PART IV
THE SCOPE OF SCIENCE

DISTINGUISHING BETWEEN NATURAL PHILOSOPHY AND SCIENCE: THE CASE OF ANCIENT MECHANICS

JEAN DE GROOT

I. INTRODUCTION

In his book, *The Degrees of Knowledge*, speaking of philosophy and experimental science, Jacques Maritain says, "The whole structure of the experimental science of the ancients has doubtless crumbled and its collapse may well appear to anxious minds to spell the ruin of everything the ancients had thought."[1] Maritain makes this point several times in the context of separating the science of the ancients from their metaphysics and philosophy of nature.[2] His obituary for ancient science contrasts markedly with a recent judgment of his countryman, François De Gandt, the eminent historian of science, who says that the themes and fundamental concepts of both ancient astronomy and mechanics "*sont passés presque intacts dans la science moderne de la nature.*"[3]

Along with De Gandt, I believe there is continuity between ancient and modern within classical mechanics, not only in concepts but also in

[1] Jacques Maritain, *The Degrees of Knowledge*, trans. Gerald B. Phelan (Notre Dame, Indiana: University of Notre Dame Press, 1995), II.28, 64.

[2] Maritain, *Degrees*, II.16, 44–45, especially 49.

[3] François De Gandt, "Force et science des machines," in *Science and Speculation: Studies in Hellenistic Theory and Practice*, ed. J. Barnes, J. Brunschwig, M. Burnyeat, and M. Schofield (Cambridge: Cambridge University Press, 1982), 96. See also Meli's account of how early modern mechanics took its point of departure from ancient texts in mechanics (Domenico Bertoloni Meli, *Thinking With Objects*, [Baltimore: The Johns Hopkins University Press, 2006], ch. 1). It has long been recognized that the Greeks had in hand the basic principles of both steam power and simple machines. On the debate as to why the Greeks did not industrialize, see Helmuth Schneider, *Das griechische Technikverständnis: Von den Epen Homers bis zu den Anfängen der technologischen Fachliteratur* (Darmstadt: Wissenschaftliche Buchgesellschaft, 1989), 1–9, 52–62.

the fundamental framework for perceiving and conceptualizing motion. Indeed, it can also be shown that, in Aristotle's thought, mechanical notions served both in a natural philosophical account, as Maritain would define *physica*, and in an account recognizable to us as scientific. (To make clear the precise connotation of 'mechanics' here, let me specify that, like other contemporary scholars, I distinguish between 'mechanism' understood as the corpuscular philosophy, which is one type of materialist interpretation of the physical world, and 'mechanics,' which is a set of mathematical principles that describe and predict the movement or balancing of weights.[4] It is mechanics in the latter sense that is relevant to Aristotle's natural philosophy.)

The underlying strategy of my paper is roughly this: Let us accept that there is continuity between ancient and modern in practical mechanics. If there is also a connection between ancient mechanics and Aristotle's natural philosophy, then examining that connection may be instructive for approaching how science and philosophy—especially the philosophy of being for sensible things—should be understood in relation to one another in our own time. We can learn from Aristotle how a universal and timeless science, practical mechanics, is fittingly related to a perennial natural philosophy. Accordingly, in what follows, I will sketch how Aristotle made use of the central principle of ancient mechanics, the principle behind the lever, to develop a key concept of natural philosophy, namely *dunamis*, potentiality or power.

From this vantage point, we can evaluate Maritain's very strong division between science and natural philosophy. His division is based on the inability of science to grasp the ontological dimension of nature. One part of my project, which can only be touched upon here, is to show how the difference between science and natural philosophy emerges—perhaps in one of the first instances of this difference, in the Aristotelian *Mechanical Problems* (hereafter *MP*). The most important thing to come out of the line of research described here, however, is a new perspective on Aristotle's concept of *dunamis*. In my sections II and

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[4] For examples of contemporary scholarship that separate mechanics and the mechanical philosophy, see Sylvia Berryman, "Ancient Automata and Mechanical Explanation," *Phronesis* 48 (2003): 344–69; Meli, *Thinking With Objects*, ch. 1 and 5; and Peter Dear, *The Intelligibility of Nature: How Science Makes Sense of the World* (Chicago: University of Chicago Press, 2006), ch. 1.

III, we see how this concept has a strong physicalistic connotation, and this helps us to understand it as part of the philosophy of nature. Finally, my contention is that there is not as strong a separation between science and philosophy of nature as Maritain believed, at least from the standpoint of Aristotle himself and in the case of the ancient example I will present.

