Chapter 7
Momentum

We mentioned in Chapter 4 that the Greeks were a unique people in that they developed the idea that the world functions according to certain rules that are inherent in nature -- no direct action of the gods, spirits, sprites, and demons required. Aristotle, Aristarchus, and Ptolemy all lived in the area of the eastern Mediterranean sea -- where Europe, the Middle East, and Africa come together. And, they lived in a 600-year time period from roughly the year 400 B.C. (Aristotle) to roughly the year 200 (Ptolemy).

Now the story of astronomy moves to a different place, a different time, and a different unique people. The unique people were western and central Europeans. Just as the Greeks developed ideas about the world that other cultures never developed, and just as the story of science has roots in the Greeks in ways that are not shared with any other people, so also did these Europeans develop ideas about the world that other cultures never developed, and the story of science will now focus on these Europeans. But note that during the centuries when Aristotle, Aristarchus, and Ptolemy were doing their work in Greece and Egypt, there was very little scientific work being done in, for example, England and Germany. England and Germany were rough, underdeveloped places in those times. This change of place and people in the story of science tells us that science is not just the business of one place or one group of people. Thus in future centuries different parts of the world and different peoples may become the ones that develop scientific ideas, and the story of science will then focus on them.

The development of European scientific thought sprang from studying Aristotle. Aristotle did not naturally appeal to Europeans because of something else that had developed since the time of Ptolemy -- Christianity. Aristotle and Aristarchus lived centuries before Christ, and Ptolemy lived when Christianity was a small sect of Judaism. In the thousand years following Ptolemy, Christian thought became widespread. From the Christian point of view, Aristotle was a pagan. Christians focused their energies on the study of Christian sacred scriptures and on Christian thinkers (such as Augustine of Hippo[1], an African bishop and theologian in the Christian church whose ideas will play a part in the third section of this book).

This began to change with Thomas Aquinas of Italy. Aquinas, who lived and worked during the 13th century[2], thought that there could be no conflict between what was discovered as true through the use of reason (such as what was found in Aristotle's work, or what you might find through watching the sun rise and set), and what was revealed as true by God through Christian faith (such as what was found in Christian scripture). Aquinas argued that --

> *The natural dictates of reason must certainly be quite true: it is impossible to think of their being otherwise. Nor again is it permissible to believe that the tenets of faith are false, being so evidently confirmed by God. Since therefore falsehood alone is contrary to truth, it is impossible for the truth of faith to be contrary to principles known by natural reason.*[3]

With this confidence in reason, Aquinas felt free to dive into and expound upon Aristotle's work, despite the fact that Aristotle was not a Christian.

Aquinas brought the ideas of Aristotle fully into the Christian world. However, the ideas of Aristotle were controversial in the Christian world of Aquinas's day. For example, at the University of Paris various works of Aristotle were condemned or banned, off and on, throughout the 13th century -- while at the same time the University of Toulouse (also in France) tried to lure students and scholars from Paris by advertising that

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1 Augustine lived from 354 - 430 (note -- approximately two centuries after Ptolemy). His ideas are considered very influential even today by Catholic, Protestant, and Evangelical branches of Christianity; he is frequently referred to as "St. Augustine".

2 Aquinas lived from 1225 - 1274. Aquinas's ideas eventually became nearly as influential in the Christian world as those of Augustine; he is frequently referred to as "St. Thomas Aquinas".

3 *Of God and His Creatures: An Annotated Translation (with some abridgment) of the Summa Contra Gentiles of St. Thos Aquinas* by Joseph Rickaby (London: Burns and Oates, 1905). Available on-line via the Jacques Maritain Center of the University of Notre Dame -- Book I: Of God As He Is In Himself, 7: That the Truth of Reason is not contrary to the Truths of Christian Faith. Note that Aquinas wrote in Latin, not English -- thus this is a translation.

Aristotle's works were *not* banned at Toulouse. Occasionally the Popes of the time weighed in on the controversies. In 1231 Pope Gregory IX ordered that Aristotle's works be edited but made available for study:

> *But since, as we have learned, the books on nature which were prohibited at Paris in provincial council are said to contain both useful and useless matter, lest the useful be vitiated by the useless, we command your discretion, in which we have full faith in the Lord, firmly bidding by apostolic writings under solemn adjuration of divine judgment, that, examining the same books as is convenient subtly and prudently, you entirely exclude what you shall find there erroneous or likely to give scandal or offense to readers, so that, what are suspect being removed, the rest may be studied without delay and without offense.*[4]

Then, in the year 1277, shortly after Thomas Aquinas died, Pope John XXI instructed the Bishop of Paris, Stephen Tempier, to look into the Aristotle controversies at the University of Paris. Tempier did just that. He ended up issuing a broad condemnation of 219 Aristotelian ideas, which Tempier called "errors". These errors included teaching[5] that God was limited to making only one world (error #34), teaching that time and motion were eternal (error #87), and teaching that God could not make the heavens move in a linear fashion (instead of circles) if God saw fit to do so (error #49). These Aristotelian ideas put limits on the power of God; for Christians, God is all-powerful, and can do things beyond the ability of human reason to comprehend, and so these ideas were condemned as "errors".[6]

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4 "The Command to Expurgate Aristotle's Books on Natural Philosophy (1231)", as found in *A Source Book in Medieval Science* by Edward Grant, editor (Cambridge Massachusetts: Harvard University Press, 1974), pg.43. Translation from Latin into English by Lynn Thorndike. The information concerning the universities of Paris and Toulouse is from *A Source Book in Medieval Science* as well (pg. 42-43).

