects the same idea may perhaps be that he has in mind the general case which may include situations in which the force may be too small to project the body, as is suggested by his phrase "it sometimes happens that ..."

Marshall Clagett writes:

"It is the *mail qasrî*, however, which is imparted to a projectile and continues its motion. Avicenna sometimes used the expression "impressed force" (*quwwat mustafâdat*) in the same context as *mail qasrî*, thus obscuring the distinction between 'inclination" and "force". The action of the *mail* differs according to the weight of the body to which it is communicated. And thus it would seem that Avicenna takes the first step toward quantification of the *mail* or impressed force. ..."[14]

Ibn Sînâ's hesitation or vacillation may also stem partly from his having failed to reach sufficiently strong convictions concerning the relationship of a force applied to a body and the speed thereby produced. He devoted almost an entire chapter[15] of his Kitâb ash-Shifâ to this question which seemed unsettled and quite controversial to him. Men like William Ockham (1280-1347) and Thomas Bradwardine (1290-1349), and, to some extent, Buridan (d. 1358?) himself felt the need of the same sort of critical approach to this issue,[16] and it is conceivable that their attitude was partly inspired by Ibn Sînâ. Indeed, Ibn Sînâ could serve as a good source to impress upon the mind the confusion that seemed to reign in the rather vast domain covered by the attempt to solve the unsolvable problem of finding a unique mathematical definition of velocity in terms of impressed force and resistance.

[14] Clagett, *op. cit.*, p. 513.

[15] Chapter 15 of the fourth discourse (*maqâla*) of *fan* 2 of the Physics part of the Kitâb ash-Shifâ.

[16] See, Moody, "Galileo and Avempace", pp. 398, 399-400; Clagett, *op. cit.* pp. 551-552, 562-564.

Ibn Sînâ's long insistence on his hesitation of expressing in clear-cut mathematical formulas the relationship between velocity (V), force (F), and resistance (R) is somewhat reminiscent of Ockham's treatment of the subject. Ockham asserted that just because V=(F/R) is satisfactory for cases wherein there is material resistance offered by the medium through which the moving body proceeds, this does not mean that such a relationship holds also for cases in which the medium does not resist the movement. In such a case V=F holds, and not V=(F/R). But conversely, this should not lead us to infer that, where R≠0, V=F-R would be valid.[17] All this gives the impression that both Ibn Sînâ and Ockham felt discouraged in their attempt to resolve the difficulties encountered in the endeavors to formulate the notions concerning dynamics on a mathematical basis. Ockham's situation was somewhat clearer because he had two rival theories to contend with and, if possible, to reconcile with one another. Bradwardine of course came closer to achieving this goal in a reduced scope.

Marshall Clagett writes, "We are now in a position to consider Buridan's contributions to the acceleration problem. We are immediately struck with the similarity of Buridan's views with those of his Arabic predecessors although there is no evidence of his having had access to their accounts. ..."[18]

The identity of Buridan's and Ibn Sînâ's ideas of impetus in so far as they both believed in a non-self-expending variety of violent impetus is striking, and Marshall Clagett's statement concerning the similarity of Buridan's views of impetus with those of his "Arabic predecessors" should undoubtedly include, or refer to, this parallelism in particular. There are, however, in addition, other parallelisms in the details concerning the nature of the impetus on which both Ibn Sînâ and Buridan dwell. For, as we have seen, Buridan too speaks of the opposition a moving body offers to an effort to stop it, both in natural and violent motions, exactly in the same way as Ibn Sînâ does.

Moreover, Buridan notes that the greater the weight of the moving body, the more difficult it is to stop it. And Buridan asserts that the greater the weight of a body, the greater its capacity to gain a violent impetus, and

[17] Moody, "Galileo and Avempace", pp. 397-398.
[18] Clagett, *op. cit.*, p. 551.

the greater the initial velocity with which a body is hurled, the greater its impetus. This impetus thus becomes proportional both to speed and weight, and the expenditure of force is required in order to decrease its magnitude, an idea which adumbrates Newton's second law of motion.[19]