II. THE LEVER PRINCIPLE IN ARISTOTLE'S TREATMENT OF ANIMAL MOTION

When Aristotle developed his natural philosophy in the 4th century BC, what is called rational mechanics had not yet been separated from the principles of constructing simple machines. The lever, pulley, wedge, and rudder were known to the ancients as devices for moving weights. Probably only a few of the craftsmen who could make such simple machines, however, were familiar with the account of their functioning in terms of the geometry of the circle. Not only the author of the Aristotelian *MP*, but also Aristotle himself, ascribed the power of these devices to one principle, the moving radius (See Figure 1).

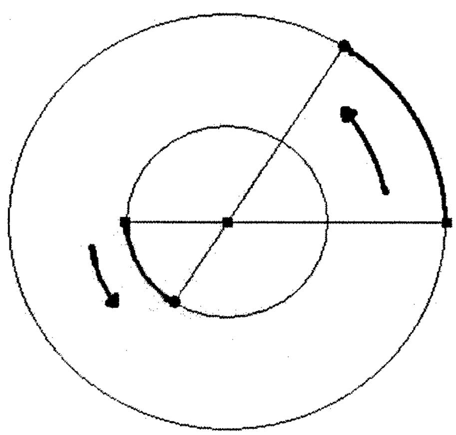

Figure 1 Points on a moving radius

POINTS ON A MOVING RADIUS ARE ALL MOVING DIFFERENT SPEEDS PROPORTIONAL TO THEIR DISTANCE FROM THE CENTER. THE MORE DISTANT POINTS ON THE RADIUS COVER A GREATER DISTANCE, A LARGER ARC, IN THE SAME TIME.

The principle is cited by Plato at *Laws* X, 893c–d, by Aristotle in *De Caelo* II.8, 289b34–35, and II.10, 291a35–b1, and in *MP* 1, 849a3–b18.[5] To our minds, it might seem that points moving along the circumferences of larger and smaller circles move with the same speed, i.e. the same angular velocity. As the ancients thought of this state of affairs, however, the arc distance belonging to a segment of a circumference with a longer radius is simply a longer distance. A point on a radius farther from the center moves faster than one nearer the center. Arcs of larger and smaller concentric circles were compared only indirectly, in terms of the lengths of their radii.[6] The greatest interest of the principle comes when we consider opposite arcs of larger and smaller circles. Applied to opposite arcs, the principle provides an explanation of why a lever can move a weight unmovable by human effort alone (See Figure 2).

A small force applied at the end of the longer arm of a beam will move a great weight at the end of the shorter arm, a weight that could not be moved by that force if applied to the object directly. The movements at ends of the lever are arcs of circles with the same center, the fulcrum. The ancient formulation is that, depending on placement of the weight along the beam, the same force would move the weight shorter and longer distances in the same time.

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[5] I use the recent edition of *MP* by M. E. Bottecchia Dehò (*Problemi meccanici. Introduzione, testo greco, traduzione italiana, note; Minor Works.* Soveria Mannelli [Catanzaro]: Rubbettino Editore, 2000). I follow the chapter divisions of the Teubner edition, which are followed also by Hett in the Loeb edition of *MP* (Aristotle, Minor Works, trans. W. S. Hett [Cambridge, Massachusetts: Harvard University Press, 1980]).

[6] The role of π in determining the area and circumference of circles did not play a role in the Greek understanding of the circle until Archimedes' *Measurement of the Circle* (3rd century BC). Archimedes derived the ratio between the circumference and diameter of a circle. An approximation of π appears in the Rhind Papyrus (2nd millennium BC). Thales is said to have shown that the diameter divides the circle in half and Anaxagoras devoted attention to the squaring of the circle. On these topics, see Thomas L. Heath, *History of Greek Mathematics* (New York: Dover, 1981), vol. 1, 220–35, and E. J. Dijksterhuis, *Archimedes*, trans. C. Dikshoorn with a new bibliographic essay by Wilbur R. Knorr (Princeton: Princeton University Press, 1987), 222–23.

This principle had great versatility in explanation. The citations of the principle by Plato in *Laws* X and by Aristotle in *De Caelo* II.8 are central to accounts of the different speeds of the planets. In *Laws* X, Plato alludes to the principle being also the source of all sorts of wonders (*thaumata*) outside the realm of astronomy (893b3).

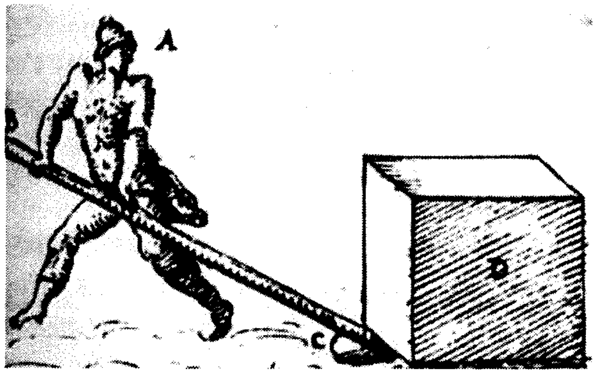

Figure 2 Opposite arcs of larger and smaller circles[7]

A SMALL FORCE APPLIED AT THE END OF THE LONGER ARM OF A BEAM WILL MOVE A GREAT WEIGHT AT THE END OF THE SHORTER ARM.

