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THE GENESIS OF THE CONCEPT OF PHYSICAL LAW*

INVESTIGATION of physical laws is among the most important tasks of modern natural science. The naturalist observes recurrent associations of certain events or qualities. He is convinced that these regularities, observed in the past, will hold in the future as well, and he calls them "laws of nature", especially if he has succeeded in expressing them by mathematical formulas. Knowledge of physical laws is of the greatest importance both to the theorist and to the engineer. Whoever knows a law of nature is able to predict and, consequently, to control events: without investigation of laws there is no modern technology. As Western civilization of the modern era is based materially on its technology, so it is distinguished spiritually from the cultures of all other periods and nations by making the investigation of natural laws the basic task of science. To primitive and oriental civilizations the concept of physical law is quite unknown. We shall see that it was virtually unknown to antiquity and the middle ages, and that it did not arise before the middle of the seventeenth century.

It is strange that, in spite of its importance, the genesis of the concept of natural law has not yet been thoroughly investigated. Yet this is but a symptom of the rather unsatisfactory state of research in the field of the history of ideas in general. We must not confuse, however, the juridical term "natural law" with the same term in the sense in which it is used by our naturalists. As is generally known, the juridical concept (*ius naturale, lex naturalis*) desig-

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nates moral commands that are based not on statute law but on reason, divine commandment, and moral instinct, and are common to all nations. It asserts how reasonable beings *shall* behave, whereas natural laws, as they are studied by modern naturalists, state and describe as a mere matter of fact how physical processes *do* take place. Numerous historical inquiries on the former concept have clarified its development.[1] On the other hand, the historical remarks on the concept of physical law are as rare as they are poor. In this field the most valuable preliminary work has been done, up to now, by the authors of a few dictionaries.[2] We shall use the material collected by them and try to increase it in essential points. Since the historical problem we are dealing with is intricate and the literature that must be taken into account is very extensive, we do not make a claim to completeness. The juridical concept of natural law will not be discussed in this article. Yet we cannot disregard it completely, since it cannot be neatly separated from the naturalist's concept in its embryonic stage.

The concept of physical law, as it is used in modern natural science, does not contain any ideas of command and obedience. Yet it obviously originates in a juridical metaphor. In a well governed state there will be laws which are for the most part observed by the citizens. Lawbreaking will occur comparatively seldom, and will be punished when detected. The more powerful the government and the cleverer the police is, the rarer it will be. Let us suppose now the government to be omnipotent and the police to be omniscient. In this ideal case the behavior of the citizens would completely conform to the demands of the lawgiver

[1] *Cf.* the article "Natural Law" in the *Encyclopaedia of the Social Sciences* (New York, 1933), xi, 284ff. (Georges Gurvitch).

[2] The remarks in Ernst Cassirer, *Das Erkenntnisproblem* (2nd ed., Berlin, 1911), I, 367ff. and especially in Franz Borkenau, *Der Übergang vom feudalen zum bürgerlichen Weltbild* (Paris 1934), 15-97 are not quite reliable. The article "law" in Murray's *New English Dictionary* gives most valuable material. Some material is to be found in Littré's French, in Liddell-Scott's Greek, and in Harper's Latin Dictionary. The *Thesaurus Linguae Latinae* has not yet proceeded to the article "lex". The *Vocabulario della Crusca* and Du Cange, *Glossarium Mediae et Infimae Latinitatis,* do not contain material referring to our problem. Hans Kelsen in his article "Die Entstehung des Kausalgesetzes aus dem Vergeltungsprinzip", *Journal of Unified Science (Erkenntnis),* 1940, 69 ff., and his book *Vergeltung und Kausalität* (which will appear in Holland) derives the ideas of causality and physical law from the juridical idea of retribution. Kelsen's valuable paper could not be used in this article.

and laws would be always observed. With such an ideal state nature was compared in the seventeenth century. The observable recurrent associations of physical events, in which the philosophers and scientists of the period began to be interested, were interpreted as divine commands and were called natural *laws*. Thus the concept of natural law originated in theological ideas. Later these non-empirical components fell gradually into oblivion. Our historical investigation, therefore, will have to trace the idea of God as a lawgiver to nature and the influence of this idea on the rising natural sciences. Since one is, generally speaking, inclined to consider contemporary ideas as a matter of course and to ascribe them uncritically to thinkers of the past, we shall bring into prominence the differences from modern thinking before the seventeenth century. Finally we shall try to explain sociologically why the concept of physical law was lacking then and why it developed in the period of Descartes, Hooke, Boyle, and Newton.

2. The roots of our concept go back to antiquity. They consist in a few passages of the Bible and the *Corpus Juris*. A few other ancient ideas are of less importance.