There is a partial parallelism, with respect to these details also between Ibn Sînâ and Buridan. Ibn Sînâ does not speak explicitly of the proportionality of violent impetus with the initial speed of projection. But so long as one subscribes to the idea that the initial speed of projection produces an impetus, it almost goes without saying that these should be proportional with each other. As we have seen, Ibn Sînâ hesitated to decide that heavier bodies possess greater capacity to acquire a violent impetus, but he clearly referred to such an impression on more than one occasion. Ibn Sînâ is therefore in a unique position to serve as a source of inspiration for Buridan in this respect also if this part of his Kitâb ash-Shifâ was accessible to Buridan in one form or another.[20]

In speaking of various views held with respect to the movement of the projectile, Ibn Sînâ refers also to the concepts of *tawallud* and *i'timâd.* These terms apparently go back to the Mu'tazilites. The term *i'timâd* was used both as a synonym of the word *mayl* and also in the sense of the movement produced by a body possessing such an inclination in the bodies which are contiguous to it and which constitute an obstacle to it in its motion, and the term *tawallud* means "birth", "being engendered", or "being produced". These questions had been dwelled upon and discussed at some length by the Mu'tazilî theologians Abû 'Alî Jubba'î (d. 915), his son Abû Hâshim (d. 933), and their contemporary Ibn 'Ayyâsh.[21]

Certain terms encountered in the literature of the subject thus seem conducive to make Ibn Sînâ dwell upon the idea of the force exerted by a moving body against the bodies putting up a resistance against that movement and to lead him to back up his idea that expenditure of force was required to bring about a change in the impetus by factual evidence derived

[19] For these ideas of Buridan, see, Rene Dugas, *op. cit,*, pp. 48-50; Clagett, *op. cit.*, pp. 505-525, 519-520, 522-525, 530-540.

[20] See also, Clagett, *op. cit.*, pp. 511-512.

[21] See, S. Pines, "Etudes sur Awḥad al-Zamân Abû'l Barakât al-Baghdâdî", pp. 44-47.

from concrete examples of such resistance. He may therefore have, in turn, acted as source of inspiration for Buridan who integrated these ideas into a more consistent form.

We therefore seem confronted with the somewhat strange situation that Ibn Sînâ influenced Buridan on questions he dealt with in the parts of the Kitâb ash-Shifâ which are not supposed to have been translated into Latin, or for which there is no evidence of having been translated into Latin Nevertheless, one such passage referring to the non-evanescence of violent impetus, though perhaps in a bit vague manner from the standpoint of specification, was accessible in Latin. Moreover, Analiese Maier has cast into serious doubt the veracity or the likelihood of Duhem's claim that Al-Bitrûjî served as a source of transmission for the idea of the self-consuming variety of impetus from the World of Islam to Western Europe.[22] Under these circumstances, Ibn Sînâ's possible role as the originator and the source of Buridan's non-self-expending impetus assumes perhaps even greater significance and semblance of truth. It may be then that a greater part of the Kitâb ash-Shifâ was translated than it can be ascertained at the present, or that Buridan had means of consulting parts of that book from its Arabic text also.

It may be conjectured, e.g., that Buridan read chapter 8 of discourse 2 of the first book *(fan)* of the Physics in the Kitâb ash-Shifâ and was influenced by it as is attested or suggested by his adoption of a non-evanescent type of impetus, by his reference to the relation between the shape of a body and the resistance offered to it by the medium through which it moves, and as the passages quoted above from Albertus Magnus would tend to corroborate. He may have thus felt anxious to gain a knowledge of the contents of the chapters that followed and he may somehow have managed to get acquainted with them.

Ibn Sînâ seems favorably disposed toward the idea that in projectile motion there is an increase of speed in the middle part of the trajectory and also his feeling toward the notion of *quies media* tends to be rather midl if not favorable. These aspects of his knowledge of mechanics give

[22] See, above, pp. 145-147 and notes 7 and 10. See also, A. Maier, *Zwei Grundprobleme der Scholastischen Naturphilosophie*, pp. 129-133, and, Clagett, *op. cit.*, p. 514 and note 20.

him undoubtedly a less modern outlook. Furthermore, if we study more closely his texts we find it at times difficult to pin down his ideas at points of detail, and in many cases he himself clearly states the difficulty he feels in coming to final decisions. These should be deemed as indicative of the objectivity of his approach to these complicated questions and definitely not as a shortcoming on his part.