The author of the Aristotelian *MP* makes the principle underlie a host of natural and craft phenomena. Unlike movement in the heavens, these other applications involve exertion of force. The principle explains why it is easier to raise water from a well with a windlass—a crank and axle—than simply pulling on a rope (*MP* 13), and why the helmsman trims his sails in order to control his craft better in heavy weather (*MP* 7). By means of the principle, Hero of Alexandria provided instructions for how to translate movement from one plane to another so as to make figures above a platform simulate life-like movements.[8]

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[7] The figure is from Pseudo-Juanelo Turriano, *Los Ventiun Libros de los Ingenios y de las Maquina*, 1595 (image jt519a posted on Database Machine Drawings of The Archimedes Project of the Max Planck Institute, http://dmd.mpiwg-berlin.mpg.de).

[8] Hero of Alexandria, *Automatopoiêtica*, in *Opera Omnia*, vol. 1, ed. Wilhelm Schmidt (Leipzig: B. G. Teubner, 1899), ch. vii–viii (362–65). Automata were artificial figures designed to be capable of a range of movements, usually the movements belonging to living things. Hero of Alexandria (AD 1st century) describes the apparatus for simulating animate movements as part of an automatic theater conceived as a whole. Whether or not Plato and Aristotle

The principle lies behind the modification of speed possible by means of gears, which are basically different-sized wheels in contact.[9] In the automatic theater, wheels linked by cables and turning in different planes become the basis for a variety of useful or surprising alterations in speed and direction of movement.

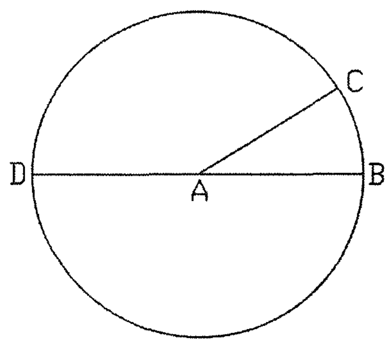

Figure 3 Aristotle's description of limb movements

ARISTOTLE UNDERSTANDS THE MOVEMENT OF A LIMB AS AN INSTANCE OF THE LEVER. IF A IS AN ELBOW, THEN THE FOREARM MOVES FROM B TO C.

knew the entire automatic theater of Hero's design, they both speak of apparently jointed figures moved by sticks or wires attached to limbs of the figures. Both allude to or address directly the principle behind the mimetic effects. Simple and complex devices were made in accordance with the same few principles. Note that Homer refers to *automatoi* as heat-driven self-moving cauldrons (*Iliad* XVIII, 373–77).

9 *MP* 1 presents the principle of wheels in contact moving in opposite directions (848a20). The discovery of the Antikythera device established that the Greeks had a capability for precision gearing not previously known to historians. The device is a set of gears in a metal box that tracked the position of heavenly bodies by display on a cover surface like a clock-face. It is dated to the 1st century BC. See E. C. Zeeman, "Gears from the Greeks," *Proceedings of the Royal Institute of Great Britain* 58 (1986): 139–56, and Derek de Solla Price, "An Ancient Greek Computer," *Scientific American*, June 1959: 60–67.

In *Movement of Animals* (*MA*) 1, Aristotle describes the movement of a limb as the action of a moving radius, where the moving force is applied near the center of the circle[10] (See Figure 3). If A is an elbow, then the forearm moves from B to C.

That Aristotle understands the movement of a limb as an instance of the lever is clear from his use of the moving radius principle later in the treatise in a general account of the powers of animal movement. In *MA* 7, he wishes to explain how a sense percept or imagining causes such great changes as the coordinated movement of an entire animal body to attain an object of desire, or the shivering and shuddering produced by a terrifying thought (701b16–22). He cites the amplification of effect accomplished by a slight shift in a ship's tiller in the hands of the pilot. There is a very great change in the position of the prow of the ship (b24–28). The author of *MP* gives a more extended treatment of the rudder in similar terms, making the rudder a lever moved by the slight movement of the tiller (*MP* 5, 850b28–34). For both authors, it is important that the tiller lies near the fulcrum (*hupomochlion*) of the lever and that the tiller's movement is small but correlated to another movement larger by some proportion. Aristotle makes the point explicit in connection with his tiller example: "It is not difficult to see that a small change occurring at an origin produces great and numerous differences at a distance" (701b25). Aristotle takes the moving radius principle as describing a kind of vector, a line of amplification of effect of a single cause. Aristotle says that the alteration in the body caused by perception and imagination, though small, produces greater alterations and different kinds of effects in the parts of the body.