The divine lawgiver is the central idea of Judaism. Since God in addition is the creator of the world, it is easy to understand that the idea arose of his not only having given the moral and ritual laws to his people, but also having prescribed certain prohibitions to the physical world. In a description of God's power and omniscience *Job* 28, 26 says that God made a *law* for the rain (and a way for lightning and thunder). The Hebrew text uses the word *chok*. This is derived from the verb *chokak*, meaning to engrave, and is the same term which is used for moral and ritual laws in the Old Testament. The Septuagint translates very freely "he *numbered* the rain (ἠρίθμησεν)", the Vulgate literally gives *ponebat legem*. The same word *chok*, which however in this context means rather boundary, is used in *Job* 26, 10, which says that the Lord made a *boundary* (Septuagint: πρόσταγμα, Vulgate: *terminum*) to the water, until light and darkness come to an end. Likewise *Job* 38, 10 says the Lord set a *boundary* (*chok*, ὅρια, *terminos*), bars, and doors to the ocean. The following verse 11, without using the term "law", pronounces the wording of a divine command or, better, prohibition: the Lord says to the sea:

"Hitherto shalt thou come but no further; and here shall thy proud waves be stayed". The Hebrew text uses the future to express the command, as is usual in Hebrew and is done also in the Ten Commandments. The Septuagint and the Vulgate too translate literally by the future.

There are a few more analogous passages in the Old Testament. *Psalm* 104, 9 says the Lord has set a *boundary* (*gevol, terminum*) to the waters that they may not pass over; that they turn not again (Hebrew: future) to cover the earth. *Proverbs* 8, 9 even twice uses the word *law* (*chok*), for which in the translations, however, two different terms are used. It says the Lord gave his *decree* (*chok, terminum*) to the sea that the waters should not pass his *commandment* (*chok, legem*). And *Jeremiah* 5, 22 says the Lord has placed the sand for the bound of the sea by a perpetual *decree* (*chok*, πρόσταγμα, *praeceptum*), that it cannot pass it; and though the waves thereof toss themselves, yet can they not prevail; though they roar, yet can they not (Hebrew: future) pass over it.[3]

We have met with the most ancient stage of the concept of physical law in ten verses of the Old Testament. The influence of the Bible on occidental thinking is immense. These verses were quoted through centuries again and again, and have decidedly contributed to the formation of concepts in rising natural science. Viewing the text of the Vulgate (which before the rise of Protestantism was the really effective factor), we twice find the term *law* (*lex*) (*Job* 28, 26 and *Prov.* 8, 29) and once (*Job* 38, 11) the wording of a divine prohibition. In this passage and especially in *Jeremiah* 5, 22 the idea is distinctly implied that the sea, to which the divine command is addressed, wishes to offer resistance but, being too weak, is forced to bow before the supreme power of the Lord. This might be a survival of primeval animism and demonology. As subject to divine commands rain, lightning and thunder, winds, and earth and, especially, the sea are given: the laboratory, which is the very birthplace of the scientific concept of natural law,

[3] The following *Job*-verses are somewhat less important: 28, 25 The Lord made the *weight* for the winds and the *measure* for the waters; 38, 5 He gave the *measures* to earth and stretched a *line* upon it; 38, 8 He shut up the sea with *doors*.—I am greatly indebted to Dr. Boas Kohn, librarian of the Jewish Theological Seminary of America, for his information on the Hebrew text.

still is far remote. The empirical background of the biblical idea, presumably, is the observation that there are certain permanent traits in nature: the waves of the sea advance and recede, when tossed up by a gale, but, eventually, the dividing line between sea and land remains unchanged; wind and weather produce considerable destruction, but, after all, life goes on as usual. These observations refer to certain empirical regularities and would not be so different from the statements made in modern physical laws, if only the regularities were specified. A statement of the circumstances with which, in spite of storms, the situation of the seashore is regularly associated, would make predictions possible and would be a geophysical law. Of course, the authors of the Old Testament were not interested in statements like that. They were inspired by the emotional idea that nature, being ruled by the Lord, *must* behave as it does, and they restricted themselves to the vaguest indications as to *how* nature behaves. The same idea of "must" participated in the formation of the modern concept of physical law, but it was supplemented by the exact description of the empirical facts. In the further development the idea of necessity gradually receded to the background and eventually vanished, the observable recurrent associations of events remaining as the only content of physical laws.[4]

3. To classical antiquity also the idea is not quite foreign that physical processes are superintended and enforced by God or gods as by judges. It is implied as early as in the oldest philosophical fragment in the Greek language that is literally left to us. In the first half of the sixth century B.C. Anaximander says[5] that all

[4] It is remarkable that in the great document of ancient Egyptian monotheism, in Akhenaton's major *Hymn to Aton,* the sun-god Aton is praised as the creator of the universe but not as lawgiver: neither moral nor physical laws are mentioned (*cf.* James H. Breasted: *The Dawn of Conscience,* New York 1933, 281 ff.). This is possibly connected with the fact that, apparently, some social conditions obstructed the development of legislation in Egypt, in contrast to Babylonia which produced the code of Hammurabi. Actually the Babylonian creation-story in the Gilgamesh epic conceives the sun-god Marduk as the lawgiver to the stars. Tablet 7 raises the rhetorical question: "who prescribes the laws for (the star-gods) Anu, Enlil, and Ea, who fixes their bounds?" and explains that Marduk "maintains the stars in their path" by giving "commands" and "decrees" (*cf.* Morris Jastrow: *The Civilization of Babylonia and Assyria* (Philadelphia 1915), 441 last line ff.).

