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GALILEO AND THE SCIENTIFIC REVOLUTION OF THE SEVENTEENTH CENTURY

MODERN science did not spring perfect and complete, as Athena from the head of Zeus, from the minds of Galileo and Descartes. On the contrary, the Galilean and Cartesian revolution—which remains, nevertheless, a revolution—had been prepared by a strenuous effort of thought. And there is nothing more interesting, more instructive, nor more thrilling, than to study the history of that effort; to write the story of the human mind dealing obstinately with the same everlasting problems, encountering the same difficulties, struggling untiringly with the same obstacles, and slowly and progressively forging for itself instruments and tools, new concepts, new methods of thinking, which will enable it to overcome them.

It is a long and thrilling story; too long to be told here. Yet, in order to understand the origin, the bearing and the meaning of the Galileo-Cartesian revolution, we cannot dispense with throwing at least a glance backwards, on some of the contemporaries and predecessors of Galileo.

Modern physics studies, in the first line, the motion of ponderous bodies, *i.e.*, the motion of bodies which surround us. Thus it is from the effort to explain the facts and the phenomena of common, everyday, experience—the act of falling, the act of throwing—that proceeds the trend of ideas which leads to the establishment of its fundamental laws. Yet it does not proceed therefrom exclusively, or even principally, or in a direct way. Modern physics does not originate from earth alone. It comes, just as well, from the skies. And it is in the skies that it finds its perfection and end.

This fact, the fact that modern physics has its "prologue" and its "epilogue" in the skies, or, to speak a more sober language, the fact that modern physics takes its origin from the study of astronomical problems and maintains this tie throughout its history, has a deep meaning, and carries important consequences. It expresses the replacement of the classic and medieval conception of the Cosmos—closed unity of a qualitatively determined and hierarchically well ordered whole in which different parts (heaven and earth) are subject to different laws—by that of the Universe, that is of an open and indefinitely extended entirety of Being, governed and united by the identity of its fundamental laws; it determines the merging of the *Physica coelestis* with *Physica terrestris*, which enables the latter to use and to apply to its problems the methods—the hypothetico-deductive mathematical treatment—developed by the former; it implies the impossibility of establishing and elaborating a terrestrial physics, or, at least, a terrestrial mechanics, without a celestial one; it explains the partial failure of Galileo and Descartes.

Modern physics, which, in my opinion, is born with, and in, the works of Galileo Galilei, looks upon the law of inertial motion as its basic and fundamental law. It does so quite correctly, for *ignorato motu ignoratur natura,* and modern science aims at the explaining of everything by "number, figure, and motion". True, it was Descartes, and not Galileo—as I believe I have established in my illfated *Galilean Studies*[1]—who for the first time fully understood its bearing and its meaning. And yet Newton is not wholly incorrect in giving full credit for it to Galileo. As a matter of fact, though Galileo never explicitly formulated this principle—nor could have—his mechanics, implicitly, is based upon it. And it is only his reluctance to draw, or to admit, the ultimate consequences —or implications—of his own conception of movement, his reluctance to discard completely and radically the experiential data for the theoretical postulate he worked so hard to establish, that prevented him from making the last step on the road which leads from the finite Cosmos of the Greeks to the infinite Universe of the Moderns.

The principle of inertial motion is very simple. It states that a body, left to itself, remains in its state of rest or of motion as long as it is not interfered with by some external force. In other

[1] A. Koyré, *Études Galiléennes,* Paris, 1940.

words, a body at rest will remain eternally at rest unless it is "put in motion". And a body in motion will continue to move, and to persist in its rectilinear uniform motion, as long as nothing prevents it from doing so.[2]

The principle of inertial motion appears to us perfectly clear, plausible, and even, practically, selfevident. It seems to us pretty obvious that a body at rest will remain at rest, *i.e.*, will stay where it is—wherever that may be—and will not move away on its own accord. And that, *converso modo,* once put in motion, it will continue to move, and to move in the same direction and with the same speed, because, as a matter of fact, we do not see any reason nor cause why it should change either. All that appears to us not only plausible, but even natural. Yet it is nothing less than that. In fact, the "evidence" and the "naturalness" which these conceptions and considerations are enjoying are very young: we owe them to Galileo and Descartes, whereas to the Greeks, as well as to the Middle Ages, they would appear as "evidently" false, and even absurd.