He makes clear in *MA* 7 that the multiplier effect of the lever principle is not to be taken as the means of reducing all movement to a species of locomotion (701b10–16). He says that what distinguishes living things from non-living things is precisely that living things have capacities (*dunameis*) for genuine growth, increase, and alteration (b13). In the passage, whatever is the species of 'greater effect' produced by

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[10] The text used is Martha Nussbaum, *Aristotle's De Motu Animalium. Text with Translation, Commentary, and Interpretive Essays* (Princeton: Princeton University Press, 1978).

an initial change, Aristotle ascribes the greater effect to underlying *dunamis*.

We see from this consideration what Aristotle believes to follow from the principle of the lever if we apply it more generally to all kinds of change, namely an explanatory scheme for increase and diversification of effect. This point is made more vividly in another part of *MA* 7, where Aristotle speaks of *automata*—puppets, marionettes, or figures in an automatic theater. In accounting for the response of an animal to an object of desire or imagination, he says:

> The movement of animals is like that of automatic puppets, which are set moving when a small motion occurs: the cables are released and the pegs strike against one another; and like that of the little cart (for the child riding in it pushes it straight forward, and yet it moves in a circle because it has wheels of unequal size: for the smaller acts like a center, as happens in the case of the cylinders) (701b1–6).

It has been puzzling to scholars that Aristotle seems to take the *automata* to illustrate the same thing as the toy wagon (*hamaxion*).[11] The toy wagon is a cart with either two or four wheels in which the wheels are smaller on one side than the other. The cart is a very simple device compared to the complexity of the wheels, cables, and moving figures of an automatic theater. Elsewhere I have shown that the *automata* and the *hamaxion* both refer to the moving radius principle as exemplified in the rolling cone.[12] (See Figure 4.) The rolling cone has circles in its surface perpendicular to its axis that are mapped onto the plane surface on which it rolls.

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[11] In general, scholars have read into the reference to *automata* the modern understanding of a mechanism as an arrangement of material parts transmitting movement from one part to the next by contact. See Nussbaum, *De Motu*, 347; David Furley, *Two Studies in the Greek Atomists* (Princeton: Princeton University Press, 1967), 216; Berryman, "Ancient Automata," 359; Mohen Matthen, "The Four Causes in Aristotle's Embryology," *Apeiron* 22 (1989), 176–77. From this standpoint, the similarity Aristotle assumes between the toy wagon and the *automata* is puzzling because the toy wagon is such a simple device. There is not a succession of movers.

[12] Jean De Groot, "*Dunamis* and the Science of Mechanics: Aristotle on Animal Motion," *Journal of the History of Philosophy* 46, no. 1 (2008): 43–68.

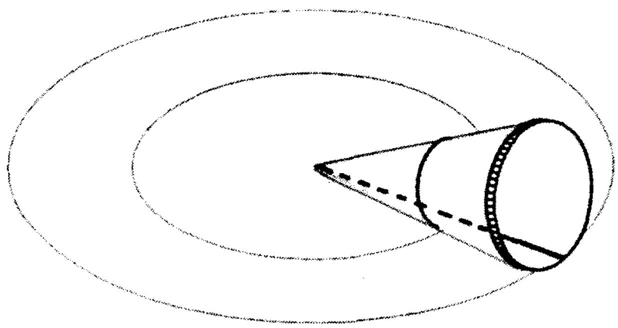

Figure 4 A rolling cone on a plane surface

THE ROLLING CONE HAS CIRCLES IN ITS SURFACE PERPENDICULAR TO ITS AXIS THAT ARE MAPPED ONTO THE PLANE SURFACE.

At its points of contact with the plane surface, the rolling cone describes a rotating radius. In his *Automatopoiêtica* (AD 1st century), Hero of Alexandria uses the rolling cone, and the different speeds of the concentric circles located on its surface, to explain how a hidden apparatus can translate the movement of a descending plumb-weight into circular movements proceeding in different directions at different speeds. He speaks of wheels located within a cone and extends the trope to a wheel in a different cone related to the first cone. As Hero uses it, the rolling cone is a shorthand expression for the amplification of effect produced by means of different-sized wheels in contact and connected by axles. This shorthand expression incorporates the translation of circular motion from one plane to another, which is so important for the surprising effects associated with *automata.*