[5] Diels, *Fragmente der Vorsokratiker,* 5th ed., Berlin 1934, 12 B 1.

things arise from the indefinite, the primary substance, and return to it "according to necessity. For they pay fine and penalty to each other for their iniquity according to time's order." The inevitability of a certain physical process is expressed here in juridical terms. Yet gods as lawgivers or judges are not mentioned. They appear half a century later in Heraclitus. "The Sun", Heraclitus says, "will not transgress his measures; otherwise the Erynyes, the bailiffs of Dike (the goddess of justice), will find him."[6] In Anaximander the physical regularity which is interpreted by him half mythologically, half juridically, is still based on metaphysical construction; nobody had ever observed that all things spring from and return to the indefinite. In Heraclitus, on the other hand, the physical statement is based on actual observation, the regular course of the sun being an empirical fact. The regularity itself, however, is presumed as obvious and not described.

With progressing rationalism the scanty indications of a juridical interpretation of the course of nature vanished again in the following period. In the period of the sophists the terms "law" and "nature", φύσις and νόμος, became even opposites, "law" designating everything that is, as a mere convention, artificially introduced by men. Democritus therefore did not know anything of "natural laws", though he attempted to explain all physical phenomena by causes. A century later Aristotle for the same reason never used the law-metaphor.[7] Plato uses the term "laws of nature" only once to characterize the behavior of the healthy in contrast to the sick human body.[8] As a characterization of the healthy and normal state the phrase occurs also in the second century A.D.

[6] *Ibid.*, *22* B 94. Fragment B 114 says: "all human laws are derived from the one divine law. This . . . is stronger than everything." In a somewhat dubious scholium to a medical poem of Nicander Heraclitus is said to have called fire and the sea slaves to the winds "according to divine law" (κατὰ θεῖον νόμον *ibid.*, *22* A 14a).

[7] *Cf.* Bonitz, *Index Aristotelicus*. In *Physics* II, 193a15, Aristotle points out that, if a wooden bed is dug in and sends up a shoot, the shoot is wood but not a bed. He contrasts the perishable and artificial shape of the bed with its permanent and natural material by calling the former a mere "arrangement according to law" (κατὰ νόμον διάθεσιν). This is the strict opposite to the terminology of modern science, in which laws always refer to the permanent traits of the physical processes.

[8] *Tim.* 83e: when a man is sick, the blood picks up the components of the food "contrary to the laws of nature" (παρὰ τοὺς τῆς φύσεως νόμους). *Cf.* Ast, *Lexicon Platonicum*.

in Lucianus.[9] The law-metaphor plays a certain part in the Stoics only. The Stoics were determinists and believed in fate and divine providence. Living in a period of rising monarchies they viewed the universe as a great empire, ruled by the divine Logos. Consequently the idea of a natural law was not unknown to them. For the most part it referred to moral prescriptions based on reason. This Stoic idea is the source of the juridical concept of natural law, which influenced jurisprudence and political philosophy through two thousand years. A few times, however, although the two meanings were never neatly separated, the idea was applied by the stoics to physical processes too. Zeno, the founder of the school, speaks of natural laws in this ambiguous way. His disciple Cleanthes mentions the "law according to which the prince of nature steers the universe" three times in his well known hymn to Zeus. A few verses later the first passage speaks of the obedience of the firmament and the stars; the two other passages refer to moral law. His follower Chrysippus once compares the universe at length to a state and calls reason (λόγος) a *law* (νόμος) to nature.[10] In Cicero *On Laws,* however, the concept of natural law is not applied to physical objects.

The Stoics were not much interested in physical phenomena and never gave instances of natural law in its physical meaning. Such instances appear about the beginning of the christian era in Ovid. Ovid complains once of the betrayal of a friend; his faithlessness is so monstrous, that the rivers will flow uphill, the sun will go backwards, water will produce fire and fire water, in short, "all things will proceed reversing nature's laws (*naturae praepostera legibus ibunt*)".[11] Possibly the idea that the ordinary course of nature must be ascribed to laws is influenced by the Stoics. On the other hand the term "law" in Ovid designates hardly more than the opposite to disorder: in several passages unarranged hair is

[9] *Amores 22*: "the legislature of nature" (ἡ τῆς φύσεως νομοθεσία) is observed among animals, as pederasty is unknown to them.

[10] Zeno: Arnim, *Stoicorum Veterum Fragmenta,* I fg. 162; Cleanthes: *ibid.,* I fg. 537 p. 121 l. 35, p. 122 l. 20, p. 123 l. 5; Chrysippus: *ibid.,* II fg. 528, *cf.* fg. 919.

