J ATHANASIUS WEISHEIPL, OP.

NATURE AND GRAVITATION

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INTRODUCTION

MOTION has always aroused wonder in the minds of thinking men throughout all centuries. Why does a body move? In particular, why does a body fall to the ground? Although gravitation is a fact of daily experience, the cause of this motion is very obscure. The great variety of explanations offered by the ancient Greek philosophers shows this obscurity.

Newton himself frequently acknowledged that he did not know the cause of gravitation.[1] Boyle and Hooke lamented that of all natural phenomena gravitation is the least explainable.[2] At the turn of the last century Karl Pearson admitted the difficulties of explaining why bodies move; he ended his discussion by saying that science can well afford to neglect the *why* and be content for the present to say: *Ignoramus.*[3] Even in our own day scientists who consider the problem clearly acknowledge that for all of science's progress in showing how bodies move, we still do not know *why* a body falls to the ground.[4] Of course, a great deal depends on what we mean by an "explanation." Scientific literature of the past few decades bears witness to the fact that modem science has become increasingly critical of its own methods and basic theories; and the very meaning

11. Newton, *Principia Mathematica,* Gen. Scholium, ed. F. Cajori, Berkeley, Calif. 1947, p. 547; see also Cajori's notes, pp. 632-635.

[2] Robert Boyle, *On the Usefulness of Experimental Philosophy,* P. I., *Works,* ed. Thomas Birch, London 1744, vol. III. Paper of R. Ilooke read to the Royal Society 1665, printed in Boyle's *Works,* vol. V, pp. 546-8; see also M. Boas, " The Establishment of the Mechanical Philosophy," *Osiris* X (1952), 412-541.

SK. Pearson, *The Grammar of Science,* London 1949, pp. 230-234.

* F. Cajori, notes to the *Principia, ed. cit.,* pp. 671, 665, 632-37; see also Cajori's *History of Physics,* N. Y., 1916, p. 62, note 1, and Sir Edmund Whittaker, *Prom Euclid to Eddington,* Cambridge 1949, pp. 112-4.

of " explanation " has undergone a change. Today it is necessary to consider every explanation in terms of a complete physical theory of nature, in terms of basic principles of reference.

After the time of Newton it was commonly thought that the problem of gravitation was conveniently disposed of by universal attraction. But the theory of Relativity in our own day forces us to face not only the problem of gravitation, but also the basic principles and assumptions of a physical theory which attempts to explain gravitation. The obligation of the Thomistic philosopher of nature is to join in the critical examination of physical theory and to help reconstruct a realistic theory of nature. It is idle for the Thomist to seek a *rapprochement* between Aristotelianism and pre-Relativity conceptions. The task today is a re-examination of all the principles of physical theory and an organic integration of human knowledge concerning the physical world.

The purpose of this dissertation is to re-examine those principles of physical theory which relate to gravitation as understood of both terrestrial and celestial movement. The method here employed is both historical and critical. Ernst Mach has amply shown the importance of an historical sense in examining physical theories. He wisely said, " One can never lose one's footing, or come into collision with facts, if one always keeps in view the path by which one has come." [5] But an historical sense alone will not build a true theory of nature. One needs also a critical sense in evaluating the logical and psychological foundations of scientific theories. The purpose of all such criticism is to produce an integrated unity in which all the parts make sense and are well established. To do this the fallacy of certain assumptions must be pointed out, the foundations of

*E. Mach, *History and Root of the Principle of the Conservation of Energy,* trans. by P. Jourdain, Chicago 1911, p. 17.

true principles must be established, and the necessary distinctions must be recognized. In the present problem of gravitation the desired organic unity of physical theory can be attained only by acknowledging an essential distinction between a strictly mathematical and a properly philosophical theory of nature. This is brought out by an historical examination of the main theories of gravitation which have been proposed throughout the centuries.

The thesis proposed in this dissertation can be expressed very briefly: Mathematical and philosophical theories of gravitation are two essentially distinct "explanations"; and the mathematical theory of Relativity can be corroborated only by a re-understood and re-vitalized Philosophy of Nature in the Aristotelian sense of the phrase. To defend this thesis it is necessary, first of all, to place the special problem of gravitation in the wider problem of motion itself, for without realizing this essential relevance the problem cannot be properly understood. In trying to solve this problem an analysis of the concept of ' nature ' must next be made, since the Aristotelian conception is frequently misrepresented and insufficiently analyzed, especially with regard to gravitation. The distinction between natural and compulsory motion must be examined, since it is commonly thought that such a distinction has been abolished by the principle of inertia. Finally a critical examination must be made of the principal modem theories of gravitation: Cartesian Vortices, Newtonian Attraction, and Einsteinian Relativity. Since no complete history of gravitational theories has yet been written, only the main outlines of the purely historical development can be indicated in this brief work. However, by means of the data available we hope to point out the historical and theoretical necessity of the thesis.

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CHAPTER II

The Concept of Nature

WORDS can exercise a very strong tyranny over the mind, unless one realizes that words are merely a feeble medium in which to communicate our thoughts and oar experience of reality. Words are symbolic, not immediately of things, but of ideas; and those ideas ultimately involve a highly complex human experience of a reality which cannot be fully comprehended. There is, however, a common tendency, unconscious of course, to substitute words for the reality, thinking that in knowing the right word or phrase, we thereby know the reality we are talking about. This tendency is particularly dangerous in a philosophical tradition, in which words are carefully selected and definitions canonized. When such scientific terms and definitions are employed without sufficient analysis of meaning they deceive us into thinking we understand reality, while actually they are an impediment to true understanding. Modern philosophers, for the most part, shy away from traditional terminology for fear of being misunderstood or not understood at all. They tend to coin their own words, free of undesired implication, or juxtapose unexpected phrases to jolt the reader into seeing the meaning intended. Logical positivism has at least this merit that it insists on a careful analysis of meaning as a necessary factor in philosophical and scientific understanding.[1]

[1] Cf. A. Whitehead, *Modes of Thought* (Cambridge, Mass., 1938), pp. 1-171; also *Process and Reality* (New York, 1941), pp. 16-20.

The term “nature” has particularly suffered great abuse. In medieval thought the term was used in many senses, but each sense was clearly specified. Renaissance philosophy regarded nature as something divine and self-creative; it distinguished *natura naturata,* or the complex of observable changes and processes, from *natura naturans,* or the immanent force which animates and directs them. The Aristotelians whom Bacon, Boyle, and Newton attacked seemed to have avoided scientific research, claiming “ nature ” as a sufficient explanation of physical phenomena. While today the term has been applied in so many different senses, it seems to have no specific implication at all, much less is it an explanation. Therefore it is important that we analyze carefully the concept of nature to see its precise meaning.

In contemporary usage the term “nature” is on the whole most often used in a collective sense for the sum total or aggregate of natural things. We often speak of nature in the sense of the “universe” or “cosmos,” meaning by that the whole of natural reality outside the mind. This sense implies a bifurcation of mind and external reality, which can be misleading. But the important point is that this notion of “ nature ” signifies something global and self-contained; it is a *nomen abso- lutum.* Even when we refer to the “nature” of man, of law, or any other reality, our reference is usually to its essence in the static sense of what makes it to be what it is. In other words, the ordinary use of the term “ nature ” is by no means a functional one, but rather a static and self-contained term. It is synonymous with “essence,” or *quod quid est.* At the same time, this is not the only sense in which the word is used in modem languages. There is another sense, which we recognize to be its original and, strictly, its proper sense: when it refers not to a collection, but to a *principle,* or *source.* We often say that a man has an affectionate or quarrelsome nature, meaning that the man’s own temperament in some way accounts for his expression of affection or irascibility. We say it is the nature of water to flow down hill, the nature of dogs to bark. In this sense the word " nature " refers to something intrinsic which is responsible for the behavior. This is more clearly implied in the common distinction between natural behavior, that is, behavior resulting from something intrinsic to the thing itself, and compulsory, which arises from external constraint contrary to its proper activity. "Nature" as used in this sense of an intrinsic source is a *relative* term, that is, it is spoken of and thought of always in relation to a characteristic behavior or property. There is a great difference between these two senses. The absolute term merely connotes existence. The relative term, on the other hand, always implies source and responsibility. Although both senses are used in English, it is easy to see that the relative use of the term is prior and logically, as well as etymologically, would antecede its use in the absolute sense.[2]

Early Greek philosophy employed the term *phusis,* from which we derive our word " physics " and its variants, only in the relative sense of a source, or *arche.* Not until relatively late is the term employed in the secondary sense of an aggregate of natural things, that is, more or less synonymous with the word *lcosmos.*[3] The term *phusis* originally seems to have meant the process of generation, but the existing fragments of the pre- Socratics invariably employ the term to signify the " source " of the process. The Ionians, for example, were principally concerned with finding the original material " out of which " the entire universe is formed, an original source which would ex

[2] Cf. R. G. Collingwood, *The Idea of Nature* (Oxford, 1945), pp. 43-48.

[3] For example Gorgias, the famous Sicilian of the late 5th century, wrote a treatise entitled *PERI TOO MU 'ONTOS, 0 PERI PH08EOS-,* from what Sextus tells us, it is clear that *phusis* does not mean a principle but merely the world of nature; for Gorgias maintained: 1) that nothing exists; 2) if anything exists, it is incomprehensible; 3) if it is comprehensible, it is incommunicable. Cf. H. Diels, *Fragmente der Vorsokratiker,* 5th ed. (Berlin, 1934-8), 82 B, frag. 3. References to Diels abbreviated to *Vorsok.*

plain the evident phenomena of various movements in the universe. The single element of fire, air, or water was regarded by the Ionians as the true " nature " of things; it was the ultimate reality responsible for activity. Empedocles, realizing the insufficiency of a single element, regarded the four elements as the true nature of things. He makes a point of insisting that only those four elements should be called *phusis,* and reprimands his contemporaries who apply the term even to mixtures of these elements/ It is very important to remember that the pre-Socratic problem was the search for an ultimate explanation of sensible phenomena, and not merely a question of the "one" or the "many." The ultimate "one" postulated by the Ionians was not a static substratum, but a source, a *phusis* from which flows movement and sensible reality. Although the term was applied to a great many things, the essential connotation remained the same, namely, a material source of changing phenomena.[6]

* Diels, *Vorsok.,* 31 B, frag, 8.

B Over the past forty years a strong controversy has raged concerning the principal meaning of *phusis* among the pre-Socratics. Cf. summary in A. Mansion, *Introd. a la Physique Aristotilicienne,* 2nd ed. (Louvain, 1945), pp. 59-63; also bibliography in W. A. Heidel, " Perl phuseos, A study of the conception of Nature among the presocratics," *Proceed, of the Am. Acad, of Arts and Sciences,* XLV, n. 4, p. 96, note 69. The main point of the controversy seems to be whether the term primarily signified the eternal primary material of which the world is made Burnet, *Early Greek Philosophy,* 4th ed. (London, 1945), pp. 10-11; Appendix, pp. 363-4) or the universal process of growth W. A. Heidel, *op. cit.*; W. B. Veazie, " The Word PHUSIS," in *Archiv filr Gesch d. Philos.,* Bd, XXXIII, H. 1/2 (1926), 3-22. Mansion attempts to harmonize the opposing positions by insisting that " pour les penseurs anWrieurs *b,* Socrate la *phusis* cosmique englobait l'ensemble des pMnom^nes naturels, dont le monde est le theatre avec la r£alit6 materielle primitive, source et origine de ces ph6nom4nes " (*op. cit.,* p. 63). It would seem that the difficulty depends upon accepting or rejecting Aristotle's claim *(Metaph.,* V, c. 4, 1014bl7), that the term originally signified the process of birth, and then transferred to designate the source of this process. Cf. below p. 384, note 22. If Aristotle's claim is correct, then *phusis* is a *relative term* designating the " source " but always connoting "movement"; this is not a compound sense, but a single relative sense. Then, too, although the pre-Socratics considered this source

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In a very famous passage of the *Laws* Plato accuses his predecessors and contemporaries of impiety and of leading young men away from the gods.[6] All other philosophers, he says, teach that this beautiful universe, the regularity of celestial movements, and the human soul arise " not because of mind, nor because of any god, nor by art, but as we may say, by *nature* and *chance."* [7] Plato recognizes that all things which come about in the universe are the result either of art (*techne*), nature *(phusis),* or chance (*tuche).*[8] But the ancient philosophers and even his own contemporaries attribute the origin of the universe and its phenomena to nature, a blind material element which operates by chance. He asks how was it that " nature " in the first place acquired movement and force to produce the order of the universe? How, he asks, can soul be a result of material *phusis,* since intelligence must be anterior in order to direct growth and order?[9] If *phusis* means the " first source," then the term should not be applied to fire, air, or earth, but to Soul *(psuche).*[10] For Plato it is Soul (God) which is the first source of all being and becoming, the ruler of the heavens, the law-giver.[11] The ancient philosophers who attribute all phenomena to nature, derogate from the rights of God, "Who is the true Nature, unseen by the senses of the body, but perceived by the intellect.[12] In his explanation of the ma-

(*phUsis*) to be "ageless and deathless," as Burnet points out (op. *cit.,* p. 10), it would seem that this eternal and absolute characteristic of *phusis* is a subsequent attribute of the One, which was called nature.

" Plato, *Laws* X, 884 A-913 D.

[7] *Laws* X, 889 B. Cf. Aristophanes, " Zeus is dethroned and Vortex *(ding)* reigns in his stead." *Clouds,* 828; see also Diogenes IX, 31-34, Diels, *Doxographi Graeci* (Berlin, 1929), pp. 142-3; and Burnet, *Early Greek Philosophers,* pp. 338-9, 341-7.

[8] *Laws* X, 888 E. Plato implies that this division was employed also by his adversaries, cf. also 889 C.

[9] *Laws,* 891 B-892 A.

[10] *Ibid.,* 892 C.

[11] *Laws,* 896 D-897 C.

[13] *Ibid.,* 898 D-E.

terial world Plato gives to art a preeminence over nature and chance. That is to say, Plato insists that the material universe is a product of the *art* of God.[ls]

Plato, however, does not use the term *phusis* consistently throughout his works, for sometimes he opposes the two classes of being, *phusis* and intelligence,[14] and sometimes he attributes the traditional role of *phusis* to Soul, maintaining that the use of the term to designate material elements must be absolutely condemned.[16] In fact, it must be admitted that Plato did not develop a doctrine of nature; rather he replaces the theory of nature by a theory of Soul.[16] His concern is to show that all material reality proceeds from divine intelligence, which necessarily must be anterior to the world. Furthermore, in the course of developing his arguments against his adversaries, he shows that all corporeal movement without exception depends upon the influences and direction of the Soul which permeates space.[17] Therefore, for Plato it is not nature which is primary in the explanation of physical reality, but the divine Soul which produces the world and directs movement by *art.*

Undoubtedly Aristotle had in mind Book X of the *Laws* when he developed his own doctrine of nature in Book II of the *Physics.* The threefold division of causes into nature, art, and chance is Plato's point of departure for attacking his adversaries. This same threefold division is Aristotle's starting point for rehabilitating the naturalist theories of the pre-Socratics in face of Plato's criticism. Whereas Plato, insisting on the priority of Soul, had rejected the idea of nature and attributed

[13] Aristotle himself employed this explanation in his early work, *De Philosophia,* where he represents the world as produced " by the very perfect art of God." V. Rose, *Fragmenta,* Biblioth. Teubneriana (Leipzie, 1886), frag. 21.

[14] Cf. *Apol.,* 22 C.

[15] *Laws,* X, 892 B-C.

A. Mansion, *op. cit.,* p. 83.

[17] *Laws,* X, 899 D ff.

most of the characteristics of *phusis* to Soul, Aristotle tried to maintain both the priority of Soul and the reality of " nature." Before analyzing Aristotle's idea of nature, it is necessary to consider the passage in Book V of the *Metaphysics* where he discusses the various meanings of the word *phusis.*[19] In this philosophical lexicon, probably an earlier work than the Second Book of the *Physics,*[19] Aristotle intends to explain the various senses in which the word is used. Realizing that different senses of the same word are somehow related, he attempts to show the primary sense of the word and how other senses are related to it. He lists six principal meanings of the term *phusis;* these he reduces to one which is the primary and strict sense.[20] For Aristotle the primary and strict sense of the term *phusis* is a formal, or active principle of movement and rest in all corporeal reality.

1) Aristotle tells us that the word originally meant "the genesis of growing things—the meaning which would be suggested if one were to pronounce the *u* in *phusis* long." That is to say, the word is probably derived from *phuo* which has *u* long in most of its forms, so that the connotation of *phusis* is that of a process. It is impossible to convey this sense in English, but there is a similarity in Latin for it seems that *natura* originally signified *nativitas.*[21] For Aristotle, then, *phusis* originally meant the process of growing.[22]

[18] Arist., *Met.,* V, c. 4, 1014bl7-1015»19.

[19] This is the opinion of Zeller and Jaeger; cf. Zeller, *Die Phil. d. Grie- chen* (Leipzig, 1879), II, 2, 157. But W. K. C. Guthrie has presented some strong arguments in favor of a very late composition; cf. *Classical Quarterly,* XXVII (1933), 162-71; XXVIII (1934), 90-98.

[20] Arist., *Met.,* V, c. 4, 1014>>17-1015[a]19. St. Thomas very frequently lists and discusses the analogy of these different senses, especially *In V. Met.,* 5, nn. 808-826; *In III Sent.,* d. 5, q. 1, a. 2; *Sum. cont. Gent.,* c. 35; *De Unione verbi Incarnati,* a. 1; *Summa Theol.,* I, 29, 1 ad 4.

[11] " Fundamentally *natura* signified 'birth' (as in Terence, *Ad.,* 126, 902), i.e., the process by which living objects come into being." *Hasting's Encyclopedia of Religions and Ethics* (Edinburgh, 1917), IX, 244b.

[a*] Burnet, however, doubts *(op. cit.,* pp. 10-12; 363-364) that *phusis* ever

2) From the activity of growth, the word was transferred to signify the active principle of growing things. St. Thomas explains this by saying that " active powers are customarily named from the activities." [23]

3) Then the term was extended to signify "the source of the primary movement in each natural object which is in it in virtue of its own essence *(onsia),"* [2i] that is, it signifies *the active 'principle of movement in all natural things.* That Aristotle means here the *active* source of each body's characteristic movement is clear from his example of growing things.[25]

4) But this sense of *phusis,* as we have seen, was first applied to " the primary material out of which any natural object is made." [26] Aristotle notes that some have called it fire, others earth, others air, others water, others something else of the sort, and some named it more than one of these, and others all of them.[27]

5) But *phusis* was soon applied also to the form and total composition of natural objects. We have seen that the earliest

had this meaning, as he has been unable to find this exclusive sense in any of the pre-Socratic fragments. He is followed in this by Lovejoy in the *Philosophical Review,* XVIII (1919), 369 ff., as well as by Sir David Ross (*Aristotle's Metaphysics* [Oxford, 1924], I, 296-298) and by R. O. Colling- wood *(The Idea of Nature* [Oxford, 1945], pp. 80-81). This specialized difficulty must be left to the scholars. But it must be admitted that the word at least had this connotation, as we can see from Plato's use of *genesis* in *Laws* X, 892 C and Aristotle's strange arguments from Antiphon, in *Phys.,* II, c. 1, 193al2-17, 193b8-13.. Considering the origins of human language there is no reason to suppose that such a connotation is not indicative of the original sense Aristotle mentions.

[23] ". . . quia virtutes agentes ex actibus nominari conseuverunt." *In III Sent.,* d. 5, q. 1, a. 2; cf. *In V Met.,* 5, n. 809.

[2*] Arist., *Metaph.,* 1014bl9-20.

[25] Cf. also St. Thomas: " Inde ulterius processit nomen naturae ad significandum principium activum cuiuslibet motus naturalis." *In III Sent.,* d. 5, q. 1, a. 2; " Et haec est definitio posita in II Physicorum." *In V Met., 5,* n. 810.

*• Arist., Met., 1014b27-28.

[27] *Ibid.,* 1014b32-35.

philosophers wanted to restrict the term *phusis* to the elements, but Empedocles, quoted by Aristotle on this point, acknowledges that men give the name even to mixtures.[28] It is really this sense of *phusis* that Aristotle develops in his philosophy of nature. The background of this must be understood in the light of his frequent attack on the pre-Socratics in that they considered only matter to be " substance," failing to distinguish between " first matter " and the material substance.[29] As the pre-Socratics were unable to explain essential changes, the immutable matter was " substance," to which they applied the idea of *phusis;* the composition (form), although theoretically only a mixture, was nevertheless called *phusis* by ordinary men.[30] Aristotle's explanation of substantial change allows him to justify and to develop this common use of " nature " as the specifying form of bodies which manifest characteristic activities.

6) Finally " by an extension of meaning from this sense of *phusis* every essence in general has conte to be called a nature." [31] This is the static sense of nature as " the essence, which the definition signifies," [32] or " the informing specific difference in each and every thing." [33] In this transferred sense *phusis* is a *nomen absolutum,* quite different from the preceding

[28] Diels, *Vorsok.* 31 B. frag. 8. For the exegesis of this passage cf. Burnet, *op. cit.,* pp. 205-6, note 4.

[29] Cf. Arist., *Metaph.,* I, c. 3, 983b6-19; c. 7, 988al8-b22; VII, c. 3; cf. also St. Thomas, *In VII Met.,* 2, nn. 1281-1293, where he develops this idea very clearly.

[30] Diels, *Vorsok.,* 31 B, frag. 8. St. Thomas explains: " Decipit autem antiquos philosophos hanc rationem inducentes, ignorantia formae sub- stantialis. . .. . Forma autenj substantialis non est sensibilis nisi per accidens; et ideo ad eius cognitionem non pervenerunt. Sed totum subiec- tum, quod nos ponimus ex materia et forma componi, ipsi dicebant esse primam materiam, ut aerem, aut aquam, aut aliquid huiusmodi. Formas autem dicebant esse, quae nos dicimus accidentia. . . ." VII *Metaph.,* lect. 2, n. 1284.

[31] Arist., Met., 1015all-12.

[32] Cf. St. Thomas, *Sum. con. Gent.,* IV, 35.

[33] Boethius, *De Dual. Nat.,* PL 64, 1341.

uses. In his *Commentary on the Metaphysics* St. Thomas does not list this among the principal significations of the word, but as an extension " secundum quamdam metaphoram." [84] Considering these various senses, Aristotle concludes, " It is plain that nature in the primary and strict sense is the essence of things which have in themselves, as such, a source of movement." [36] But matter, too, can be called nature, "because it is qualified to receive this." [88]

In the *Metaphysics* Aristotle presents all of this without proof or elaboration. He is concerned only with classifying the various meanings of the term " nature " and in pointing out the primary meaning. However, Aristotle's own position in the history of Greek thought is very clear from this passage. It is mainly in Books II and VIII of the *Physics* that he justifies and elaborates his conception of nature as an intrinsic principle of movement.

The Aristotelian conception of nature must be understood in contrast to art and chance. We have already seen that this tripartite division was commonplace at the time of Plato. By art is meant any production by human intelligence, anything produced by the human mind acting upon reality.[37] By this is meant not only pictures, statues, machines, and other works of craftsmanship, but every result of human interference, such as pushing, pulling, throwing, twirling, holding, and so forth. In other words, a stone which is thrown into the air would not be considered to move upward naturally, but to be the result of "art." This does not mean that every human action on the physical world is " artistic," or "intelligent," but that there

[34] *In V Met.,* 5, n. 823; but in parallel places St. Thomas lists all the senses together as analogically similar,

[85] Arist., *Met.,* 1015al3-15.

"*Ibid.,* 1015al5-16.

[87] Plato seems to have been the first to apply " art " to the activity of divine intelligence in the world. But in the present context Aristotle means to discuss only the work of human intelligence.

are phenomena in the world which *can be accounted for* as the work of human activity. Besides the result of human activity, there are many phenomena which are the result of mere *chance,* or accident. Chance is the irrational element in the world. Certainly after a chance event has occurred the phenomenon can be explained rationally as the concurrence of such and such a factor. But the event itself is unpredictable; it is the unexpected, the unintended. Just as in human experience many things happen merely by chance, so too in the physical world many events are the result of two factors, each of which has its own history. But every result of chance presupposes factors which have an individual history, a make-up and intelligibility which are proper to each. That is to say, just as not every phenomenon can be explained by human control, so neither can every phenomenon be explained by chance. For chance is not a thing, but a concurrence; and every concurrence involves things.[88] Therefore some agent other than " art " or " chance " is necessarily operative in the universe; for convenience this agency may be called *nature.*

From what has been said it is clear that human activity in the world and chance both presuppose phenomena which cannot be accounted for by either of them. Human activity presupposes not only the existence of things and phenomena upon which to work, but even a qualitative differentiation which must be acknowledged. For example, an artist cannot make a statue out of air, nor can an aviator fly through the earth.

*[8] Chance plays a very large role in the Aristotelian view of the universe, but Aristotle is careful to point out that chance as such is the *meeting* of particular bodies, and indeed, the meeting of *individual* bodies. That is to say, such a meeting is not within the intentionality of any particular body (cf. *Phys.,* II, c. 5-6). Thus he defines chance as a "causa per accidens" (Phys,, II, c. 5, 197a5-6), meaning that the event is *not intended* by either factor. St. Thomas insists that nowhere within the whole physical universe is there a cause which per *se* intends the chance event, concursus; cf. *Sum. cont. Gent.,* Ill, 86; c. 93; *Summa Theol.,* I, 115, 6; 116. Chance is not to be understood here as "probability."

There are, in other words, objective phenomena which must be recognized before they can be utilized by man. The results of chance also presuppose the concurrence of qualitatively different phenomena each with its own characteristics, and functioning according to its own determined laws. It is only the simultaneity of definite factors which result in an explosion, the birth of a monster, or a devastating cyclone. Chance results are irrational precisely because they involve the meeting of qualitatively different phenomena, each acting according to its own laws.

The fundamental assumption in the Aristotelian conception of nature is that natural phenomena, that is, those arising from neither art nor chance, are intelligible; there is a regularity, a determined rationality about these phenomena which can be grasped. This must be the basic assumption of all science, for without it science itself is impossible.