The same sort of observation may be made about Buridan. Ernest A. Moody writes:

"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."[23]

Moody says, "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

[23] Moody, "Buridan", *Dictionary of Scientific Biography*, vol. 2, 1970, pp. 606-607. Stillman Drake too believes that Buridan had a conception of the variation of speed in free fail in the form of discrete steps or successive quanta (See, Drake, "Impetus Theory Reappraised", *Journal of the History of Ideas*, vol. 36, 1975, pp. 27-46), but Allen Franklin believes such not to be the case (See, A. Franklin, "Stillman Drake's 'Impetus Theory Reappraised' ", *Journal of the History of Ideas*, vol. 38, 1977, pp. 307-316.). Buridan's own statement is given by Marshall Clagett (*op. cit.*, p. 560-561. See also, pp. 551-552.).

to be a handmaiden of theology or a mere exposition of the doctrines of Aristotle."[24]

The theologians of Islam, i. e., the thinkers representing *kalâm*, tried to develop a theoretical system in which movement and the subject of mechanics were based on the idea of the omnipotence of God, and the idea of causality was pushed to a side.[25]

In Islam such examples were remarkably rare. In spite of the existence of many sayings of the Prophet concerning medicine, there was no attempt to base medicine upon these Traditions. This was because although Prophetic Traditions on medicine were often quite useful, medical knowledge of higher standards were available especially in Greek sources. Moreover, such a policy did not run counter to the advice of the Prophet.[26]

Medieval Moslem thinkers seem to have raised certain epistemological questions and to have criticized the methodology of astronomy by contrasting it to the Islamic method of *ijmâ'*, i. e., concensus of opinion. The question of reliability and trustworthiness also was probably touched upon in such criticisms. The question of the trustworthiness of reports was a weighty problem which received much attention in connection with the study of the transmission of the sayings of the Prophet, and it seems that the Moslem jurists sought to apply the criterion established in that field to astronomical work. The acceptance of astronomy as a handmaiden of religion may have been instrumental in these considerations. It is quite clear, however, that all this did not constitute an unreasonable interference and encroachment on the part of the theologians and jurists into the work of the Astronomer[27] in so far and in the condition at least that medieval astronomy and cosmology made no revolutionary strides in their theoretical and conceptual aspects.

[24] Moody, "Buridan", *Dictionary of Scientific Biography*, vol. 2, p. 605.

[25] Mehmet Dağ, "Kelâm ve İslâm Felsefesinde Hareket Kuramı", *Ankara Üniversitesi İlahiyât Fakültesi Dergisi*, vol. 24, 1981, pp. 221-248.

[26] See, e. g., E. G. Browne, *Arabian Medicine*, Cambridge 1921, pp. 12-14; A. Sayılı, "The Emergence of the Prototype of the Modern Hospital in Medieval Islam", *Belleten* (Turkish Historical Society), vol. 44, 1980, pp. 279-286.

[27] See, A. Sayılı, *The Observatory in Islam*, Ankara 1960, Arno Press, New York, 1981, pp. 28-29.

The fields of physics and cosmology received scientific and objective treatment in the hands of such men as Kindî, Râzî, and Fârâbî in particular, before the time of Ibn Sînâ. But Ibn Sînâ himself most certainly was exemplary in this respect, and he was careful to bring out the uncertainties and vague points of the knowledge of his time on the subjects he dealt with. His approach was always rational and based upon data of observation and experience. It must be added that to a large extent, the situation was the same with the late medieval thinkers of Western Europe before Buridan.