[11] *Tristia* I, 8 verse 5. In *Met.* 15, 71 (Rim) Ovid says of Pythagoras that he knew all secrets of nature, the origins of snow, lightning, and earthquakes—and the "law according to which the stars move".

called "hair without law (*sine lege*)" by him.[12] A rather isolated passage in the Stoic Seneca, however, seems nearer to the modern usage of language. Seneca is not surprised that comets, being a very rare phenomenon, are "not yet subjected to certain laws (*nondum teneri legibus certis*)"; posterity will be surprised, he says, that we ignored such obvious things.[13] Possibly the Stoic idea of the divine law which is identical with the divine reason is here involved.

At any rate the law-metaphor was not quite unknown to the ancients. This is illustrated by the term *astronomy*. The Greek word *nomos* means law, and the science of the stars could not have been called astronomy if the idea had not existed that the order and regularity of the stellar movements were analogous to human law. The names astronomy and astrology originally were synonymous.[14] As early as the fifth century B.C. the term "astronomy" was familiar to Aristophanes.[15] Some authors, such as Aristotle, Archimedes, Polybius, and Hipparch, use the term "astrology" only. Others, such as Pappus and Seneca, prefer "astronomy". With the increasing influx of oriental superstition magical aspects eventually prevailed in the term "astrology". In the fifth century A.D. the Latin encyclopedias for monks explain "astronomy", literally translating the Greek term, as the science dealing with the "law of the stars (*lex astrorum*)".[16] In the astrological literature of late antiquity sometimes laws of nature are mentioned in an entirely magical sense. Thus the astrologer Vettius Valens (about 150 A.D.), discussing astrological predetermination, speaks of the "legislation" of nature, fate, and the stars.[17]

[12] *Met.* I, 477; *Ars. amat.* III, 133. (On Ovid *cf.* Deferrari-Barry-McGuire, *A Concordance of Ovid,* Washington 1939, *s.v. lex.*)

[13] *Natural. quaest.* VII, 25, 3-5.

[14] On the names "astronomy" and "astrology" *cf.* Pauly-Wissowa, *Real-encyclopädie d. class. Altertumswissensch.,* Stuttgart 1896, *s.v.* Astronomie (Hultsch). In addition *cf. Thesaurus Linguae Latinae s.v.* astrologia, astronomia, astronomicus, astronomus.

[15] *Nubes* 194, 201.

[16] Cassiodorus *inst.* 2, 7; Isidorus *diff.* 2, 152.

[17] *Anthologiae* (Kroll) 5, cap. 9 p. 219 l.26ff. fate (εἱμαρμένη) *has given a law* (νενομοτέθηκεν) to every being, surrounding it with an unbreakable wall; (The term εἱμαρμένη seems to indicate influence of the Stoics); 7 cap. 3 p. 272 l.9ff.: nature (φύσις) *gave a law* (ἐνομοτέθησεν) and encompassed man with the wall of necessity; 9 cap. 7 p. 343 l.33ff.: the stars order the universe by their influence *without ever transgressing the boundaries of legislature* (νομοθεσίας).

4. On the whole one must take good care not to overestimate the similarity of the classical concept of nature and modern natural science. Deterministic ideas were known to the ancients. They were indicated as early as in Heraclitus' doctrine of the fiery Logos who rules the universe and expresses himself in the cyclic change of matter. They were explained in detail in the Stoic doctrine of fate. Nevertheless two points must not be overlooked. First, ancient determinists spoke much more frequently of the *logos* than of the *nomos,* more frequently of the *reason* than of the *law* of the universe. Secondly, the classical determinist doctrine had a tinge of myth and emotion rather than of science and experience. Heraclitus and the Stoics felt the development of the whole universe as necessary and enforced, but were not interested in single physical laws. How far remote from natural science the determinism of the Stoics was is revealed by their giving vaticination as a verification of their doctrine of fate.[18] The superstitious Stoics were determinists. On the other hand the ancient representatives of the scientific interpretation of nature, such as Democritus and Lucretius, who consistently advocated causal explanations of nature, did not use the law-metaphor. It is significant that, whereas modern translations of Lucretius speak of physical laws again and again, this term was unknown to Lucretius himself.[19] Lucretius, following Epicurus, stressed three basic principles of nature. In his poem they play a part analogous to physical laws in modern science: nothing can be produced from nothing, nothing can be annihilated, and the amount of motion in nature is constant.[20] But since all quantitative details are lacking, his "laws of conservation" (as one is tempted to call them) are extremely vague. Moreover, Lucretius does not call them *laws,* but speaks of *principles.* In Epicurean philosophy there are and can be no "laws" of nature, since the gods do not take care of the world.

[18] *Cf.* Arnim, *loc. cit.* vol. 2 cap. 6 § 4 pp. 270-272.

[19] The very complete *Index Lucretianus,* Gotoburgi 1911, by Johannes Paulson, gives only three passages in which the term "law" is used in a non-juridical sense. III, 692 (Munro) states that the human soul is not immortal but is subject to the "law of death (*leti lege*)"; V, 58 states that all things must perish and nothing can break" the laws of time (*aevi leges*)"; and V, 720 denies the existence of chimeras, stating that members of the body can combine only if they are adapted to each other; all animals are bound "by these laws" (*teneri legibus hisce*).