When the great variety of " natural " phenomena has been classified scientifically, their individual characteristics and laws noted, we are still left with the question of their radical source, the ultimate accountability of all such phenomena. Even the action and reaction of various elements, the variation of circumstances, the intricate dependencies and interplay of everything from electrons to cosmic rays still leave the question of *source* unanswered. What is the source of any of this activity? It does not make much difference what name is applied The important thing is that we must in the last analysis acknowledge a certain *internal spontaneity* in all things from the smallest to the largest in the universe. When one considers, for example, the great variety of activities proper to chemical elements, electrons, and other physical bodies, the phenomena of illumination and ultra-violet rays, one can only say that they proceed automatically and spontaneously from the bodies themselves. There can be no other " source " for characteristic activities, except internal spontaneity. Obviously these phenomena are not the result of chance; this is precluded by a regularity and constancy which can even be measured. Nor can it be said that such movement is acquired from something else, for experience shows that even the transmission of activity depends essentially on the internal disposition and " willingness " of each body in view of its proper activity; thus not all bodies can be acted upon in the same way. Therefore, we must admit that in each physical reality there is something ultimately *given* in experience, which is none other than the spontaneous manifestation of its characteristics and proper activities. There is nothing " behind " this spontaneity, as far as the body is concerned; it is just "given" in experience. All the factors involved in the event must be considered, the circumstances of variation, intensity, prevention, and so forth, but in the last analysis there is the spontaneity " given," as from the body itself. Together with this spontaneity there are also certain receptivities for external influence, receptivities which are compatible with the spontaneous characteristics of each body. To both of these intrinsic sources, the spontaneous and the receptive, Aristotle gives the name *nature,* which he defines as " the principle of movement and rest in those things to which it belongs properly (per *se*) and not as concomitant attribute (per *accidens*)."[39]

Fundamentally this is Aristotle's procedure, but more specifically, he draws a comparison between natural and artificial bodies.[40] Natural bodies come into being through natural agencies; artificial bodies are produced by man. Moreover, the essential difference between them is that natural bodies *do* some-

" This definition (*Phys.,* II, c. 1, 192b21-3) is repeated, more or less complete, in various works of Aristotle: *Phys.,* Ill, c. 1, 200bl2-13; VIII, c. 3, 253b5-6; c. 4, 254bl6-17; *De Coelo,* I, c. 2, 268bl6; III, c. 2, 301bl7- 18; *De Anima,* II, c. 1, 412bl5-17; *De Gen. Animal.,* II, c. 1, 735a3-4; *Metaph.,* VI, c. 1, 1025b20-21; IX, c. 8, 1049b8-10; XII, c. 3, 1070a7-8; *Ethic. Nic.,* VI, c. 4, 1140a5-6; *Rhet.,* I, c. 10, 1369a35-bl.

[40] Arist., *Phys.* II, c. 1, 192b8-32.

thing: some grow and decay, others move and manifest activities, and so forth. But artificial compositions merely exist as an expression of an idea. Whatever " activity " there is about an artificial composition is the result, not of the artistic as such, but of the natural elements of which it is composed; or it is the result of calculated compulsion. For example, a painting falls to the ground, burns, or decays, not because it is a painting, but because of the materials of which it is made. Everyone realizes that the movement of a watch or mechanical doll does not come about spontaneously, but from a spring which is wound by the user. Therefore, Aristotle concludes that the difference between natural and artificial things is that natural things have within themselves an intrinsic source of movement and rest, " in virtue of itself and not in virtue of a concomitant attribute." [41]

For Aristotle, then, nature is this intrinsic source of characteristic movement. Things " have a nature " or are " natural " which have such a principle. He insists that, " each of them is a substance, for each is a subject; and nature always implies a subject in which it inheres." [42] Mansion notes that, " C'est l'expression du realisme peripateticien, qui veut accorder une realite aux principes abstraits, mais a condition de ne la recon- naitre que dans un substrat materiel dont ils sont separables

[41] Arist., *Phys.,* II, c. 1, 192b22-23.

[4a] *Ibid.,* 192b33-34. The punctuation here used is that of Hamelin (Aris- tote, *Physique* II, pp. 40-41) and Mansion (op. *cit.,* p. 100) which is suggested by the paraphrase of Themistius and Philoponus. This seems to be clearer than the usual reading given by Bekker, Didot, and Ross: " Each of them is a substance; for it is a subject, and nature always implies a subject in which it inheres" (Ross trans. *Basic Works,* p. 236). On the basis of this usual punctuation, also employed by William of Moerbeke, St. Thomas finds it necessary to give this interpretation: "Et talia sunt omnia subiecta naturae: quia natura est subiectum, secundum quod natura dicitur materia; et est in subiecto, secundum quod natura dicitur forma " *{In II Phys.,* 1, n. 6). But it seems that Aristotle does not have this in mind, for he has not yet shown that nature can be said of both matter and form; this he does in 193a9-21.

par la pensee seule." [43] In other words, Aristotle is insisting that if we wish to understand natural phenomena, we must admit an internal spontaneity (nature) within concrete bodies for their characteristic behavior. He is not appealing to an abstraction,[44] nor to anything outside the acting body. He is insisting that we see spontaneous activity and all we can say is that it *is* spontaneous; the source of characteristic spontaneity he calls " nature." Therefore he says, *that* such a reality exists is obvious, and it would be absurd to attempt any "proof." [45]

It has been shown that bodies in the universe manifest not only a certain " spontaneity " for characteristic behavior, but also certain " receptivities " for external influence. This leads Aristotle to point out that " nature " is used in two senses: as an *active* (spontaneous) principle and as a *passive* (receptive) principle.

In Book II of the *Physics* Aristotle is merely concerned with showing that the ancient use of *phusis* should be applied not only to the " matter " out of which things are made, but also, and more properly to the " form " of the thing itself. The ancients rightly attributed *phusis* to matter, but as they were unable to account for intrinsic change, " matter " for them meant the " substance " which was conceived as an *active* principle of behavior. Aristotle, relying on his doctrine of potency and act, insists that the true " matter " is antecedent to substance ; this " matter " is purely *passive,* being a pure potentiality for being (substance). Employing the analogy of art, he says, " We should not say that there is anything artistic about a thing, if it is a bed only potentially, not yet having the form of bed; nor should we call it a work of art." [48] Simi-

[48] A.. Mansion, *op. cit.,* p. 100.

** " Thus in the second sense of " nature " it would be the shape or form (not separable except in statement) of things which have in themselves a source of motion." Arist., *Phys.,* II, c. 1, 193b3-5.

" Arist., *Phys.,* II, c. 1, 193a2-8.

'e Arist., *Phys.,* II, c. 2, 193a33-35.

larly in natural products, "what is potentially flesh or bone has not yet its own 'nature,' and does not exist 'by nature,' until it receives the form specified in the definition, which we name in defining what flesh or bone is." [47] That is to say, nature as an *active* and spontaneous principle, which the ancients attributed to matter, properly applies to " form "; if the term is applied to " matter," it connotes passivity.

The scholastics developed to a considerable extent this twofold sense of nature as an active and as a passive principle. Nature as matter, or *natura secundum materiam* [48] signified not only the pure potentiality of the first matter, but all passivities of bodies which require a natural agent to actualize it. Nature as form, or *secundum principium formate,* signified the active and spontaneous source of all characteristic properties and behavior; ultimately this active principle was considered to be the " substantial form " which functions through active qualities.[48] Thus in scholastic terminology nature as "matter" is equivalent to *principium passivum*, *receptivum,* and *materiale*; while nature as " form " is equivalent to *principium activum,* or *formate.*[50] These two senses of " nature " in scholastic philosophy must be explained briefly.

[47] *Ibid.,* 193a36-b2.

[41] St. Thomas, *In II Phys.,* 1, n. 4.

*• Cf. St. Thomas, VII *Metaph.,* lect, 8, n. 1448; II *Sent.,* dist. 14, q. 1, a. 5 ad 2.

[80] The equivalence of *principium materiale* and *passivum* on the one hand, and *principium form ale* and *activum* on the other is very clear in St. Thomas: " Habet enim huiusmodi motus in mobili *principium,* non solum *materiale et receptivum,* sed etiam *formale et activum." (De Pot.,* V, 5) ; ". . . non est naturalis propter *activam inclinationem formalis prin- cipii* in corpore caelesti ad talem motum, sicut est in elementis " *(ibid.,* ad 12). "Non autem potest esse quod motus caelestis sequatur *formam* caelestis corporis sicut *principium activum* . . . sed solum *ratione principii passivi, quod est materia" (Sum. cont. Gent.,* Ill, 23). ". . . eonti'arietas motuum naturalium consequitur proprietatem *principiorum activorum sive formalium,* ad quae consequitur motus; non autem contrarietatem *principiorum passivorum sive materialium" (In De Coelo,* 16, n. 13; cf. Ill, 7, nn. 5-9). " Non enim oportet ad motum naturalem quod semper prin-

St. Thomas lays down the general principle that natural bodies have within them a principle of movement precisely to the extent to which they have motion: inasmuch as they spontaneously *move,* they have an " active " principle; and inasmuch as they must *be moved,* they have the " passive " principle, which is matter.[01] Experience alone can indicate whether bodies spontaneously act or are being acted upon by an external force.

I. Nature as Passive Principle

Some of the medieval writers, notably St. Albert, thought that " nature " always implies some *active* source, and that the term " natural " should be restricted to those phenomena which proceed more or less actively from the body. Since for St. Albert the movement of the heavens is caused by separated intelligences, such movement was not considered the work of nature, but of intelligence.[62] Even substantial change, according to him is " natural " in view of a certain incomplete active principle, an *inchoatio formae,* which assists the external agent.[63] St. Albert, however, does distinguish between " form "

cipium motus, quod est in mobili, sit *principium activum, et formale;* sed quandoque est *passivum et materiale" (In VII Met.,* 8, n. 1442z). This equivalence was also common to the 14th cent, scholastics, as Walter Burley testifies: " Primo quod cum dicitur quod naturalia inquantum huius- modi habent in Beipsis principium motus et status, ibi hoc nomen principium accipitur communiter *pro principio secundum materiam, idest, pro principio passivo,* et *pro principio motus secundum formam, idest, pro principio activo."* (Burlaei, *In Physicas Arist. Expositio et Quaestiones* (Venetiis 1501), Lib. II, fol. 36r col. 1.

" Et ideo dicendum est quod in rebus naturalibus eo modo est principium motus, quo eis motus convenit. Quibus ergo convenit movere, est in eis principium activum motus; quibus autem competit moveri, est in eis principium passivum, quod est materia " *In II Phys.,* 1, n. 4.

" St. Albert, *In II Phys.,* tr. I, cap. 2, (ed. Borgnet).

•* " Dicunt ergo quidam quod etiam in huiusmodi mutationibus [sub- stantialibus] principium activum motus est in eo quod movetur; non quidem perfectum, sed imperfectum, quod coadiuvat actionem exterioris agentis. Dicunt enim quod in materia est quaedam inchoatio formae, . . . et ab hoc principio intrinseco generationes corporum simplicium naturales dicuntur." St. Thomas, *In II Phys.,* 1, n. 3. The *quidam* here refers to St.

as the perfect active principle and " matter " as a passive potentiality, having only the beginning of form and requiring an external mover to actualize it fully.[5*]

St. Thomas, however, rejects the *inchoatio formae* as an impossibility.[55] He insists that for natural phenomena it is not necessary that all movement proceed from an active principle; natural receptivity itself is sufficient to render the motion " natural." [56] Consequently the celestial movements are natural because the heavenly bodies have a natural potentiality for being moved by spiritual beings. That is, if they are moved by intelligences, then it is natural to the celestial bodies to be moved.[57] And substantial generation is natural, because the pure potentiality of first matter is intrinsically capable of *being moved.*

Every body which is *acted upon* is in some sense passive, but this is not to be identified with " nature " as a passive principle. Three passivities must be distinguished: i)for compulsory movement; ii) for artistic formation; and iii) for natural production. A stone which is thrown into the air has a certain passivity for this motion, but as the motion itself is not natural,[58] neither is the potentiality. When an artist chooses his material, he must choose something suitable with which to work,

Albert and St. Bonaventure; cf. St. Albert, *In II Phys.,* tr. I, cap. 9; *Summa Theol.,* P. 2, tr. I, q. 4. *n.* 2, a. 1, p. 82; St. Bonaventure *(In II Sent.,* d. 18, a. 1, a. 3) ; and to Giles of Rome *(In Phys.,* II, lect.l, dub. 9).

[s'] Cf *In VIII Phys.,* tr. II, cap. 4. He defines the passivity of nature as " illud quod habet in se susceptivam et passivam potentiam recipiendi formam, sec. quam movet motor suus per inchoationem ipsius formae in ipso." *Ibid.*

[55] Cf. *In II Phys.,* 1, n. 3; *In VII Met.,* 8, n. 1442a-z.

[60] " Non enim oportet ad motum naturalem, quod semper principium motus, quod est in mobili, sit principium activum et formale; sed quan- doque est passivum et materiale." St. Thomas, *In VII Met.,* 8, n.l442z.

[57] " Et sic etiam motus localis corporum caelestium est naturalis, licet sit a motore separato, inquantum in ipso corpore caeli est potentia naturalis ad talem motum." St. Thomas, *In II Phys.,* 1, n. 4.

[58] This question will be taken up in a subsequent article: " Natural and Compulsory Movement."

as not all materials present the same possibilities. But since such potentialities are realized by art and not by nature, they are not properly called “ natural.” [58] In the strict sense, a “ natural ” potentiality is one which *intrinsically tends* toward perfect realization, and which can be actualized by a natural agent.[60] In other words, nature as a passive^ principle essentially implies an intrinsic *intentionality* of final realization, a receptivity which tends toward the *good* of the whole. That is to say, it implies first of all, the order of final causality. The actualization of a natural potentiality is not to be conceived as something superadded, like the addition of a number. Rather the potentiality itself intrinsically tends toward, aims at realization, just as the mind essentially tends toward knowledge. The scholastic philosophers called this an “ appetite ” and a “ desire ” for realization, which realization is its assimilation to being and perfection. Secondly, nature as a passive potentiality implies a capacity for realization by natural agencies, that is, agencies which are neither “ art ” nor “chance.” Nothing in the universe is isolated and self-sufficient; everything depends upon innumerable external factors for its coming into being and for its very survival. It is to these receptivities for external influence that the idea of nature as a passive principle applies.

All such passive potentialities, obviously, must be actualized by external agencies. It is in this sense that Aristotle expressed the well-known axiom, that “ whatever is moved is moved by something else.” [61] When Aristotle discusses the causes of mo-

E“ “ Et propter hoc factiones rerum artificialium non sunt naturales: quia licet principium materiale sit in eo quod fit, non tamen habet poten- tiam naturalem ad talem formam.” *Ibid.*

to “ Differentia tamen est inter materiam naturalium et artificialium: quia in materia rerum naturalium eat [1] *aptitudo naturalis ad formam,* et [2] *potest reduci in actum per agens naturale;* non autem hoc contingit in materia artificialium.” St. Thomas, *In VII Metaph., 8,* n. 1442z. (Italics mine.)

01 The point is that this axiom applies only to nature as a *passive* prin-

tion in Book VIII of the *Physics,*™ he considers three classes of movement: living, compulsory, and spontaneous. The movement of living things is easy enough to explain, for living things move themselves, as we can see; therefore, they are the cause of their own motion (254bl4-24). Compulsory motion is also easily accounted for, since it is derived from the agent which imparts compulsion, for example, the hoy who throws the ball (254b24-33). But the greatest difficulty is presented in explaining the *cause* of spontaneous movement. " It is in these cases that difficulty would be experienced in deciding whence the motion is derived, e. g., in the case of light and heavy things" (255al-2). Obviously such bodies do not move themselves, that is, they cannot be the cause of their own motion, for this is the prerogative of living things (255a5-19). But Aristotle shows that although inanimate bodies spontaneously manifest their proper activities unless an obstacle intervenes, they first have to be generated *(moved)* from potentiality. For example, hydrogen exists potentially in water and must be generated by some agency before it can manifest the characteristic behavior of hydrogen. Thus inasmuch as each natural reality was at one time not yet actually existing, it had to be brought into actual being by an external agent. Aristotle's explanation depends upon his theory of intrinsic change: substantial natures

ciple. Sometimes this phrase is interpreted as " Everything that is in motion must be moved by something else," in the sense that every motion here and now requires a mover for the preservation of movement. (Ross' trans. of 241b24).. Sir David Ross, among many others, interprets Aristotle as meaning all motion requires actual contact with the mover for the duration of the motion; cf. *Aristotle's Physics* (Oxford 1936), comm, on 266al0-ll (pp. 721-22), 266b27-267a20 (pp. 725-26). Philosophically there is no need for a constant physical mover to account for motion; nor is this what Aristotle himself intends to say, as will be explained. We are not here discussing nature "inquantum agit in virtute Dei" *(Sum. cont. Gent.,* Ill, 66; cf. 67). That is a different question altogether. St. Thomas acknowledges that, " non est contra rationem naturae [i. e., ut principium activum] quod motus naturalis sit a Deo sicut a primo movente." *Summa Theol.,* I-II, 6, 1 ad 3. [sa] *Phys.,* VIII, c. 4, 254bl4-256a2.

are generated (moved) from pure potentiality into the full reality of a substance by an adequate agency. When such bodies are generated (moved), they must be moved by something else. But once such natures are actually existing, they spontaneously, *statim* (*euthus*), manifest their characteristic behavior unless externally impeded. However, every formal nature still has innumerable secondary receptivities whereby it depends upon and is woven into the whole fabric of the universe. Even these receptivities, by which every body is " open " to the universe, require external influence to achieve fulfillment.

Briefly, then, nature as a passive principle involves two factors. It essentially implies intentionality of ends, which are necessary for the good of the whole being. And it presupposes natural agencies which can actualize it.

II. Nature as Active Principle

In the proper and strict sense of the term, " nature " signifies an active principle of spontaneous behavior. It is a matter of experience that each physical reality in the universe steadfastly insists on being itself; it behaves in a characteristic way and, in a sense, refuses to behave in any other way. In other words, every physical reality manifests determined properties and behavior; and it is through such characteristics that different realities can be recognized. This is the very foundation of physical science. The human intellect, however, has no direct or *a priori* knowledge of " essences " or " natures "; it must carefully examine the sensible characteristics and behavior of natural bodies in various settings.[63] Since no physical unit operates in a void, but always in an actual environment, the qualitative characteristics of the actual environment must be taken into consideration when accounting for the various natural phenomena, for even the same reality will act differently in

[63] " Natura enim uniuscuiusque rei ex eius operatione oatenditur." St Thomas, *Summa Theol.,* I, 76, 1; cf. *Sum. cont. Gent.,* Ill, 69.

different environments. However, neither the environment, nor the proximity of sociable or unsociable factors should be confused with the actual spontaneity the body manifests under those circumstances. There is always the danger of thinking that we have found the explanation of a natural phenomenon when we have merely discovered a secondary factor. Apart from the natural receptivities each body has for external influence, there remains the fundamental spontaneity by which the body acts in its own right, acts as itself.

Aristotle's definition of nature as a *principle* must be understood in the strict sense of a relative term.[64] That is to say, " nature " is not some complete entity within physical bodies which springs forth now and then in its performance. *It neither is, nor can be known as a complete entity.* Our knowledge of it involves the experience of sensible manifestations and the realization that certain characteristic manifestations are spontaneously " given " in reality. Indeed, " natures " exist only in the concrete, existing individual, so that our knowledge of nature in general or any particular nature involves the actual experience of innumerable individual phenomena; and in no way can our " concept " of nature be separated from these personal experiences.[66] " Unde," St. Thomas says, " deridendi sunt qui volentes definitionem Aristotelis corrigere, naturam per aliquid absolutum definire conati sunt, dicentes quod natura est *vis insita rebus,* vel aliquid huiusmodi." [86] John Philoponus, considering Aristotle's definition to be rather a description *per*

[e4] " Ponitur autem in definitione naturae *principium,* quasi genus, et non aliquid absolutum, quia nomen naturae importat habitudinem prin- cipii." St. Thomas, *In II Phys.,* 1, n. 5.

[*s] " De ratione autem huius naturae est quod in aliquo individuo existat, quod non est absque materia corporali; sicut de ratione naturae lapidis est quod sit in hoc lapide, et de ratione equi est quod sit in hoc equo, et sic de aliis. Unde natura lapidis, vel cuiuscumque materialis rei, cognosci non potest complete et vere, nisi secundum quod cognoscitur ut in particular! existens." St. Thomas, *Summa Theol.,* I, 84, 7.

[«•] *In II Phys.,* 1, n. 5.

effectum, thought it should be corrected to " life or a force radicated in bodies, forming and directing itself." [67] St. Albert[68] and Roger Bacon [09] also defined nature as a *vis insita rebus.* In the latter half of the 15th century Basil Valentinus, a Benedictine alchemist, introduced an *archaeus* into the known alchemical elements by which the ruler of the universe determined the phenomena of chemical changes; other alchemists introduced a " celestial virtue." [70] Even at the time of J. B. van Helmont (1577-1644) the *archaeus* continued to be invoked as the seminal efficient cause which accounted for the figure, motion, and so forth of chemical elements.[71] Aristotelians of the 17th century referred to " nature " as a *virtue* or as an *occult specific quality.*[12] While it is true that "nature " is a kind of force, or

[7] Ioannis Philoponi, *In Arist. Physicorum liiros tres priores.* (Comm. Graeca, XVI) (Berlin, 1887) Lib. II, cap. 1, p. 197: 33-35.

[8] St. Albert: " Est enim natura vis insita rebus naturalibus ex similibus secundum naturam similia procreans." *In II Phys.,* tr. I, cap. 7 (ed. Borgnet, t. Ill, 103b) ; also cap. 5, p. 101a.

[60] Roger Bacon, *Quaestiones supra libros Quatuor Physicorum,* Lib. II, q. 7 *(Opera Hactenus inedita,* fasc. VIII, ed. Delorme, [Oxford, 1938], pp. 58-9; q. 8, pp. 59-00; *et passim.)*

[70] W.. C. Dampier, *A History of Science,* 4th ed. (Cambridge, Eng., 1949), p. 114. Dampier *(loc. cit.)* erroneously refers to Basil Valentinus as a Dominican monk. There can be little doubt that he was a Benedictine monk of Erfurt. Cf. Sudhoff in *Die Deutsche Literatur des Mittelalters: Verfasserlexikon,* Bd. I (Berlin, 1933), pp. 176-7; Herman Kopp, *Die Alchemie in alterer und neuerer Zeit* (Heidelberg, 1882). The oldest known Ms. of Valentinus (Oxford, Ash. 1447) refers to him as " monachi Ger- mani," which would not be accurate if he were a Dominican Friar. Cf. *Catalogue of the Ashmolean Manuscripts,* 1447 (IX, 3) : " Medicina catho- lica Basilii Valentini monachi Germani, chymiatri summi, ab ipso lapis ignis vocata cum quibusdam aliis medicinis et experimentis."

[71] Cf. A. Crombie, *Augustine to Galileo* (London 1952), pp. 355-7. "The seminal efficient cause archaeus containeth the Types or Patterns of things to be done by itself, the figure, motion, houre, respects, inclinations, fitnesses, equalizings, proportions, alienation, defect, and whatsoever falls under the succession of dayes, as well as in the business of generation, as of government." J. B. van Helmont, *Oriatrike,* chap. 4, quoted by Dr. Crombie, *op. cit.,* p.. 356.

[73]Cf. I. Newton, *Opticks* (London, 1704), pp. 375-8; R. Boyle, *A Free inquiry into the received 'Notion of Nature, Works* (London, 1744), IV, 358-424.

power, this way of speaking too easily conveys the idea of a little imp contained within bodies, which accounts for the various phenomena. In a precise analysis of meaning it is more accurate to say that our concept of nature is a reflexive realization that certain phenomena are spontaneously " given " as from the body itself.

Prof. Collingwood describes Aristotle's nature as a world of self-moving, living things.[73] But this is to confuse the spontaneity of nature with the prerogative of living bodies. Aristotle himself was careful to point out the essential difference between living and non-living things.[74] The fundamental attribute of living things is that they *move themselves,* that is, they themselves are the *cause* of their own motion. The soul of living things is the sufficient mover, the *causa efficiens,* of such activities as flying, walking, swimming, digestion, reproduction, and growth. But there are other characteristics of each and every living body of which the soul is not the " mover," but merely the spontaneous source, for example, the color and size of the creature,[75] its position on the earth and its falling down,[70] the chemical processes of metabolism, and the throbbing of life itself.[77] In other words, when discussing the characteristics of living things, two aspects must be carefully distinguished: i) those characteristics which arise spontaneously from the very existence of the being, given the necessary environment; ii) those phenomena which are actively caused by it. Nature as an active principle is not the " mover," or the " efficient cause " of natural phenomena, but only the " given " spontaneous source which was begotten by some effective agency.

For St. Thomas the " formal principle " of every physical being is truly an *active* •*principle* of characteristic behavior, but

*• R. Collingwood, *Idea of Nature, op. cit.,* pp. 82-85.

T' Cf. Arist., *Phys.,* VIII, c. 4; *De Anima* I, c. 3, 5, etc.

" St. Thomas, *In II De Anima,* 8, n. 332.

St. Thomas, *In VIII Phys.,* 7, n. 3.

·T St. Thomas. *In De Motu Cordis,* n. 7-8, *Opuscula Omnia* (Paris, 1949), t. I, 67-68.

not the *motor* or *principium motivum.* The reason for this is obvious. If the essential characteristics of a living thing is *to move itself,* then self-movement cannot be the property of a non-living thing. That is, an inanimate being cannot be the cause of its own activity. In a very technical sense, the " efficient cause" (if one raises the question) of spontaneous phenomena is the agency which brought such a being into existence. In other words, whatever agency produces a physical body must also be acknowledged as the agency responsible for all the inseparable and spontaneous characteristics of that body. But physical bodies not only exist, they also manifest activity and movement. Therefore, St. TJ imas very frequently insists that " in heavy and light bodies i~.;ure is a formal principle of movement, for just as the other attributes follow upon substantial form, so too does place, and consequently motion toward place; not that the natural form is a mover, but the mover is the progenitor which produced such a form, upon which such motion follows." [78]

[78] In *II Phys.,* 1, n. 4 (text below) ; cf. *In I De Coelo,* 18, n. 1; II, 2, n. 6; III, 7, nn. 5-9; *In II Phys.,* 5, n. 5; IV, 12, n. 9; VIII, 8, nn. 5-7; *Bum. cont. Qent.,* Ill, 82, 84; *De Pot.,* V, a. 5.

The text of *In II Phys.,* 1. 1, n. 4 is given in all printed editions, including the Leonine, a9 follows:

" In corporibus vero gravibus et levibus est principium formale sui motus *(sed huiusmodi principium formale non potest did potentia activa, ad quam pertinet motus iste, sed comprehenditur sub potentia passiva: gravitas enim in terra non est principium ut moveat, sed magis ut moveatur)* : quia sicut alia accidentia consequuntur formam substantialem, ita et locus, et per consequens moveri ad locum: non tamen ita quod forma naturalis sit motor, sed motor est generans, quod dat talem formam, ad quam talis motus consequitur."