Aristotle's *hamaxion* with its different-sized wheels illustrates in very simple terms the moving radius principle; the *automata* illustrate the same principle applied within an arrangement of interlocking wheels. Aristotle brings this understanding of practical mechanics to bear on the question of why animal movement proceeds without continual contact with an agent cause and why change in living things can so far outstrip the magnitude of the initial impulse to change. The moving radius is a model for the relation between the soul's initial action in the body—sensing—and the consequent responses to imagination and desire. His account of these responses is what he takes to be a very real condition of pent-up activity that shows itself in natural phenomena and simple machines. He characterizes this condition as *dunamis.*

Aristotle makes an explicit connection between *automata* and the concept of *dunamis* in *Generation of Animals* (*GA*) II.1. He explains how embryological development continues apace, after the initial effect of the parent sperm is spent. He says it is due to the potentiality resident in the materials contributed by the female. Making an analogy to the principle of the automatic puppets, he says:

> For the parts of such puppets while at rest have a sort of potentiality of motion in them (*echonta gar pôs huparchei dunamin ta moria êremounta*), and when any external force (*ti tôn exôthen*) puts the first of them in motion, immediately the next is moved in actuality (734b10–13).

This is a striking and significant use by Aristotle of the *automata* analogy. He says development of the embryo depends on pent-up power resident in matter, the female contribution, and in whatever parts of the embryo are already present. Aristotle has a vivid sense of the locomotive energy held in reserve because of a principle of mechanics. Something similar is at work in embryological development, he says, though the potentiality is not simply for movement from place to place.

III. ARISTOTLE'S *DUNAMIS* AND MECHANICAL ADVANTAGE

Let us consider more carefully the notion of power, or potency, that Aristotle draws from the mechanical devices he mentions. *Dunamis* is often understood as a kind of invisible characteristic belonging to something already fully actual on another level. E.g., water is clear and liquid, but it has the power to nourish living things. Usually, *dunamis* is a passivity that supports additional action or essence, upon the reception—in an appropriate time, place, and way—of a robust enough form from something other than the *dunamis*. E.g., blood and bone become a vertebrate body. On this conception, only what acts on *dunamis* has the form that the potentiality comes to possess when actualized. Other causes besides *dunamis* are determinative of what *dunamis* becomes. *Dunamis*, then, is passive power.

Dunamis conceived on the model of the lever does not fit this characterization. With the lever, the power itself is exerted or activated and is manifest in action. *Dunamis* in the case of the lever does not receive form but rather a push or initiating impulse, and the latency immediately issues in action of a distinctive sort. At the same time, this activity comes out of a receptivity harbored in an arrangement and structure of materials. The power of the lever is power in both a receptive and active sense.

Does this understanding of form as present in *dunamis* fit Aristotle's account of power and potentiality in *Metaphysics* Θ, the *locus classicus* for the meaning of potentiality in Aristotle? In *Metaphysics* Θ.1, Aristotle says the original meaning of potentiality is its meaning in relation to motion (1046a2). *Dunamis*, he tells us there, is a principle productive of movement in *some other thing* or *in the thing itself* possessing the potency but *qua another* (1046a11). These two senses have generally been understood as active and passive potency respectively.

This assumption is closely linked with another received view, namely, that capacities are either for motion or for being something. Both these divisions are given in *Metaphysics* Θ.1, it is said.[13] In regard to active and passive powers, *dunamis* is defined in *Metaphysics* Θ.1 as "a principle (*archê*) of change in another or [in the thing itself] *qua* another" (1046a11). Aristotle immediately explicates this definition in terms of change of the second sort residing in what undergoes change (*tôi paschonti*) (a13). So, here is passive potency, contrasted to active, as the ability to receive action and be changed.

As for the division between potencies for change or for being, Aristotle says in *Metaphysics* Θ.1 that, although the prior meaning of *dunamis* is in reference to motion, it is not the most useful for his present purposes (1045b36). This has been taken to signal his greater interest in potencies for being. The development of Book Θ, although perhaps not the first five chapters, in general bears out this interpretation. The two contrasts have a textual basis, then. Nevertheless, both dichotomies—between active and passive potencies and between potency for motion or being—have been under revision in recent scholarship.