The words of Albertus Magnus quoted above bring vaguely to mind the possibility that Ibn Sînâ may have shown an inclination toward considering velocity to be proportional to force minus resistance as adopted later by Ibn Bâjja rather than to force divided by resistance in conformity with Aristotelian thought, since Albertus Magnus mentions the names of Ibn Sînâ and Ibn Bâjja together as having had similar opinions.[28] Ibn Sînâ deals in a somewhat detailed manner in the fifteenth chapter of the fourth discourse (*maqâla*) of Book (*fan*) One of the Physics of his Kitâb ash-Shifâ with the subject of the mathematical relation between motive force, velocity, and resistance. He is very careful to point out the shortcomings of the Aristotelian formula, but in this critical exposition of the matter he nowhere speaks of a relationship of the type propounded by Ibn Bâjja. In dealing with the field of dynamics, and, I may say, throughout his philosophical encyclopedia, the Kitâb ash-Shifâ, Ibn Sînâ is seen to be very careful to openly express his doubts whenever he feels he is not in a position to clarify a problem. Not infrequently he concludes his discussion with a suspension of judgment quite appropriate to the true scientific attitude.

Koyré strenuously objects to the assertion or thesis that the medieval idea of impetus was a precursor of a similar idea adopted by Galileo.[29] Koyré even says that the physics of impetus was incompatible with the principle of inertia.[30]

Ernest A. Moody writes :

[28] See, above, pp. 144-145, note 6.

[29] Alexandre Koyré, *Etudes Galiléennes*, Paris 1939, pp. 93-95 (vol. 2, pp. 19-21).

[30] Koyré, *op. cit.*, p. 58.

"... But in considering the historical sources and philosophical background of Galileo's Pisan dynamics, we are concerned with the fourteenth century tradition in a negative sense. For if the dynamics of Avempace, and of the self-corrupting *virtus impressa*, was abandoned and opposed by the scholastics of the fourteenth century, it will follow that Galileo's Pisan dynamics was not, as Koyré has assumed, an abortive effort to give mathematical formulation to the *impetus* mechanics of the fourteenth century."[31]

Koyré does refer also, with respect to medieval thought, to the type of impetus which was considered not to be self-corrupting, but he claimed that it was associated especially with circular motion. According to Koyré, Cardano, Piccolomini, and Scaliger believed that in movements taking place on horizontal planes, impetus remained intact, while Buridan and Piccolomini were of the opinion that in certain cases, and notably in the case of circular motion, impetus was eternal, or immortal.[32]

Buridan's belief in the permanence of impetus was by no means limited to circular motion, as is well known. In addition to the non-self-consuming impetus of the projectile, however, he spoke also of the impetus of the turning wheel and of that of the circular motion of the stellar bodies, and he expressed the belief that their impetus also was of the non-self-consuming type. Both these latter should be classified as rotational motions, however, and not as revolution or circular motion referred to by Giovanni Battista Benedetti who for the first time explicitly spoke of impetus as continuing in the same direction, i. e., along a straight line. According to Dugas, Benedetti too, like Buridan, believed impetus (along a straight line) not to be evanescent. Moreover, he believed that because, due to impetus, parts of a turning wheel would tend to conserve their motion along lines tangential to their trajectory, their rotational motion would, of itself, gradually lose its force and would come to a stop.[33] This is contrary to the law of the conservation of angular or rotational momentum of course, and Benedetti's position thus becomes one of retrogression with respect to that of Buridan, in case, as is natural to think, the latter did not have in mind circular motion

[31] Moody, "Galileo and Avempace", p. 395.

[32] Koyré, *op. cit.*, pp. 58, 93.

[33] René Dugas, *Histoire de la Mécanique*, p. 102.

along trajectories when he spoke of the movements of stellar bolies, despite the fact that Benedetti's explicit reference to the constancy of direction of impetus marked a forward step.

Koyré seems to construe the term impetus more often as a force, and his objection to it is partly based on this interpretation of the concept of impetus. It is of interest that Ockham reduced motion merely to the occupation of successive positions by a body and saw no need of positing a further cause in projectile motion. For he denied the existence of motion as an entity separate from the moving body.[34]

Marshall Clagett says:

"In the case of projectile motion Ockham argued vigorously against the Aristotelian position and its modification, both of which held the necessity of a continuous force; he declared rather that the motion of the projectile is *secundum se.* Again it should be observed that we do not have in this terminalistic analysis the modern inertial doctrine, for there is no attempt to assert the *indefinite* continuance of this relational mode of the moving body as a state or a condition."[35]

Moreover, according to Ockham, the cause which could bring about the continuation of the motion of a projectile could not reside in the projectile. For in such a case the moved and the mover would be identical with each other. His idea that local motion should not be looked upon as an effect that would require constant renewal, or, in other words, that would be in need of constant presence of a motive power, was therefore a conforting solution as brought about by Ockham.[36] An identical problem could be raised, however, and had actually been raised by Averroes,[37] in relation to the natural motion of a heavy body, and there seems to be no indication that Ockham felt the need of making a provision, in connection with his solution, that its scope of applicability was strictly limited to the case of movement with no acceleration. Galileo does not seem to have followed this line of reasoning.