[20] I, 149ff.; I, 216ff.; II, 71 (Munro).

There hardly is room for physical laws in ancient science either. Aristotle makes a few general statements approximately corresponding to laws of motion—sublunar bodies tend to their natural place, celestial bodies move in circles—but they are vague, incorrect, and formulated teleologically. And, of course, they were not called "laws" by Aristotle.[20a] Peculiarly enough only three physical laws were correctly known to the ancients: the law of the lever, the optical law of reflexion, and the law of buoyancy. All three of them are discussed in Archimedes, who, however, never used the term "natural law". Although Archimedes, by far the most eminent physicist of antiquity, certainly verified all three laws by experiments (the law of buoyancy was even discovered by him experimentally), he does not explain them empirically. He rather follows the deductive method of Euclid, starts from postulates, and deduces and proves his physical statements, as if they were mathematical theorems.[21] Even from a mere external point of view his method is Euclidean, in so far as all theorems are numbered as the theorems in Euclid. In a mathematical treatise, however, there is obviously no room for the law-metaphor: Archimedes speaks as little of the "law" of buoyancy as Euclid speaks of the "law" of Pythagoras.[22] The deductive method in Archimedes probably originated in the same remarkable sociological phenomenon which also caused the poor state of physics in antiquity. Ancient civilization was based on slave labor and, in general, their patrons and representatives did not have occupations, but lived on their rents. In ancient opinion, therefore, logical deduction and mathematics were worthy of free-born men, whereas experimentation, as requiring manual work, was considered to be a slavish occupation. Archimedes himself gave expression to this contempt for manual labor and technology.[23] On the whole the development of

[20a] The *Mechanica,* ascribed to *Aristotle,* is probably spurious. It knows the principle of the lever without using the term "law." *Cf.* above footnote 7.

[21] Buoyancy: *de corp. fluit.* I theorems 3—7; lever: *de plan. aequ.* theor. 6f. The law of reflexion is used half a century before Archimedes in Euclid's *Optics,* theor. 19 (Euclid, *Opera,* ed. Heiberg-Menge vol. 7 p. 31); it was known to Archimedes (cf. scholium 7 to Euclid's *Catoptrics, ibid.* p. 348; Archimedes' *Catoptrics* is lost) and is given as theorem 1 in the (spurious) *Catoptrics* of Euclid.

[22] Even today physicists still speak rather of the *principle* than of the *law* of Archimedes.

[23] *Cf.* Plutarch, *Vitae,* Marcellus 14 and 17.

physics was seriously impaired in antiquity by the contempt for manual work, technology, and experimentation. And where physics comes to a standstill in a rather embryonic stage the concept of physical law cannot develop.

Another literary document of antiquity has contributed a few ideas to the modern concept of physical law. This is the *Corpus Juris*. In the introductory sections, both of the Pandects and of the Institutes, the Stoic idea of natural law (*jus naturale*) is explained. In contrast to statute law natural law is based on mere reason, does not change, and is common to all nations. For the most part moral obligations—veneration of God, obedience to parents—are given as examples.[24] On the other hand it is stated that "nature has taught all animals the natural law". From it the intercourse of male and female, begetting and education of the offspring, derive. Obviously in this explanation two different ideas are mixed. On the one hand a statement is made on matters of fact. The empirical fact that mammals propagate by sexual intercourse and take care of their offspring could be called a biological law in the modern meaning of the word. On the other hand these facts are interpreted as results of a sort of legal permission or command, nature or God being the lawgiver.[25] This confusion facilitated the application of the law-metaphor to physical facts even centuries later. In the history of ideas the *Corpus Juris* was almost as influential as the Bible.

5. The Christian Middle Ages did not make any contribution to the development of our concept. We need not enlarge, therefore, on medieval authors. Of course the Bible passages on God as the lawgiver of the universe were often quoted and paraphrased by the church fathers and Scholastics. The ideas also of the Stoics and the *Corpus Juris* on natural law (*jus naturale*) were exerting some influence. A passage in the Christian orator Arnobius (about 300 A.D.) is of some interest, since it gives a few instances of the physical regularities which were explained by the theologians through divine laws. In order to prove that the Christian religion is not anything monstrous Arnobius[26] asks his audience whether

[24] *Dig.* I, 1, 3; *Inst.* I, 2.
[25] *Inst.* I, 2, 11: naturalia iura . . . divinā providentiā constituta.
[26] *Adv. Gentiles* I, 2.