At first sight the phrase in parentheses seems to contradict the doctrine expounded in the text. The phrase in question actually disrupts the smooth flow of thought in St. Thomas' reasoning. The Leonine editors admit that the text in question is not to be found in any of the codices: " Haec omnia, quae parenthesi clausimus omittuntur a codicibus. Et revera non videntur necessario postulari a contextu, et iis omissis, ratio quae immediate ponitur, *quia sicut alia,* melius cohaeret cum praecedentibus, ad quae referri debet, nempe *In corporibus vero,* etc." (*Opera Omnia,* ed. Leonine, t. II, p. 56a, note a). This passage is really taken from St. Thomas' *Commentary on*

From this it is clear that Aristotle did not explain natural motion by the constant exerted efficiency of a mover, as is often thought.[79] Aristotle insists that " it is not the action of another body that makes one of these bodies move up and the other down; nor is it constraint, like the ' extrusion ' of some writers." [80] Commenting on this passage St. Thomas says there

the Metaphysics, 14 (n. 955), probably in answer to Scotus' position (cf. Venice ed. of St. Thomas' commentary, 1595, fol. 31a). In this passage St. Thomas is discussing the different senses of *potestas.* The first sense expresses a " principium motus et mutationis in alio inquantum est aliud," that is, an *efficient cause.* (Cf. also *In IX Met.,* 7). In Aristotelian terminology an efficient cause is frequently called *potentia activa;* as has been explained, " nature " is not an efficient cause, although it is an *active* and *formal principle.* A careful reading of the collated text of this passage of the *Commentary on the Metaphysics* will show the precise point St.. Thomas has in mind:

> "Est enim quoddam principium motus vel mutationis in eo quod muta- tur, ipsa scilicet materia vel aliquod principium formale, ad quod consequitur motus, sicut ad formam gravis vel levis sequitur motus sursum aut deorsum. Sed huiusmodi principium non potest dici potentia activa, ad quam pertinet motus iste. Omne enim quod movetur ab alio movetur. Neque aliquid movet seipsum nisi per partes, inquantum una pars eius movet aliam, ut probatur in 8 Phys. Natura igitur, secundum quod est principium motus in eo in quo est, non comprehenditur sub potentia activa, sed magis sub passiva. Gravitas enim in terra non est principium ut moveat, sed magis ut moveatur. Potentia igitur activa motus oportet quod sit in alio ab eo quod movetur, sicut aedificativa potestas non est in aedificato, sed magis in aedificante."

The meaning of the passage, then is that nature as a formal principle is not a *potentia activa* or *effectiva.* Therefore even the phrase inserted in the parentheses above does not contradict our exposition, for nature as a formal, or active principle is not an efficient cause..

The above text of the *Commentary on the Metaphysics* has been collated with the following MSS.: Brit. Museum, Add. 18,375; Vat. lat. 767;
\ at. lat. 768; Vat. lat. 769; Vat. Pal. lat. 1063; and Ms.. Leonina (s. xiv). Sincere gratitude is due to Father A. Dondaine, 0. P., for valuable aid in checking this passage as well as others in the course of our study.

7" P- Hoenen, *Cosmologia,* 4a ed. (Rome, 1949), p. 494; Liberatore, *Institutions Philosophicae, Cosmologia,* n. 99 (Prati, 1881), p. 95; H. Butterfield, *The Origins of Modern Science* (London, 1951), pp. 3-4; W. C. Dampier, *op. cit.,* p. 131; A. C. Crombie, *Augustine to Galileo* (London, 1952), p. 82.

80 Arist., *De Coelo,* I, c. 8, 277bl-2; the reference is to the Atomists,
Leucippus and Demoe-itus, who postulate the Vortex *(dine)* to account for motion.

are some who postulate a *per se* mover to account for the movement of bodies even after such bodies already exist; this Aristotle is denying, for light bodies are moved upward and heavy bodies downward by the progenitor inasmuch as it produced that type of body in the first place.[81] In a secondary sense whatever deflects the normal path of motion or whatever removes an obstacle to spontaneous movement can also be called an accidental cause of the movement.[82] The important point is that once a particular body is in existence, there is *no need* for an agent constantly acting upon it to account for its activity. The body itself *acts.*

Nor can the " form " be said to be the " mover accompanying the bodies which it moves." [83] For Aristotle as well as for St. Thomas the form is *not the mover,* but the *source* of necessary and spontaneous movement. Avicenna in his *Sufficientia* [81] and

*1 " Per quod quidem intelligendum est quod removet exteriorem motorem, qui per se huiusmodi corpora moveat postquam sunt formam specificam sortita. Moventur enim levia quidem sursum, gravia autem deorsum a generante quidem, inquantum dat eis formam quam consequitur talis motus; sed removente prohibens, per accidens et non per se. *Quidam vero posuerunt quod postquam speciem sunt adepta huiusmodi corpora indigent ab aliquo extrinseco moveri per se: quod hio Philosophus removet" In I De Coelo,* 18, n. 1 (italics mine).

•* Cf. *In VIII Phys.,* 8, n. 7: " sicut si sphaera, idest pila, repercutiatur a pariete, per accidens quidem mota est a pariete, non autem per se; sed a primo proiiciente per se mota est. Paries enim non dedit ei aliquem im- petum ad motum, sed proiiciens: per accidens autem fuit, quod dum a pariete impediretur ne secundum impetum ferretur, eodem impetu manente, in contrarium motum resilivit. Et similiter ille qui divellit columnam, non dat gravi superposito impetum vel inclinatonem ad hoc quod sit deorsum: hoc enim habuit a primo generante, quod dedit ei formam quam sequitur talis inclinatio. Sic igitur generans est per se movens gravia et levia, removens autem prohibens per accidens."

>! Hoenen, *Cosmologia, op. cit.,* pp. 497-502; Crombie, *Augustine to Galileo, op. cit.,* p. 82.

•* Cf. H. A. Wolfson, *Crescas' Critique of Aristotle* (text, trans. and commentary) (Cambridge, 1929), pp. 672-5; also Carra de Vaux, *Avicenne,* pp. 184-5. The late 14th century Jewish philosopher, Crescas, also follows the Arabian tradition, cf. *Critique (Or Adonai)*, ed. Wolfson, prop. XVII, pp. 296-9.

Algazel's paraphrase, *Maqacid el-falacifa,*[85] propound the theory that in natural movement the form is the mover of the body which it informs. In a certain sense Averroes too follows this opinion.[86] But the Aristotelian answer to this theory is obvious: if the natural form moves the body which it informs, then what is the difference between living and non-living things? For Aristotle and St. Thomas no such distinction can be drawn in non-living things between form as mover and body as moved, for each non-living thing is a single continuous whole, without parts; only by part moving part can the living organism exercise self-motion.[87]

Thus nature as an active principle differs both from life and from pure inertia; it partakes of the activity of living things inasmuch as natural bodies have within themselves an active source of spontaneous activity, and it partakes of the passivity of potentiality inasmuch as such activity is the result of having been brought into existence by some external agency. Because natural spontaneity is not to be confused with life, St. Thomas sometimes refers to nature as a *principium passivum.*[88] But in every one of these passages St. Thomas is merely insisting that this principle (nature) should not be considered as a *principium motivum* (*efficiens*), or *causa se movens.*

[85] *Algazel's Metaphysics,* ed, J. T. Muckle (Toronto, 1933), pp. 30-31; 99-102. Concerning the nature of the *Maq&cid,* cf. D. Salman, " Algazel et les Latins" in *Arch, d'hist. doctr. et litt. du M. A.,* X (1935), 103-127.

[86] Averroes, Phys., VIII, c. 4, comm. 29-32; theory proposed and refuted by St. Thomas, *In III De Coelo,* 7, nn. 8-9. See also Ernest A. Moody, "Galileo and Avempace," in *Journal of the History of Ideas,* XII (1951), 163-193, 375-422.

[87] Cf. Arist., Phys., VIII, c. 4, 255a5-19; St. Thomas, *In Till Phys.,* 7, nn. 6-8; *In VII Phys.,* 1, n. 2. The basic error of Avicenna is his conception of form as a *thing* in its own right, cf. St. Thomas, *Summa Theol.,* I, q. 110, a. 2; *Sum. cont. Gent.* Ill, c. 68; also P. Hoenen, *De Origine Formae Materialis* (Rome, 1932). In animate activity the whole subsistent being is responsible for the subsequent movement, which it accomplishes through the various organic parts. Since inanimate things have no organic parts, they cannot move themselves.

[88] St. Thomas, *In VIII Phys.,* 8, n. 7; *In I De Coelo,* 3, n. 4; II, 2, n. 6; 3, n. 2; III, 7, nn. 8-9.

The linguistic inadequacies of expressing both the natural spontaneity of physical bodies and the obvious fact that they are not living produced considerable confusion among later scholastics. Duns Scotus, following Avicenna, describes nature as an active principle which in a sense moves itself to activity.[89] Dominic de Soto (1494-1560) insists that in no sense can nature be called an " active principle " for this is the prerogative of living things.[90] By the 17th century John of St. Thomas (1589-1644) could refer to the " celebrated difficulty," whether natural bodies are moved by an intrinsic active or passive principle.[91] But the difficulty was more verbal than real. Even Dominic de Soto proposed the now common distinction among Thomists, that the nature of inanimate things is a *principium " quo "* of their activities, while the cause of the nature is the *principium " quod."*[92]

Nature is not only a source of activity, but also of rest *(eremein)* ,[93] This should not be understood as the mere absence of activity, but as the positive possession of fulfillment. In

" Joannis Scoti, *Comm, in II Sent.,* d. 2, q. 10.

[60] Dominici de Soto, *Super Octo Physicorum Quaestiones,* 2a ed., Salman- tice, 1551, super II, q. 1, fol. 31v-34r; cf. super VIII, q. 3, fol. 104r-v.

[91] Joannis a S. Thoma, *Cursus Philosophicus,* Phil. Nat., I P., q. IX, a. 2, ed. Reiser (Rome, 1933), t. II, p. 184b; q.. 23, a. 1, p. 461a.

" Mens igitur Aristotelis est quod principium naturalis motus elemen- torurn est duplex: aliud *quo,* et aliud *quod-,* principium *quo* principale est forma ipsa substantial is; minus autem principale et instrumental, est gravitas et levitas; principium autem *quod* est generans." Soto, *Quaest. super Till Phys.,* q. 3. *ed. cit.,* fol. 104r, col. 2; cf. J. a S. Thoma, *op. cit.,* q. 23, a. 1 ad 3; *ed. cit.,* p. 458a; C. Alamano, *Summa Philosophiae,* P. II, q. 34, a. 2 ad 4 (Paris, 1890).

·s Arist., *Phys.,* II, c. 1, 192b20. Some of the ancient commentators, notably Alexander and Porphyry (according to Simplicius, *Commentaria in Arist. de Physico,* [Venetiis, 1546] Lib. II, fol. 42v-43r), Simplicius himself *{ibid.),* and Philoponus *(In Physica,* ed. Vitelli, [Berlin, 1887] t. XVI, 198- 199) were more or less embarrassed with this part of Aristotle's definition, since there is no rest to celestial motions. But St. Thomas points out that Aristotle only wishes to say that " nature " is responsible for rest as well as for activity in those bodies which naturally come to rest. Cf. *In II Phys.,* 1, n. 5.

other words, all movement essentially implies the attainment of something; it necessarily implies some kind of aim to be attained.[94] This is not to say that absolute *rest* exists in the universe. Constant movement is an evident phenomenon of experience. But to every particular movement there corresponds some finality attained, even if it is only the self-preservation of the individual. Strictly speaking, movement for its own sake is inconceivable, for the very reality of movement consists in some " otherness " to be attained, some achievement through activity. Therefore " nature " cannot be the source of mere activity, but it must primarily aim at some achievement acquired through movement. In other words, just as all movement implies some " aim," the spontaneous source of movement necessarily has some aim in view.[05] As we shall see, it was this consideration which led the ancients to postulate celestial movers for the heavenly bodies which move locally without attaining any internal finality. The " rest " of which Aristotle speaks must be taken in the wide sense of the possession of fulfillment, whether of characteristic attributes or of internal finality acquired through activity. This internal finality and fulfillment may be described aptly by Whitehead's expression as " self-enjoyment."

•* If there were no aim whatever, the body could not move at all, for the aim is the reason for the movement. Since motion is not an end in itself, St. Thomas insists that " natura nunquam inclinat ad motum propter movere, sed propter aliquid determinatum quod ex motu consequitur." *De Pot., V, 5;* cf. *Sum cont. Gent.,* Ill, 23.

This is not to say that inanimate beings have consciousness or knowledge of their aim. While it is true that such terms as " aim," " desire," " appetite," " intentionality," etc. are primarily used in the context of human activity, the *analogical* use of these terms with regard to inanimate movement does not mean to imply consciousness of aim in the bodies themselves. However, this aim does imply a Supreme Intelligence which directs natural things. " Tendunt enim in finem sicut directa in finem a substantia intelligente, per modum quo sagitta tendit ad signum directa a sagittante." (St. Thomas, *Sum cont. Gent.,* Ill, 24). The scholastic terminology was commonly attacked in the 17th century by such men as Bacon, Boyle, etc. as the expression of animism and anthropomorphism; this was due to a misconception of *analogical usage—a* human necessity.

The Aristotelian conception of active nature is remarkably similar to Whitehead's description of nature as " life." [80] Whitehead is fully aware of the essential difference between animate and inanimate reality. However, he sees such a vast similarity that he considers the notion of " life," in the wide sense of the term, as the key to understanding the whole of reality. Against a background of a temporal advance and essential inter-connectedness of physical reality each unit manifests a similarity to organic life. This analogy consists in three aspects, which Whitehead terms " creative activity," " aim," and " self-enjoyment." [97] By creative activity is meant the spontaneous and novel production of an event, so that every being, in a sense, creates from within its own structure and activity. " It is the clutch at vivid immediacy " and the principle of novelty.[98] By " aim " Whitehead means " the exclusion of the boundless wealth of alternative potentiality, and the inclusion of that definite factor of novelty which constitutes the selected way of entertaining those data in that process of unification." [99] That is, every body intrinsically aims at a particular way of enjoyment, utilizing the environment for its proper fulfillment. Finally, " self-enjoyment " is the organic unity and self-identity of the individual " arising out of this process of appropriation." [100] Whitehead strongly objects to the lifeless and inert character of the Newtonian-Humean universe. He insists that " nature is full-blooded; real facts are happening." [101] Thus Whitehead has reintroduced into philosophy spontaneous activity and finality, the two essential elements in the Aristotelian conception of nature.

[86] Cf. *Modes of Thought,* Part III, " Nature and Life," pp. 173-232.

[87] *Ibid.,* p. 208.

[88] *Process and Reality,* p. 160.

[88] *Modes of Thought,* pp. 207-8.

[100] *Ibid.,* pp. 205-6.

[101] *Modes of Thought,* p. 197; see also pp. 173-201, and his *Science and the Modern World* (Cambridge, 1946), pp. 49-141.

Nature, then, as an active principle involves two essential factors. It is essentially a source of spontaneous activity and characteristics; conceptually it is the reflexive realization that certain characteristic manifestations of every physical body are spontaneously " given " in reality. And this implies an intrinsic finality, or aim, which is the fulfillment and " self-enjoyment " of the individual. Just as intentionality of purpose and passivity characterize the idea of nature as a passive principle, so intentionality and intrinsic spontaneity characterize the idea of nature as an active principle.

CHAPTER III

Natural and Compulsory Movement

THE CONCEPT of nature which has been expounded[1] necessarily implies a selection or determination of activities which are conducive to the well-being of the individual. Nature as an active principle is a spontaneous source of purposeful activities, determined characteristics which are for the fulfillment of the individual. Thus carbon does not act in the same way as, let us say, helium. Likewise the " natural " receptivities of any physical being are only those which are conducive to the well-being of the whole, as was explained. Thus if nature both as an active and as a passive principle has a determined " aim," that is, intrinsic intentionality of purpose, there necessarily follows a distinction between those activities within the ambit of intentionality and those which are not. That is to say, there necessarily follows a distinction between " natural " and non-natural activity. In this sense, " natural " activity would be any characteristic behavior spontaneously produced by the body in a particular environment, or at least one for which the body has a connatural receptivity in its favor. Conversely, non-natural activity would be all movements which are foisted upon it from without. These non-natural movements may be the result of chance, human control, or violent force. The essential characteristic of non-natural or compulsory movement is that there is no intrinsic intentionality of that activity on the part of the being itself.

Whenever the notion of " aim " is introduced, such a distinction between natural and non-natural activity necessarily follows. Thus, although A. N. Whitehead attacks the Aristotelian

[1] J. Weisheipl, " The Concept of Nature," in THE NEW SCHOLASTICISM XXVIII (1954), 377-408.

distinction as an unfortunate and hasty classification,[2] his own principles of philosophy demand this distinction. Whitehead maintains the essential self-identity of each individual reality in the universe and the self-identity of different types. He insists that each unit of reality, which spontaneously creates its activity, *aims* at producing its own individual and typical " self-enjoyment." By *aim* Whitehead explicitly acknowledges " the exclusion of the boundless wealth of alternative potentiality, and the inclusion of that definite factor of novelty which constitutes the selected way of entertaining those data in that process of unification." [3] That including of definite factors in the process of unification is what Aristotle calls " natural movement." Those potentialities which are intrinsically excluded, but which results from an external intrusion, are called nonnatural by Aristotle.

This distinction between natural and non-natural movement would have no meaning in a world of complete inertia, that is, in a world where intrinsic intentionality of purpose is excluded —really or philosophically. The relevance of this distinction lies properly in the order of final causality. When final causality is denied, the distinction ceases to have any meaning.

Pierre Duhem's monumental studies on the precursors of Galileo are designed to prove a thesis which has subsequently found favor among many historians of modern science. Duhem maintains that it was the overthrow of the Aristotelian distinction between natural and compulsory movement by means of the theory of impetus which led to the principle of inertia, the corner-stone of modern physics.[4] Anneliese Maier, however,

[3] " The greatest curse to the progress of science is a hasty classification based on trivialities. An example of what I mean is Aristotle's classification of motions into violent and natural." A. Whitehead, *Essays in Science and Philosophy* (London, 1948), pp. 174-5.

[3] A. Whitehead, *Modes of Thought* (Cambridge, Eng., 1938), pp. 207-8.

'P. Duhem, *etudes sur Leonard de Vinci*, 3 vols. (Paris, 1906, 1909, 1913); *Systeme du Monde,* 5 vols. (Paris, 1913-17); "Physics—History of," *Catholic Encyclopedia* (New York, 1911), XII, 47-67. Cf. also R. Dugas, maintains that Duhem has exaggerated the role of impetus and has partly misrepresented the historical problem.[5] In fact, Maier maintains that the theory of impetus is a natural development of Aristotelian doctrine, and that this theory is very different from the principle of inertia proposed in the 17th century.[6] Without delving into this vast subject, it is important to consider briefly the theory of impetus and the principle of inertia in order to see more clearly the significance of " natural " motion.

I. The Theory of Impetus

The problem of explaining the movement of projectiles and every " non-natural " motion inevitably arises in an attempt to maintain the reality of nature as a source of determined behavior. The difficulty is to explain the continuation of such motion after it has left the source of projection. If the upward movement of a stone is not due to the stone itself but to the hand which threw it, what is responsible for the continued movement after it has left the hand? The principle of sufficient reason demands that *something* be responsible. It is obvious that the

Histoire de la Micanique (Neuchatel, 1950), pp. 19-104; H. Butterfield, *The Origins of Modern Science* (London, 1951), pp. 1-14; P. Hoenen, *Cosmologia,* 4th ed. (Rome, 1949), pp. 482-508; E. Whittaker, *A History of the Theories of Aether and Electricity* (London, 1951), I, 1-6; R. Masi, " Nota sulla storia del principio d'inerzia," in *Rivista di Filosofia Neo- scolastica,* XL (1948), 121 ff.

[6] "Duhem hat in grossangelegten Untersuchungen, die freilich der Nach- priifung im einzelnen nicht immer standhalten, den Ursprung der Ge- schichte der Theorie verfolgt, und das Verdienst, als erster auf sie hinge- wiesen und sie herausgestellt zu haben, wird ihm immer bleiben. Aber in der Beurteilung ihrer Bedeutung ist er, wenn nicht zu einer uberschatzung, so doch mindestens zu einer falschen Einschatzung gekommen. Die scho- lastische Naturphilosophie stellt im Vergleich zu der physikalischen Vor- stellung der Neuzeit eine so heterogene Gedankenwelt dar, dass wir sie nur von ihren eigenen Voraussetzungen aus begreifen konnen." *Zwei Orund- probleme,* II Abschnitt: *Die Impetustheorie,* 2nd ed. (Rome, 1951), pp. 113-4.

[8] A. Maier, *op. cit.,* pp. 113-4; cf. *Die Vorldufer Oalileis im Ilf. Jahr- hundert* (Rome, 1949).

stone does not move itself upward, for this is a property of living things only. The stone does not move upward spontaneously, for this movement is contrary to its " nature." The hand which threw it does not continue the movement, for the stone is no longer in contact with the hand. Since something must be responsible for the continuation and none of these possibilities are admissible, the problem arises of finding the explanation.

Aristotle himself saw the difficulty, but his solution, which is subject to some misunderstanding, was later found to be erroneous. However, it is important not only to know precisely what Aristotle maintained, but also *why* he maintained it, for in this lies the validity of Aristotle's position.

Aristotle considers the problem in three brief passages; [7] and in all of these passages his insistence is that not even violent movement can take place unless the natural is presupposed. In Book VIII of the *Physics* Aristotle proposes the problem and suggests two solutions: that of Plato and his own. For Plato bodies have only one proper movement, namely motion to their proper place in the Receptacle. Even this movement is explained by the shape of the elementary bodies and the shaking of the Receptacle by the Soul.[8] All other movements take place by collision and mutual replacement, *avTLTrepicrTacrLs,* that is, the air or water pushed in front of the projectile gathers in behind it and so pushes it on.[9] Aristotle objects that in this explanation

[7] Arist., *Phys., IV,* c. 8, 215al-18; VIII, c. 10, 266b27-267a22; *De Coelo,* III, c. 2, 301bl7-33.

[8] Cf. Plato, Timaeus, 49 A-53 A; 57 B-58 C. See also P. Cornford, *Plato's Cosmology* (London, 1937).

[9] " And, indeed, with respect to all the motions of water, the falling of thunder, and the wonderful circumstances observed in the attraction of amber, and the Herculean stone,—in all these, no real attraction takes place at all; but as a vacuum can nowhere be found, the particles are mutually impelled by each other; hence, as they all individually, both in a separate and mingled state, have an attraction for their own proper place, it is by the mutual intermingling of these affections, that such admirable effects present themselves to the view of the accurate investigator." Plato, *Timaeus,* 80 C; cf. 59 A, 79 B, C, E.

only motion itself is conferred by the mover, in which case " all the things moved would have to be in motion simultaneously and also to have ceased simultaneously." [10] He insists that the only way to explain the continuation of movement in the projectile is to say that the mover gives not only motion but also a power of moving (δύναμις τοῦ κινεῖν 'γγίγνεται) to the " air or to water or to something else of the kind, naturally adapted for imparting and undergoing motion." [11] Movement is thus retarded when the motive force imparted decreases until finally " one part of the medium no longer causes the next to be a mover but only causes it to be in motion." [12]

In Book III of the *De Coelo* Aristotle shows why this power of moving must be given to the medium. Since projectile motion is " violent " and violence implies " a source of movement in something other than itself or in it *qua* other," [13] the source of such motion cannot be in the body itself. To attribute this motive force to the body would be to give it an internal principle, while violence is always from without. Furthermore, that external source of violent motion must be naturally adapted to producing the motion, otherwise the same problem arises as with the projectile itself. But air and water, according to Aristotle's doctrine, are naturally both " heavy and light," depending upon the actual environment. Thus the motive power can be given to the medium; the air " *qua* light produces upward motion, being propelled and set in motion by the force."[14] Therefore, in Aristotle's view, the upward movement of the projectile is possible, because the medium is naturally endowed with this function of upward and downward motion; and he insists that "if the air were not endowed with this function, constrained movement would be impossible." [15]

[10] Arist., *Phys.* 266b34-267a2.
[xl]*Ibid.,* 267a4-5; see 267a8-9.
[12] *Ibid.,* 267a9-10.
[13] *De Coelo,* III, c. 2, 301M8-19.
[14] *Ibid.,* 301b24-25.
[1E] *Ibid.,* 301b29-30.

This same idea lies behind the passage in Book IV of the *Physics*.[16] He argues against the existence of a void by insisting that violent motion cannot arise from a source internal to the projectile, but must be caused by an external medium. Since in a void there is no medium, Aristotle concludes that even violent motion would be impossible if actual space were a void.

The important point to notice is that Aristotle appeals to air to explain projectile motion, not because all movement must be *ab alio,* but because such movement is " violent," and *therefore* must be from an extrinsic source. Aristotle defines violent movement as " that whose moving principle is outside, the thing compelled contributing nothing." [17] This is the fundamental reason for appealing to an external source, such as the air. It is this idea of an " extrinsic," " non-natural " source which lies behind the scholastic development of impetus.

The Christian scholar, John Philoponus of Alexandria (6th century), seems to have been the first to show that the medium cannot be the cause of projectile motion.[18] If it is really the air which carries the stone or the arrow along, as Aristotle claims, then why must the hand touch the stone at all, or why must the arrow be fitted to the bow string? One can beat the air violently and still not move the stone. Furthermore, a heavier stone can be thrown farther than a very light one, but if air is the cause of this motion, a very light stone should obviously travel farther. Then, too, why is motion deflected when two bodies collide and not when they merely pass each other? In fact, Philoponus points out, the air—and every medium—offers resistance to motion, so that instead of being a cause, it is rather an obstacle. Therefore, he concludes that violent motion cannot be explained by the Aristotelian theory. " On the con-

™*Phys.,* IV, c. 8, 215al3-18.

[17] Arist., *Eth. Nic.,* Ill, c. 1, lllOblo; cf. 1110a2; *De Coelo,* III, c. 2, 301bl8-19.

[13] Ioannis Philoponi, *In Arist. Physicorum libros quinque posteriores commentaria,* ed. Vitelli, *Commentaria Graeca,* XVII (Berlin, 1888), Lib. IV, cap. 8, pp. 336-642,

trary, it is necessary that a certain incorporeal motive power (κινητικήν τινὰ δύναμιν ἀσώματον) be given to the projectile through the act of throwing." In other words, Philoponus insists that it is not to the medium that the thrower gives the motive power but to the projectile itself. This, Duhem says, is the language of " common sense." [19] However, Philoponus points out that this motive " energy " (ἐνέργεια) is only borrowed and is decreased by the natural tendencies of the body and the resistance of the medium.

