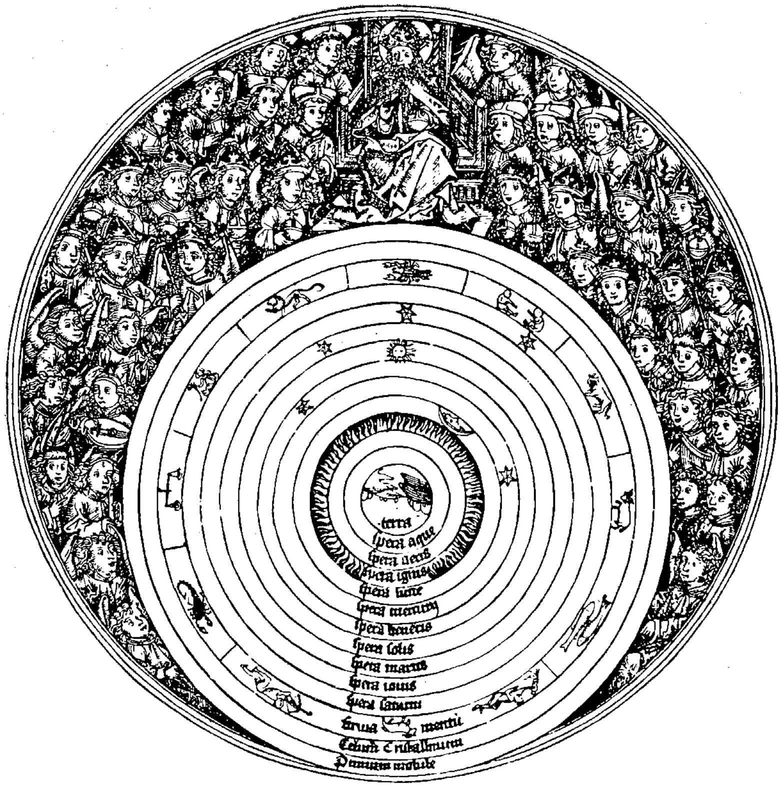

The order of the Aristotelian cosmos. Woodcut from the Schedel Chronicle, published at Nuremberg in 1493.

Some Valuable, Mistaken Notions on

MATTER IN MOTION

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ARISTOTLE'S VIEWS on matter in motion are firmly forgotten today. So dead are they that they have long since stopped receiving wide credit for assisting the rise of modern science. Instead, they are more apt to be regarded as obstructing the rise of science. Yet they were an inspiration and a goad to the creation of modern physics and astronomy, and the fact that they encouraged and discouraged better ideas all at the same time is only typical of the provocative way scientific knowledge grows.

In many respects Aristotelian mechanics was more credible than some of the far-fetched ideas Newton and his precursors invented. Above all, it placed the earth at the center of things. The idea that the earth is the center of all things has always been a very appealing idea. It underlies the natural importance of man and, as far as the ancients were concerned, it removed all doubt as to where man was going. He wasn't going any place. He was staying right where he was, at rest in the center of the universe. Whatever went on in the cosmos went on *around him,* as anybody who lifted an eye to the celestial regions could see.

When Newton and his precursors shattered this view of things, neither man nor the earth remained at the center of the world. Instead, the cosmos became a vast, impersonal mechanism in which the earth was a very minor and scarcely essential cog. Fortunately, it also became a more understandable and predictable cosmos.

This change from the Greek to the Newtonian view was a slow, rather toilsome process, in its way extremely dramatic, and by no means a finished job. Indeed, at the present moment there is little evidence that the job is finished yet, for we do not altogether understand the world we see.

The whole story revolves around an age-old question: What is physical reality? The answers offered by Greek scientists and philosophers have persistently affected European and American thought because of the way they approached the problem. These answers rested on observed facts. Then, as now, some of the observed facts were obvious and impressive. These Aristotle was able to incorporate into a massive, impressive, persuasive system, a view of the physical world that accounted for a wide variety of observed phenomena on earth and in the sky and that infused purpose into the process of events. In a sense, purpose was presumed to be the reason for the obviously complicated orderliness of nature.