Michael Frede addressed the two oppositions together, as he sought to re-center the meaning of *dunamis* as defined by action, whether the

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[13] Ross, *Metaphysics*, 240–41. Frede criticizes the interpretations of both Ross and Bonitz in "Aristotle's Notion of Potentiality in *Metaphysics* Θ," in *Unity, Identity, and Explanation in Aristotle's Metaphysics*, ed. T. Scaltsas, D. Charles, and M. L. Gill (Oxford: Clarendon Press, 1994), 173-93, at 179.

capacity is for change or for being.[14] Frede believes the division between active and passive potencies, as well as the discernment of potentiality (*potentialitas*) as a "a kind of item in the ontology, a distinct, somewhat mysterious kind of possibility," are both accretions of centuries of commentary on Aristotle in changing philosophical contexts.[15] Neither common interpretation of *dunamis* is a compelling reading of the original text. He believes, contrary to the standard interpretation, that being-capacities get their meaning from change-capacities. Capacities are real, but within a much more pedestrian ontology than the one developed within the Aristotelian tradition. Frede's formulation of this position is clear and useful: "Aristotle thinks that there are truths of the form 'A possibly is F,' in some special sense of 'possibly,' which cannot be reduced to truths of the form 'A is actually G.' " The physical world just is characterized by this fact, that there are *dunameis* as well as *energeiai* or *entelecheiai*, actualities.[16] In this context, Frede points out the artificiality of separating potencies for change or for being. Without existing, a thing can no more *be changed* than it can change something else. So, potencies are not merely conceivable possibilities, but exist. Let us consider a particular example that can illustrate Frede's point about *dunamis*, an example also relevant to the relation of small and large changes.

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[14] See Frede, "Potentiality." Most other treatments of *dunamis* in *Metaphysics* Θ.1 focus on potencies for motion as a springboard to potential being, which lacks sense without reference to its prior actuality (*energeia*). See, for instance, L. A. Kosman, "Substance, Being, and *Energeia*," *Oxford Studies in Ancient Philosophy* 2: 121–49; Stephen Menn, "The Origins of Aristotle's Concept of *Energeia* and *Dunamis*," *Ancient Philosophy* 14 (1994): 73–114; and Charlotte Witt, *Ways of Being: Potentiality and Actuality in Aristotle's Metaphysics* (Ithaca: Cornell University Press, 2003).

[15] For an interpretation of *Metaphysics* Θ.1 that contrasts markedly with Frede's, see Witt, *Ways of Being*. It is questionable how different, in the final analysis, Frede's interpretation is from the traditional one. He understands *dunamis* as a mode of existing of forms of sensible things, so his interpretation is rooted in substance.

[16] Frede, "Potentiality," 173. For another statement of capacity as real because of its relation to change, see Stephen Makin, *Aristotle: Metaphysics Book Θ. Translated with an Introduction and Commentary* (Oxford: Clarendon Press, 2006), 18.

Aristotle's treatment of 'oily' (*to liparon*) as a passive power illustrates the close relation of receptivity and action for *dunamis*. Something oily is what can burn (*kauston*) (1046a24). Oiliness is a power that requires some agent in order for the power to act. So, "oily" is a receptivity. Yet, oil's flammability shows that even a capacity conceived as passive is an active power when it shows itself by the impulse of some external agency. A warehouse fire started from a match dropped in oil is destructive in multiple ways, threatening even to take calamitous control of all the surroundings. More oil burns and the warehouse is set ablaze. It is hard to say that the passive *dunamis*, in the way it exists in this case, simply follows along behind the power that acts on it, as a weaker double.[17] The match is not "more" than the fire it caused. The flammability of the oil is the more powerful active power of the two contributors, agent cause and capacity. Someone might counter that there is a clear transition from passive power to active exercise in this case, since the flammability turns into actual burning. Furthermore, the match is actuality and to that extent "more," being already alight before it hits the oil. In contrast, I would point out that by the burning power of the oil, the oil burns. Combustion spreads through the body of the oil by the oil's own power. Oil has the power to burn itself, which is something active. In this case, so-called passive power and active power are very closely allied.[18] Passive power might be better called something's "*receptivity* to exertion of its own active power." Indeed, the present analysis supports Frede's suggestion that passive and active powers should not be separated into two.

In many Aristotelian contexts, "passive" is a poor English translation for the Greek *pathêtikos* which has a connotation of "undergoing." In *Nicomachean Ethics* II.5, *pathê* is often translated as

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[17] Makin treats the puzzles of correlating passive and active powers in his commentary on *Metaphysics* Θ.1 (Book Θ, 29–34).

[18] I am not unmindful of the tenet of Aristotle's philosophy, which has drawn much attention in recent years, that any motion has an unmoved mover, in this case the match already alight or the parts of oil already aflame setting other parts on fire. See, for instance, *Physics* VIII, 258a5–12. For now, I wish to draw attention to a neglected part of Aristotle's natural philosophy, the structure of active capacities and their connection to latent power. In this context, Aristotle conceives of motion as having some version of agency.