"the laws initially established" have been overthrown since the time the new faith has spread. All instances are given in the form of rhetorical questions. He explains that the elements have not changed their qualities. The structure of the machine of the universe (presumably he has in mind the astronomical system) has not dissolved. The rotation of the firmament, the rising and setting of the stars, have not changed. The sun has not grown cold. The change of the moon, the turn of the seasons and of long and short days, have neither stopped nor been disturbed. It still rains, seeds still germinate, trees still produce and lose their leaves, etc. On the whole he takes his instances from the same field as the Bible and Ovid do; and, of course, there is no question of laboratory physics. A certain predilection for astronomical and cyclic processes is significant. About 400 A.D. St. Augustine[27] developed the concept of God's *eternal law* by which the universe is ruled. Augustine's eternal law stems from the biblical idea of the divine lawgiver, but is an entirely teleological concept. It is identical with the impenetrable providence of God and has nothing to do with the physical laws of the modern scientists.

An extensive discussion in Thomas Aquinas throws light on the Scholastic concept of law and may be analysed here, as far as our subject is concerned. Thomas combines seeming logical exactness with considerable empirical vagueness. A law, according to his definition,[28] is "a rule and measure of acts". Yet we shall see that in one case physical processes and phenomena are also covered by this concept. Thomas distinguishes positive from natural law (*jus naturale*).[29] The former needs promulgation by the lawgiver (and consequently has no bearing on our subject); the latter does not, since "it is promulgated by the very fact that God instilled it into man's mind, so as to be known by him naturally".[30] Later, natural law is defined as "the participation of the eternal law in reasonable creatures".[31] With the "eternal law" (*lex aeterna*) we have transcended the province of human actions. It is "the

[27] *E.g.*, de lib. arb. I, 6; *de civ. dei* XIX, 12.
[28] *Summa Theol.* II, 1 qu. 90, art. 1 resp.
[29] *Ibid.* qu. 71, art. 6, resp. 4.
[30] *Ibid.* qu. 90, art. 4, obj. 1 resp. The agreement with the ancient concept of natural law is obvious.
[31] Qu. 91, art. 2, obj. 2 resp. Here the term *lex naturalis*, not *jus naturale*, is used.

type (*ratio*) of divine wisdom as directing all acts and motions".[32] Thomas explains that God governs the acts and motions of all creatures and is to the world as the artist is to his work. Since in every artist the type of the order (*ratio ordinis*) which is produced by him pre-exists, the type (*ratio*) of the divine wisdom bears the character (*rationem*) of law. So the idea is distinctly expressed that the whole of nature (not only human actions) is subject to law. Two points, however, must be brought into prominence. First, the whole idea that the type of the order of the world pre-exists in God is obviously Platonic. And, secondly, the order Thomas has in mind is a teleological, not a causal one: to the words "divine wisdom", quoted above, he makes the significant addition "moving everything to its due end (*ad debitum finem*)".[33] The distance from the modern concept of physical law is considerable.

Somewhat later[34] objections are discussed, stating that irrational beings cannot be subject to the eternal law, since it cannot be promulgated to them and since they do not participate in reason. The objections are refuted and it is expressly stated that "all movements and actions of the whole of nature are subject to the eternal law". What promulgation is to man "the impression of an inward active principle" (i.e. an Aristotelian entelechy) is to natural things. As the only instance, however, the sea is given, which, according to *Prov.* 8, 29, received a law from God. As to natural law Thomas shares the ambiguity with the *Corpus Juris*. On the one hand he gives moral precepts as instances (evil has to be avoided); on the other he quotes the *Pandects* and explains that sexual intercourse and education of the offspring among animals are based on natural law. Man has some natural laws in common even with inanimate things: not only man, but, as Thomas maintains, every substance strives to preserve its being.[35]

[32] Qu. 93, art. 1 resp (cf. qu. 91, art. 1).

[33] The teleological character of the order of the world is stressed and identified with divine providence I qu. 22, art. 1. *Ibid.* art. 2 obj. 1 and 3 it is explained that Democritus and the Epicureans denied providence (and with it, as we may add, order and eternal law) by ascribing the course of nature to "necessity of matter".

[34] *Op. cit.* qu. 93, art. 5, obj. 1 and 2.

[35] *Ibid.*, qu. 94, art. 2—It is not quite clear whether in Thomas physical regularities belong to natural or to eternal law. In the article just quoted

On the whole Thomas combines the biblical idea of God as the lawgiver of the universe and the ancient concept of natural law with Platonic and Aristotelian ideas. His concept of eternal law, therefore, is entirely teleological and identical with the idea of divine providence. Moreover, our discussion is apt to give a distorted view of his interest in physical regularities. The passages of the *Summa Theologica* in which they are mentioned have been singled out from a very extensive exposition. In the edition of Pope Leo XIII (Rome, 1892) they fill just two pages, whereas his whole discussion of law extends over two hundred and seven pages. Actually the *Summa Theologica* is interested in all theological problems connected with the concept of law and deals with physical phenomena only in so far as they are mentioned in the Bible and the *Corpus Juris*.

6. In discussing authors of the modern era we have to show, first, that the concept of physical law was not known before the seventeenth century. Since numerous authors must be considered, we shall treat them in groups without strictly observing the temporal sequence. We may begin with a few theologians and jurists.