Poor ideas and good

Aristotelian physics enjoyed a long life. True, it did not satisfy everyone, but with a few modifications it withstood assault century after century before finally, weakened by earlier attacks, it yielded to the view we associate with Isaac Newton's name. We are tempted to look back upon this Aristotelian cosmology as absurd and a fine example of the ignorance of the experts, but it was a very live and acceptable and persuasive idea. If we can understand why it was a useful, long-lived world-view, we shall have a keener feeling of the difficulty men perpetually encounter in separating the poor ideas from the good.

It helps to grasp the view of the universe that was most widely held in Europe for about 2,000 years if the reader will forget all he knows, abolish all he takes for granted, and willingly suspend his disbelief. Then, with the slate wiped clean, it's easier to accept the idea that all matter on earth is made up of four elements, as Aristotle said, borrowing from Empedocles. These are earth, water, air, and fire. Further, in accord with Parmenides' assumption of a plenum and denial of a vacuum, these elements fill all space out to the moon. The moon and beyond are of different stuff, for the celestial regions are different. They are perfect. They suffer no generation or corruption, no beginning or ending, no birth or death, no novel occurrences. Comets and meteors are probably atmospheric phenomena.

The perfect heavens continue perfect, changeless. They are filled with a perfect substance, a fifth element, aether. This fifth essential (whence our extravagant word, "quintessence") is the stuff of which the moon, sun, planets, and stars are made, and it makes up most of the cosmos. But it has its limit; the world is finite. It is a sphere in shape—that most perfect "animal" and geometric figure, according to Plato's *Timaeus*.

And in the center is man. The sub-lunar region he dwells in is neither perfect nor changeless. If this seems difficult to face, nevertheless the experience of living compels it. His is a world of being, becoming, beginning, and ending, and its lack of static perfection is explained by the nature of the four elements. Each of these elements has its natural place: earth at the center, next water, around these air, and finally fire. This helps explain why rocks fall and why flames rise, why the oceans seem to be bottomed and the atmosphere to be light. The elements always tend to seek their *natural places*.

Now none of the crude substances we perceive is one of the four pure elements, for these in their pure form we never see. We know only the coarse approximations and compounds of these, and *all* that we know are composed of some or all of the four elements.

Ideally we could arrange these elements in four concentric spheres with earth at the center and fire the fourth and outermost, but actually the sub-lunar region we live in is not so arranged. Why? Because of the four qualities the four elements share. These qualities are: hot and cold, wet and dry. Earth is dry and cold, water is cold and wet, air is wet and hot, and fire is hot and dry. These qualities are always acting to change any one element into its neighboring elements, and this process accounts for change and generation and corruption in the physical realm. It is a kind of natural transmutation of unstable elements. But here the fortuitous resemblance to modern nuclear physics stops, for Aristotle had no use for the atomic ideas of his predecessors, Leucippus and Democritus. One of their assumptions he could not swallow was the idea of a void in which the atoms swarmed. A void meant a non-full universe, and Aristotle (like Descartes) preferred a filled-up cosmos.

The nature of physical reality

These speculations upon the nature of physical reality explained many phenomena. The existence of clouds was just what one would expect in a world where air was continually changing into water. Stones and rain fell because the dominant elements in these objects tended to seek their natural places, just as air and fire tended to rise in seeking their natural places. A stone twice as heavy would contain twice as much material seeking its natural place, so it would fall twice as fast, and this explained why a heavier object made a deeper dent when it struck.

Now let us pause to make a simple picture of this cosmos we have constructed with the help of Aristotle and his commentators. We start at the center with earth. Around that is water, around that air, and around that fire. Finally, from the moon on out to the fixed stars—the end of the cosmos—all is aether. Here we have pictured all the matter in the universe.

This matter is in motion, as we know very well, so let us add motion to our picture. We shall start at the center again, with the sub-lunar world. The four elements come in pairs of opposites, water and fire, earth and air. The natural motion of each of the elements is up or down, and each of these opposite elements is paired with an element whose natural motion is in a direction contrary to its own: water down, fire up; earth down, air up. And just as weight is an expression of the natural tendency downward toward the center, so is levity an expression of the natural tendency up out from the center. Levity, then, is not mere lack of weight; it is a positive force that air and fire possess. Like weight it is a *tendency,* a tendency of an object to seek its natural place in the cosmos.

The motions of these elements, which are simple bodies, are simple motions. They are also motions in a straight line, up or down: rectilinear motion, natural motion. The fifth element, aether, is likewise a simple body, and it has its simple motion, too. This is curvilinear. Has the fifth element an opposite, like the other four? No. So neither has its motion an opposite.