5 Not only teaching the errors, but defending or supporting the errors in any way, or even listening to someone else teach or defend or support them. Information on Tempier's condemnation of 1277 and the errors is from *A Source Book in Medieval Science* (pg. 45-50).

6 Error #147 was teaching that God could not do the impossible!

Tempier backed up his condemnation with the threat of excommunication. The Pope backed Tempier up. Tempier was acting as a censor, and censorship is usually thought of as supressing new and creative thinking. But, oddly enough, Tempier's censorship seems to not have suppressed such thinking so much as to have redirected it towards coming up with ideas that were contrary to Aristotle. The University of Paris became a center of new ideas in science in the century following Tempier's condemnation of 1277.

One of these new ideas was an alternative to Aristotle's ideas on motion. We discussed Aristotle's ideas in Chapter 4:

- ✔ Things on Earth are made of four elements (earth, water, air, and fire).
- ✔ The natural tendency of things on Earth is to move in straight line paths until they reach their natural positions (a dropped rock falls straight to the ground if by reason of its gravity; a flame rises straight up on account of its levity).
- ✔ Things tend toward a state of rest, moving only if they are being powered by some kind of "mover" (if you push a wagon it will move; once you stop pushing the wagon it quickly comes to rest; the harder you push it, the faster it moves).

A tough case for Aristotle was that of a stone which had been tossed (or any other thing which stayed in motion once its mover was no longer touching it). As Aristotle saw things, as soon as the stone leaves the hand of the person tossing it, and thus does not have a mover, it should fall straight to the ground. Since it does not, something else must take over the process of moving that stone. Aristotle explained the stone's flight by saying that the air becomes the mover of the stone. As the stone passes through the air, the air is moved aside. But then it moves back in behind the stone, carrying the stone along its trajectory. Here are some of Aristotle's own words on the motion of a tossed stone:

> *[If all things move only if powered by movers] how is it that some of them, like things thrown, are continuously in motion when the mover is not touching them? If the mover moves at the same time something else also such as air, and if it is this air which causes the motion while being in motion, it is likewise impossible for this air to be in motion when the first mover neither touches it nor causes it to be in motion, so all of them should be simultaneously in motion, or they should*

all cease simultaneously when the first mover ceases even if, like a stone, it [the first mover] makes that which it causes to be moved to act like a mover.

We must then say this, that the first mover causes air or water or some other such object, which by nature can move another and be moved by another, to be like a mover. But this object does not simultaneously cease being a mover and an object moved. It ceases simultaneously being moved when the mover ceases causing it to be moved, but it may still be a mover; and in view of this, it may cause some other consecutive object to be moved (and the same may be said of this other object).[7]

Dear Reader, if you do not think that Aristotle's explanation is perfectly clear, well, neither do I!

John Buridan[8] of the University of Paris challenged Aristotle's explanation. He used the motion of a spinning toy top or a freely spinning grinding wheel to argue against Aristotle. Buridan argued that air cannot be what keeps a spinning object in motion, because such objects spin in place; air does not move aside and then back in behind them as must happen with a tossed stone. Buridan even experimented with trying to block air from flowing around a spinning object in any way, in order to see if that caused the object to stop spinning. It did not. Buridan further argued that if air was what carried a tossed object through its trajectory, then it would be possible to throw a feather farther than a stone, which it is not.[9]

So Buridan put forth a theory of motion that was contrary to Aristotle's idea that anything that moves requires a mover. Buridan argued that air simply resists motion, and that the reason a tossed stone flies through the air is because the hand, in throwing the stone, imparts to the stone a kind of self-moving action. Buridan called this action

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7 This quote from Aristotle's "Physics" (Book VIII, part 10) is from *Aristotle: Selected Works*, translated from Greek into English by H. G. Apostle and L. P. Peterson, 2nd edition (Grinnell, Iowa: The Peripatetic Press, 1986), pg. 237.

8 Buridan lived from 1300 to 1358.

9 John Buridan, "The Impetus Theory of Projectile Motion", translated from Latin into English by Marshall Clagett, as found in *A Source Book in Medieval Science*, pg. 275-276.

impetus; today scientists refer to it as *momentum*[10]. The impetus or momentum of the stone keeps it moving despite the resistance of the air. Buridan described impetus/momentum this way:

- ✔ It is in the direction the stone is moving.
- ✔ All things being equal, a heavier stone has more of it than a lighter stone moving at the same speed.
- ✔ All things being equal, a faster-moving stone has more of it than a slower-moving stone of the same weight.