This fact can only be explained if we admit—or recognize—that all these "clear" and "simple" notions, which form the basis of modern science, are not "clear" and "simple" *per se et in se,* but only as a part of a certain set of concepts and axioms, apart from which they are not "simple" at all. This, in turn, enables us to understand why the discovery of such simple and easy things as, for instance, the fundamental laws of motion, which today are taught to, and understood by, children, has needed such a tremendous effort—and an effort which often remained unsuccessful—by some of the deepest and mightiest minds ever produced by mankind: they had not to "discover" or to "establish" these simple and evident laws, but to work out and to build up the very framework which made these discoveries possible. They had, to begin with, to reshape and to re-form our intellect itself; to give to it a series of new concepts, to evolve a new approach to being, a new concept of nature, a new concept of science, in other words, a new philosophy.

[2] Sir Isaak Newton, *Philosophiae Naturalis Principia Mathematica;* Axiomata sive leges motus; Lex I: Corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum, nisi quatenus a viribus impressis cogitur statum ille mutare.

We are so well acquainted with, or rather so well accustomed to, the concepts and principles which form the basis of modern science, that it is nearly impossible for us to appreciate rightly either the obstacles that had to be overcome for their establishment, or the difficulties that they imply and encompass. The Galilean concept of motion (as well as that of space) seems to us so "natural" that we even believe we have derived it from experience and observation, though, obviously, nobody has ever encountered an inertial motion for the simple reason that such a motion is utterly and absolutely impossible. We are equally well accustomed to the mathematical approach to nature, so well that we are not aware of the boldness of Galileo's statement that "the book of nature is written in geometrical characters", any more than we are conscious of the paradoxical daring of his decision to treat mechanics as mathematics, that is, to substitute for the real, experienced world a world of geometry made real, and to explain the real by the impossible.

In modern science, as well we know, motion is considered as purely geometrical translation from one point to another. Motion, therefore, in no way affects the body which is endowed with it; to be in motion or to be at rest does not make any difference to, or produce a change in, the body whether in motion or at rest. The body, as such, is utterly indifferent to both. Consequently, we are unable to ascribe motion to a determined body considered in itself. A body is only in motion in its relation to some other body, which we assume to be at rest. We can, therefore, ascribe it to the one or to the other of the two bodies, *ad libitum.* All motion is relative.

Just as it does not affect the body which is endowed with it, the motion of a body in no way interferes with other movements that it may execute at the same time. Thus a body may be endowed with any number of motions, which combine to produce a result according to purely geometrical rules; and, *vice versa,* every given motion can be decomposed, according to these same rules, into any number of component ones.

Yet, all this notwithstanding, motion is considered to be a *state,* and rest another state, utterly and absolutely opposed to the former, so that we must apply a *force* in order to change a state of motion of a given body to that of rest, and *vice versa.*

It is therefore perfectly evident that a body in a state of motion will persist in this state forever; and that it will no more need a force or a cause by which to explain, or to maintain, its uniform, rectilinear movement, than it will need one by which to explain or to maintain its rest.

Thus, in order to appear evident, the principle of inertial motion presupposes (a) the possibility of isolating a given body from all its physical environment, (b) the conception of space which identifies it with the homogeneous, infinite space of Euclidian geometry, and (c) a conception of movement—and of rest—which considers them as *states* and places them on the same ontological level of being.

No wonder that these conceptions appeared pretty difficult to admit—and even to understand—to the contemporaries and predecessors of Galileo; no wonder that to his Aristotelian adversaries the notion of motion as a persistent, substantial relation-state appeared just as abstruse and contradictory as the famous substantial forms of the scholastics appear to us; no wonder that Galileo Galilei had to struggle before he succeeded in forming that conception, and that great, but somewhat lesser, minds, such as Bruno and even Kepler, failed to reach that goal. As a matter of fact, even today, the conception we are describing is by no means easy to grasp, as anyone who ever attempted to teach physics to students who did not learn it at school will certainly testify. Common sense, indeed, is—as it always was—medieval and Aristotelian.