The widely read handbook of jurisprudence *Doctor and Student* by Christopher Saint Germain, published in Latin in 1532 and in English in 1530 and 1531, briefly repeats the opinions of Thomas and the *Corpus Juris* on eternal law, to which the universe is subject, and on natural law. Of the latter two meanings are distinguished, one referring to reasonable creatures only, the other to all creatures.[36] The first meaning is merely juridical, the second covers also biological and physical phenomena. Seventy years later, Richard Hooker advocates the same ideas more extensively in the first chapters of his well known treatise *The Laws of Ecclesiastical Polity,* published in 1592 or 1594.[37] Of course he knows and discusses God's eternal law which is identical with divine providence. As to natural law he separates the natural law of reasonable

a few of them are counted with natural law. In qu. 93, art. 5, on the other hand, they are counted with eternal law. Natural law is restricted to reasonable beings in qu. 91, art. 2, obj. 2.

[36] 15th edition, London 1571, chap. 1 p. 3 and chap. 5 p. 5f. On the first editions cf. S.E. Thorne, "St. Germain's Doctor and Student", *The Library,* IVth series, vol. X (1930) pp. 421-426.

[37] Book I, chap. 3. *Works* (ed. Keble, 7th ed., Oxford 1888) I 200ff.

beings and the natural law which is kept "unwittingly by the heavens and elements".[38] He adds that the latter "hath in it more than men as yet attained to know or perhaps ever shall attain". The very laws of nature, which one century later became the most important subject of scientific investigation, are considered unrecognizable. Hooker quotes the Bible on God as the lawgiver of rain and sea and gives an enumeration of natural laws reminiscent of Ovid and Arnobius.[39] The elements do not change their qualities; the celestial spheres, sun and moon, move regularly; the turn of the seasons, wind and rain, enable the earth to bear fruit. If this order were disturbed, "what would become of man whom these things do all serve"? Obviously Hooker's concept of natural law is still entirely anthropocentric and teleological.

Nothing essential about our problem is contained in Jean Bodin, the most eminent political philosopher of the period.[40] On the other hand an important advance to logical clarification of the law-concept was made in Suarez. In his *Tractatus de Legibus* (1612) the Spanish Neo-Scholastic consistently clings to the distinction between "morals" and "nature"[41] and restricts the term "law", in its proper meaning, to the former. Suarez opposes the definition of law in Thomas Aquinas because it disregards this distinction.[42] "Things lacking reason", he says,[43] "properly, are capable neither of law nor of obedience. In this the efficacy of divine power and natural necessity . . . are called law by a metaphor." The wording of the Scripture (he quotes the well known passages) is said to be in accordance with this explanation. In the section on eternal laws[44] the Bible passages are interpreted in the same way and the statement that irrational and even inanimate beings can be subject to the eternal law is called "a mere mode of expression".[45] The *Corpus Juris* too, when speaking of natural laws among animals

[38] Chap. 3 p. 206. [39] *Ibid.* p. 207.

[40] *De la République* (1577) does not give a general analysis of the law-concept. *Universae Naturae Theatrum* (Francofurti 1597) restricts itself in the preface (fol. 3) to a few generalities on the unchangeable course of the celestial spheres. *Methodus ad facilem historiarum cognitionem* (1566) mentions "some eternal law of nature" according to which everything undergoes a cyclic change: vices follow virtue, ignorance science, darkness light (VII, 36). The astronomical pattern is manifest.

[41] *Moralia et naturalia* II, 2 §12.

[42] I, 1 §1. [43] I, 1 §2. [44] II, 2 §§4, 10, 12, 13.

[45] II, 2 §12: *quaestionem esse de modo loquendi.*

(which, actually, are led "by natural instinct"), makes use of a "metaphor".[46] "The real natural law inheres in the human minds only."[47] Certainly, Suarez knows as little of natural laws in the modern meaning of the word as Thomas did, but his concept of law is considerably more modern. The intellectual change from Thomas to Suarez will be explained in our last paragraph.

7. Beyond the ranks of theological and juridical writers about 1600 natural law is scarcely mentioned. In 1570 John Dee, the alchemist to Queen Elizabeth, mentions that nature "abhorreth empty space so much, that, contrary to ordinary law, the Elements will move or stand".[47a] Montaigne in his *Essais* (1582) uses the term natural law only once and in its juridical sense.[48] Shakespeare once makes Falstaff speak jokingly of natural law in its juridical meaning. In *Cymbeline* (1609), on the other hand, he calls it "nature's law" that the human embryo remains nine months in its mother's womb.[49] Shakespeare thus adds one more instance of a prescientific natural law to the instances in the Bible, Ovid, Arnobius, and Hooker.