Buridan said that when you throw a stone, you give it momentum, and the stone keeps moving due to that momentum. The stone's momentum is continually decreased by the resistive action of the air, while the stone's gravity turns the momentum's direction downward, so that eventually the stone drops to the ground. Here are some of Buridan's own words on the motion of a tossed stone (compare them with Aristotle's words on the same subject):

> *Thus we can and ought to say that in the stone or other projectile there is impressed something which is the motive force of that projectile. And this is evidently better than falling back on the statement that the air continues to move the projectile. For the air appears rather to resist. Therefore, it seems to me that it ought to be said that the [mover] in moving a moving body impresses in it a certain impetus or a certain motive force of the moving body, in the direction toward which the mover was moving the moving body, either up or down, or laterally, or circularly. And by the amount the [mover] moves that moving body more swiftly, by the same amount it will impress in it a stronger impetus. It is by that impetus that the stone is moved after the projector ceases to move. But that impetus is continually decreased by the resisting air and by the gravity of the*

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10 Dear Reader, if a historian of science reads this he or she may well object to my saying Buridan's "impetus" is the same thing as the momentum of modern physics. However, in a modern college physics class the quantity that Buridan describes -- the product of an object's mass (the amount of matter in the object) and its speed, having a direction initially given to the object, is called momentum ($\mathbf{p} = m\mathbf{v}$). Buridan's discussion of a tossed stone would fit well in a in college physics lecture on "projectile motion with air resistance" done from a momentum standpoint.

stone, which inclines it in a direction contrary to that in which the impetus was naturally predisposed to move it. Thus the movement of the stone continually becomes slower, and finally that impetus is so diminished or corrupted that the gravity of the stone wins out over it and moves the stone down to its natural place.

This method, it appears to me, ought to be supported because the other methods do not appear to be true and also because all the appearances are in harmony with this method.

For if anyone seeks why I project a stone farther than a feather, and iron or lead fitted to my hand farther than just as much wood, I answer that the cause of this is that the reception of all forms and natural dispositions is in matter and by reason of matter. Hence by the amount more there is of matter, by that amount can the body receive more of that impetus and more intensely. Now in a dense and heavy body, other things being equal, there is more of prime matter than in a rare and light one. Hence a dense and heavy body receives more of that impetus and more intensely, just as iron can receive more calidity [heat] than wood or water of the same quantity. Moreover, a feather receives such an impetus so weakly that such an impetus is immediately destroyed by the resisting air. And also if light wood and heavy iron of the same volume and of the same shape are moved equally fast by a projector, the iron will be moved farther because there is impressed in it a more intense impetus, which is not so quickly corrupted as the lesser impetus would be corrupted. This also is the reason why it is more difficult to bring to rest a large smith's mill [like a grinding wheel] which is moving swiftly than a small one, evidently because in the large one, other things being equal, there is more impetus. And for this reason you could throw a stone of one-half or one pound weight weight farther than you could a thousandth part of it. For the impetus in that thousandth part is so small that it is overcome immediately by the resisting air.[11]

11 This quote is from John Buridan, "The Impetus Theory...", *A Source Book in Medieval Science*, pg. 276-277.

According to Buridan, a spinning top spins because it is given momentum. Absent any resistance, it would keep spinning indefinitely. No "mover" is required to keep a top spinning, or to keep a stone flying.

Buridan thought the same concept that explained the motion of tops and stones could be used to explain the motions of the heavens, especially if the heavens contained no air or other resisting substance. Buridan wrote that the Bible does not state that heavens are moved by a mover, so it could well be that

> *...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; "for thus on the seventh day He rested from all work which He had executed by committing to others the actions and the passions in turn." And these impetuses which He impressed in the celestial bodies were not decreased nor corrupted afterwards, because there was no inclination of the celestial bodies for other movements. Nor was there resistance which would be corruptive or repressive of that impetus.*[12]

Thus, once set in motion, the heavens could keep going indefinitely on impetus, with no mover to power them.

In the long run the idea of impetus/momentum endured -- from Buridan to the present day. Momentum is a core concept in the science of physics today. Students in physics classes in high schools and colleges everywhere study momentum. In the short run, however, Buridan's impetus theory did not win out over Aristotle. Throughout the centuries after Buridan, different European thinkers followed Buridan's ideas and challenged Aristotle's ideas, but Aristotle's ideas still continued to dominate. Some times Aristotle's ideas did not dominate completely. Many thinkers adopted a watered-down version of impetus. In this version, an object like a spinning top was given an impetus that kept it moving, but that impetus only lasted a little while before it naturally disappeared. Thus any motion that was ongoing over time still required a mover to power it, just like Aristotle said. Buridan's idea of an impetus/momentum that remains with an object

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12 John Buridan, "The Impetus Theory...", *A Source Book in Medieval Science*, pg. 277.

indefinitely, so that (absent the effect of air or some other corrupting influence) motion naturally continues on indefinitely, and thus even ongoing motion over a vast period of time requires no mover to power it, did not catch on.