We must now give our attention to the pre-Galilean, chiefly Aristotelian, conception of motion and of space. I will not, of course, endeavor to give here an exposition of Aristotelian physics; I will only point out some of its characteristic features as opposed to the modern; and I would like to stress, because it is fairly widely misappreciated, that the Aristotelian physics is a very thoroughly thought out, and very coherent, body of theoretical knowledge, which, besides having a very deep philosophical foundation, is, as stated by P. Duhem and P. Tannery,[3] in pretty good accordance—a much better one, indeed, than the Galilean—with the experience, at least with the commonsense experience, of our everyday life.

Aristotelian physics is based on sense-perception, and is therefore decidedly non-mathematical. It refuses to substitute mathematical abstractions for the colorful, qualitatively determined facts of common experience, and it denies the very possibility of a mathematical physics on the ground (a) of the nonconformity of mathematical concepts to the data of sense-experience, (b) of the inability of mathematics to explain quality and to deduce movement. There is no quality, and no motion, in the timeless realm of figure and number.

As for motion—κίνησις—or rather "local motion"—Aristotelian physics considers it a kind of process of change—in contradistinction with *rest,* which, being the goal and the end of motion, is to be recognized as a *state.*[4] Motion is change (actualization or decay) and consequently a body in motion changes not only its *relations* to other bodies, but, at the same time, undergoes itself a processus of change. Motion, therefore, always affects the body which endures it, and, consequently, if a body is endowed with two (or more) movements, these movements interfere with each other, impede each other, and even are, sometimes, incompatible with each other. Besides, Aristotelian physics does not admit the right, nor even the possibility, of identifying the concrete world-space of its well ordered and finite Cosmos with the "space" of geometry, no more than it admits the possibility of isolating a given body from its physical (and Cosmical) environment. In dealing with a concrete physical problem it is, therefore, always necessary to take into account the world order, to consider the realm of being (the "natural place") to which a given body belongs by its nature; and, on the other hand, it is impossible to try to subject these different realms to the same laws, even—and perhaps especially—to the same laws of motion. *E.g., heavy* things descend whereas

[3] P. Duhem, *Le Système du Monde* I (Paris, 1915) 194 sq; P. Tannery, "Galilée et les principes de la Dynamique", *Mémoires scientifiques* VI (Paris, 1926) 399 sq.

[4] For Aristotle rest, being a deficiency, *privatio,* is on a lower ontological level than motion, *actus entis in potentia inquantum est in potentia.*

light ones ascend; terrestrial bodies move in right lines, celestial ones in circles, and so on.

It is evident, even from this brief account, that motion, considered as *processus of change* (and not as *state*), cannot go on spontaneously and automatically, that it requires, for its persistence, a continuous action of a mover or cause, and that it stops dead as soon as this action does not exercise itself upon the body in motion, *i.e.*, as soon as the body in question is separated from its mover. *Cessante causa, cessat effectus.* It follows therefrom, with absolute necessity, that the kind of motion which is postulated by the principle of inertia is utterly and perfectly impossible, and even contradictory.

And now we must come to the facts. I have said already that modern science originated in close connection with astronomy; more precisely, it takes its origin in, and from, the necessity of meeting the *physical* objections formulated by some of the leading scientists of the time against the Copernican astronomy. As a matter of fact, these objections were nothing less than new: quite to the contrary, though presented sometimes in a slightly modernized form, as by replacing the throwing of a stone of the older argument by the firing of a cannon ball, they were fundamentally identical with those that Aristotle and Ptolemy raised against the possibility that the earth moves. It is very interesting, and very instructive, to see them discussed and rediscussed by Copernicus himself, by Bruno, Tycho Brahe, Kepler, and Galileo.[5]

Divested from the imaginative clothing which they gave them, the arguments of Aristotle and Ptolemy can be boiled down to the statement that, if the earth were moving, this movement would affect the phenomena occuring on its surface in two perfectly definite ways: (1) the tremendous velocity of this (rotational) movement would develop a centrifugal force of such a magnitude that all the bodies *not connected* with the earth would fly away, and (2) this same movement would cause all bodies not connected, or temporarily disconnected with it, to lag behind. Therefore, a stone falling from the summit of a tower would never land

[5] Cf. my *Études Galiléennes,* III, *Galilée et le principe d'inertie,* Paris, 1940.

at its foot, and, *a fortiori*, a stone (or a bullet) thrown (or shot) perpendicularly into the air would never fall back to the place from which it departed, because, during the time of its fall or flight, this place would be "quickly removed from below it and rapidly moved away".