Unfortunately, Simplicius (d. 549) did not bother to present Philoponus' position clearly, but in two of his " Digressiones contra Ioannem Grammaticum," [20] he attacks the denial of what he thinks to be the fundamental principle involved, namely, the denial of " whatever is moved must be moved by something else in contact with it." He himself develops a peculiar theory whereby the projectile and the medium alternately act upon one another until the *vis motrix* is exhausted. He confesses that he is insisting upon this for two reasons: whatever is moved must be moved by something else, and the two must be in contact.[21] Medieval knowledge of Philoponus was largely limited to the report of Simplicius.

It is not clear what influence, if any, Philoponus' theory had on the formation of the scholastic notion of impetus. Duhem believes that it came through the *Theorica Planetarum* of the Spanish-Arabian astronomer, Alpetragius (A1 Bitruji),[22] which work was translated into Latin by Michael Scot in 1217.[23]

[18] P. Duhem, *Le Systeme du Monde,* I, 383.

[20] After VIII *Phys.,* comm. 8 and comm. 12, Simplicii *Commentaria in octo Libros Physicorum* (Venice, 1546), 2a pars, fol. 51v-54v; fol. 57v-59r.

[21] *Ibid.,* fol. 91r a.

[22] Duhem, *fitudes sur Leonard de Vinci,* II, 191 ff.; Ill, 23; also R. Dugas, *Eistoire de la M4canique,* ed. cit., p. 47. The title, *Theorica Planetarum,* was given to this work by Calonymos ben David whose translation from the Hebrew was printed in Venice in 1531, fol. 277-303. Today the work is more correctly known as *De Motibus Celorum.*

[23] Cf. C. Haskins, *Studies in the History of Mediaeval Science,* 2nd ed. (Cambridge. .Mass., 1027), pp. 272-298. A critical edition of the Latin

But Maier has shown that Duhem quotes from the printed edition of 1531 in which the theory of Philoponus is very clear, but the Scot translation of the pertinent passage has no connotation whatever of an impetus theory.[24] Pines, discussing the Arabic theories of impetus, suggests that it may have been through Avicenna's commentary on the *Physics.*[25] But the Latin version, known as the *Sufficientia,* contained only the first four books, and the single vague reference in Book II, chapter 8, can be understood in an Aristotelian sense.[26] Maier believes that the scholastics developed the theory independently, mainly through their discussions of instrumental causality in the sacraments and reproduction.[27]

Although the Aristotelian theory was generally accepted in the thirteenth century, the reason for accepting it is clear: violent motion cannot be accounted for by an internal, innate source.[28] St. Thomas, discussing reproduction, points out the essential difference between natural and non-natural motive forces: " virtus quae est in semine a patre, est *virtus permanens ab intrinseco, non influens ab extrinseco,* sicut virtus moventis quae est in proiectis."[20] Since violent motion is always alien

translation of Michael Scot has been edited by F. Carmody, *De Motibus Celorum* (Berkeley, 1952).

[24] A. Maier, *Zwei Grundprobleme,* pp. 127-129. See Scot's trans. VIII, 11, ed. Carmody, p. 93.

[25] S. Pines, " Les precurseurs musulmans de la th^orie de l'impetus," *Archeion* XXI (1938), 298 ff.

[20] Cf. A. Maier, *Zwei Grundprobleme,* pp. 129-133.

[21] *Ibid.,* pp. 133-34.

[28] Cf. St. Albert, *In Phys.,* VIII, tr. IV, cap. 4; *In Phys.,* IV, tr. II, cap. 5; *In De Coelo,* III, tr. I, cap. 7; St. Bonaventure, II *Sent.,* dist. 31, a. 1, q. 1; Roger Bacon, *Quaestiones super libros Physicorum,* Lib. VII, ed. Delorme (*Opera hactenus inedita,* fasc. XIII [Oxford, 1935]), pp. 338-347. "Non est autem intelligendum quod virtus violenti motoris imprimat lapidi qui per violentiam movetur, aliquam virtutem per quam moveatur, sicut virtus generantis imprimit genito formam, quam conse- quitur motus naturalis: *nam sic motus violentus esset a principio intrinseco, quod est contra rationem motus violenti."* St. Thomas, *In III I>e Coelo,* lect. 7, n. G (emphasis mine).

[29] *De Anima,* 11 ad 2.

and borrowed, it lasts only as long as the force remains, being resisted by the natural forces of the body.[30]

The scholastic theory of impetus seems to have been first suggested by the Franciscan, Franciscus de Marchia. While discussing sacramental causality, he raises the question of impetus, in order to show that both the sacraments and the projectile have a certain force resident within by which something is produced.[31] After a long and careful discussion of the Aristotelian theory, he concludes that projectile motion cannot be explained by the air, but must be explained by a *virtus derelicta in lapide a motore*.[32] However, he is careful to point out that this force is not permanent or innate; it is rather an " accidental and extrinsic force," a " certain extrinsic form." [83] Therefore, this accidental force is alien and repugnant to the natural inclination of the body; it is, indeed, a "violent" and nonnatural source of movement.[34]

[80] " Instrumentum intelligitur moveri a principali agente, quamdiu retinet virtutem a principali agente impressam; unde sagitta tamdiu movetur a proiciente, quamdiu manet vis impulsus proicientis." St. Thomas, *De Pot.,* Ill, 11 ad 5; cf. *Sum. cont. Gent.,* Ill, c. 24: " Sicut enim sagitta consequitur inclinationem ad finem determinatum ex impulsione sagittantis, ita corpora naturalia consequuntur inclinationem in fines na- turales ex moventibus naturalibus, ex quibus sortiuntur suas formas et virtutes et motus." A. Rozwadowski, basing himself on the last three cited texts *(De Anima,* 11 ad 2; *De Pot.,* Ill, 11 ad 5; *Sum. con. Gent.,* Ill, c. 24), tries to show that St. Thomas held the theory of impetus in the same sense in which it was later expounded by Jean Buridan and his school. Cf. " De motus localis causa proxima secundum principia S. Thomae," *Divus Thomas* (Piacenza), XLII (1939) 104-113. Duhem thinks that in these passages St. Thomas is using a popularly expressed similarity. Father M.-D. Chenu rejects Rozwadowski's thesis as a forced reading. Cf. " Aux Origines de la Science Moderne," in *Revue des Sc. Phil, et Theol.,* XXIX (1940), 217, note. A careful consideration of the above-quoted texts will show that they are all perfectly consistent with the Aristotelian theory, and there is no reason to suppose that St. Thomas held the impetus theory which was developed later. However, the theory of impetus is a clear development of his principles.

[31] Text edited from the MSS by Maier, *Zwei Grundprobleme,* pp. 166-180.

[8!] *Ibid.,* line 305, p. 174.

[83] Cf. *ibid.,* lines 313-359, pp. 175-6.

[81] " Movens enim sive agens non confert ipsi mobili passo vim [sive]

Jean Buridan, twice Rector of the University of Paris between 1328 and 1340, reached the same conclusions, but it is most probable that he did so independently of Marchia's teaching. In his *Quaestiones super octo libros Physicorum*[35] and in his *Quaestiones de Caelo et Mundo*,[se] he considers the Platonic and Aristotelian theories of projectile motion, but both seem to offer great difficulty. He points out that the Aristotelian theory cannot account for the rotational movement of a grindstone or a disk, for the motion continues even when a covering is placed close to the bodies, thus cutting off the air. Furthermore, a stone can be thrown farther than a pebble, while violent beating of the air will not move the stone. Therefore, he concludes that the mover must impress a certain *impetus* upon the body itself by which it continues to move until overcome by the resistance of the air and natural gravity.[37] And like Marchia he insists that the impetus is "sibi [corpori] violentus et innaturalis, quia suae naturae formali disconveniens et a principio ex- trinseco violenter impressus, et quod natura ipsius gravis incli- nat ad motum oppositum et ad corruptionem ipsius impetus."[38]

perfectionem aliquam naturalem sive [sibi?] intrinsecam, nec etiam confert vim sive perfectionem aliquam accidentalem et extrinsecam sibi convenien- tem, sed magis dispositionem sibi convenientem auferre, dando enim quod sibi disconveniens est et contra eius naturalem inclinationem aufert quod conveniens est." *Ibid.,* lines 336-343.

[86] Paris 1509, Lib VIII, q. 12; this question about which we are concerned was critically edited by Maier, *op. cit.,* pp. 207-214.

[88]Edited by Ernest A. Moody (Cambridge, Mass.), 1942, Lib. II, q. 12-13, pp. 176-184; Lib. Ill, q. 2, pp. 240-3.

[87] " Ideo videtur mihi dicendum, quod motor movendo mobile imprimit sibi quendam impetum vel quandam vim motivam illius mobilis ad illam partem ad quam motor movebat ipsum, sive sursum sive deorsum sive lateraliter vel circulariter, et quanto motor movet illud mobile velocius tanto imprimet ei fortiorem impetus . . . Sed per aerem resistentem et per gravitatem lapidis inclinantem ad contrarium eius ad quod impetus est natus movere, ille impetus continue remittitur." *Ibid.,* lines 124-132, p. 211; cf. *Quaestiones de Caelo et Mundo,* lib. II, q. 13, line 34 (p. 183) — line 7 (p. 184) ; Lib. Ill, q. 2, line 18-39 (p. 243).

[38] *Quaest. sup. oct. lib. Physicorum,* Lib. VIII, q. 12, ed. Maier, *op. cit.,* lines 198-202.

Albert of Saxony and Marsilius of Inghen likewise teach that a certain force is given to the body by which it moves, but they insist that this "accidental and extrinsic force" is violent and therefore continually decreases until finally it is destroyed.[39] This became the common "Aristotelian" teaching throughout the 15th and 16th centuries. Since the theory of impetus is actually consistent with the principles of Aristotle, later scholastics such as Laurence Londorius, the first Rector of St. Andrew's, Augustine Nipho, Cardinal Cajetan, Alexander Pic- colominus, and Scaliger interpreted Aristotle's words in a wide sense consistent with the theory. Thomists such as Capreolus and Dominic de Soto claimed it as the " opinion of St. Thomas."[40] Some writers of the 16th century, however, conceived the impetus as a *mover.*[41] Against such a conception Dominic de Soto argues that the impetus cannot be a *mover,* the *efficient cause* of violent motion, for this would be to conceive the body as living. Rather it is the *instrument* of the agent who is the efficient cause.[42] He points out the analogy between impetus and nature, for just as the "cause" of natural activity is the progenitor and not " nature," so too the " cause " of violent motion is the agent and not the " impetus." [43] Thus

[30] Cf. Marsilius of Inghen: " Et si quaeras quare impetus sic ultra non sufficit movere, respondetur quod hoc est, quia est violentus corporibus motis, quae ipsum continue remittuntur et tandem corrumpunt." Text ed. Maier, lines 141-3, p. 283.

[40] Capreoli, *Defensiones Theologiae D. Thomae,* Sent. II, dist. 6, q. 1, a. 3; Dominici de Soto, *Super octo libros Physicorum Quaestiones* (Salamanca, 1551), Lib. VIII, q. 3, fol. 103vff.

[41] E. g., Girolamo Cardano: " Cum supponitur quod omne quod movetur ab alio movetur, verissimum est. Sed illud quod movet est impetus ac- quisitus, sicut calor in aqua, qui est ibi praeter naturam ab igne inductus et tamen igne sublato manum tangentis exurit." *De subtilitate rerum,* Lib. XXI (Lyon, 1551), p. 90.

[42] " Impetus ergo quia non est suppositum, non agit, sed est virtus agentis, puta motoris." Dominici de Soto, *op. cit.,* fol. 104v-105r.

[43] " . . . pro coperto reliquisse ex analogia gravium et levium, quae est prima ratio affirmandi huiusmodi impetum. Nempe quod sicut generans grave tribuit illi naturalem qualitatem, quae est gravitas, qua illud per- movet usque ad centrum, sic et proiciens impingat proiecto quo ipsum

impetus is a foreign and borrowed quality which automatically acts without being a "mover," a quality which necessarily diminishes due to the opposing natural forces.

From this it is clear that the theory of impetus is strictly an Aristotelian development. Not only was it developed within the framework of Aristotelianism, but it follows from Aristotle's principles and is consistent with experience. It safeguards the distinction between natural and compulsory motion, for the impetus always remains an alien and extrinsic quality, even though foisted upon the projectile, while nature is a permanent and radical source of characteristic behavior. Furthermore, the theory embodies the principle of finality, for nature intrinsically strives towards its own fulfillment and, therefore, strives to overcome the alien force; the only finality involved in impetus is that which is given by the extrinsic source of projection. This is very different from the principle of inertia, which not only eliminates the distinction between natural and compulsory motion but destroys the notion of finality as well.

II. THE PRINCIPLE OF INERTIA

During the 16th century a new philosophical spirit emerged, anti-Aristotelian in character. This spirit seems to have originated among logicians who wished to replace traditional logic with mathematics.[44] But with Cardano, Benedetti, Telesio, Bruno, and Galileo, this spirit appeared in natural philosophy as well. Particularly in questions of projectile motion the new .scientists took occasion to attack Aristotle.[45] In their minds the

eminus moveat." *Ibid.,* fol. 104v. See our previous article, " The Concept of Nature," in THE NEW SCHOLASTICISM, *art. cit.*

"Although there were earlier works of this nature, Peter Ramus (1515- 1572) exercised the most noticeable influence, mainly through his *Dia- lecticae Institutiones.* His best known followers were Sturm in Germany, Arminius in Holland, du Naniel in Belgium, and Temple in England.

[45] Cf. Bernardino Telesio, *De rerum natura iuxta propria principia,* 2nd ed. (Naples, 1570), Lib. I, cap. 46, fol. 32v; Giordano Bruno, *Camoeracensis Acrotismus, seu Rationes articulorum adversus Peripateticos Parisiis pro*

scholastic theory of impetus was conceived in a *quantitative* manner; and it is this new theory which has become known as the principle of inertia.[46]

Giovanni Benedetti (1530-90) had already insisted that every body, naturally falling or projected, tends to move in a straight line. But it was Galileo (1564-1642) who first formulated the principle of inertia. In his *Discourses on the Two New Sciences,* the third day, he assumes that the momentum of a given body falling down an inclined plane is proportional only to the vertical distance and independent of the inclination; from this he concludes that a body falling down one plane would acquire momentum which would carry it up another to the same height. The fact that the descent and ascent of a pendulum are exactly equal regardless of the length of the cord and of the weight of the bob are adduced to confirm his view.[47] The momentum of a falling body is accelerated by gravity; it is retarded and eventually overcome by an equal gravity. But if a body moved along a horizontal plane where all causes of acceleration or retardation were absent, its motion would be perpetual and uniform. Thus Galileo says, " Any velocity once received by a body is perpetually maintained as long as the external causes of acceleration or retardation are removed, a condition which is found only on horizontal planes."[48] On the fourth day Gali-

positorum, Opera Omnia Latina (Naples, 1879), I, 138. Even in his youthful work *De Motu* (c. 1590) Galileo begins the chapter on projectiles as follows: " Aristoteles, sicut fere in omnibus quae de motu locali scripsit, in hac etiam quaestione vero contrarium scripsit." Ed. Nazionale, *Opera Omnia,* I, 307.

[48] Cf. A. Maier, *op. cit.,* 303-314; also *Die Vorldufer Galileis in l'f. Jahr- hundert, ed. cit.,* 132-154.

[47] Cf. Galileo, *Discorsi e Dimostrazioni Mathematiche intorno a Due Nuove Scienze attenenti alia Meccanica, et ai Movimenti Locali,* Giornata Terza, *Opere di Galileo Galilei* (Padua, 1744), III, 96.

[48] ". . . velocitas gradus, quicunque in mobili reperiatur, est in illo suapte natura indelebiter impressus, dum externae causae accelerationis, aut retardationis tollantur, quod in solo horizontali piano contingit . . . Ex quo pariter sequitur, motus in solo horizontali esse quoque eternum: si enim est aequabilis, non debilitatur, aut remittitur, et multo minus

leo considers the movement of projectiles. He imagines a perfectly round body projected along a horizontal plane where all adverse forces are removed. He concludes that according to his previous arguments the velocity of the projectile would remain uniform and perpetual if the plane were extended to infinity.[49] Thus the *impeto* as such is a uniform velocity in a straight line wThich is accelerated or retarded only by extrinsic forces; were it not for these forces, the velocity would remain constant perpetually.

For Galileo the *impeto,* or *momento* is not a quality by which motion takes place, as was held by the scholastics, but the *quantity of motion* measured by the mass times the velocity (*mv*). Rather than an alien source of violent motion, it is the measure of all motion. By considering only the quantitative aspect of motion he reduces both “ natural ” and “ violent ” motion to the same category of impetus so that the distinction ceases to have meaning. The important point to notice is that Galileo is not concerned with explaining the existence of motion, but only with the *change* or cessation of motion. For him it is not the continuation of motion which needs to be explained but change of direction and velocity. Motion which does not involve change of direction or velocity is thus called “inertial motion”; and the resistance to this change is commonly called the “ force ” of inertia.

About the same time Isaac Beeckman, the close friend of Descartes, expressed the principle of inertia clearly when he wrote in his *Journal,* “ A thing once moved would not come to rest but for some external impediment.”[50] Christian Huygens

tollitur.” *Discorsi,* Giornata Terza, prob. IX, prop. 23, Scholium, *ed. cit.,* p. 123.

“““Mobile quoddam super planum horizontale projeetum mente concipio omni secluso impedimento: iam constat ex his, quae fusius alibi dicta sunt, illius motum aequabilem, et perpetuum super ipso piano futurum esse, si planum in infinitum extendatur.” *Ibid.,* Ill, 141.

[50] “ Omnis res semel mota nunquam quiescit nisi propter externum impedimentum.” quoted by Maier, *Zwei Grundprobleme, ed. cit.,* p. 311.

had a clearer idea of the principle and formulated it as an " hypothesis " for his work on the pendulum.[51] Descartes (1596-1650), however, extended the principle to cover the whole of natural philosophy by making it " the first law of nature." [52] The principle of inertia reached its classical formulation in Isaac Newton's *Principia*: "Every body continues in its state of rest or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it." [53]

The principle of inertia is, indeed, as Whitehead calls it, " the first article of the creed of science." [54] But the numerous and varied studies, criticisms, and justifications of this principle show that its meaning is not as clear as one might hope.[55] Einstein's criticism of the Newtonian formulation and the "unification of inertia and gravitation" in relativity physics have obscured even more the meaning of the principle.[56] It is clear that the Galilean and Newtonian theory established an entirely new outlook on nature, but as Whitehead points out, " it is noticeable that no reason was produced in the 17th cen

[61] " Si gravitas non esaet, neque aer motui corporum officeret, unum- quodque eorum, acceptum semel motum continuaturum velocitate aequabili, secundum lineam rectam." *Horologium Oscillatorium,* Part II, Hypothesis, Paris 1693.

[62] " Prima lex naturae: quod unaquaque res quantum in se est, semper in eodem statu perseveret; sicque quod semel movetur, semper moveri pergat." *Principia Philosophiae* (1644), P. II, art. 37, *Oeuvres,* ed. Adam- Tannery, VIII, 62.

[58] " Corpus omne perseverare in statu suo quiescendi vel movendi uni- formiter in directum, nisi quatenus illud a viribus impressis cogitur statum suum mutare." *Philosophiae Naturalis Principia Uathematica,* Law I. The first ed. of this work was printed in London 1687; modern English trans. of the 2nd ed., F. Cajori (Berkeley, 1947). For the background of Newton's 2nd ed., *ibid.,* pp. 628-632.

[54] *Essays in Science and Philosophy* (London, 1948), p. 171.

[55] Cf. G. Whitrow, " On the Foundations of Dynamics," *British J. for the Phil, of Sc.,* I (1950), 92 ff.; R. J. Nogar, "Toward a Physical Theory," The New Scholasticism, XXV (1951), 397-438.

[56] Cf. A. S. Eddington, *Space, Time, and Gravitation* (Cambridge, 1920), pp. 136-151; *The Nature of the Physical World* (London, 1947), pp. 115-139.

tury for the Galilean as distinct from the Aristotelian position." [57] Since the principle of inertia played such an important role, it is necessary to consider not only its relation to Aristotelian natural philosophy, but also the meaning and logical foundation of the principle.

It is clear that the doctrine of inertia had its rise in the science of mechanics. Mechanics in its proper sense is a practical science of determining the amount of force to be applied in order to produce a certain effect. This is clear in such elementary problems as the lever, equilibrium, displacement, and so forth, in which the resistance afforded by a body is taken into aucount (force of inertia) or the irrelevant state of a body is disregarded (principle of inertia).[58] In this sense the principle was not first discovered by Galileo, but was already recognized by Stevinus, Da Vinci, and Archimedes. However, it is one thing to justify the principle in mechanics, and quite another to establish it as " the first law of nature."

FOUNDATION OF THE PRINCIPLE

What is the logical foundation for the principle of inertia? Is it self-evident that every body continues in its state of rest, or of uniform motion in a straight line, except so far as it may be compelled by force to change that state? Usually the proposition is stated as immediately evident. It is pointed out that a block of wood thrown along a rough road slides only a short distance, along a floor a longer distance, and along ice still farther. "From examples like these, it is reasoned that if friction could be eliminated entirely, which cannot actually be done, a body once set into motion on a level surface would continue to move indefinitely with undiminished velocity; thus uniform motion is a natural condition." [59] But such reasoning

[57] *Science and the Modern World* (Cambridge, 1946), p. 60.

[58] This point is explained at length below, pp. 56 ff.

[68] *Physics,* E. Hausmann and E. P. Slack, 3rd ed. (New York, 1948). " Intuitively, also we recognize that were it not for disturbing and ex-

neither proves the proposition nor manifests its self-evidence. The fact that a body continues longer over a smoother surface does not prove that, were the surface infinitely smooth, it would continue indefinitely.[60] Nor is this self-evident. It assumes that the body itself is a null factor and that external factors can be excluded to render the motion uniform. In actual experience there is no manifestation of the first assumption, for in all evident phenomena such motion is resisted, and this resistance is relative to the body.[61] In other words, actual experience is against such an assumption. Relativity physics denies the second assumption, for bodies are always in a gravitational field— and indeed, constitute it; thus the motion would not be uniform, but accelerated.[62] It seems clear, then, that the usual examples

traneous forces, especially friction, this constant speed in a straight line might be maintained forever." H. B. Lemon, *From Galileo to the Nuclear Age* (Chicago, 1946), p. 6.

[0] This argument by extrusion can be answered on experimental grounds. Increasing the smoothness of two surfaces in contact does not reduce their friction indefinitely, for a point is reached where further polishing increases the friction. Cf. Fred. Palmer, " Friction," *Scientific American,* CLXXXIV (1951), 54-59.

[61] Jean Buridan suggested that since the heavenly bodies do not offer resistance (an Aristotelian doctrine, cf. *De Coelo,* II, c. 1, 283b26-284a25), the original impetus given to them by God would be sufficient to keep them moving forever. " Posset dici quod non apparet necessitas ponendi huiusmodi intelligentias, quia diceretur quod Deus quando creavit mun- dum, unumquemque orbium caelestium movit sicut sibi placuit et movendo eos impressit sibi impetus moventes eos absque hoc quod amplius moveret eos, nisi per modum generalis influentiae, sicut ipse concurrit coagendo ad omnia quae aguntur. . . . Et illi impetus impressi corporibus caelestibus non postea remittebantur vel corrumpebantur, quia non erat inclinatio corporum caelestium ad alios motus, nec erat resistentia quae esset cor- ruptiva vel repressiva illius impetus. Sed hoc non dico assertive, sed ut a dominis theologis petam quod in illis doceant me, quomodo possunt haec fieri." *QQ. in Till Physicorum,* q. 12, ed. Maier in *Zioei Grundprobleme,* lines 170-184; also in *QQ. de Coelo et Mundo,* Lib. II, q. 12, ed. Moody, pp. 180-1.

[62] Eddington says pointedly that the teacher " glosses over the point that if there were no interference with the motion—if the ice were abolished altogether—the motion would be by no means uniform, but like that of a falling body." *Space, Time, and Gravitation, ed. cit.,* p. 136.

given to display the "self-evidence" of this principle are unsatisfactory.

In the early days of modern science it was thought that the principle of inertia was philosophically demonstrated and experimentally verified.[63] In Descartes' system the principle is founded on the conservation of momentum. He alleged that in the beginning God created not only matter, but also a determined *quantitas motus,* which could neither be augmented nor decreased.[64] This he thinks is necessary, for otherwise God would have to continue creating motion; and this is contrary to His immutability! Throughout the entire universe the " quantity of motion" remains constant so that when one body is at rest, another is in motion; when one moves twice as fast, another moves half as fast as previously.[65] Descartes determined the " quantity of motion " to be measurable as the product of the mass moved into the velocity with which it is moved, that is, Galileo's momentum, *mv.* Change, then was to be explained as the transference of momentum from one body to another through impact. Since the quantity of motion in the universe *(mv)* must be constant, *id quod movetur, quantum in se est, semper moveri*,[66] Thus for Descartes the principle of inertia was based upon the conservation of momentum *(mv),* conservation was thought necessary because of the immutability of God.

[88] Cf. H. Poincare, *Science and Hypothesis* (London, 1905), 94-95.

[84] " Deum esse primariam motus causam: et eandem semper motus quantitatem in universo conservare." *Prin. Phil.,* P. II, art. 36, *ed cit.,* VIII, 61.

[80] " Ita scilicet ut putemus, cum una pars materiae duplo celerius movetur quam altera, et haec altera duplo maior est quam prior, tan- tundem motus- esse in minore quam in maiore; ac quanto motus unius partis lentior sit, tanto motum alicuius alterius ipsi aequalis fieri celeri- orem." *Ibid.,* p. 61.

[88] *Prin. Phil.,* P. II, art. 37, *ed cit.,* VIII, 62. Spinoza's presentation of Descartes' argument, *more geometrico demonstratum,* shows clearly the supposed logical foundation of the principle of inertia. " (Propositio XIX: Unaquaeque res, quatenus simplex et indivisa est, et in se sola considera- tur, quantum in se est, semper in eodem statu perseverat.) Demonstratio: cum nihil sit in aliquo statu, nisi ex solo Dei consursu (per prop. 12.