Since circular motion has no contrary, it is essentially nobler, according to Aristotle. So the simple body to which circular motion is natural will not be subject to change, but will be eternal. Which objects in human experience fit this definition? Those in the sky, of course.

So we have put the matter in our picture in motion. The four elements of the sub-lunar region seek their natural places by moving in straight-line paths, and the nobler aether without a contrary moves eternally in circular paths at constant speeds. And though all of this explains much that we see—has empirical, common-sense support—it has a curious and rather drastic consequence: the sub-lunar world is a different kind of world from the celestial. The kinds of things that go on in man's realm are not the things that go on in the changeless, perfect heavens. Significantly, every astronomical system devised by the astronomers, through Copernicus, accepted this fact. The cosmos was not a *uni*verse.

Projectile motion

Aristotelian physics was not flawless. Generally credible though it was, it had a few small difficulties. One of these was the problem of projectile motion. Another was the acceleration of falling bodies. Before the Galilean and Newtonian explanations appeared, there were many discussions of these two difficulties. As we look back we can see how our widely divergent modern explanation depended on these discussions, for it was out of them that our contemporary knowledge grew.

Projectile motion was not natural motion, in the Aristotelian scheme; it was "violent motion." It was a stone hurled in a direction away from its natural place. The problem was, what kept it moving? For objects not being moved toward their natural place must have a mover, whether it be the hand that pushes the chair across the floor or the horse that draws the chariot. Usually, in such cases, the mover remains in physical contact with the moved, and when the mover stops applying its force, the moved stops.

Not so in a projectile, however. How explain this? Aristotle suggested weakly that perhaps the agitation of the air kept the stone or the arrow in motion until, finally dissipated, it allowed natural motion to take over and drop the object toward the earth. It is interesting to see how he speaks of this. In his discussion he is also concerned with denying that there can be a void.

Aristotelian explanation

"In point of fact," he says in the fourth book of his *Physics*, "things that are thrown move, though that which gave them their impulse is not touching them, either by reason of mutual replacement, as some maintain, or because the air that has been pushed pushes them with a movement quicker than the natural locomotion of the projectile wherewith it moves to its natural place. But in a void, none of these things can take place, nor can anything be moved save as that which is carried is moved. Further, no one could say why a thing once set in motion should stop anywhere; for why should it stop here rather than there? So that a thing will either be at rest or must be moved *ad infinitum,* unless something more powerful get in its way."

To Aristotle, such a possibility was preposterous, yet note its similarity to Newton's first law of motion: that objects at rest tend to remain at rest or objects in motion tend to remain in motion until acted upon by some outside force.

It's not always easy to know good ideas when we see them. Aristotle had as much trouble as the rest of us, and in this instance he had other reasons for denying these ideas. In his always full world, a force moved an object through a resisting medium. If you varied the force or the density of the medium, you varied the speed of the object in motion. The more you reduced the resistance of the medium, the faster the object would go. Indeed, if you eliminated the medium altogether, all resistance would be gone, and the speed would reach infinite dimensions. An object would move instantaneously from here to there. This was patently absurd; therefore, the existence of a void was impossible.

Against this array of interlocked ideas systematically worked out to explain the nature of physical reality, what could be more absurd than the idea that all objects fall to earth at the same speed, regardless of their weight? What could be harder to stomach than the idea that an object in motion tends to keep on moving in the same direction without help forever? What connection did this have with the world of chariots and stones that men knew, or with the perfect world of the heavens? What could be more fantastic and inscrutable than the mysterious property of inertia or the attractive force of something called "gravitation"? No, the Aristotelian system had answers that were generally much easier to digest and relate to the world around us.

Except that today we know the physical and astronomical views of the Greeks were just about all wrong. They described two worlds that didn't exist.

Their breakdown occurred gradually, partly because few had as complete and satisfying a system to substitute, and partly because many critics were simply interested in testing single timbers, not in rebuilding the whole structure. Take John Philoponus in the sixth century, A.D., for instance. He wrote:

"According to Aristotle, if the medium through which the motion takes place be the same, but the moving bodies differ in weight, their times must be proportional to their respective weights. . . . but that is wholly false, as can be shown by experience more clearly than by logical demonstration. For if you let two bodies of very different weights fall simultaneously from the same height, you will observe that the ratio of motion does not follow their proportional weights, but there will be only a slight difference in time, so that if their difference in weight be not very great, but one body were, say, twice as heavy as the other, the times will not perceptibly differ."