[34] Marshall Clagett, *op. cit.*, pp. 519, 520.

[35] *Op. cit.*,p. 521.

[36] René Dugas, *Histoire de la Mécanique*, 1950, p. 48.

[37] Moody, "Galileo and Avempace", p. 189, 377-378.

Koyré also says that Galileo preserves the term impetus but completely transforms its meaning. For he changes its meaning from *cause of movement* to the *result* or *effect of movement.*[38] As Anneliese Maier says, the meaning of the term impetus, or its ontological nature, was far from being clearly fixed.[39] But a similar remark may be made, to some extent at least, for the concept of momentum after Galileo's time also. Indeed, there was a dispute, which lasted for more than half a century and which was first settled by d'Alembert, as to whether momentum or *vis viva* should be con-sidered the measure or the effect of force.[40] It may be of added interest therefore that not only does the idea of impetus of a non-evanescent type make its first appearance with Ibn Sînâ, but he also seems to be the initiator of the idea of detecting impetus through its effect. Moreover, he uses the term *impressed force* only exceptionally, his usual word being inclination (*mayl*).This may be construed therefore to indicate that to him impetus was the effect of a force, and these may be said to be roughly applicable to Buridan also.

In trying to appraise the significance of contributions to scientific knowledge we automatically take advantage of the superior knowledge of our own day. The process of the growth and progress of scientific knowledge has actually led to the level attained to in the various fields of science at the present. The ultimate goal of that progress has thus become either the science of our time or else a stable state of knowledge reached some time in the past, in case revolutionary changes have since then come to alter radically the line or orientation of scientific development.

Achievements of men such as Ibn Sînâ and Buridan in the field of dynamics are therefore referred to and compared with Newtonian mechanics. It is a fact, nevertheless, that certain outstanding historians of science have expounded somewhat divergent views as to the extent to which Galileo was the precursor, or a precursor, of Newton in the field of dynamics. Under such a circumstance it may appear at first sight a bit farfetched to attribute to men of several centuries earlier, to men like Ibn Sînâ, ideas that adumbrate those of Newton. It would therefore not be out of place to look into the matter a

[38] *Op. cit.*, p. 93.

[39] A. Maier, "Die Naturphilosophische Bedeutung der scholastischen Impetustheorie", *Scholastik*, Jahrung 30, Heft 3, 1955, pp. 321-344.

[40] See, Henry Crew, *The Rise of Modern Physics*, Baltimore 1935, pp. 139-142.

bit more critically and say a few words concerning the restricted sense in which Ibn Sînâ may be said to have foreshadowed or adumbrated certain ideas of Newton.

It has been pointed out above that although Ibn Sînâ seems to have hit upon certain cogent ideas in connection with the violent motion of the projectile, when we look into his knowledge concerning other topics of dynamics, he certainly appears in a much less favorable light. This brings to the mind the thesis that every period should be studied in itself as a whole and that one should not try to evaluate the achievements or merits of such a period on the basis of other periods or of progress materialized in later eras. There is no doubt, however, that scientific knowledge embodies at least certain elements of cumulative and progressive nature, and, likewise, that continuity is a factor of undeniable significance and moment in history.

Now, undoubtedly Ibn Sînâ's or Buridan's knowledge of mechanics hanged together each in certain ways and were determined to a large extent by the possibilities offered by the scientific knowledge available in their times respectively. This being so, naturally, an isolated item of progressive knowledge would not, generally speaking, be expected to influence and modify the whole body of the knowledge of dynamics of the period, not at least within a short span of time and not without the help of other developments of a substantial nature.