We must not smile at this argument. From the point of view of the Aristotelian physics it is perfectly sound. So sound that, on the basis of this physics, it is utterly irrefutable. In order to destroy it we must change the system as a whole and evolve a new concept of movement: The concept of movement of Galileo.

As we have already seen, motion for the Aristotelian is a process which affects the moved, which takes place "in" the body in motion. A falling body moves from A to B, from a certain place, situated above the earth, toward the latter, or, more exactly, towards its center. It follows the straight line which connects these two points. If during this movement the earth revolved around its axis, it would describe, in respect to this line (the line leading from A to the center of the earth) a movement in which neither this line, nor the body which follows it, take any part whatever: the movement of the earth does not affect the body which is separated from it. The fact that the earth beneath it moves away has no effect on its trajectory. The body cannot run after the earth. It follows its path as if nothing happened because, in fact, nothing happened *to it*. Even the fact that the point A (the summit of the tower) did not stay still, but participated in the movement of the earth, does not have any bearing on its motion: what happened to the point of departure of the body (after it left it) has not the slightest influence on its behavior.

This conception may appear strange to us. But it is by no means absurd: it is exactly in that way that we represent ourselves the movement—or propagation—of a ray of light. And it implies that, if the earth were moving, a body thrown from the top of a tower would never fall at its foot; and that a stone, or a cannonball, shot vertically in the air, would never fall back to the place where it went from. It implies, *a fortiori*, that a stone or a ball falling from the top of the mast of a moving ship will never fall at its foot.

What Copernicus himself has to reply to the Aristotelian is very poor. He argues that the unhappy consequences deduced by this latter would follow, indeed, in the case of a "violent" movement. But not in that of the movement of the earth, and to the things that belong to the earth: for them it is indeed a *natural* movement. This is the reason why all these things, clouds, birds, stones, etc., etc., partake in the movement, and do not lag behind.

The arguments of Copernicus are very poor. And yet they bear the seed of a new conception which will be developed by later thinkers. The reasonings of Copernicus apply the laws of "celestial mechanics" to terrestrial phenomena, a step which, at least implicitly, involves abandoning the old, qualitative division of the Cosmos into two different worlds. Besides this, Copernicus explains the *apparently rectilinear* path of the falling body by its participation in the movement of the earth; this movement, being common to the earth, to the body, and to ourselves, remains for us "as if it were non-existent".

The arguments of Copernicus are based on the mythical conception of a "community of nature" between the earth and "earthen" things. Later science will have to replace it by the concept of the physical system, of the system of things sharing the same movement; it will have to rely upon the *physical* and not only upon the *optical* relativity of motion. All of which is impossible on the basis of the Aristotelian philosophy of motion and makes it necessary to adopt another philosophy. As a matter of fact, as we shall see more and more clearly, it is with a philosophical problem that we are dealing in this discussion.

The conception of physical or, rather, mechanical system, which was implicitly present in the arguments of Copernicus, was worked out by Giordano Bruno. By a stroke of genius Bruno saw that it was necessary for the new astronomy to abandon outright the conception of a closed and finite world, and to replace it by that of an open and infinite Universe. This involves the abandonment of the notions of "natural" places and motions as opposed to non-natural, violent ones. In the infinite universe of Bruno, in which the Platonic conception of space as "receptacle" (χώρα) takes the place of the Aristotelian conception of space as envelope, all "places" are perfectly equivalent and therefore perfectly natural for all bodies. Therefore whereas Copernicus distinguishes between the "natural" movement of the earth and the "violent" movement of the things upon it, Bruno expressly assimilates them. All that happens on the earth if we suppose it in movement has, as he explains, its exact counterpart in what happens on a ship gliding on the surface of the sea; and the movement *of* the earth has no more influence upon the movement *on* the earth than the movement of the ship on those of the things that are in the ship. The consequences deduced by Aristotle would only take place if the origin, *i.e.*, the place of departure, of the moving body were external to, and not connected with, the earth.