Leibniz (1646-1716), however, pointed out that momentum is not constant in the universe, for it cannot be shown that every body imparts the same quantity of motion to some other body.[67] Furthermore, Leibniz maintained that it is not momentum which accounts for movement, but rather a certain *vis viva, lebendige Kraft,* which is measured not by *mv,* but by mass times the velocity squared (mv^2). He maintained that it was *vis viva* which accounted for motion in the world and which, furthermore, remained constant throughout the universe.[68] Leibniz is really pointing out here the difference between momentum and what has become known as energy. The important point is that -Leibniz bases the principle of inertia on the conservation of energy, instead of on Descartes' momentum.[69] However, as Leibniz denies any *real* interaction between the unextended monads which make up the real world, the conservation of energy is a *phenomenological principle* which depends upon " pre-established harmony " in which God alone is the true cause. In the *Discours de Metaphysique,* § 18, Leibniz says:

part. I) ; et Deus in suis operibus sit summe constans (per Coroll. Propos. 20. part. I) ; si ad nullas causas externas, particulares scilicet, attendamus, sed rem in se sola consideramus, affirmandum erit, quod ilia, quantum in se est, in statu suo quo est, semper perseverat. Q. E. D." Spinoza, *Renati Des Cartes Principiorum Philosophiae More Geometrico demon- stratae, Opera,* ed. Van Vloten et Land (The Hague, 1914), IV, 159.

e7 Principally in his *Systeme nouveau de la nature,* ed. by C. J. Ger- hardt, *Die philosophischen Schriften von G. W. Leibnitz,* (Berlin, 1S90),

IV. For the controversy between the followers of Descartes and Leibniz on this point, cf. H. \V. B. Joseph, *Lectures on the Philosophy of Leibniz* (Oxford, 1949), pp. 27-54.

"9 ". . . eandem motricis potentiae summam in natura conservari." Leibniz called this active force *vis viva* because it seemed to multiply itself in the square of the velocity. Prof. Joseph points out that the importance of the squared velocity for Leibniz was that it led to some reality beyond mere mechanics; Leibniz was fully aware that a velocity could not be really (physically) squared, but that it was a mental process which yielded a number corresponding to a physical effect. Therefore, the reality which could not be attained in Cartesian mechanics, had to be sought in his " metaphysical " monads. Cf. Joseph, *op. cit.,* pp. 41-61.

•• Cf. Leibniz, Letter to Voider, *Philosophische Schriften,* II, 170.

Although all the particular phenomena of nature can be explained mathematically or mechanically by those who understand them, yet nevertheless, the general principles of corporeal nature and even of mechanics are rather metaphysical than geometrical, and belong to certain forms or indivisible natures, as the causes of what appears, than to corporeal or extended mass.[70]

Descartes realized that his doctrine of conservation seemed to preclude every activity of the soul upon the body. To reconcile the conservation of momentum in the world and the activity of the soul on the pineal gland, Descartes maintained that the soul cannot give momentum to the body but only change of direction. In answering this " ingenious " distinction, Leibniz points out that even change of direction requires a force, but he acknowledges the impossibility of the soul's acting upon the body even to change the direction of the " animal spirits "— " a thing which appears as inconceivable as to say that it gives them movement, at least unless one has recourse as I do, to the pre-established harmony." [71] For Leibniz the phenomenological world may be described through mechanical laws, but the real world and even the foundation of mechanical laws are to be found in the realms beyond mechanics. Furthermore, the conservation of *vis viva* in the world depends upon the will of God.

Even Isaac Newton, as will be shown more clearly in the next article,[72] insisted that mechanical laws applied in the universe *as though* bodies themselves were the *cause* of such motion. Newton tried to distinguish very carefully between the mathematical principles which could describe the activity of nature and the " metaphysical reality " about which he would make no " hypotheses " but in which he firmly believed. Under the direct influence of Henry More's Platonism and Jacob Boehme's mysticism he attributed the real cause of material effects to

[70] Leibniz, *Philosophische Schriften,* IV, 444.
[71] Leibniz, *Systeme nouveau, Phil. Schriften,* IV, 497.
[73] " Space and Gravitation " to be published in the next issue.

God, Who operates through space, His " Sensorium." [16] Prof. Snow summarizes Newton's philosophy as follows: "While the motion of matter follows the general laws of mechanics, the real or final cause of motion does not, but a Divine Providence creates, conserves, and regulates motion, in order that 'bodies may not go off their course [74] Newton, however, did believe that the first two laws of motion were substantiated by Galileo's work on the inclined plane and by Huygens' work on the pendulum.[75]

In the 17th century, therefore, the principle of inertia was thought to rest on conservation of momentum or energy. This latter principle was thought to be based upon: i) certain experimental phenomena, namely, the inclined plane and the pendulum; and ii) upon "metaphysical" (or theological) considerations. But it is clear that the experiments on the inclined plane and on the pendulum are strictly mechanical in the proper sense of the word; they neither manifest the self-evidence of the principle of inertia, nor do they demonstrate it. Much less do these experiments establish it as a universal law of nature. It is true that the so-called principle is *involved* in these and other experiments, as will be shown later, but this is not to establish

[73] The most extensive study of Newton's personal philosophy has been made by Prof. A. J. Snow of Northwestern University in his *Matter and Gravity in Newton's Physical Philosophy* (London, 1926). Arguing against Descartes, Henry More insisted that although the material effects of nature are mechanical, the real cause must be immaterial and spiritual—by penetrating matter, it is the source of motion, of cohesion, or separation of parts of bodies; it is the directing force of all motion, animate and inanimate. (Cf. More, *Immortality of the Soul,* Bk. I, chap. ii, art. 11-12.) More attributed " spiritual substance " to God, the angels, the mind of man, and to space, the extension and "sensorium" of God. (Cf. More, *Enchiridion Metaphysicum,* chap. 28, par. 2; chap. 8; also preface to the *Immortality of the Soul.)*

[74] A. J. Snow, *op. cit.,* p. 210. The phrase "final cause" is used in the accepted 17th cent, sense of "metaphysical"; ever since Francis Bacon relegated the study of final causes to metaphysics, the phrase had become identical with metaphysical among English writers.

[75] Cf. Newton, *Principia,* Scholium to Definitions, *ed. cit.,* pp. 21-28.

it as the first law of nature. It should not he necessary to consider the "metaphysical" (or theological) arguments which were adduced in defense of the principle, as hardly anyone today relies upon them, at least in the present context.

When Immanuel Kant tried to establish the universality of Newtonian physics in the face of Hume's scepticism, he reduced the principles of mathematics and natural philosophy to *a priori* judgments or conditions of the mind. Thus he believes the principles of inertia and conservation to be universally valid, because they are demanded by the law of causality, an *a priori* necessity which the mind imposes on events. But by the law of causality Kant means that " every change must have a cause "; this cause is not only extrinsic but must act continually upon the body whenever there is a change of *state,* that is, a change from rest to motion or a change in velocity.[76] In other words, Kant's idea of causality presupposes the validity of the principle of inertia, as his very concept of causality implies.[77]

With the development of thermodynamics in the last century and the universal application of the conservation of energy by Helmholtz (1821-1894), it was generally believed that the principle of inertia had universal validity.[78] But Poincare

[78] Cf. *ICritik der reinen Vernunft,* B. II, Kap. II, sect. 3, 3 A.

[77] It may be pointed out that in Kant's scheme of the sciences there is no room for natural philosophy in the Aristotelian sense of the word. By " pure natural science " Kant understands the application of mathematics to phenomena, or what the Aristotelian would call mathematical physics. (Cf. Kant, *Prologomena,* § 14.) Thus it is not surprising that his concept of causality should be that of the mathematical physicist, which concept implies the principle of inertia. Cf. Josef Schmucker, " Der Ein- fluss des Newtonschen Weltbildes auf die Philosophie Kants," in *Philosophisches Jahrbuch,* LXI (1951), 52-58.

[78] Cf. Hermann von Helmholtz, " On the Conservation of Force," in *Harvard Classics* (Scientific Papers), XXX, 181-220; see also Ernst Mach's *History and Root of the Principle of the Conservation of Energy* (Chicago, 1918). Mach however believes that the principle has a more universal, i. e., non-mechanical, validity than Helmholtz maintained (cf. pp. 38-39; 59-74). For Mach the principle of conservation is based on the theorem of excluded perpetual motion; this in turn he derives from another form of the causal principle, viz., " it is not possible to create work out of nothing." But

pointed out that the laws of thermodynamics are valid only in a particular set of phenomena and cannot be extended to the whole universe by giving the laws an absolute meaning.[79] Poincare himself believed that the principle of inertia is neither imposed on the mind *a priori,* nor universally demonstrated. Biit he adds, " This law, verified experimentally in some particular cases, may be extended fearlessly to the most general cases; for we know that in these general cases it can neither be confirmed nor contradicted by experiments." [80]

From these considerations the following points seem to emerge, i) *The principle of inertia is not self-evident.* While it is true we may conceive or imagine a being with uniform motion in a straight line, unable to change except by an external agent, no such being can possibly exist in the world we know, ii) *The principle is not demonstrated as a universal law of nature.* Philosophical reasoning does not demonstrate it, for the data of human experience are contrary to the statement of the principle; the various branches of physical science which "involve" the principle cover only particular phenomena, that is, limiting cases, and therefore cannot manifest it for the whole of natural reality, iii) *The principle is not even demonstrated in any of the existing branches of physical science.* While it is true that the principle seems to be " involved " in many particular cases, so that we can say with Poincare that it is " verified experimentally in some particular cases," there is no actual proof of it as a " law." Rather than proving the principle, the mechanical and mathematical science of nature *assumes* it. Yet there is a necessity in this: the mathematical sciences must assume it, if they are to remain mathematical. But this necessity of assuming it can be brought out only by explaining the actual meaning of the principle of inertia.

a careful study of Mach's arguments will show that this statement is to be understood in a mathematical, and not a philosophical context.

H. Poincar6, *Science and Hypothesis,* pp. 129-135.

[80] *Ibid.,* p. 97.

Meaning of the Principle

When discussing- the meaning of this " principle," care must be taken not to confuse it with secondary factors, which although very important in mathematical physics, do not express the essential meaning of the principle. For example, the fundamental idea of the principle should not be confused with a " force of resisting " an external deterrent to the actual course of a body. Certainly every natural body in a gravitational field will have a *vis resistendi,* but this is not what is meant by the "law" of inertia. Nor should the law be limited to the particular phrase " uniform motion," that is, motion in a " straight line."[81] Although this aspect of Newton's formulation has important consequences in *determining* the motion of a body, the essential idea is that a body once moved continues to move— whether with uniform or accelerated motion is of secondary importance, as far as understanding the principle is concerned. Relativity physics has brought out very clearly the ambiguity of this part of Newton's proposition; since all measurements of moving bodies depend upon the position and condition of the observer, how are we to know whether the motion is uniform or accelerated? Nevertheless, the essential idea implied in the principle of inertia remains even in relativity physics.

It is commonly claimed that the greatest triumph of the 17th century was to rid the celestial spheres of spiritual movers and to effect the unification of celestial and terrestrial mechanics. As Prof. Butterfield puts it, " The modern law of inertia, the modern theory of motion, is the greatest factor which in the seventeenth century helped to drive the spirits out of the world and open the way to a universe that ran like a piece of clock

[81] Strictly speaking uniform motion and motion in a straight line are identical in the language of physics inasmuch as any change in either requires an external agent. But for the sake of clarity both expressions are frequently used in these articles as though they were distinct.

work." [82] An examination of how this was done and what it means will lead to a clarification of the concept of inertia.

In the Aristotelian philosophy of nature a distinction is drawn between celestial and terrestrial bodies. The distinction fundamentally lies in the different ways the two are moved: terrestrial bodies naturally come to rest, the celestial do not. As was pointed out previously, nature as an active principle necessarily involves some *finality,* "for since nature always tends determinately towards one [perfection], not being indifferently suited to many, it is impossible that a given nature aim at motion for its own sake."[83] With regard to motion in place a given nature tends toward a suitable place, a congenial environment, in which it is relatively at rest. But we see that the heavenly bodies move continually without a particular place in which to rest. Even if it could be shown that the celestial motions are gradually coming to rest, such a rest would not be a good thing for either the planet or the universe, so that this cessation of movement could not be called the natural aim of celestial motion. Whether the earth is considered to be one of the moving planets or not does not alter the case: bodies on this earth must have a determined place for survival, while planetary bodies move continuously in their orbits.[84] Since celestial bodies have no intrinsic finality accruing to them in rest, St. Thomas concludes that their motion arises not from an intrinsic *active* (formal) principle, but from an intrinsic *passive* (material) principle, which needs to be continually moved by some non-corporeal being.[85] This was the real basis for distinguishing

[82] *Origins of Modern Science* (London, 1951), p. 7; see also C. Singer, *A Short History of Science* (Oxford, 1943), pp. 212-217.

[83] " Cum enim natura semper in unum tendat determinate, non se habeas ad multa, impoasibile est quod aliqua natura inclinet ad motum secundum se ipsum." St. Thomas, *De Pot.,* V, 5.

[84] " Caelum autem non pervenit suo motu in aliquid *ubi,* ad quod per suam naturam inclinetur, quia quodilibet *ubi* est principium et finis motus." *Ibid.-,* cf. *Sum. cont. Gent.,* Ill, c. 23; *In II De Coelo,* lect. 18, n. 1.

[83] " Unde non potest esse suus motus naturalis quasi sequens aliquam

the two classes of bodies—a functional division. All the other properties attributed to the heavenly bodies are secondary. They were thought to be " ingenerable and incorruptible," because no generation or corruption was observed.[86] They were thought to be of a different element to account for this.[87] This teaching was the general, although not the universal, opinion of medieval philosophers.[88]

From the earliest days of astronomy men have tried to determine the relative positions, periods, and velocities of the heavenly bodies. The astronomers assumed the motion of the planets and attempted no explanation of why they moved; this

inclinationem naturalis virtutis inliaerentis, sicut sursum ferri est motus naturalis ignis." *De Pot.,* V, 5; cf. ad 12; II *Phys.,* lect. 1, n. 4. Whether the heavenly bodies are animated as Aristotle believed, or moved extrinsically by God or angels; does not affect the immediate point, for in any of these cases continual motion can be explained, for the finality is in the mover. But St. Thomas insists, " *Non autem, esset via solvendi, si moverentur per solum naturae impetum, sicut corpora gravia et levia." In II De Coelo,* lect. 18, n. 1.

[86] Cf. St. Thomas, *In I De Coelo,* lect. 7, n. 6.

[87] Cf. St. Thomas, *In I De Coelo,* lect. 4.

[88] Even in the 13th century there were some who dispensed with the need for angels to move the heavenly bodies and who explained this motion as " a natural inclination to move in circular motion." An *active* inclination toward such motion would dispense with a continual mover, as has been explained. Notably Robert Kilwardby, O.P., defends this position of *quidam* in his response to the 43 questions sent by the Master General, John of Vercelli, in 1271. Cf. text of q. 2, n. 3 from Bordeaux Ms. 131 published by M.-D. Chenu: " Aux Origines de la Science moderne," in *Revue des Sc. Phil, et Theol.,* XXIX (1940), 211-212; also " Les reponses de S. Thomas et de Kilwardby a la consultation de Jean de Verceil," in *Melanges Mandonnet* (Paris, 1930), I, 191-222. Fr. Daniel Callus, 0. P., has pointed out that this idea can be traced to the earliest days of Aristote- lianism in Oxford; some 60 years before Kilwardby John Blund expounded the same doctrine in his unpublished *De Anima,* now being collated by Fr. Callus. Cf. D. A. Callus, " The treatise of John Blund On the Soul," Autour d'Aristote: Receuil d'Etudes de Philosophie Ancienne et Medieval Offert a Monseigneur A. Mansion (Louvain, 1955), 471-495. This theory was not unknown in the 14th century, for Jean Burdian and Albert of Saxony defend it as a probability (cf. above, note 61). Likewise Copernicus tends to explain the circular movement of the earth and other planets by a natural inclination of the form; cf. *De Revolutions Orbium Caelestium,* Lib.
I, cap. iv and viii, ed. Thorn, pp. 14-15, 21-24.

was the task of philosophers. Even Copernicus did not attempt to explain why the planets moved as they do; he merely assumed that this was their nature.

Descartes, however, believed that a completely mechanical explanation of the universe was possible, and he sought a physical cause to keep the heavenly bodies in motion. This cause he found in vortices, a subtle material fluid which whirled around carrying the heavier bodies with it.[80] The Cartesian vortices were proposed as a causal explanation of both terrestrial gravitation and celestial movement.[90] Johannes Kepler (1571-1630) discovered his three famous laws from the observatal data amassed by Tycho Brahe; they are strictly empirical laws, in so far as one may call an astronomical law empirical. Nevertheless, he tried to find some physical force emanating from the sun which could supply the planet's motion in an elliptic path. In the introduction to his *Astronomia Nova* of 1609 Kepler proposes the hypothesis that the sun propagates into the depths of the universe a *species immateriata* of itself.[91] Giovanni Borelli (1608-79) followed Kepler in the view that the planets need a force emanating from the sun to push them around in their orbits, and he added that if it were not for this centrifugal force, the planets would fall into the sun by the effect of gravity, which he described as a *natural instinct* in bodies to fall towards the sun.[92] But all such attempts to find a physical cause impelling the celestial bodies lacked astronomical verification, as they arose mainly from a philosophical desire to unite all physical phenomena in a mechanical explanation of movement.

The great triumph of Newton was that he reached the goal

[8'] Cf. Descartes, *Principia Philosophiae,* III, art. 53-157, *ed. cit.,* 106-202.

[•°] Cf. Letter LXI, *Oeuvres* I, 314; Letter CLXXIX to Mersenne, *Oeuvres* II, 635; *Prin. Phil.,* P. IV, art. 24, p. 214.

[91] *Opera Omnia Kepleri,* ed. Frisch, III, 156.

Cf. A. Armitage, Borelli's Hypothesis and the Rise of Celestial Mechanics," *Annals of Science,* VI (1948-50), 268-292. This article explains admirably the development of celestial mechanics up to Newton's formulation.

which eluded his contemporaries. The cornerstone of his success was the principle of inertia. Two concepts were very much to the fore during the latter part of the 16th and early part of the 17th centuries: the concepts of centrifugal force and attraction. Giambattista Benedetti, Borelli, Descartes, Hooke, and Huygens had described at great length that the motion of a stone in a sling naturally tends to move along the tangent to the circle described, so that it is the tension in the cord, curbing this tangential motion, which keeps the stone in the arc.[93] The notion of attraction had become popular with the publication of Sir William Gilbert's *De Magnete* in 1600. It was these two ideas that Newton united in his famous proof that the earth attracts the moon in the inverse proportion of its distance, as was required by Kepler's three laws.[94] Since the earth's circumference and the distance of the moon were known, the orbital velocity of the moon could easily be calculated on the basis of the lunar month. The problem was to find out how much the moon would fall were there no centripetal force holding it in its orbit; or in other words, how much force was needed to counteract the velocity of the moon. Newton found that it would fall loi Paris feet per minute, which corresponded to Huygens' figures for the movement of the pendulum.[90] Thus Newton maintained that the attraction, varying inversely as the square of the distance, held good universally, allowing for minor discrepancies.

It is easy to see how important the principle of inertia is in

[83] Cf. A. Armitage, *art. cit.,* p. 275.

[84] Newton, *Principia Mathematica,* Bk. Ill, prop. IV, Theorem 4, ed. Cajori, pp. 407-409; for the derivation of the inverse square law from Kepler's third law, cf. Max Born, *Natural Philosophy of Cause and Chance* (Oxford, 1949), Appendix 2, p. 129.

[83] " And therefore the force by which the moon is retained in its orbit becomes, at the very surface of the earth, equal to the force which we observe in heavy bodies there. And therefore (by Rule 1 and 2) the force by which the moon is retained in its orbit is that very same force which we commonly call gravity." *Ibid.,* ed. Cajori, p. 408. Cf. also F. Cajori, *A History of Physics* (New York, 1916), pp. 56-62.

this demonstration. Newton assumes that the moon does move; he assumes moreover that it would move at a constant rate at a tangent to the circle were it not for the attracting force. The point is to find two quantities which will equate: in this case it is the velocity of the moon and the rate of supposed fall. (The applicability of this equation to terrestrial gravitation establishes the universal law.) In every equation something must be considered irrelevant, that is, something must be assumed as not affecting the quantities. In the present case it is the actual movement of the moon or the observer. Newton assumes that the moon would move with uniform motion in a straight line, *so that motion does not have to be considered in the equation.* Once the quantities are obtained it is as though the bodies were at rest. In other words, the argument begins with considering the velocity (and mass, which is measured through acceleration), but once the quantities have been obtained it is no longer a question of the actual motion but only of the proportionality of these quantities. Thus it must be assumed that every body continues in its state of rest, or of uniform motion in a straight line, except so far as it may be compelled by force to change that state. That is to say, uniform motion, rest, and even actual movement can be considered null factors in the equation, for they do not affect the case. Only new quantities, such as those which change the velocity or direction, have meaning and so must be considered in devising an equation. Thus inertial motion, or an inertial system is one in which certain factors are disregarded.

Exit at this point the question arises as to what is meant by uniform motion in a straight line. Does not this statement presuppose an absolute frame of reference in which this statement has meaning? But if all measurements of time and space are relative to the observer who may or may not be moving in an inertial system, then there are factors which are not null, but definite quantities which must enter into the equation. How are we to know that a certain system is inertial? In the Newtonian theory this may be answered in two ways: i) it moves with uniform motion if it is not affected by external forces; or ii) it is an actual fact that we can choose a series of co-ordinates with reference to which bodies at rest remain at rest and bodies in motion continue in uniform rectilinear motion. With regard to the first Einstein answers that "it involves an argument in a circle: a mass moves without acceleration if it is sufficiently far from other bodies; we know that it is sufficiently far from other bodies only by the fact that it moves without acceleration." [96] With regard to the second Einstein showed that there is no reason to give preference to an inertial system over one moving with accelerated motion.[97] By identifying inertial and gravitational mass and by showing how a field may be regarded as both inertial (uniform) and gravitational (accelerated), Einstein established his principle of equivalence, that is, a physical event described in an inertial system may be described equivalently in a non-inertial system. In formulating his general theory of relativity, Einstein carries the equivalence of systems to an extreme limit: "All Gaussian four-dimensional co-ordi- nate systems are equally applicable for formulating the general laws of Physics." [98] It is clear, then, as Sir Edmund Whittaker says, "What Einstein's theory really does is to abolish the old idea of gravitation altogether, and to replace it by *the idea of inertial frameworks*."[99] In other words, although relativity physics disagrees as to what is inertial motion, that is as to *what* may be regarded as a null factor, the ultimate agreement lies in the acceptance of something as irrelevant and null in the

[98]A. Einstein, *The Meaning of Relativity* (London, 1950), p. 57. Cf. also A. Eddington, *Space, Time and Gravitation, ed. cit.,* pp. 13G-7.

Cf. A. Einstein, *The Theory of Relativity,* 8th ed. (London, 1924), pp. 59-79; see also L. Silberstein, *The Theory of Relativity,* 2nd ed. (London, 1924), pp. 294-312.

[98] E. Freundlieh, *Einstein's Theory of Gravitation* (London, 1924), pp. 45-61; also essay by Prof. H. L. Brose, *ibid.,* p. 127.

[89] E. Whittaker, *From Euclid to Eddington* (Cambridge, 1949), p. 115. (Italics mine.)

equating of quantities. It is this acknowledgment of the irrelevance, the nullity of certain factors, which constitutes the principle of inertia.

The basis for the principle of inertia lies, therefore, in the nature of mathematical abstraction. The mathematician must equate: a single quantity is of no use to him. In order to equate quantities he must assume the basic irrelevance or nullity of other factors, otherwise there can be no certainty in his equation. The factors which the mathematician considers irrelevant are, as we have seen, motion, rest, constancy, and unaltered directivity; it is only the *change* of these factors which have quantitative value. Thus for the physicist it is not motion and its continuation which need to be explained, but change and cessation of motion—for only these have equational value. The principle of inertia which is necessitated by every equation must exclude the vitality of real existence, spontaneity, motion, and finality. In other words, the logical function of inertia in mathematical abstraction necessarily relinquishes the reality and spontaneity of nature.

To return to the question of spiritual movers, it is clear that the principle of inertia has not done away with their need. It would be more accurate to say that mathematical physics is not concerned with who or what moves the heavenly bodies. A spiritual force moving the planets would be of no use to the mathematician, for he could never get two quantities to equate. But neither is it true to say that the principle of inertia has done away with their need. In the early part of the 17th century physicists tried to find a physical cause to explain the movement; Newton merely disregarded the question and looked for two quantities which could be equated. In Newtonian physics there is no question of a cause, but only of differential equations which are consistent and useful in describing phenomena.[100]

[100]« when we say force is the cause of motion, we are talking metaphysics; and this definition, if we had to be content with it, would be

From what has been said it is clear that the principle of inertia, the foundation of mathematical physics, is neither self- evident, nor demonstrable in any way. The logical basis of the principle lies in the nature of mathematical abstraction, which must leave out of consideration the qualitative and causal content of nature. That is to say, mathematical physics can never attain the ultimate reality of "nature," its spontaneity and intentionality, its qualitative characteristics and causal dependencies—all of which are given in human experience. Furthermore, since mathematical physics abstracts from all these factors, it can say nothing about them; it can neither affirm nor deny their reality, although a mathematician can be led to believe in a reality wider than his abstractions. If, therefore, the concept of nature, as expounded, is justified in human experience, so too is the distinction between natural and compulsory movement. Since these realities are of no use to the mathematician as such, he must reduce whatever he can to the common factor of quantity. But to the natural philosopher, who embraces the *whole* of human experience, the distinction between natural and compulsory motion is of utmost importance. The two pictures of the universe afforded by mathematical abstraction and philosophical experience, far from being incompatible, are the necessary binoculars of physical knowledge.

absolutely fruitless, would lead to absolutely nothing. For a definition to be of any use [in mathematical physics] it must tell us how to measure force." H. Poincare, *Science and Hypothesis, ed. cit.,* p. 98.

CHAPTER IV

Space and Gravitation

THIJS EAR IN our study we have considered nature as a taneous principle of determined behavior, or behavior which is actually " given " in human experience. Since all such determined behavior manifests an intrinsic intentionality of purpose, congruent activities find their explanation within the beings themselves, while the *raison d'etre* of compulsory activity lies in the external force imposed upon nature. Thus in a philosophy of nature, strictly so-called, a fundamental distinction must be made between natural and compulsory movement, for the explanation of these two phenomena is different. Furthermore, we have seen that there is another science, which although considering the same world of nature, reduces all phenomena to quantitative proportions. In this mathematical science of nature spontaneity, finality, and " natural " motion have no meaning, for as such they cannot be quantitatively expressed in the form of equations.