Nevertheless, Ibn Sînâ's observation that a body with a violent motion offered to an agent trying to stop it an opposition and that this opposition was roughly the same as that offered by a body moving with a natural motion was based on an observation easily subject to verification, and it is therefore not surprising at all that it was adopted by Buridan and that it proved to be an enduring idea. It seems, indeed, to have persisted within the texture of what appears to us as a much more primitive system or perspective of ideas as a nucleus of a more solid and viable knowledge and to have perhaps helped bring about changes in other items of knowledge more or less related to it. It should be of some significance also that this item of knowledge was probably conducive to weakening the opposition between the concepts of inclinations toward natural and violent motions. In fact, with Buridan impetus is seen to be conceived as associated both with the process of the production and extinction of motion, and a step in this direction is already discernible in Ibn Sînâ in a nascent stage.

This paper thus claims that Ibn Sînâ hit upon certain seminal ideas that, primitive though they were, adumbrated Newton's first and second laws of motion, and that they actually did bring about or set on foot developments that through Buridan, and Galileo, lead to the actual appearance and formulation of these two laws.

I. B. Cohen writes, "Near the beginning of Isaac Newton's masterpiece ..., Newton attributed to Galileo a knowledge of the first two laws of motion and of the first Corollaries depending upon them". Then the same author continues as follows :

"I shall not inquire here into the debated question of whether or not Galileo actually knew the principle of inertia in its fullest Newtonian generality; in point of fact, the *Prima Lex* of Newton's *Principia* was derived directly from the *Prima Lex* of Descartes' *Principia*, as I have been able to document by identity of language as well as of concept. As to the Second Law, considered as a mathematical relation between an impulse and the resulting change in momentum (defined as the product of mass and vector velocity), which is the form in which it appears in Newton's *Principia*, surely there can be no valid claim that this might have been known to Galileo. And yet it is certainly more than a mere courteous gesture to the great Florentine founder of dynamics, whose birth we are celebrating, to suggest that Galileo was indeed the source of this fecund principle. By this seemingly paradoxical statement I mean only that Galileo did distinguish between ac-celerated motion which is caused by a force and non-accelerated motion which occurs when no force is acting, and thus appreciated both that a force tends to produce an acceleration — not merely movement — and that the vector directions of the force and the acceleration it produces are identical : he did so, however, only for one force, gravity weight, and hence only for one acceleration *g* which he found to be a constant, and he did not ever generalize his result into a general rule for different forces, or a statement connecting force with a rate of change of speed. Nevertheless, there can be little doubt that it is to Galileo primarily that we owe the modern conception of vector resolution and composition, expressed in a more advanced form by Newton in the first two Corollaries to the Laws of Motion. Finally, even though Newton's statement concerning Galileo and the Laws of Motion is not a strictly accurate statement of Galileo's procedure, we shall see at the conclusion of this article that there is a symbolic level on which Newton's tribute to Galileo is both meaningful and significant."[41]

In investigations on the degree to which such a man as Galileo anticipated ideas that were finally clarified in Newton, or clarified by him to a greater extent, the emphasis is often placed on what were the shortcomings in Galileo's thought. When we go further back in time to deal with people like Buridan or Ibn Sînâ, however, the more important aspect of the problem has necessarily to shift to the question as to what these men knew that came close to Newton's knowledge or that could be reminiscent of it, rather than what were things they still did not know or understand. For their shortcomings were too great to be of interest in such investigations, when one wishes to compare and establish parallels or trends of thought. In these therefore we should gear ourselves to an attitude of being satisfied with more modest and less clear achievements, provided that in the course of history or with the passage of time these modest beginnings should prove fruitful or pregnant in the evolution and growth of knowledge. With Ibn Sînâ too, naturally, there is here in this article merely the question of detecting a few strategic observations or a piece of good thinking or suggestion which in the course of relatively long spans of time is seen to have proved viable, or thought-inspiring at least, because it contained the kernel of a significant sector of truth.

[41] I. B. Cohen, "Newton's Attribution of the First two Laws of Motion to Galileo", *Atti del Simposio su "Galileo Galilei nella storia e nella filosofia della scienza"* (Firenze-Pisa, 14-16 September 1964), pp. XXV-XXVI.