Bruno states that the place of origin *as such* does not play any role in the determination of the motion (the path) of the moving body, that what is important is the connection—or lack of connection—of this "place" with the mechanical system. It is even possible—*horribile dictu*—for the selfsame "place" to pertain to two or more systems. Thus, for instance, if we imagine two men, one of them on the top of the mast of a ship passing under a bridge, and the other on that bridge, we may imagine, further, that at a certain moment, the hands of both of them will be in the selfsame place. If, at that moment, each of them shall let a stone fall, the stone of the man on the bridge will fall down (and in the water), but the stone of the man on the mast will follow the movement of the ship, and (describing, relatively to the bridge, a peculiar curve) fall at the foot of the mast. The reason for this different behavior, explains Bruno, is simply the fact that the last stone, having shared the movement of the ship, retains in it a part of the "moving virtue" which has been impressed into it.

As we see, Bruno substitutes for the Aristotelian dynamics the *impetus*-dynamics of the Parisian nominalists. It seems to him that this dynamics provides a sufficient basis for his construction. A belief which, as history has shown us, was an error. It is true that the conception of the *impetus,* virtue, or power, which animates the moving body, produces its motion, and uses itself up in this production, enabled him to refute the arguments of Aristotle; at least some of them. Yet it was not able to meet all of them; still less was it able to carry the structure of modern science.

The arguments of Giordano Bruno appear to us perfectly reasonable. Yet in his time they made no impression whatever; neither on Tycho Brahe, who in his polemics with Rothmann repeats imperturbably the old Aristotelian objections (though in a somewhat modernized presentation); nor even on Kepler, who, though influenced by Bruno, deems himself obliged to return to those of Copernicus, replacing, indeed, the great astronomer's mythical conception of the community of nature by a physical conception, that of the force of attraction.

Tycho Brahe flatly denies that a bullet falling from the top of the mast of a moving ship will come down at its foot. He affirms that, quite on the contrary, it will lag behind, and lag behind the more the faster the ship is moving. Just as cannonballs, shot vertically in the air, would never—on a moving earth—be able to come back to the cannon.

Tycho Brahe adds that, if the earth were moving, as Copernicus wants it, it would never be possible to send a cannonball to the same distance to the east and to the west: the extremely rapid movement of the earth, if it were shared by the ball, would impede its own movement and even, if the ball had to move in a direction opposite to that of the movement of the earth, render it utterly impossible. The point of view of Tycho Brahe appears to us pretty strange. Yet we must not forget that to him the theories of Bruno seemed utterly unbelievable and even exaggeratedly anthropomorphic. To pretend that two bodies, falling from the same place and going to the same point (the center of the earth), will follow two different paths, describe two different trajectories, for the reason that one of them was associated with the ship, whereas the other was not, means for the Aristotelian to pretend that the bullet in question *remembers* its past association, knows where it has to go, and is endowed with the power and the ability to do so. Which, in turn, implies that it is endowed with a soul.

Besides, as we have already mentioned, from the point of view of the Aristotelian dynamics—as well as from the point of view of the dynamics of the *impetus*—two different movements always impede each other, which is proved by the well known fact that the speedy motion of the bullet (in a horizontal flight) prevents it from moving downwards and enables it to stay in the air much longer than it would be able to do if we simply let it fall to the bottom.

In short, Tycho Brahe does not admit the mutual independence of motions—nobody did till Galileo; he is therefore perfectly right not to admit the facts, and the theories, which imply it.

The position taken by Kepler is of a quite particular interest and importance. It shows us, better than any other, the ultimate *philosophical* roots of the Galilean revolution. From a purely scientific point of view, Kepler—to whom we owe, *inter alia,* the very term *inertia*—is, undoubtedly, one of the foremost—if not *the* foremost—genius of his time: it is needless to insist upon his outstanding mathematical gifts, equalled only by the intrepidity of his thought. The very title of one of his works, *Physica coelestis,* is a challenge to his contemporaries. And yet, philosophically, he is much nearer to Aristotle and the Middle Ages than to Galileo and Descartes. He still reasons in terms of the Cosmos; for him motion and rest are still opposed as light and darkness, as being and privation of being. Consequently, the term *inertia* means for him the resistance that bodies oppose, not to change of state, as for Newton, but only and solely to movement; therefore, just like Aristotle and the physicists of the Middle Ages, he needs a cause or a force to explain motion, and does not need one to explain rest; just like them, he believes that, separated from the mover, or deprived from the influence of the moving virtue or power, bodies in motion will not continue their movement, but, on the contrary, will immediately stop. Therefore, in order to explain the fact that, on the moving earth, bodies, even if they are not attached to it by material bounds, do not "lag behind", at least *not perceptibly;*[6] that stones thrown upwards come down to the spot they were thrown from; that cannonballs fly (nearly) as far to the west as to the east, he must admit—or find out—a real force which binds them to the earth, and pulls them along.