The significance of every science lies in its *explanation.* Every science, if it is to be a science at all, must explain something. It is the different kinds of explanation afforded by the various sciences which distinguish one science from another. This is not to say that every system of philosophy may proffer its own explanation and be just as true as any other explanation. Contradictory explanations of the same phenomenon from the same point of view cannot be equally true. Nature does not tolerate contradictions. But if two sciences look at the same phenomenon from two entirely different points of view, points of view which are both humanly legitimate, then these two sciences are not contradictory but complementary. Such is the case between a natural and mathematical view of nature. It is because the mathematical view leaves out of consideration the underlying structure of reality and considers only quantitative proportionality that its " explanations " differ so radically from the natural philosopher's. The philosopher of nature must accept *everything* which is given in human experience and his explanation will be in terms of value, purpose, causal structure, and experience. The mathematician can deal only with equations in which the variables seem to affect each other as " efficient causes," but which in reality are only " functional dependencies." [1] Thus a mathematical " explanation " is in terms of a variable quantity, or measure, which necessarily affects a dependent quantity. Such an explanation is not interested in the structure of the phenomenon itself but only in indicating the necessary proportionality involved in the measures. It is the element of necessary proportionality, rather than efficient causality itself which is manifest in mathematical " explanations " of nature.[2] This

[1] " To avoid all these dangers of reading metaphysics into physics it might be well to drop the habit of expressing connections between physical properties in terms of causality. In practice what is actually used is a system of *functional dependencies,* and it may be left to other than physicists to decide, if they wish, the extent to which these can be summarized in any law of causality." M. Johnson, *Time, Knowledge and the Nebulae* (London, 1944), p. 35. See also V. Lenzen, *The Nature of Physical Theory* (New York, 1931), pp. 289-290. St. Thomas very frequently points out that mathematics necessarily abstracts from efficient and final causality. Cf. *In III Meta.,* 4, n. 375; *In Boeth. de Trim.,* V, 4 ad 7; *Summa Theol.* I. 44, 1 ad 3; Jn I *Phys.,* 1, n. 5. In Thomistic terminology the causality actually employed in mathematics by means of functional dependencies reduces to extrinsic formal causality, which is a proportion or proportionality between two patterns, or forms. Cf. St. Thomas, *In III Meta., 4,* nn. 379-381.

[2] Only in this context can one understand the preeminence of " necessity " in the Humean and Kantian search for the foundation of the principle of causality. Cf. D. Hume *A Treatise of Human Nature,* Bk. I, pt. Ill, sect. xiv (Oxford, 1940), pp. 164-170; I. Kant, *Kritik der reinen Vemunft* (Leipzig, 1926), pp. 246-277.

type of explanation is clear in the mathematical theories of gravitation from the seventeenth century to our own day. The big difficulty, however, is that the problem of gravitation needs a much wider explanation than is afforded by mathematics; and history shows that thinkers have tried to reach a physical theory of gravitation—through mathematics.

The problem of gravitation in our day is complicated by two particular factors. First of all, there is the failure to distinguish between the kinds of explanation afforded by natural philosophy and mathematical physics. It is further complicated by a special problem "which seems to be equally lodged in both sciences, namely, the problem of space. It is this problem of space which has brought mathematicians to a reconsideration of their classical position, and it is this problem which challenges the traditional position of the Aristotelian philosopher of nature. Since the problem of gravitation involves a change of position in space—heavy bodies falling down and light bodies rising upward—the notion of " space " in some form or other is intricately bound up with the general problem. The background of every mathematical explanation is a " space " in which the equations are verified. What is the reality of space? How does it affect the falling and rising of bodies? Is mathematical space real? Is it the same as natural place? These questions must be answered in the course of explaining gravitation. The most suitable procedure is to treat the problem of space and gravitation in its historical development, considering principally the Aristotelian, Newtonian, and Einsteinian views. Throughout this discussion emphasis must be laid on the nature and role of " space " in gravitation and the distinct explanations afforded by natural philosophy and mathematical physics, their validity and relation one to the other.

I. Aristotelian Space

The background for the Aristotelian view of space is to be found in his predecessors. Parmenides, denying the possibility of plurality and movement, held that what underlies the illusory world of sense is a corporeal, spherical, continuous, eternal and immutable *plenum*.[8] Parmenides had formed a clear conception of space, as Burnet says,[4] but only to deny its reality. The absolute conception of space, the reality of which Parmenides denied, was taken over by Empedocles and filled compactly with bodily elements. Even though Empedocles insisted that all bodies move continually in the *plenum,* so as to leave no void, the *positions* which can be occupied by various bodies remain fixed and absolute.[0] It is as though space with its determined positions were something over and above the bodies which exist. When the atomists introduced the void they gave, it a reality equal to that of bodies.[6] Although the void was introduced by the atomists to explain the movement of bodies upward and downward, it was deficient in two respects. First, the void was supposed to be characterless,[7] but a characterless void could in no way influence a body to move upward rather than downward. Second, void itself moved in the void, allowing the vacuous bodies to move upward; but if void moves in void, then they cannot be the same characterless reality, nor can either void explain movement. " What is the cause of its movement? Not, surely, its voidness: for it is not the void only which is moved, but also the solid." [8] Yet in spite of these shortcomings it is clear that the Empedoclean and atomistic void came close to being a fixed framework with determined

* Cf. Diels, *Vorsok.,* 28 B.
* J. Burnet, *Early Greek Philosophy,* 4th ed. (London, 1945), p. 337.
" Cf. Diels, *Vorsok,* 31 B, frag. 17.
* Cf. Diels, *Doxog.,* p. 483; J. Burnet, *op. cit.,* p. 337.
''*Phys.,* IV, c. 8, 214b28-35.
[8] *De Coelo,* IV, c. 2, 309a27-28.

positions, a reality apart from the bodies which occupied the various positions.

Perhaps Plato was the first to have a clearly mathematical conception of space.[9] For him space, the receptacle of all things, is as real as the eternal ideas and more real than the bodies which occupy it. Plato conceives space as absolutely intelligible dimensions, independent of bodies, but capable of receiving bodies. For example, the dimensions of any room can be thought of independently of the room itself or of anything in it. It is as though *dimensions* were given a subsistence independent of mind and bodies, an absolute framework in which bodies can be conceived to exist. Whether one conceives geometrical figures or physical bodies there is necessarily a framework of dimensionality in which bodies succeed one another in the same place; the " place " of a body is none other than " that part of space which is actually occupied by a body." In other words, Plato conceives space as subsistent dimensionality " separated from any body." [10] That part of space which is occupied by the dimensions of a body is its " place "; and a " vacuum " is that part of space which is not occupied by any body.

Plato's conception of space as subsistent dimensionality is a very human and, therefore, common notion. Whenever we imagine any kind of magnitude whatever, it is set in a framework of unlimited dimensionality. For example, when we imagine a circle, there is room around it for any number of circles; when we see a mountain, we can imagine room for an infinite number of mountains next to it. But what is the reality of this " dimensionality " which is even a condition of our imagining anything physical? Plato made it a condition not only of imagination but of real existence. He projected a condition of human imagination into the physical world and

* Cf. Plato, *Timaeus,* 48 E-53 A.

[10] Cf. Aristotle, IV *Phys.,* 2, 209b5-33; St. Thomas, *In IV Phys.,* 3, n. 5; 6, n. 10; 7, n. 3; *In I de Coelo,* 9, n. 3.

made it a subsistent reality in itself—-as real as the eternal ideas which it reflects.

But Aristotle rightly objected that there can be no such extension existing apart from bodies.[11] " If there were an extension which were such as to exist independently and be permanent, there would be an infinity of place in the same thing." [12] Since all dimensions are infinitely divisible, each body would be existing in an infinite number of places at once.[1*] Dimensionality is the quantitative characteristic of bodies. Unless there i3 a body which is quantified, there can be no real dimensionality. In other words, dimensions such as length, distance, area, are quantities; these quantities are real provided there is a real body which has these dimensions. If absolute dimensionality really existed apart from the bodies which move about from one place to another, two bodies would always be occupying the same " place "—indeed, the moving body would always occupy an infinite number of places. Furthermore, Aristotle argues that " place " would be continually " changing " with the various bodies which occupied it; but strictly speaking, it is not place which changes but rather the bodies which move from place to place.[14]

The difficulty lies in the fact that we can conceive quantity apart from matter, apart from the real bodies which alone possess quantity. Just as we can think of circles, lines, and numbers apart from any physical body, so too we can think

[11] *Phys.,* IV, c. 4, 211bl3-29. Rosa thinks that here Aristotle is not attacking the Platonic view of a single space, distinguishable from the bodies that occupy it and move about in it, but the view that inside each container there is a self-subsistent interval specially connected with the container. (Cf. Ross, *Aristotle's Physics, ed. cit.,* p. 56, 572-3). However, it is difficult to see why the position attacked is not that of Plato, as St. Thomas seems to think (IV *Phys.,* lect. 6), especially as Aristotle actually presents the position, and Ross thinks it " curious " that he does not consider it *(ibid.,* p. 56).

[L] *Ibid.,* 211bl9-21.

[!S] Cf. St. Thomas, *In IV Phys.,* 6, n. 7.

[14] *Phys.,* IV, c. 4, 211b23-29.

of distance, volume, and dimensionality apart from any really existing body. But this imagined dimensionality is not a physical quantity; an imagined volume of 500 cubic centimeters is not an existent reality—-for nothing can be poured into it. This abstraction from physical bodies is not restricted to mathematical speculation, but is true of any consideration of quantities. Relations of length, distance, area, and the like are commonly discussed, and, indeed, independently of any particular body which actually has those quantities. Nevertheless, for any quantity to be *real* there must exist a physical body which is actually so quantified. We inevitably imagine a universal space, a general dimensionality over and above the bodies existing in the universe, but this in itself does not give reality to space. To have extra-mental reality, space or any other kind of extension must be a physical quantity of real bodies. This point is very important, but it can be brought out only by distinguishing this imaginative space from physical place and mathematical space.

Place, Natural and Otherwise

Aristotle rightly showed that Platonic space is of no value in explaining the movement of bodies. Why should one body go up rather than down? In one sense Platonic space is perfectly undifferentiated and characterless, as Plato says,[15] yet in another sense this space cannot be characterless, for otherwise why should a body be in one place rather than in another? Plato himself compares space to a winnowing basket which has holes of different sizes.[16] He attributes to his receptacle fixed positions suitable for the differently shaped elements.[17] Because Platonic space must be both differentiated

[15] " It must be called always the same; for it never departs at all from its own character; since it is always receiving all things, and never in any way whatsoever takes on any character." Plato, *Timaeus,* 50 B.

[18] *Ibid.,* 52 E-53 A.

" *Ibid.,* 57 B-58 C; also 63 A-E.

and undifferentiated, Plato is forced to admit that it is " very obscure and difficult to explain." [18]

Aristotle, who has little to say about space, insists that real motion can be explained only in relation to real place, a physical ambient for which a body has an innate preference. There are two essential features to the Aristotelian notion of place. It is first and foremost an environment, " the innermost boundary of what contains." [19] Secondarily, it is motionless, allowing bodies to move from one place to another. From the natural philosopher's point of view the environment is very important in explaining the movement and survival of bodies; the mathematician, abstracting from all qualitative considerations, is much more concerned with the immobility of place and the relations of distance.

Nothing in the universe is isolated and self-sufficient, for all natural phenomena manifest mutual dependencies. Since the first dependency of every body is upon its immediate environment, it must seek a suitable environment in which to thrive. This dependence upon a suitable place is more clearly evident in the higher categories of nature. A human being will adapt the environment to suit his needs or else move elsewhere. Birds fly south for the winter; different flora are found in different climates and conditions must be favorable to foster their growth. An analogous situation must explain the falling of bodies to the earth and stability thereon. It must be admitted that terrestrial stability is a decided advantage to the human body, trees, mountains, and minerals. These natural places, which are conducive to the very well-being of different natures, are environmental conditions toward which bodies necessarily move. In other words, different environments, or natural places must be acknowledged if motion is to be explained at all. Indeed locomotion is inexplicable without natural places toward which

[18] *Ibid.,* 49 A; also 51 B.
Phys., IV, c. 4, 212a20-21.

bodies determinate!}' move.[20] But the important point is that the place toward which a body naturally moves is essentially an environment suitable for the very survival and achievement of various natures.[21] When discussing bodies without consciousness and deliberate effort, we can only say that the active principle of nature automatically and spontaneously moves to that end.[22] To say that different kinds of bodies have different " natural places " is not to say that they have an absolute localization in space. A natural place is essentially a qualitative environment which is congenial to a particular nature and to which that nature spontaneously moves. Should the environment itself move, the body would not remain fixed in a point of space but would accompany or spontaneously seek out the nearest suitable environment.

Once Aristotle has shown that it is place which is the cause of motion, he tries to establish the absolute immobility of place. In this he is really trying to justify the absolute character of Platonic space. Plato had insisted that space is a dimensional framework over and above bodies. Aristotle rejects this because real dimensions must be the quantities of real bodies. But for Aristotle the whole universe is a plenum;[23] that is to say, physical bodies are contiguous to each other throughout the

[20] Cf. St. Thomas, *Sum. cont. Gent.,* Ill, cc. 22-23; *De pot.,* q. V, a. 5; *In IV Phys.,* 11.

[21] " Videmus enim quod unumquodque horum fertur in suum proprium locum quando non impeditur, grave quidem deorsum, leve autem sursum. Ex quo patet quod locus liabet quandam virtutem conservandi locatum: et propter hoc locatum tendit in suum locum desiderio suae conservationis. Non autem ex hoc ostenditur quod locus habeat virtutem attractivam, nisi sicut finis dicitur attrahere." St. Thomas, *In IV Phys.,* 1, n. 7.

[22] " Sic enim forma est principium motus localis, inquantum alicui corpori, secundum suam formam, debetur aliquis locus, in quem movetur ex vi suae formae tendentis in locum ilium, quam quia dat generans, dicitur esse motor." St. Thomas, *Sum. cont. Gent.,* Ill c. 23.

[23] *Phys.,* IV, cc. 7-9; see also J. de Tonqu<klec, *Questions de Cosmologie et de Physique chez Aristote et saint Thomas,* I. Le systeme du monde (Paris, 1950), pp. 7-71.

entire universe. Therefore, real dimensionality is established in the contiguity of bodies from the center to the circumference of the universe. Aristotle gives absolute meaning to the common expressions " up " and " down," so that a body which tends to fall " down " is really tending to an absolute center in the universe.[2'1] Therefore for Aristotle the earth must be immovable and the upward places must be spheres geometrically located around the earth as a center.[25] In other words, Aristotle's conception of determined spheres for the elementary bodies with the earth as an immovable center follows from the absolute immobility which he attributes to place.

But there are two difficulties involved in this part of Aristotle's doctrine: i) the validity of such an absolute localization of positions; ii) the spatialization of place.

While it is very easy to imagine an absolute dimensional framework in which the spheres of the heavens and the position of bodies are geometrically ordered, what actual meaning can such a conception have? When we see a row-boat moving across a lake, we see the relative positions of boat to shore. We say that the boat, is not moving if the relative positions remain unchanged. But can we say that even that relative order is absolutely immobile? If we are talking about an order or situs existing in reality, what basis is there for saying that it has absolute immobility? According to what framework is that order the same and immovable? To say that there exists an absolute matrix against which the immobility of positions has absolute physical significance is to assert something without justification. All we can really assert is that the relative positions *quoad nos* are the same and immovable. This is quite different from asserting an absolute immobility to place. When we speak of the universe as a whole, the absolute localization of positions is clearly impossible. Our notions have only

[!*] *Phys.,* IV, c. 4; *De Coelo,* I II; cf. St. Thomas, *In IV Phys.,* 1, n. 7.
[15] *De Coelo,* I, c. 8, 277bl ff.; St. Thomas, *In II de Coelo,* lect. 6, nn. 5-6.

relative value *quoad nos.* This is all we are justified in meaning and this is all we need to mean.[20]

But the more important point is that physical place is not space. It is not to a position in space that natural bodies spontaneously move but to an environment. Heavy bodies do not fall to a point in the universe but to this earth. There is no logical justification for identifying natural place with fixed positions in the universe; in fact this identification is illogical, for we do not know what a fixed position is. Aristotle's cosmology as expounded in his *De Coelo et Mundo* very clearly spatializes natural place and reduces it to a fixed position in the universe. Jean Buridan is more realistic when he rejects this as pure imagination.[27] For him natural place has meaning only relative to a particular environment; thus the natural place of air is to be above water wherever it may be, and it is the nature of solids to fall below irrespective of +heir position in space.[28] In other words, actual experience shows that various bodies move to determined environments; it does not show that they move to mere positions in space.

The important point is that physical place is essentially a

[2“] “ Est animadvertendum, quod punctum ad quod locus dicit ordinem et ex quo immobilitatem desumit, necesse est ut et ipsum sit quodammodo ftxum et immobile; at huius immobilitas non est pensanda simplieiter et absoluta, ut quidam etiam recentiores scholastici (v. g., Lorenzelli) tenere videntur; sed est solum secundum quid et relativa.” A. M. Pirotta, *Bumma Philosophiae* (Turin,1936), II, 193, n. 294. Among contemporary scholastics who attribute absolute immobility to place we must mention P. Hoenen, who identifies place with an all-pervading and absolutely fixed *ether*. Cf. *Cosmologia,* 4th ed. (Rome, 1949), pp. 66-68; 460-467.

Buridan, *Quaestiones de Caelo et Mundo,* Lib. IV, q. 7, *ed. cit.,* pp. 266-7.

[ss] “ Nee valet ilia imaginatio quod terra superior subdistracta inferiore terra, moveretur deorsum; quia si terra esset perforata usque ad centrum, non solum esset naturale quod terra proiecta in illud foramen descenderet ad centrum, imo etiam aqua ibi proiecta descenderet usque ad centrum, . . . quia hoc est naturalis inclinatio aquae quod sit sub aere; et aer etiam, ibi praeexistens, ascenderet naturaliter ad finem essendi supra aquam.” Buridan, *Hid.,* p. 267, lines 4-20.

temporal conditions.[31] Tlie second characteristic arises from the nature of the human intellect, which can disregard matter, physical bodies, movement, and causality in a consideration of pure quantity. In other words, it is the abstractive character of an intellect radicated in a quantified, sentient body which conceives an all-pervading, homogeneous " space " separated from physical bodies.[82] It is this space which Plato objectivized, and it is this space which Kant, canonized. The point is that we must acknowledge a certain subjective condition of the human mind, a universal spatial izing condition, which makes geometry and even human experience of physical reality possible. But it is clear that this spatializing condition is not to be confused with real dimensions. Furthermore even if such an absolute space were to exist, it is clear that no undifferentiated space could account for the movement of bodies to one place rather than to another. It is only a physical environment, a qualitative circumstance, which can attract a nature spontaneously aiming at its proper self-enjoyment.

Strictly Mathematical Space

By a strictly mathematical space is meant the geometrical description of a phenomenon in reference to determined co-ordinates. Until the late nineteenth century Euclidean geometry was thought to be sufficient to describe all natural phenomena; and, indeed, it was generally accepted as the only geometry.[33] Coordinates chosen in astronomy were thought to have an

[81] St. Thomas, *In Boeth. de Trin.,* VI, 1-2; cf. *In II de Anima,* 5, nn. 283-285, lect. 12-13; see also *In III de Anima,* 8.

[Ea] A complete analysis of the psychological predispositions for knowing " space " has not yet been made, as far as we know. Partial attempts have been made by Poincare, *Science and Hypothesis, ed. cit.,* pp. 51-88, and by H. Weyl, *Philosophy of Mathematics and Natural Science* (Princeton, 1949), pp. 95-137.

[.3] On the history of non-Euclidean geometries, cf. A. Whitehead, *Essays in Science and Philosophy, ed. cit.,* pp. 177-226.

absolute value so that all movements could be described adequately in relation to them. Euclidean geometry so used was an identification of imaginative with purely mathematical space. While it is true that all geometry is ultimately projected against the background of imaginative space, it would be an error to identify them. In practical mathematics the principal aim is to determine positions by measurements and to describe them in equations valid in some coordinate system. As soon as it is a question of measurement, then more than imaginative space is involved. What is actually involved is a space constructed in accord with our measurements. This space is utilized in what Einstein calls " practical geometry "; and " its affirmations rest essentially on induction from experience, but not on logical inferences only." [34]

All measurements are made relative to fixed frames of reference, or at least to frames which can be assumed as fixed. In classical mechanics all inertial systems constructed with Galilean coordinates were simply transformable one into the other. An inertial system, as has been shown in the last chapter, presupposes an absolute space in which the Newtonian principle of inertia has meaning. It was thought that the propagation of light waves through interstellar space demanded a substantial carrier of some kind—an " ether absolutely at rest." But all experimental attempts, for example, those of A. A. Michelson and E. W. Morley, to measure the absolute motion of the earth with respect to the ether had failed. The failure to determine an absolute space led to a critical examination of the meaning of space and time in mathematics. This work, begun by Henri Poincare, H. A. Lorentz, G. F. Fitzgerald and others, was synthesized in 1905 by Albert Einstein in his restricted theory

"* Einstein, " Geometry and Experience," an address given to the Prussian Academy of Sciences in Berlin, Jan. 27, 1921, in *Sidelights on Relativity* (London, 1922), p. 32.

of relativity, which emphasized the special character of mathematical space as distinct from imaginative space.

The peculiar characteristic of mathematical space is that it is constructed from our measures. Mathematical measurements depend upon the position and condition of the observer; since the mathematician himself is situated in a particular place in the universe and makes his measurements at a particular time, his measurements are necessarily relative to himself as a physical " event." Classical mechanics, which assumed an absolute space or ether to justify inertial motions, thought that a mathematical description of an event for one observer would serve equally for another observer through a process of simple transformation. This is to say, the straight line *PQ* for observer A would be described in co-ordinate system *x, y, z, t;* and the same straight line would be described for observer B, moving uniformly along the *x* axis, in co-ordinate system *x', y', z, t'.* Thus the description for the square of the line element *PQ* remains invariant for both systems as $(x_2 — x_i)^2 + (y_2 — y_i)^2 + (22 — z_i)^2$, *or* dx^2 -f $dy^2 + dz^2$. But this assumes that each observer ascribes the same values *to* the other's lengths and times as to his own, a thesis which cannot be supported unless there be an absolute space which can be determined. The special theory of relativity rejects absolute motion, that is, the possibility of measuring motion in relation to absolute space. Following Lorentz, Einstein insists that all measurements of space and time are strictly relative to the observer. Assuming that the velocity of light is constant for any given observer, he shows that no observer can detect his own movement, but another observer moving uniformly and rectili- nearlv with respect to it would detect a slight " contraction " of A's length in the direction of motion. Thus while A cannot detect any contraction of his own measuring rods, B can; and conversely. Therefore, Einstein concludes, a simple transformation cannot be made between A's system and B's, but account must be taken of the relative difference in measurement. The equivalence of these two systems is accomplished by a new transformation, known as the Lorentz transformation, in which

$$x' = \frac{x - ut}{\sqrt{1 - \frac{u^2}{c^2}}}, \quad y' = y, \quad z' = z, \quad t' = \frac{t - \frac{u}{c^2}x}{\sqrt{1 - \frac{u^2}{c^2}}}$$

where c = the velocity of light *in vacuo.* According to this transformation the interval between P and Q, observed by two observers moving in uniform rectilinear motion, remains invariant in the description $dx^2 + dy^2 + dz^2 - c^2dt^2$, since the discrepancv of the two observers is rectified in the subtractive term. By means of the constant velocity of light for any given observer Einstein explained the Fitzgerald "contraction" and the Lorentz transformation, both of which were offered to explain the failure of the Michelson-Morley experiment to determine the absolute velocity of the earth relative to a stationary ether.

The equivalence of these two systems by means of the Lorentz transformation is reallv a unification of two different co-ordinate systems, as Minkowski later showed. The result is a kind of " curvature," which merely means that the relations between the mutual distances of the points are different from the relations which obtain in Euclidean geometry. As Sir Edmund Whittaker points out,

> Curvature (in the mathematical sense) has nothing to do with the *shape* of the space—whether it is bent or not—but is defined solely by the metric, that is to say, the way in which " distance " is defined. It is not the space that is curved, but the geometry of the space.[35]

Furthermore the event PQ which is described in either inertial system embodies a curvature. That is to say, time is not considered as an independent co-ordinate, but as an element intrinsically affecting the measurement of space itself. Thus in the

[35] E. Whittaker, *From Euclid to Eddington, ed. cit.,* p. 40.

description of relativity it is not the *distance* between points *P* and *Q* which is specified, but the *interval* between two events emerging in time. In the four-dimensional continuum of spacetime every event is described as emergent in time; when this emergence is designated by co-ordinates, the matrix is a set of Gaussian curves. Thus in the extended theory of 1916 Einstein presented the exact formulation of the general principle of relativity as " All Gaussian co-ordinate systems are essentially equivalent for the formulation of the general laws of nature." [38]

The important point to notice is that geometric space is constructed from measurements. It is not a question of the real space of the universe, but of the geometric space which must be used by us to describe measurents accurately. When dealing with velocities considerably less than that of light, the discrepancy of systems is not sufficiently great to give a " curvature " to geometric space. The essential point is that geometric space is not identical with imaginative space; rather it is constructed either from axioms in " axiomatic geometry," or from measurements in " practical geometry." [37] But it is clear from what has been said that all systems of geometry are projected against the background of homogeneous imaginative space.

It is evident, then, that neither imaginative nor mathematical space, strictly so-called, constitute the space of the universe, for real space is the objective dimensionality of a body or of the sum total of all bodies. But we have no means of determining the real nature of universal space, for all our statements about it are relative to our own position within the universe. Hence our statements about the " immobility " of real space have no absolute meaning. Furthermore even assuming that an absolute immobility could be ascribed to space, this space would have no value in explaining the movement of bodies to one place

[36] Einstein, *The Theory of Relativity* (London, 1924), p. 97.

[17] Cf. Einstein, " Geometry and Experience," in *Sidelights on Relativity,* pp. 27-56.

rather than to another. An undifferentiated " space " cannot account for the difference of movement. It is place rather than space which yields an explanation of locomotion. Physical place, being a qualitative environment, can account for the spontaneous movement of a body to one place rather than to another, for it is within the intentionality of natures to seek a suitable environment in which to thrive and to reach fulfillment. While it is true that place must manifest a certain " immobility," there is no need to think of it as absolute. All that is evident in experience is the relative immobility of natural place; and this is all that is required to explain the movements given in human experience.

The difference between space and natural place has been pointed out in order to show that it is to place as such that natural bodies move. Nature as an active principle is a source of spontaneous movement, of movement which aims at some realization of fulfillment for the being itself. The first requisite for natural bodies is that they be in a suitable habitat; thus if they are not, nature necessarily moves toward an environment conducive to conservation and " self-enjoyment." It is on this basis of natural spontaneity and the final causality of place that the Aristotelian and Thomistic tradition explains gravitation. However, the more popular explanation of gravitation is the mechanical theory of attraction.