Logical demonstration

The method of logical demonstration continued to dominate, however, and the method of experience that Philoponus found so clear received no widespread attention until Francis Bacon's and Galileo's time. Still, Philoponus did not go unread. Some of the Islamic natural philosophers read him attentively. They knew that Aristotelian physics described motion as the consequence of a force acting against a resistance, and that movement was unthinkable without a resisting medium (else there could be a void). Philoponus, on the other hand, pointed out a kind of motion that could well exist in a vacuum—the motion of a body revolving in place upon its axis.

Philoponus went further. Suspecting that a resisting medium was not necessary to motion, he argued that the medium, air, was not what kept a projectile in motion. Rather, an impressed force, some kind of incorporeal power to move, was put into the projectile by its hurler and kept it moving until finally overcome by the tendency of the body to seek its natural place.

This intangible "dunamis" was a provocative idea to the great Islamic philosopher of the early eleventh century, Avicenna. In his *Book of the Healing of the Soul*, a compendium on Aristotelian ideas, he supported Philoponus and even went beyond him. He suggested that two kinds of tendencies could accomplish motion. One was the natural inclination of the falling body to seek its natural place, the other was the violent inclination of the projectile to remain in motion. Here emerged the "*mayl* theory" of projectile motion.

Avicenna defined *mayl* as the inclination in a moving body which can be perceived sensibly and which is a tendency or power for the body to keep moving. The *mayl* resists attempts to stop the body or immobilize it, and seeks to continue the motion.

The germ of an intertial idea can be detected in the *mayl* theory. However, Avicenna never suggested that rest and motion could be interchanged in this regard.

He was interested in the effects of violent *mayl*. Could it last forever? Supposing you impressed a *mayl* in a stone in a void. . . . Then the stone would continue to move indefinitely. Absurd, said Avicenna; Aristotle was right, the existence of a void is impossible.

Abu'l Barakat (who died about the middle of the twelfth century) added another twist to the discussion. He raised the idea of a *mayl* whose function fell in between the two kinds Avicenna had listed. *Mayl*, said Abu'l Barakat, could be used to explain the acceleration of a falling body. He took from Simplicius, a contemporary of Philoponus, the idea that some of the upward force remained in a stone thrown up in the air, even after the stone had started down. This would explain why the stone dropped slowly at first. But the tendency to seek its natural place is acting on the stone throughout the whole of its fall. In each succeeding instant of fall this natural tendency impressed more *mayl* into the body, and the *mayl* increased its speed. Speed thus was proportional to, and a result of, the amount of *mayl* impressed.

Here was a relation of force to acceleration, but in an Aristotelian-physics frame of reference, not a Newtonian. For the Aristotelian view required a constant force to keep a body in motion at a constant speed, and an increased force was necessary if acceleration were to occur. Like Aristotle and unlike Newton, Abu'l Barakat had to increase his force—the amount of *mayl* in the body—to obtain accelerated movement.

Testing and replacing

So Abu'l Barakat, too, was wrong. But Abu'l Barakat, like Avicenna and Philoponus and Simplicius before him, and like a handful of others that followed him, was engaged in the essential job of testing weak timbers in the Aristotelian structure and trying to replace them with something better. Al-Bitruji in twelfth-century Spain carried on these inquiries, as did Aquinas, Roger Bacon, and Peter John Olivi among those in the thirteenth century, and as did Gerard Oddo, Jean Buridan, and Albert of Saxony in the fourteenth century—but that is another story.

The result of their efforts was an accumulation of ideas along one line of development in physics. Similarly, the astronomers were engaged along another line of development, inquiring into the implications of the Aristotelian cosmology and improving upon the Ptolemaic system. Still others, medieval schoolmen, engaged in elaborate discussions on the kinematics of moving bodies. All contributed toward a loose continuity of events, and it was this continuity, this sort of an approach—the piecemeal efforts of a handful of men over many centuries, inspired and goaded by the Aristotelian explanations to understand them and test them—that finally culminated in the creation of Newtonian mechanics and the overthrow of Aristotelian physics.