"emotions," but *pathê* are really the non-rational side of our responses to things that happen to us, i.e., responses to our "undergoings." The undergoing of a trial or bad experience is also the expression of anger or sadness coming from the experience. *Pathê* are emotions that are expressed because they are evoked. We have *dunameis* for *pathê* (1105b25). It is by virtue of *dunameis* that we are said to be *pathêtikos* (b26). The ethical virtues and vices are not *dunameis* but states (*hexeis*) we are in relative to *pathê*, when our responses have been formed to the stable and predictable by repetition in behavior. *Dunamis* needs a translation that connotes both receptivity and response. The word "reactivity" for *pathêtikos* has too much of a connotation of stimulus-response or action due to irritability in the subject. The neologism "ractive," though ugly, at least illustrates the seamless combination of receptivity and activity most appropriate to *dunamis* as Aristotle develops its meaning for animal motion in *MA* 1–7.

Let us consider this more detailed sense of *dunamis* in Aristotle's account of embryological development in *GA* II.1. This is the passage where Aristotle compares embryological development to the movement of *automata*. Here, Aristotle insists that neither the animal nor any complete part of it is contained in the sperm, but that the sperm does play a role as agent (the *huph'hou*) of form, a role that it passes on to another part of the developing embryo later in the process. The agent depends upon the *dunamis* in the materials acted upon, in order for development to proceed. Aristotle in effect says that the male seed has the parent's form as part of the parent's body and not as a 'carrier' of the form to the offspring. Aristotle says, "If, of soul, there is nothing which is not in some part [i.e., if every part of a living thing has soul in it], also this part (the seed) would be straightaway ensouled" (734a14–15). So, the male seed shares in the soul of the true agent cause, the parent. Aristotle emphasizes that this secondary agent is partial, not a whole. Yet, its partialness includes the ability to sustain a process that will achieve substantial form in actuality. So, the substantial form of the developing embryo, the form it will have when development is completed, depends on a condominium of the *dunamis* in matter and the resident active agent. This means that matter must be very specific to form. It also means embryological growth is a system and that the teleology governing the development is spread throughout the entire system.

This understanding of power and agent is consistent with the way that, in a simple machine, mechanical advantage passes into actuality by means of a blow or pressure applied at the end of a balance arm. In this case, the mover is a cause that does not itself possess the form of what is accomplished. How much more so, then, may the seed, which shares in soul, be an agent that brings about an amplified effect, the offspring. This understanding of power and agent helps to understand *Metaphysics* H.6. In this chapter, Aristotle asks what accounts for 'what is potentially' (*to dunamei on*) existing actually (1045a30–31). In the case of things subject to generation, he says, there is no other cause beyond the agent. This is because of how matter and form make up a unity, he says. They are the same thing, the one (matter) potentially, and the other (form) actually (1045a23, b18). This view makes the form present in the condition of actuality something that belongs to the matter as well.

The approach to understanding *dunamis* that I have articulated adds physical content to the *dunamis* concept without making it into some already actual thing. Indeed, the defining of *dunamis* in terms of motions and proportional relations shows that not all realities should be looked for in the realm of finished substances whose quiddity is already given. Originally, *dunamis* has content based on universal scientific and pre-scientific experience. This pre-scientific experience validates the reality of *dunamis* while also establishing the overall context for a deeper causal account.

To this extent, *dunamis* is a notion of natural philosophy in a way that a kindred mechanical idea, *rhopê*, is not. The concept of *rhopê*, force or impetus, treats the same phenomena as Aristotle's *dunamis* but in a way that makes the power of mechanical advantage like a fully actual being, an entity. In this contrast, we see the beginning of science as different from natural philosophy. I can give some indication of what I mean by returning to the Aristotelian *MP*.

In his account of larger and smaller balances, the author of *MP* introduces a concept, *rhopê*, to compare the faster and slower movements of different concentric circles. The problem is why larger balances are more accurate than smaller ones. He says the degree of advantage (*to megathos tês rhopês*) brought about by the same weight (*hupo tou autou barous*) is greater in larger circles, and this is why the same force causes a greater distance to be covered in the larger circle

(849b33–34). Here, *rhopê* is closely allied to the manifestation of latent power in movement itself. Aristotle had used the term *rhopê* in *DC* IV.1 in connection with the natural movement of the elements. He says that weight and lightness are defined by their power to be moved physically (*tôi dunasthai kineisthai physikôs pôs*). If there is a name for the corresponding actualities, he says, it might be *rhopê* (307b31). So, *rhopê* is the actuality of movement.