II. Newtonian Attraction

A gravitational theory of mechanical attraction is a very simple explanation of the phenomenon of falling bodies. It is very satisfying to the imagination, especially to an imagination which has grown accustomed to accept mechanical explanation. For more than two hundred years students of physics have been taught that bodies fall to the earth because of the gravitational " pull " of the earth; they have been taught to believe that the planets are retained in tlieir orbits because of inertia and the mutual attractions of masses scattered throughout the universe. While this explanation is very satisfying to the imagination, it leaves much to be desired intellectually and experimentally.

Of course, in the present context " attraction " is used in the sense of an efficient cause. Scholastic philosophy also used the term to signify the causality exerted by a desirable good, as when a boy is attracted by candy and cakes. But in the order of final causality the good is said to " draw " or to " attract " only in a metaphorical sense.[38] In the present discussion the term attraction is meant to signify efficient causality, a pulling force, which draws other bodies as a horse pulls a cart.

IIistorical Background

Aristotle and St. Thomas considered briefly the possibility of a mechanical explanation of gravitation, both attraction of bodies by the earth and a forcing down of bodies by a whirling force.[89] But an explanation of gravitation by external forces of either the pushing or pulling kind would destroy the whole concept of nature as an intrinsic principle of the body's own movement, for " nature " is not a power of moving other bodies but a spontaneous source of a body's own proper movement. Furthermore, Aristotle argued that one or the other mechanical explanation could not account for the evident accelerated movement of light bodies upward and heavy bodies downward; each explanation might conceivably explain one type of acceleration, but could not explain both together.

Already in the thirteenth century, however, there were some

[38] " Attractio autem non est propria motio, quia motio non est transitus aliquis, ilia autem attractio solum est convenientia et sympathia unius ad alterum, ut trahatur ab illo, quod non nisi translative dicitur motio." Joannis a S. Thoma, *Curs. Phil., Phil. Nat.,* I. P., Q.XIII, a. 11, *ed cit.,* II, 276b.

[39] Arist., *De Coelo,* 1, c. 8, 277b 1-8; St. Thomas, *In I de Coelo,* 18, nn. 1-4; also *In II de Coelo,* 23, n. 4.

who attributed more than mere final causality to Ihe natural place of bodies. St. Bonaventure believed that over and above spontaneity and the final causality of place one had to attribute an attracting force to natural place and an expelling force to unnatural place.[40] Roger Bacon developed a rather complete " field " theory to account for gravitation. He maintained that besides the generator of bodies and the final causality of place, all bodies and the whole medium are permeated by an immaterial power derived from the heavenly bodies. Neither the natural form of bodies nor the suitability of place, he thought, are sufficient to account for movement; there is needed a *virtus immaterialis,* which fills all space and is concentrated more intensely in the natural place.[41] For Bacon the natural place of a body exercises not only final causality but efficient causality as well.[42] Thus in Bacon's view gravity and levity are diffused immaterial forces which, although derived from the heavenly bodies, are concentrated in various natural places.[43]

[40] " Dicendum quod ad motum gravis non sufficit solummodo gravitas sive qualitas propria, immo concurrit virtus loci attrahentis et virtus loci expellentis et virtus corporis quanti, praeter ilia dua moventia, quae ponit Philosophus, soil, generans grave et leve, et removens prohibens." *In II Sent.* 14, p. 1, a. 3, q. 2; also Richard of Mediavilla, *In II Sent.* 14, a. 2, q. 4 (Brescia, 1591).

[41] " . . . movetur a principio intrinseco, scil. a forma immateriali, quae non est actus ipsius materiae gravis, unde non movetur a forma materiali, quae est actus suae materiae, quia ilia forma non est aliquid praeter hoc, quod sit actus materiae, immo est purus actus materiae, et nulla talis forma sufficit ad hoc, quod aliquid de se movetur; sed movetur a forma immateriali quam participat, quae non est actus materiae ipsius, sed virtus ipsa caelestis minus complete ab ipso gravi participata, a loco autem deorsum magis complete." *Questiones supra libros 8 Physicorum, Lib. Till, Opera hactenus intdita,* fasc. XIII (Oxford, 1935), pp. 398-9; cf. pp. 396- 410; also *Quaestiones supra libros I Physicorum ibid.,* fac. VIII (Oxford, 1928), p. 173 ff,; *Communia Naturalium,* I p. Ill, d. 2, c. 3; *ibid.,* fasc. Ill (Oxford, 1911), pp. 204-5.

[42] " finis non movet secundum veritatem, sed metaphorice." However, " locus est causa motus in genere finis et etiam efficientis excitantis." *Ibid.,* fac. XIII, p. 409.

*' " Dicendum quod gravitas et levitas non solum attenduntur a parte mobilis, sed etiam a parte medii, quia quantum attendit magis ad inferiorem

At least as early as the fourteenth century some conceived place as a total efficient cause of gravitation. Buridan mentions this opinion of *aliqui,* who say that " *locus est causa movens ipsum, grave per modum attractionis, sicut magnes attrahit fer- rum."* [44] He attacks this opinion as contrary to experience, " because if iron is near a magnet, it immediately starts moving more quickly than if it were farther removed; but this is not the case of heavy bodies with regard to their natural place." [45]

The revival of Platonism in the fifteenth and sixteenth centuries popularized the theory that all similar bodies tend to congregate. Copernicus himself proposed this explanation to account for the rotundity of bodies and spheres, as well as for gravitation.[46] This Platonic and Pythagorean theory of gravitation was generally employed by Copernicans who rejected the absolute space of Aristotle.[47]

However at this time many experiments were performed with the magnet. In 1600 Sir William Gilbert of Colchester (1546- 1603), personal physician to Queen Elizabeth, published his influential work *De Magnete,* in which he suggests that gravitation is nothing but the attraction of the great magnet, the Earth.[48] The Englishman, Nicholas Hill, whose *Philosophia Epicurea* appeared in 1601, equated magnetic attraction and

partem medii, tanto magis acquirit de ilia forma diffusa a centro ad circumferentiam per medium, quae continuat partes mobilis et est virtus immaterialis, qua unumquodque fertur ad locum." *Communia Naturalium, loo. cit.*. The Pseudo-Grossetete and John Baconthorp also follow this teaching of Roger Bacon. Cf. A. Maier, *An der Qrenze, ed. cit.,* pp. 181-2.

[41] Buridan, *Quaestiones de Caelo,* II, q. 12, *ed. cit.,* p. 177; cf. p. 179 and IV, q. 2, pp. 248-50.

[45] *Ibid.,* 11, q. 12, p. 179, lines 5-7: "quia si ferrum sit propinquius magneti, statim incipiet velocius moveri quam si esset remotius; sed non est ita de gravi respectu sui loci naturalis."

*' Copernici, *De Revolutione Orbium Caelestium,* lib. 1, cap. 9 (Thorn, 1873), pp. 24-25.

[47] Cf. A. Maier, *An der Grenze, ed. cit.,* pp. 170-173.

[48] W. Gilbert, *On the Magnet, magnetic bodies also, and on the great magnet the earth* (London, 1900), cf. especially I, c. 17, pp. 41-43; VI, c. 4-5, pp. 225-230.

gravitational pull; in proposition 206 he said that " the inclination of things to the earth is nothing other than magnetic attraction *(adhaerentia)*and he maintained that this attraction is exerted reciprocally.[49] The revival of Epicurean atomism by Marke Ridley, Sebastian Basso, Daniel Sennert, and Magnen strongly fostered an attractional theory of gravitation similar to magnet attraction.[50] Pierre Gassendi (1592-1642) enunciated the prevailing atomist theory of gravitation in his popular *Animadversiones in Decimum Librum Diogenis Laertii:* " Gravitas non tam videatur qualitas ipsis gravibus inexsistens, quam vis impressa ex attractione magnetice facta ab ipsa Tellure." [51] He insisted that gravity is not a property of bodies, but rather a force externally impressed upon them by the earth.[62]

However much Descartes favored a mechanical explanation of motion he could not accept the theory of magnetic attraction, for this attraction was explained by the emission of very small and subtle particles which acted like fish hooks pulling bodies to the magnet.[53] Since every extension must be infinitely divisible, Descartes denied the possibility of atomism. Descartes rejected every theory of gravitation which made gravity an innate tendency of bodies, or which explained it by the attraction of the earth.[54] To him the prevailing opinion of " attraction," " sympathy," and " antipathy " employed occult forces which

[*"] Cf. G. McColley, "Nicholas Hill and the Philosophia Epicurea," in *Annals of Science,* IV (1939), 390-405. Quotation cited from p. 396, note 46; cf. also prop. 438, cited on p, 397, note 51.

[r'o] Cf. M. Boas, " The Establishment of the Mechanical Philosophy," in *Osiris,* X (1952), 412-541.

[31] Gassendi, *Animadversiones,* 3rd ed. (Lyons, 1675), I, 167a. See also his *Philosophiae Epicuri Syntagma* (Lyons, 1675), II, 380b-384a.

[t2] *Animadversiones, ed. cit.,* 245a; cf. 243b-255b.

[63] Cf. Gassendi, *ibid.,* I, 245b ff.

[54] " Je ne eroy point non plus que les corps pesans descedent par quelque *qualite ree'lle,* nommee pesanteur, telle que les philosophes l'imaginent, ny aussi par quelque attraction de la terre." Letter LXI, Automne 1635, *Oeuvres* I, 324.

were not conformable to strictly mechanical laws.[55] Descartes' friend, Isaac Beeckman, suggested a possible solution in his *Journal* of 1604-1634. He maintained that throughout the entire universe there is an " ether or subtle matter which is always in motion this, he said, accounts for the gravity of bodies.[56] Descartes constructed an elaborate theory of movement by means of this subtle revolving matter, which he called vortices. The ether which permeates the entire universe constitutes a perpetual whirlpool with various centers of revolution.[57] Bodies, themselves devoid of motion, are impelled by the force of the vortex, so that heavier bodies are forced to the center, while lighter bodies are carried to the circumference. Thus gravity is nothing but the impact of vortex motion forcing heavy bodies to the earth.[58] Descartes took issue with Galileo for assuming gravity to be innate in bodies and for saying nothing about its nature.[59]

Descartes' philosophy became very popular in France through

r'3 Cf. *Principia Philosophiae,* IV, pp. 184-7.

'"“Beeckman, *Journal,* I, 25-20 (1013-14); 381-2 (1626-7); cf. M, Boas, *art. cit.,* p. 434 ff. For a good study of Descartes' indebtedness to Beeckman, cf. A. Kayre, *Etudes Galileenes,* II, " La loi de la chute des corps: Descartes et Galilee" (Paris, 1939), 99-119.

SI Cf. *Prin. Phil.,* P. Ill, *ed. cit.,* pp. 80-202. Compare this with the early Atomist doctrine presented by Aristotle *(De Coelo,* I, c.. 8, 277b 1-8) and Theophrastus (Diels, *Doxog.,* pp. 142-3).

63 Cf. *Prin. Philo.,* P. IV, art. 20-27. The French translation (1647) undertaken by Abbe Claude Picot expresses Descartes' view very clearly: " Toute la pesanteur de ce corps eonsiste en ce que le reste de la matifere subtile qui est en cette portion d'air, a plus de, force a sMloigner du centre de la Terre, que le reste de la matiere terrcstre qui le compose." *Prin.,* P. IV, art. 24, *Oeuvres, IX,* p. 212. In his letter to Claude Picot Descartes says, "I have known none of them (Aristotle, Plato and the Schools) who did not presuppose weight in terrestrial bodies, but although experiment proves to us very clearly that the bodies we call weighty descend toward the centre of the earth, we do not for all that know the nature of what is called gravity, that is, the reason or principle which causes bodies to descend thus, and we must derive it from elsewhere." English trans. by Haldane and Ross, *The Philosophical* IForfcs *of Descartes,* I, 207 (Cambridge, 1911).

58 Letter XCI to Mersenne, Epistolae, Amsterdam 1714, t. 11, pp. 276- 287. Descartes goes so far as to say about Galileo, " in eius libris nihil

the efforts of Mersenne, Arnauld, and Rohault.[60] Jacques Rohault's *Traite de Physique* became a very widely used textbook for students of physics.[61] Cartesian mechanics was introduced into England by A. Digby (1603-1665); and it flourished at the University of Cambridg'e even after the time of Newton.[62] It is interesting to note that the Cartesian system became known as the "mechanical" philosophy.

The supporters of an attractional, or " non-mechanical " theory of gravitation strongly opposed the Cartesian system of vortices. However, little advance was made until Newton published his *Principia Mathematica* in 1687 in which he commonly employed the term *attractio* in explaining universal gravitation. Although Newton carefully avoided any explanation of the " cause of gravity," his use of the term *attraction* immediately suggested the idea of a force similar to magnetism; and readers of the first edition inevitably took it as a defense of the prevailing attractional theory.[63] For this reason Leibniz strongly attacked Newtonian attraction as " a senseless occult quality, which is so very occult that, it can never be cleared up, even though a Spirit, not to say God Himself, were endeavoring to explain it." [64] The popularity of the *Principia* in England was

video, quod ipsi invideam, aut fere nihil, quod promeo vellem agnoscere." *Ibid.,* p. 281.

0 Cf. P. Boutroux, " L'enseignement de la micanique en France au XVII« sifccle," in *Isis* IV (1922), 276-294.

1 Cf. G. Sarton, " The Study of Early Scientific Textbooks," in *Isis,* XXXVIII (1947-8), 137-148.

"2 Cf. Cajori's notes in his edition of the *Principia* (Berkeley, 1947), pp. 629-632.

3 Readers of the first edition had justification for assuming that Newton intended to support the attractional theory. Newton's phrases suggest it. He savs (Book 1, Prop. EX): "If two bodies . . . attracting each other with forces inversely proportional to the square of their distance"; (Book I, Prop. LXIX) "the absolute forces of the attracting bodies"; (Book I, Prop. LXXII) "the attraction of one corpuscle towards the several particles of one sphere"; (Book I, Prop. LXXV) "the attraction of every particle is inversely as the square of its distance from the centre of the attracting sphere," etc.

4 Leibniz letter to Hartsoeker, Feb. 10, 1711, in *Phil. Schriften,* ed.

largely due to Newton's followers, Roger Cotes, Samuel Clarke, Richard Bentley, and others, rather than to any effort on Newton's part. These followers defended Newtonian physics as a refutation of " mechanical philosophy." In the famous preface to the second edition of the *Principia* (1713), Cotes refutes the Cartesian system of vortices and defends the mutual attraction of bodies throughout space, since the ultimate explanation of gravitation cannot be " mechanical." [65] Samuel Clarke, considered to have been the leading English metaphysician of his day, defended Newtonian philosophy for his bachelor's degree at Cambridge (Caius) in 1695. Two years later he made a new Latin translation of Rohault's *Traite de Physique* to which he appended Newtonian notes which virtually amounted to a refutation of the Cartesian text; gravitation is explained as attraction at a distance as against the pushing of bodies by vortices. The Rohault-Clarke treatise became the outstanding scientific textbook in England and America, so that many generations of English and American students (at Yale until 1743) learned Newtonianism in a Cartesian textbook.[66] Voltaire popularized Newtonianism in France through his *Elements de la Philosophie de Newton* (1738); this popular and witty treatise inspired many of the *Encyclopedic* (1751-1780) and did much to overthrow the Cartesian theory in France.[87]

Gerhardt (Berlin, 1887), III, 519; see also his " Antibarbarus physicus pro philosophia reali contra renovationes qualitatum scholasticarum et intelligentiarum chimaericarum," *Phil. Schriften,* VII, pp. 337 ff: Although Christian Huygens accepted the law of the inverse square, he rejected what he supposed to be Newton's theory of attraction and continued his adhesion to the tenet of Descartes, cf. Discourse de la cause de la pesanteur in his *Traits de la lumiire* (Leyden, 1690), pp. 125-180.

”5 Newton's *Principia,* ed. Cajori, xx-xxxiii; cf. Cajori's notes, pp. 632- 637.

•* Cf. G. Sarton, " The Study of Early Scientific Textbooks," in *Isis,* XXXVIII (1947-8), 137-148.

[81] Cf. H. Butterfield, *op. cit.,* pp. 124-158. Voltaire was refused a license to print his book in France by the Chancellor, Henri d' Agriesseau, a Cartesian. Writing to his old friend, Thiriot, Voltaire says, " Perhaps I

Thus the Newtonian theory of " attraction " was promulgated by men, many of them religiously inclined, who wished to overthrow the Cartesian system, considered by many as " atheistic," and to replace it with a " non-mechanical " philosophy. When Newtonian philosophy gained ground in Europe, it was the opinion of his admirers rather than that of Newton himself which became prevalent. Newton's personal opinion was very different from any magnetic-like attraction which caused bodies to fall to the ground. It is almost ironical that the popular theory should have become known as " Newtonian attraction."

Newtons Personal Explanation

Newton was very reticent about expressing his views on the cause of gravitation. He insisted that his *Principia* was designed " only to give a mathematical notion of those forces, without considering their physical causes and seats."[68] In the general scholium to his great work he plainly states,

> Hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and 1 frame no hypotheses; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy.[69]

Newton was induced to take this stand in order to avoid becoming involved in disagreeable controversies, which he always detested.[70] He maintained that his mathematical principles are

should be obliged to him. I dealt with the philosophy of Descartes as Descartes dealt with that of Aristotle ... I would have gained nothing but new enemies." (quoted by Sarton, *art. cit.,* p. 145). The work was first printed in Amsterdam in 1738.

[08] *Principia,* Def. VIII, ed. Cajori, p. 5; also Bk. I, sect. xi (p. 164); Scholium to sect. xi (p. 192) ; *System of the World,* n. 2, p. 550; *Optics,* Bk. II and III.

[e'] Ed. Cajori, p. 547.

[70] Cf. Cajori's analysis of the famous phrase, *ibid.,* note 55, pp. 671-676; also Snow, *Matter and Gravity in Newton's Physical Philosophy* (London, 1926).

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based upon observable phenomena and are not the result of metaphysical speculation, such as was the system of Descartes. Indeed he insisted that his laws of gravitation are independent of any philosophical hypotheses.

> What I call attraction may be performed by impulse, or by some other means unknown to me. I use that word here to signify only in general any force by which bodies tend towards one other, whatsoever be the cause.[71]

Although Newton refrained from declaring clearly the cause of gravitation for lack of experimental evidence, he pursued such an investigation throughout his whole life. About eight years before the publication of the *Principia* Newton wrote some of his suspicions to Robert Boyle, since he was asked to do so.[72] In this youthful period Newton believed that forces such as cohesion, repulsion, fermentation, and gravity might be explained by " an aethereal substance, capable of contraction and dilatation, strongly elastic, and, in a word, much like air in all respects, but far more subtile." [73] This " aethereal substance " is, in fact, similar to Boyle's own use of *effluvium,* or " etherical spirit " as an attracting or repelling force emitted by bodies.[74] The *effluvium,* which was commonly discussed by Gilbert, Gassendi, Boyle, and other adherents of the " corpuscular philosophy," was never clearly defined but was generally conceived as a subtle material substance, either as an elastic ether or as subtle emanations.

In later years Newton seems to have thought of gravity as due to a more immaterial cause. He certainly did not think of

[71] Newton, *Optics,* 3rd ed. (London, 1721), Q. 31, p. 351.

[71] Letter to Boyle, Feb. 28, 1678/9, first printed in *Life of Robert Boyle* by Thomas Bireh, *Works of Robert Boyle* (London, 1744), I, 70-73.

[73] *Ibid..* p. 70.

Cf. Boyle, " Of the Strange Subtility of Effluviums," *Works,* pp. 38-42; 52-3; "Of the Great Efficacy of Effluviums," pp. 18-19, 32-33; "Of the Determinate Nature of Effluviums," pp. 21, 57; "The General History of the Air," p. 641.

gravity as a force inherent in bodies which attracted other masses at a distance. In a letter to Bentley, who was then preparing a course of sermons against atheism,[75] Newton wrote:

You sometimes speak of gravity as essential and inherent to matter. Pray, do not ascribe that notion to me; for the cause of gravity is what I do not pretend to know, and therefore would take more time to consider it.[76]

In another letter he says:

That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man, who has in philosophical matters a competent faculty of thinking, can ever fall into it. *Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial,* I have left to the consideration of my readers.[77]

It is interesting to note that even at this time, Newton allowed for the possibility of an *immaterial* agent to account for gravitation.

In the general scholium added to the second edition of the *Principia* (1713) Newton devotes considerable space to showing rhe immediate dependence of the universe upon Divine Providence. All things and all motions fall under the " dominion " of God Who is eternal and everywhere present. " He endures forever, and is everywhere present; and by existing always and everywhere, *he constitutes duration and space."*[78] Absolute space is not God,[70] but it is the " sensorium of God." In the

[78] Brewster, *Life of Sir Isaac Newton* (London, n. d.), pp. 256-261.

[76] Letter to Bentley, 1692/3, in Edleston, *Correspondence of Sir Isaac Newton and Professor Cotes* (London, 1850), p. 159.

[77] *Ibid.* (emphasis mine). Note also *Principia*, Bk. I, Prop. LXIX, scholium: "whether corporeal or incorporeal," *ed. cit.,* p. 192.

[78] *Principia,* ed. Cajori, p. 545 (emphasis mine).

[78] *Ibid.;* and *Optics* (London, 1721), Q. 28.

thirty-first query, which he appended to the second edition of the *Optics* (1717), Newton insisted that " Particles have not only a *Vis inertiae,* accompanied with such passive Laws of Motion as naturally result from that Force, hut also that they are moved by certain active Principles, such as that of Gravity." [80] In other words, Newton conceives bodies to be purely passive, incapable of accounting for their motion or the motion of other bodies. Therefore, some active principle is necessary for putting bodies into motion and for conserving motion already existing.[81]

A further knowledge of Newton's notion of universal principles of motion may be gained from a consideration of his forerunners in philosophy, principally J acob Boehme and Henry More. Brewster records that Newton was a constant reader and admirer of Boehme, copying many a page from this famous Protestant mystic.[82] Boehme (1575-1624) tried to solve the problem of man's union with God. Since man is a finite being and God, infinite and removed in His heaven, how could man have experience of Him? Boehme answered that God is not removed from this universe but actually constitutes the " soul of nature." Man finds God within himself, for man is a part of the whole of nature and the drama enacted within his own soul merely reflects the drama of the divine essence in the universe.[83]

Henry More, who reintroduced Platonism into Cambridge and directed attention to Boehme, directly influenced Newton's mystical philosophy.[84] For More the whole universe is permeated by spirit, the " immaterial cause " of all motion, co-

*° *Optics,* Q. 31, *ed. cit.,* p. 397.

[81] Cf. Boas, *art. cit.,* pp. 483-520.

[82] Brewster, *Memoirs of Sir Isaac Newton,* 2nd. ed. (Edinburgh, 1860), II, 371.

[83] Boehme, *Morgenrote im Aufgang,* 1612; *Drei Prinzipien gottlichen Wcsens.* Cf. A. Koyre, *La Philosophie de J. Boehme* (Paris, 1929).

[84] Cf. Snow, *op. cit.,* p. 192 ff.

hesion, attraction and repulsion. This spirit is not God Himself; but it is the *anima mundi*.[85] The spiritual substance, which penetrates matter and is the true cause of motion, More identifies with *space,* which he calls the " extension of God, His ubiquity, and His sensorium." Following Boehme, More insists that space is a spiritual and divine reality, representing to us the divine essence. Prof. Snow says,

It is in the law of gravitation through the action at a distance which is a mathematical expression of an empirical fact—which is not by material impact nor action through a material medium—that Newton found a mathematical and empirical confirmation of More's Neo- Platonic philosophy.[86]

Therefore for Newton this gravitational action is not " mechanical," that is, it is not produced by Cartesian impact or material effluvia, but is the action of God operating through space, His " senorium." Like More, Newton attacked the "atheism" of Descartes' doctrine and insisted that although bodies move *as though* based upon mechanical laws, the ultimate cause of movement cannot be mechanical.[87] Referring to the *Principia,* Newton said in a letter to Richard Bentley (Dec. 10, 1692/3),

When I wrote my treatise about our system, I had an eye on such principles as might work with considering men for the belief of a Deity; and nothing can rejoice me more than to find it useful for that purpose.[88]

Concluding his study on Newton's personal philosophy, Prof. Snow says,

The action, as it is described in the law of gravitation, is *direct* and *immediate* in the form of immaterial etheral emanations of spiritual forces through absolute space as its medium, which space is in itself

[85] More, *Immortality of the Soul,* preface; cf. also *Enchiridion Meta- physicum,* chap. 28.
[89] Snow, *op. cit.,* p. 203.
[87] Newton, *Principi,* General Scholium, *ed. cit.,* p. 546.
[BS] Quoted by Cajori, *Principia,* n. 52, p. 669.

an immaterial " sensorium of God " . . . God becomes the " Soul of the World," being immediately substantially present everywhere— although Newton tried to guard himself against Pantheism.[89]

For Newton, then, gravitation is not to be explained by magnetic-like forces inherent in bodies which " attract," but by the direct action of God operating through space. Although the laws of gravitation may be expressed as though bodies mutually attract one another in the inverse proportion of their distance, the cause of gravily, Newton held, cannot be attraction. The theory, therefore, which has been promulgated as Newtonian attraction does not represent the personal philosophy of Newton but of his successors who seized it to combat the " atheism " of Cartesian philosophy or who accepted the *prima facie* meaning of the *Principia.*

Evaluation of Newtonian Attraction

As late as the nineteenth century the theory of gravitational attraction was defended as a " non-mechanical philosophy "; inexplicable forces which attract bodies at a distance were thought to be more conducive to theism and religion.[90] It is clear, however, that from an Aristotelian point of view both Cartesian impulsion and Newtonian attraction are *mechanical* explanations of gravitation. Whether the action be exerted at a distance or through a material medium does not affect the question. The immediate point concerns the agency responsible for a body's movement. In Newtonian attraction two bodies are said to attract each other mutually, but the actual movement of any one of them is *due* to the " attraction " of the other. Thus A's motion is due to B's pull, and B's motion is due to A's pull;

s" Snow, *op. cit.,* pp. 208-9.

"“E.g., Andrea de Guevara v Basoazabal, *Institutionum Elementarium Philosophiae* (Valentia, 1825). Ill, 154-5. This work was the common textbook in Spanish seminaries during the first half of the 19th century; cf. Spanish *Enciclopedia* (Barcelona, 1925), XXVII, 207a.

the pull ot' the earth is said to account for the motion of falling bodies. Aristotelian philosophy considers any universal theory which endeavors to explain all motion by an external agency mechanical in the strict sense of the term. Arisrolelianism acknowledges a natural spontaneity within bodies to account for their own movement relative to the environment; mechanics in the strict sense of the term refers all motion to an external agency. Thus the first point to be made is that Newtonian attraction, as it is commonly understood, is really a mechanical explanation of gravitation.