This force is found by Kepler in the mutual attraction of all material, or at least of all terrestrial, bodies, which means, for all practical purposes, in the attraction of all terrestrial things by the earth. Kepler conceives all these things as bound to the earth by innumerable elastic chains; it is the traction of these chains which explains that clouds, vapors, etc., stones, and bullets, do not stay immobile in the air, but follow the earth in its movement; and the fact that these chains are everywhere explains, in Kepler's opinion,

[6] Cf. *ibid.* 172-94.

the possibility of throwing a stone or firing a cannon *against* its movement: the attracting chains pull the bullet to the East as well as to the West and thus their influence is nearly neutralized. The real movement of the body (the cannonball shot vertically) is, of course, a combination or mixture of (a) its own movement and (b) that of the earth. But, as the latter is common to all the examined cases, it is the former only that counts. It is therefore clear (though Tycho Brahe did not grasp it) that, while the length of the path of a bullet shot to the east and of another shot to the west differ, as measured in the space of the universe, nevertheless their paths on the earth are the same or nearly the same. Which explains why the same force, produced by the same amount of powder, can throw them to the same distance in both directions.

The Aristotelian or Tychonian objections against the movement of the earth are thus satisfactorily disposed of. And Kepler points out that it was an error to assimilate the earth to the moving ship: in fact, the earth "magnetically attracts" the bodies it transports, the ship does not. Therefore, on a ship we need a material bond, which is perfectly useless in the case of the earth.

We need not dwell upon this point any longer: we see that Kepler, the great Kepler, the founder of modern astronomy, the same man who proclaimed the unity of matter in the whole universe and stated that *ubi materia, ibi geometria,* failed to establish the basis of modern physical science for one and only one reason: he still believed that motion is, ontologically, on a higher level of being than rest.

If now, after our brief historical summary, we turn our attention to Galileo Galilei, we shall not be surprised that he, too, discusses at great, and even at a very great, length, the timeworn objections of the Aristotelians. We shall, moreover, be able to appreciate the consummate skill with which, in his *Dialogues on the two greatest world systems,* he marshalls his arguments and prepares for the final assault on Aristotelianism.

Galileo is well aware of the tremendous difficulty of his task. He knows perfectly well that he has to deal with powerful enemies: authority, tradition, and—worst of them all—common sense. It is useless to present proofs to minds not able to grasp their value. Useless, for instance, to explain the difference between linear and radial velocity (the confusion between which is the whole basis of the first of the Aristotelian and Ptolemaic objections) to people not accustomed to mathematical thinking. You must begin by educating them. You must proceed slowly, step by step, discussing and rediscussing the old and the new arguments; you must present them in various forms; you must multiply examples, invent new and striking ones: the example of the rider throwing his spear in the air and catching it again; the example of the bowman straining his bow more and less and thus giving to the arrow a greater or a lesser *speed;* the example of the bow placed on a moving carriage and able to compensate the *speed* of the carriage by a greater or lesser *speed* given to his arrows. Innumerable other examples which, step by step, lead us, or rather his contemporaries, to the acceptance of this paradoxical, unheard of point of view, according to which motion is something which persists in being *in se et per se* and does not require any cause, or force, for its persistence. A hard task. Because, as I have already said, it is not natural to think of motion in terms of speed and of direction instead of those of effort, of impetus, and of momentum.

But, as a matter of fact, we cannot *think* of motion in terms of effort and impetus: we only can *imagine* in this way. Thus we must choose: either to think or to imagine. To think with Galileo, or to imagine with common sense.

For it is thought, pure unadulterated thought, and not experience or sense-perception, as until then, that gives the basis for the "new science" of Galileo Galilei.