In the *MP*, *rhopê* is given a more expansive explanatory role but at the same time a narrower meaning. In chapter 8, the author asks why curved shapes are the easiest of all shapes to move. He offers reasons having to do with resistance from a contacting surface, and how a weight at the end of a radius will be inclined to move, given its position on the circle (851b21–33).[19] Finally, he suggests that larger circles are related to smaller ones somehow by mutual resistance (*dia to antereidein*), so that a larger circle can move great weights, "on account of the angle of the larger circle having a certain *rhopê* in relation to the smaller, and the *rhopê* being in the proportion that the diameter of the longer has to the smaller" (851b38). If a circle has *rhopê* in relation to another, it is moved more easily (than the other) (852a1–2). The author does not say that both circles have *rhopê*, but one has *rhopê* in relation to the other. This advantage comes about by the system of factors, especially length of diameter, by which one circle overmatches the other in ability to move. Clearly, power latent in the arrangement underlies there being *rhopê*. The problem is that we are now inclined to ask "what is *rhopê*?" since the author ascribes to it a generalized causal power.

The author treats this causal power as entering into some relation of quantitative exchange with blows and taps. Yet the connotation of the term shifts between description of the realm of real phenomena and a realm of more permanent underlying forces and powers. He gives no indication that these forces and powers are anything other than entitative, like the elements of the phenomenon being treated. From what we have come to understand about *dunamis* in Aristotle's thought, *rhopê* should be a mode of being, an underlying power for actuality. The

[19] At the top of a vertical diameter, a weight has no greater inclination to move to one side or the other, but moved slightly off the vertical, the weight will move more in the direction of its inclination (*eph'ho rhepei*) (851b27–33).

author does not present his accounts within that horizon of explanation, however. The power of mechanical advantage is acquiring entitative status and with that, its manner of being becomes obscure.

Much more needs to be said to flesh out the contrast of *dunamis* and *rhopê* here suggested. The point is, however, that in Aristotle's own account natural philosophy and science shared a resort to potentiality or power that could be allied to metaphysics. As an effort is made to give a more complete treatment of a phenomenon and one that defines causes with the greatest perspicacity, a limitation of vision sets in. The scientist, as in *MP*, takes for granted the being of what he seeks to explain. This leads him to multiply beings on the same level as ordinary existent things and to deconstruct original phenomena into these beings rather than to seek knowledge of principles across many cases by analogical reasoning. The explanatory advantages of *dunamis* as a mode of being are not lost (and will figure in the later history of mechanics) but are poorly understood by the practitioner himself.

This seems to be an instance of the limitation of human science that is described by Maritain in *The Degrees of Knowledge*. He says, "By a kind of natural necessity, abstraction, the lot of all human science, brings with it, along with a multiplicity of partial and complementary insights, the rigid law of logical movement, the slow elaboration of concepts...."[20] The multiplication of accounts and the elaboration of concepts bring with them a constriction of philosophical perspective. For example, *dunamis* as a principle of natural philosophy becomes *rhopê*, a theoretical entity in mechanics. Nevertheless, the problem Maritain has described is both less acute and easier to diagnose in the ancient context I have presented than it is in the contemporary sciences Maritain sought to understand.

IV. CONCLUSION

The following points emerge from the line of research I have sketched so very briefly here. In contrast to Maritain, it seems to me reasonable to argue for two types of continuity in connection with science: (1) a continuity between ancient and modern science and (2) a continuity between some aspects of perennial science and a perennial

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[20] Maritain, *Degrees*, I.5, 5.

natural philosophy. Granted, continuity in both areas is not universal to all the sciences or even to one entire science, like mechanics. Nevertheless, we should not overlook the fact that some basic sciences, like practical mechanics, do not change in their fundamentals. There are aspects parallel to practical mechanics in this regard in other sciences.

In his strategy for recovering Aristotelian philosophy of nature, Maritain is adamant that there can be no continuity, ontologically, between physico-mathematical theories and philosophical knowledge.[21] This claim, of course, arises primarily from his evaluation of the different manners of conceiving the objects of physics, mathematics, and metaphysics. It is reinforced, however, by his judgment on the ancient sciences. My suggestion, based on the evidence presented, is that Maritain gave up too quickly on the continuity between natural philosophy and science, both for antiquity and the present day.

Aristotle did not think of natural philosophy and science as different endeavors. This was not simply a failure of vision on his part, since a basic physico-mathematical notion of his own time was integral to his natural philosophy. Aristotle provides us an example of the continuity between *physica* and science. Nevertheless, as Maritain saw, science in the modern age labors for the most part without the benefit of natural philosophy's perspective on subjects and attributes, the necessary and accidental, abstraction and hylomorphism. The ancient example I have presented suggests that modern science's detachment from natural philosophy is not due entirely to the exceptionalism of modern science but rather to the way scientific concepts developed (and to some extent are bound to develop) out of natural philosophy. This is at least a start on an important task of our own time: to bring into relief the value of philosophy of nature in lending self-understanding to the scientific enterprise.

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[21] Maritain, *Degrees*, II.29, 64.