Furthermore, *Newtonian attraction has never been proved;* that is to say, it has never been proved that bodies fall to the earth because of " attraction " or that planets are retained in their orbits because of solar attraction. The very fact that Newton himself did not believe in a force of this kind clearly indicates that he did not *prove* the existence of such a force. Obviously if Newton did not believe that gravitation could be explained philosophically by the " mutual attraction " of bodies according to the law of the inverse square of the distance, he did not prove that bodies fall because of the earth's " attraction." All Newton wanted to show was that if such an attraction be assumed, then a universal law of gravitation could be formulated to describe all known motions. This is merely a convenient hypothesis upon which to formulate mathematical laws. The validity of a mathematical law should not be confused with the question of physical proof. While it is true that the Newtonian equations are generally adequate in describing celestial motions with considerable accuracy, this in itself does not constitute a proof of physical attraction between bodies. The Newtonian equations which are now used in ordinary astronomy and in engineering would have the same mathematical validity regardless of the physical cause of motion. The tendency of bodies toward the earth would conform to these equations whether the bodies were i) attracted by the earth, ii) endowed with an innate tendency toward an environment, or iii) moved by immaterial forces in space. In other words, as far as the equations are concerned, it makes no difference whether the bodies are mutually " pulled " or not. Therefore, the validity of the equations does not prove the physical cause of gravitation. The important point is that Newton himself did not prove the existence of gravitational attraction within masses; the very fact that Newton did not believe in such an explanation manifests this clearly. Furthermore, the validity of Newtonian equations does not imply the truth of such an explanation, for the equations would have the same validity regardless of the actual cause of gravity. Newton himself makes this evident when he says, " What I call attraction may be performed by impulse or by some other means unknown to me." [91]

Emmanuel Kant was fully aware of the fact that Newtonian attraction was not empirically demonstrated.[92] For him it was more important to justify what he considered to be a universal and necessary *laiv* of physics. This he did by reducing the law of Newtonian attraction to simple " relations of spherical surfaces of different radii." In other words, he reduced the law to spatial relationships between points of given mass. Therefore, for Kant the law is a universal and synthetic judgment because it is derived from the nature of space itself, an *a priori* condition of the mind.[93]

On the " certainty of the proof " of universal gravitation Newton says,

> As when a stone is projected obliquely, that is, any way but in the perpendicular direction, the continual deflection thereof towards the earth from the right line in which it was projected is a proof of its gravitation to the earth, no less certain than its direct descent when

[9*] Newton, *Optics,* Qu. 31, 3rd ed. (London, 1721), p. 351.
[82] Kant, *Prolegomena,* 38.
[83] *Ibid.*

suffered to fall freely from rest; so the deviation of bodies moving in free spaces from rectilinear paths, and continual deflection therefrom towards any place, is a sure indication of the existence of some force which from all quarters impels those bodies towards that place.[94]

A careful analysis of the argument shows that this is not so much a proof of universal gravitation as an assumption of universal gravitation. While the falling of a stone proves some kind of terrestrial gravitation, the " falling " of a planet toward the sun presupposes that the planet tends to move in a " straight line "—a proposition which cannot be proved logically or from the behavior of heavy bodies whirled in a sling. A certain universality may be assumed upon which to construct mathematical laws, but this is not to be confused with the actual proof of such a universality. In this sense Kant is more correct in reducing the law to the structure of mental space than are those who consider universal attraction to be an empirically proven fact.

The Newtonian law of gravitation is usually expressed this way: Every particle in the universe attracts every other particle with a force which is directly proportional to the product of the masses of the particles and inversely proportional to the square of the distance between them.[95] Thus if M and M' denote the masses of two particles and r their distance apart, the force (F) of attraction is equal to

$$G \times M \times M' \, r^2$$

where the constant multiplier G is the constant of gravitation and measures the attraction of two particles of unit mass at unit distance apart. Since the force is always proportional to the mass acted upon, and produces the same change of velocity whatever that mass may be, the change of velocity, or " pull,"

•* Newton, *System of the World,* n. 4, ed. Cajori, p. 552.

•'From A. Ramsey, *An Introduction to the Theory of Newtonian Attraction* (Cambridge, 1949), p. 20.

tells us nothing about the mass in which it takes place, but only about the mass which is " pulling." The accelerations due to different pulling bodies, as for instance that of the sun pulling the earth, with that of the earth pulling the moon, can be compared one against the other to determine the respective masses and accelerations. But as the mass of the earth is always taken as unity, its actual mass is not determined. Astronomical calculations deal only with the acceleration, the product of *G* times mass acting and not with the actual value of *G.*

To weigh the sun, the planets, or the earth, in pounds or kilogrammes, or to find *G,* we must descend from the heavenly bodies to earthy matter and either compare the pull of a weighable mass on some body with the pull of the earth on it, or else choose two weighable masses and find the pull between them.[96]

Over the past century and a half numerous attempts have been made to measure the gravitation pull between two known masses in an effort to determine the value of *G* and *M.* It is commonly thought that these efforts prove the existence of a universal gravitational pull.

Newton himself rejected the possibility of measuring any pull between terrestrial bodies, for the force would have to be incredibly small.

A sphere of one foot in diameter, and of a like nature to the earth, would attract a small body placed near its surface with a force 20,000,000 times less than the earth would do if placed near its surface; but so small a force could produce no sensible effect.[97]

However, many attempts have been made to measure such a force. Two types of experiments have been carried out.[93] The first type, such as the " mountain experiment " of Bouguer,

J. Poynting, *Collected Scientific Papers* (Cambridge, 1920), p. 360.

7 Newton, *System of the World,* n. 22, ed. Cajori, pp. 569-570.

Cf. Newman and Searle, *General Properties of Matter,* 4th ed. (London, 1950), pp. 54-62; see also Poynting, *op. cit.,* pp. 613-644, and his own efforts, *ibid.,* pp. 1-164.

Maskelyne, and others, as well as the " mine-method " of Airy and von Sterueck, tried to measure the horizontal pull exerted on a plumb-line by some determinable density of the earth. But these attempts to utilize large natural masses were of doubtful value due to the difficulty of calculating the quantities and to the impossibility of excluding extraneous influences. The second type of experiment, employed by Cavendish, Eotvos, Poynting, Heyl, and many others, tried to deal directly with the mutual pull between bodies of comparatively small size. In this case the supposed gravitational forces must be so small that refined methods of observation are needed, and all other forces affecting the body must be negligibly small, or accurately measured. One of the principal results of this type of experiment was the realization that a highly sensitive apparatus is needed to determine the " pull "—and therefore very susceptible to disturbing influences." However from a great number of experiments by different methods, due corrections being made, satisfactory values can be ascribed to *G* and *M.* Thus Poynting says,

> In the case of such a constant as that of gravitation, where the results have hardly as yet begun to close in on any definite value, and where, indeed, we are hardly assured of the constancy itself, it is important to have as many determinations as possible made by different methods and different instruments, until all the sources of discrepancy are traced and the results agree.[100]

One important observation, however, must be made about this attempt to measure the minute pull between two small masses. Supposing that the ideal experiment could be carried out, in which all disturbances could be eliminated (which is not the case at present) and a real " pull " detected, *this in itself would*

"* Cf. Poynting, *op. cit.,* pp. 632-3; 621-027; Newman and Searle, *op. cit.,* pp. 59-61.

[100] Poynting, *op. cit.,* pp. 43-44. It must be pointed out, however, that this was written by Poynting in his famous article of 1891, *On a Determination of the Mean Density of the Earth and the Gravitation Constant by Means of the Common Balance.*

not prove that bodies fall to the earth because of that force. There is no necessary connection, logical or philosophical, between a conceivably detectable " attraction " between bodies and gravity by which heavy bodies fall to the earth. The attraction may easily be caused by forces other than gravitation. The point is that the existence of some attractive force does not in itself prove that bodies fall to the earth because of that force; the identity of the two forces would have to be demonstrated. The tendency of mathematics is to unite as many phenomena as possible. This it can do because it *abstracts* from important differences which are found in reality. The mathematician's ideal is to describe all natural phenomena in a single equation; but this cannot be done without abstracting from differences which, to the natural philosopher, are extremely significant. The point is not to deny the validity of mathematical abstractions and universal unifications but to point out that they are abstractions.

From a philosophical point of view one of the principal defects of gravitational attraction—as a philosophical theory—is over-simplification. It assumes that bodies are themselves inert and that all motion must be conferred from without.[101] It considers characterless masses spatially distant from other masses, disregarding the intricate dependencies of every body upon the whole qualitative environment. Inert masses divested of qualities, spontaneity, and finality can certainly be conceived; in fact, such conceptions are very clear and distinct. But it is another matter altogether to make these abstractions the actual structure of reality. This is what Whitehead calls the " Fallacy of Misplaced Concreteness " in which abstractions are given real existence.[102] Whitehead insists that qualitative characteristics

[101] The distinction between inertial and accelerated motion is not relevant here, for inertial motion receives no explanation and accelerated motion is defined by the external force. Cf. " Natural and Compulsory Motion," THE NEW SCHOLASTICISM, XXVIII (1954).

[10g] Whitehead, *Science and the Modem World, ed. cit.,* pp. 64-70, 72 ff.

and intrinsic dependence upon the whole spatiotemporal reality is essentially relevant to every body actually existing. Bergson had previously objected to the " spatialization of time " in which the dynamic reality of temporal duration is turned into a series of static points. In other words, it is easy enough to conceive characterless masses, located in absolute space, isolated in time, and mutually attracting. But this is an over-simplification of the real state of nature as it is perceived in human experience. Relativity physics at least insists upon the essential dependence of every event upon the spatio-temporal environment.

A further philosophical difficulty is offered by the meaning of " gravitational force." Newton insisted very strongly that the force *(F)* operating between two bodies " is one single intermediate action, by which both approach nearer together "; the bodies " do not make two but one operation between two terms." [103] From a mathematical point of view this is precisely all that the quantity F signifies. But when the attractional theory is projected into a philosophical theory, the force of attraction must be considered as a physical reality; and the question arises, " What is it? " and " Where is it? " It is commonly thought that each particle has within itself a " force of attracting " other particles, so that there are as many " forces " as there are particles. But the important point to note is that the resident " force " has nothing to do with the body's own movement; it is posited to explain the movement of *another* body. Thus even though two bodies are said to attract mutually, the actual movement of any one body is explained by the pull of the *other.* Thus the whole function of the resident " force " is to account for the movement of other bodies. It has nothing to do with the body's own behavior. It is this aspect of attractional force which makes it so unintelligible. It is easier to see how an intrinsic force may account for the behavior of the body

[108] Newton, *System of the World,* n. 20, ed. Cajori, p. 569.

actually moving; and, indeed, it is logical to suppose that the performer in nature is itself accountable in some way for its own movements. The great variety of activity we see in the world, the intricate dependencies and variations, are intelligible only if we recognize the complex variety of things themselves— things which are not characterless masses but " events " vested with qualities and woven into the whole fabric of reality. An innate force which has no relevance to the body itself must be characterless and unintelligible, for it is empty and explains nothing. What is it? Leibniz was probably right when he called it " a senseless occult quality, which is so very occult that it can never be cleared up, even though a Spirit, not to say God Himself, were endeavoring to explain it." [104] An inexplicable force such as gravitational attraction may be useful in combating atheism,[105] but it does not contribute to a philosophy of nature. To replace the Aristotelian notion of "nature" by some force of gravitational " attraction " is not only to shift the problem, but to shift it to a position where it can never even be clarified.

In concluding this section we must emphasize again the vast difference between a mathematical science of nature and the philosophy of nature. A mathematical science necessarily abstracts from qualitative differences, causality, and even from the function of nature itself. Within this limited domain there is perfect justification and unlimited possibilities. The philosophy of nature is a distinct and vastly different science, the validity of which depends upon the whole of human experience concerning natural reality. It is only when a mathematical view is projected into a philosophy without recognizing its true foundations, that serious difficulties arise. These difficulties can be solved only by an analysis of meaning and a critical examina-

[105] Leibniz, *Philosophische Schriften,* ed. Gerhardt, III, 519.

[105] De Guevara y Basoazabal, *op. cit.,* pp. 156-7; also sermons of Richard Bentley, cf. Brewster, *Life of Sir Isaac Newton,* pp. 256-263.

tion of the historical and theoretical foundations of the divergent views of reality.

III. Einsteinian Relativity

A thorough examination of Einstein's theory of general relativity would bring out more clearly the point we are trying to defend. But a complete analysis of the modern view of gravitation requires much more than a few pages. However, without even initiating such an attempt, we must draw attention to a few features of the relativity theory of gravitation.

It has already been pointed out that the history of relativity arose because of certain doubts cast upon the fundamental concept employed in Newtonian physics.[106] Even as early as the middle of the last century questions were raised as to the meaning of " inertial motion," for inertial motion requires the existence of some absolute frame of reference according to which the motion of a body is uniform and directed in a straight line. C. Neumann, for example, presented certain paradoxes which follow from the Newtonian laws, but he thought that all difficulties could be removed by considering motion as absolute and determined in relation to a hypothetical body *alpha.*[10'1] Most physicists of the time were inclined to follow him or to postulate an absolute ether. Others, however, like Ernst Mach, preferred to maintain the relativity of all motion and to take issue with the law of inertia as expressed in Newtonian physics.[108] But no satisfactory theory of relativity was reached

[10*]Cf. also R. Dugas, *Histoire de la Mecanique* (Neuchatel, 1950), pp. 419-443.

[107] In our own day this opinion is followed by P. Hoenen, who identifies it with the absolute ether, cf. *Cosmologia,* 4th ed. (Rome, 1949), pp. 64-70, 493-497. " Ita ' corpus alpha,' quod a Neumann fingebatur, sese revelat ut ens reale: aetherem, quo ceterum iam indigemus, ut relationes locales corporum, inter quae sunt stellae fixae, oriri possint." *Ibid.,* p. 496.

[108] E. Mach, *The Science of Mechanics* (Chicago, 1907), pp. 222-238, 567- 573; *History and Root of the Principle of the Conservation of Energy* (Chicago, 1911), pp. 75-85.

until 1905 when Einstein successfully interpreted the Lorentz transformation and the Fitzgerald contraction on the basis of the constant velocity of light. In 1908 the famous mathematician Minkowski made a remarkable discovery concerning the Lorentz formulae. He showed that, although each observer has his own private space and private time, a public concept which is the same for all observers can be formed by combining space and time in a four-dimensional continuum.[109] But this combination of inertial systems, as we have already seen, introduces a " curvature " in the geometry employed. When Einstein extended his theory of relativity to include accelerated systems (general theory of relativity) a non-Euclidean geometry of the Biemannian type was used.[110] According to the general theory no preference is given to any particular observer in either inertial or accelerated motion; by using the " curvature " of Biemannian geometry any event may be described, which if true for one observer, will automatically be true for all. Since the special theory of relativity is considered to be a restricted case of the general theory, all events receive the same description and there is no distinction between inertial and gravitational motion.[111] From one point of view the general theory reduces all motion to gravitational, that is, accelerated motion; for this reason it is commonly called " Einstein's theory of gravitation." But from another point of view all gravitation is reduced to inertial systems; for this reason Sir Edmund Whittaker says, " What Einstein's theory really does is to abolish the old idea of gravitation altogether and to replace it by the idea of inertial frameworks." [112]

In this geometrical picture of the universe the central place

[10“] Cf. R. Dugas, *op. cit.,* pp. 468-473.

[110] H. Wevl, *Philosophy of Mathematics and Natural Science* (Princeton, 1949), pp. 67-110.

[111] See E. Freundlich, *The Foundations of Einstein's Theory of Gravitation* (London, 1924).

'-V1':" ' r >*m* *5tfsK<? *P'f'JiniftO'i.* £"f. *cit.,* p. 115.

is held by the " curvature " of space-time, which represents the actual path, or geodesic of the moving body. The degree of curvature depends upon the intensity of the gravitational field

2, which is specified by the values of *K*^ describing the distribution of motion and matter in that region. Therefore the Einsteinian law of gravitation, G>2 = *K*/12, expresses both the curvature of space-time and the amount of mass present, mass being measured by velocity. In other words relativity presents a purely geometrical picture of physical measurements.

Many popular works on relativity triumphantly speak of the abolition of Newtonian " forces " in their account of gravitation.[113] Gravitation is pictured as the result of the curvature of space-time, or the structure of the space-time continuum. That is to say, a heavy body falls to the ground because of the structure of the field; the field is so curved that the body must take that path. But a difficulty arises from the fact that the so-called curvature of space-time depends upon the presence and motion of the matter being considered. Dr. Whitrow refers to this ambiguity which constantly arises in explaining the theory of relativity.[114]

> The expressions for the energy and momentum of a given material system depend on certain numbers characterizing the structure of space-time, but these numbers in turn depend on the distribution of matter contemplated.[115]

This ambiguity inevitably arises when we try to think of Einstein's system as dealing with the philosophical structure of reality. The tendency is to project the system into a philosophical theory and to think of gravitation as a result of the spatio-

[113] For example, B. Russell, *The AHC of Relativity* (London, 1925); A. Eddington, *The Nature of the Physical World* (London, 1947) ; Einstein and L. Infeld, *The Evolution of Physics* (Cambridge, 1947), (actually written by Infeld).

[114] G. Whitrow, *The Structure of Universe* (London, n. d.), pp. 73-74.

[115] *Ibid.,* p. 74.

temporal structure of the universe. The imagination is tempted to form a mechanical view from the theory of relativity because this is a simple picture of phenomena. But such a view, supposedly based on relativity, is even less tenable than Newtonian attraction. To explain the movement of bodies as a result of the field or the " curvature " of space-time is to present a mechanical explanation without any real basis in relativity theory. In the first place, the so-called " curvature " is not a physical reality at all; it is strictly a geometrical curvature constructed from physical measurements. " It is not the space that is curved, but the geometry of the space." [118] There is no justification for giving that curvature physical existence and ior making it the cause of movement. In the second place, the curvature does not represent merely the field in which bodies move, as though field and mass were two distinct factors, but it represents field (energy) and mass as a single measurement. The basic tenet of relativity is the equivalence of mass and energy, $E = me^2$. In this equivalence there is no theoretical basis for distinguishing body and the surrounding field.[117] What actually results is a geometric continuity of various curvatures, representing a continuous " field " of various intensities. But here " field " is taken in a new sense—as seen through the eyes of geometry. Many popularizers of relativity are perplexed by these difficulties. Bodies and the surrounding environment are obviously distinct realities, yet in relativity theory they are one. There are obviously distinct realities in the universe, yet relativity considers all as a single continuum. There must be some cause of movement, but relativity can offer no cause. The solution of these difficulties lies in the fact that the theory of relativity is not a philosophical theory, but a *mathematical* theory of nature.

[118] E. Whittaker, *From Euclid to Eddington, ed. cit.,* p. 40.

[117] H. Weyl, *Philosophy of Mathematics and Natural Science* (Princeton, 1949), p. 171; cf. also Einstein and Infeld, *Evolution of Physics, ed. cit.,* pp. 255-258.

The important point here is that a mathematical theory and a philosophical theory of nature are *two specifically distinct sciences,* each of which has a determined and limited role in human knowledge. The great value of Einstein's revolution is that it brings out more clearly than ever the determined character of a mathematical theory of nature. The scholastics had always maintained a distinction between natural philosophy and the mathematical sciences of nature, the *scientiae mediae.*[11*] But the sudden development of these sciences in the seventeenth century dislodged natural philosophy and the mathematical theory became the accepted philosophy. That is to say, the valid *mathematical* view was projected into a philosophy by a method of simple transference; abstractions became realities. Qualities, which are necessarily relinquished in mathematical abstraction, were denied also in nature. Functional dependencies in mathematics became mechanical causes in nature; and true causality, which is inconceivable in mathematics, became inconceivable in reality. Some philosophical view of nature has always been necessary for man; and it is obvious that human experience has something to say about its formation. The question is, how much can mathematics *dictate* about such a philosophy? From the seventeenth century to our own day it has been thought that a complete dictatorship exists; that a one to one relationship obtained between mathematics and philosophy. But with the theory of relativity such a one to one relationship is impossible, for if it is carried out, the greatest certainties of experience are rendered nonsensical. The mathematical theory cannot be *simply* transferred to the world of human experience, which is the world of philosophy. Such a simple transference is the " Fallacy of Misplaced Concreteness," to use Whitehead's ac- acurate expression. Therefore, the theory of relativity itself

[11S] St. Thomas, *In Boeth. de Trin.,* V, 3, ad 5, 6, 7; *In II Phys.,* 3, nn. 8-9; Averroes, *In II Phys.,* comm. 18 (Venice, 1574), VI, fol, 55r, etc.

demands a new philosophy, which is not a mere projection of mathematical abstractions but a philosophy which corroborates and justifies the mathematical theory. The relationship between mathematical theory and a true philosophy of nature is not one of identity or simple projection; nor is it one of amicable isolation. Mathematical theory and the philosophy of nature are truly distinct sciences; they differ in foundation, method, knowledges alue, and logical significance. But both constitute valid knowledge of the world we live in.

The fundamental difference between the two types of knowledge may be expressed briefly. The scope of natural philosophy is the world of human experience regarding nature. Whatever is given in human experience must be accepted; and this includes the nature of man himself. The character of mathematical science lies in the nature of mathematical abstraction. A mathematical theory of nature is based on measurements and measurements alone. Whatever cannot be measured is of no use in mathematical theory. But to the natural philosopher even the non-measurable data of experience are important. Since, therefore, mathematics leaves out of consideration the non- measurable data of experience, it is clearly quite distinct from philosophy, which considers the whole of that experience.

From our study of gravitation it is clear that the theory of relativity is incompatible with the philosophical theory of mechanical attraction. Indeed it is incompatible with the whole outlook of all the mechanical philosophies proposed throughout the centuries. For reasons strictly within the domain of mathematical abstraction the theory of relativity forces us to reject the " simple location " of isolated bodies, as Whitehead has pointed out so clearly.[119] It forces us to recognize the reality of temporal emergence, a reality which Bergson fought so hard to defend. Furthermore the theory of relativity forces us to admit

[110] Whitehead, *Science and the Modem World, ed. cit.*

a spontaneity which is *given* and essentially dependent upon the environment. The spontaneity of nature as an active principle, the intricate dependencies of bodies mutually and upon time as well as upon environment, and the internal striving for some end, are all essential to the Aristotelian philosophy of nature. Thus the Aristotelian theory of nature and gravitation finds a satisfactory complement in Einsteinian relativity.

Conclusion

The problem of gravitation is extremely difficult. Why does a body fall to the ground? The mind would like to give a simple reply, but a simple reply is often an over-simplification of a very complex reality. Furthermore, the views which have been given in explaining gravitation involve a particular outlook upon the whole of physical reality; and many of those outlooks have been formed by unjustifiable assumptions, uncritical acceptance of " proof," or even by personal prejudice. Concerning the problem of gravitation, as in other problems, what is needed ia a careful analysis of the meaning implied in various views and a critical examination of their historical and theoretical foundations.

In examining the Aristotelian view of gravitation we have seen that there are two essential factors: an intrinsic principle of spontaneous movement, called " nature," and a suitable environment, or place, which is intended by the body seeking its own fulfillment. Nature must be understood as a principle of behavior actually given in experience. That is to say, " nature " is strictly a relative concept, the content of which is merely that which is actually experienced. " Nature " must not be conceived as an absolute entity lodged in bodies or as an " efficient mover," for such a notion, besides being contrary to the actual teaching of Aristotle and St. Thomas, merely shifts the explanation to an entity which can never be known. As a relative term, " nature " merely signifies the behavior that is actually known and the fact that it is spontaneously given; it is not an entity postulated behind known behavior to which an explanation can be shifted. In other words, the concept of nature involves the acceptance of observed characteristics as necessarily given. With regard to the environment which is sought in natural motion we have seen that it is primarily a qualitative reality which a particular nature needs in order to achieve fulfillment of being. Secondarily, this place must have a certain immobility in order to account for the relational character of movement; but it is only a relative immobility which is justified in our conception of " place." That is to say, spatialization of place fails to account for the actual movement toward one place rather than toward another; and attributing absolute immobility to " place " is without real meaning. Therefore, we must conclude that the natural place of terrestrial bodies is essentially a qualitative environment which has relative immobility, at least as far as our knowledge is concerned.

An examination of the Newtonian view of gravitational attraction shows that Newton himself did not maintain the view promulgated under this name. In his personal view he attributed the cause of gravitation to God Who operated through absolute space, His extension and His " sensorium." But the mechanical laws according to which such gravitation took place were conceived by his followers as representing a mutual attraction of all particles throughout space, so that bodies fall to the ground because of the gravitational pull of the earth. Such a gravitational pull, however, has never been demonstrated by either Newton or his successors. Even the success of the mathematical laws does not prove physical attraction because of the character of mathematical abstraction. With regard to planetary movers we have seen that the law of inertia has not abolished the need of spiritual movers, but rather it has abolished the question of movers. With regard to terrestrial motion we have seen that the validity of the mathematical equations has nothing to do with the actual cause of gravitation, for those laws would have the same validity whether the cause were gravitational " pull," natural tendency, or spiritual forces. Therefore, gravitational attraction is not a physically proved explanation of gravitation.

Furthermore, the whole Newtonian picture of gravitation involves unwarranted assumptions about absolute space, time, and inertial motion, which amount to an oversimplification of a mathematical as well as of a philosophical theory of gravitation. If the whole of human experience is to be taken as a criterion, the philosophical theory of gravitation based upon mathematical theory is untenable for it involves assumptions which conflict with actual experience; and it renders a rational explanation of movement forever impossible by reducing it to an inexplicable force called attraction. The ambiguities of Newton's mathematical theory, moreover, led physicists to reject the Newtonian view of the universe and to replace it with the theory of relativity.

We have pointed out that the theory of relativity is essentially a mathematical theory, describing the measurable state of the universe in terms of non-Euclidean geometry. Although the tendency is to project this theory into a philosophical theory, every attempt to do so distorts the imagination or conflicts with the fundamental tenets of relativity t[1] eory. This apparent irreconcilability brings out most clearly the real difference between a mathematical and a philosophical theory of nature, which rests in the fact that mathematics abstracts from certain values of human experience and constructs its geometry to conform to physical measurements. Therefore, a simple transference of mathematical values into a philosophical theory is impossible; and an equivalent or congruent theory of gravitation is needed to supply the philosophical basis. Provided the distinction of the two sciences, mathematical theory and natural philosophy, be clearly kept in mind, it can be said that the Aristotelian theory of nature and gravitation offers a realistic basis and justification for the theory of relativity in its essential content.

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