Galileo is perfectly clear about it. Thus discussing the famous example of the ball falling from the top of a mast of a moving ship, Galileo explains at length the principle of the physical relativity of motion, the difference between the motion of the body as relative to the earth, and as relative to the ship, and then, *without making any appeal to experience,* concludes that the motion of the ball, *in relation to the ship,* does not change with the motion of the latter. Moreover, when his empirically minded Aristotelian opponent asks him, "Did you make an experiment?" Galileo proudly declares: "No, and I do not need it, as without any experience I can affirm that it is so, because it cannot be otherwise".

Thus *necesse* determines *esse*. Good physics is made *a priori*. Theory precedes fact. Experience is useless because before any experience we are already in possession of the knowledge we are seeking for. Fundamental laws of motion (and of rest), laws that determine the spatio-temporal behavior of material bodies, are laws of a mathematical nature. Of the same nature as those which govern relations and laws of figures and of numbers. We find and discover them not in Nature, but in ourselves, in our mind, in our memory, as Plato long ago has taught us.

And it is *therefore* that, as Galileo proclaims it to the greatest dismay of the Aristotelian, we are able to give to propositions which describe the "symptoms" of motion strictly and purely mathematical proofs, to develop the language of natural science, to question Nature by mathematically conducted experiments,[6a] and to read the great book of Nature which is "written in geometrical characters".

The book of Nature is written in geometrical characters: the new, Galilean, physics is a geometry of motion, just as the physics of his true master, the *divus Archimedes,* was a geometry of rest.

Geometry of motion, *a priori,* mathematical science of nature. . . . How is it possible? The old, Aristotelian objections against the mathematization of nature by Plato, have they, at last, been disproved and refuted? Not quite. There is, indeed, no quality in the realm of number, and therefore Galileo—as, for the same reason, Descartes—is obliged to renounce it, to renounce the variegated, qualitative world of sense-perception and common experience and to substitute for it the colorless, abstract Archimedian world. And as for motion . . . there is, quite certainly, no motion in numbers. Yet motion—at least the motion of Archimedian bodies in the infinite homogeneous space of the new science—is governed by number. By the *leges et rationes numerorum.*

Motion is subjected to number; that is something which even the greatest of the old Platonists, the superhuman Archimedes

[6a] Experiment—in contradistinction to mere experience—is a question we put to Nature. In order to receive an answer we must formulate it in some definite language. The Galilean revolution can be boiled down to the discovery of that language, to the discovery of the fact that mathematics is the grammar of science. It is this discovery of the rational structure of Nature which gave the *apriori* foundations to the modern *experimental* science and made its constitution possible.

himself, did not know, something which was left to discover to this "marvelous Assayer of Nature", as his pupil and friend Cavallieri calls him, the Platonist Galileo Galilei.

The Platonism of Galileo Galilei (a problem discussed by me elsewhere[7]) is, indeed, quite different from that of the Florentine Academy, just as his mathematical philosophy of nature is different from their neo-pythagorean arithmology. But in the history of philosophy there are more than one Platonic school, more than one Platonic tradition, and it is still a question whether the trend of ideas represented by Iamblichus and Proclus is more or less Platonic than the trend represented by Archimedes.[8]

I will not discuss this problem here. Yet I must point out that for the contemporaries and pupils of Galileo, as well as for Galileo himself, the dividing line between Aristotelianism and Platonism was perfectly clear. In their opinion the opposition between these two philosophies was determined by a different appreciation of mathematics as science, and of its role for the constitution of the science of Nature. According to them, if one sees in mathematics an auxiliary science which deals with abstractions and is, therefore, of a lesser value than sciences dealing with real being, such as physics, if one affirms that physics can and must be built directly on experience and sense-perception, one is an Aristotelian. If, on the contrary, one claims for mathematics a superior value, and a commanding position in the study of things natural, one is a Platonist. Accordingly, for the contemporaries and pupils of Galileo, as well as for Galileo himself, the Galilean science, the Galilean philosophy of Nature, appeared as a return to Plato, a victory of Plato over Aristotle.

I must confess that, to me, this interpretation seems to be perfectly sensible.

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[7] Cf. my article, "Galileo and Plato", in the *Journal of the History of Ideas*, 1943.

[8] For the whole doxographic tradition Archimedes is a *philosophus platonicus*.