The term is used more frequently in Francis Bacon. In his *Advancement of Learning* (1605) Bacon discusses the pyramid of the sciences and gives knowledge of "the Summary law of nature" as its "vertical point".[50] He expresses, however, his doubt whether this knowledge can be attained by man. The theological origin of the idea is revealed by a Latin quotation, speaking of "the work operated by God from the beginning to the end". In the *Novum Organum* (1620) the term "law" is very often used synonymously with "form". "When we speak of forms", Bacon says,[51] "we mean nothing else but those laws and determinations of the pure act which set in order and constitute a simple nature. . . . The form of heat and the law of heat are the same thing." These "laws" or "forms" were treated as rather mysterious entities by Bacon him-

[46] I, 3 §8. [47] I, 1 §9.

[47a] Preface to Billingsley's Euclid translation, Sig. dj ro.

[48] *Essais* 2, 12: there is no natural law, since the customs of the various nations are different (ed. Villey, Paris 1930, vol. II p. 494f.).

[49] *2 Henry IV,* III, 2 last lines; *Cymbeline* V, 4 verse 37.

[50] Works (Spedding and Ellis) VI 222.

[51] *Nov. Org.* II, 17 (Fowler, 2nd ed., Oxford 1889), p. 389. 6f. *cf. ibid.* I, 51 p. 228f., I, 75 p. 268; II, 2 p. 346; II, 4 and 5 p. 348ff.; II, 17 p. 399; II, 52 p. 597.

self. They are nearer to alchemy than to modern science, are considered by Bacon as the very essences of things and qualities, and are, obviously, survivals of the Aristotelian and Scholastic *formae substantiales*. The only question is how Bacon came to introduce the term "law" for this medieval concept. As the passage in the *Advancement of Learning* indicates, the Bible suggested this expression. Thus Bacon's terminology again reveals the theological roots of the concept of physical law. How far remote, however, Bacon still is from this concept is illustrated by the remarkable fact that he was ignorant even of the law of the lever.[52]

8. Now we have approached the period of rising natural science and it is time to look for the concept of natural law among its pioneers. The result, however, differs considerably from expectation.

Copernicus (1543) speaks of the "machine of the world founded by the best and most regular artificer",[53] but never of laws of this machine or of the solar system. The same holds of William Gilbert, who was among the earliest adherents of Copernicus in England. In his *De Magnete* (1600), when discussing the precession of the vernal point, he once speaks of a "rule and norm of equality" that may be ascribed to complicated astronomical movements by some hypothesis.[54] This corresponds almost exactly to the modern concept of physical law, though the term is not used. The isolated passage must not be overestimated. *De Magnete* is the first printed book on experimental physics by a scholar. Gilbert makes careful and numerous empirical observations, but still restricts himself in his theoretical explanations to metaphysical generalities on the animation of the globe and the magnet. In his extensive discussions of magnetic phenomena he once makes three rather vague statements which may be called magnetic laws.[55] They are, how-

[52] *De Augmentis* V, 3, 10.
[53] *De Revolutionibus,* preface to Paul III. Thorn edition (Curtze) p. 5 l.32.
[54] *De Magnete* VI, 9 p. 237.
[55] *Ibid.* II, 32 p. 99. Since they are for the most part overlooked, they may be discussed here. They state that equal loadstones approach each other with equal "incitation". The same holds for both magnetized and non-magnetized iron bodies.—In Gilbert's time theoretical mechanics in general and an exact concept of force in particular were not yet developed. His three laws compare magnetic forces dynamically by the "incitation" of the movement they cause, "incitation" probably being something vague between velocity, impulse, and kinetic energy. He restricts himself to the case of equality of forces and

ever, given in a short chapter, entitled "some problems", are not referred to further, and are called neither laws nor rules.

An abundance of physical laws is to be found in Galileo. In his manuscript *Le Mecaniche,* composed in about 1598 when he was a young professor in Padua, he discusses the lever, the windlass, and the pulley, and gives the conditions of equilibrium in quantitative terms.[56] Yet the term "law" is never used. His *Discourses and Mathematical Demonstrations on two new Sciences* (1638) laid the foundation stone of modern mechanics and mathematical physics in general. In this work[57] he discusses the dependence of the period of a pendulum on its length, the dependence of the number of vibrations of a string on its length, tension, cross section, and specific gravity, in quantitative terms. He does not express these relations by mathematical formulas, but paraphrases them in words. And he never calls them "laws" or "rules", but occasionally refers to the law of the pendulum as a "proportion".[58] The same work contains his greatest achievement, the statement of the law of falling bodies, and his discussion of projection.[59] Again the terms "law" and "rule" do not occur. The results are given in the form of numbered theorems, propositions, lemmata, and corollaries, connected by mathematical demonstrations. Though the investigation is a model of experimental research, its literary exposition clings to the traditional deductive form of Archimedes and Euclid.[60]

Apparently Galileo did not know the term "natural law". When he occasionally mentions the law of the lever in the *Discorsi,* he paraphrases it by a long sentence and refers to it, a few lines later, as the "ratios" (*ragioni*) of the lever and as "that principle"

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does not give a real measurement. His laws correspond approximately to Newton's third law (action equals reaction).

[56] *Opere,* edizione nazionale, II, 147ff.

[57] *Ibid.* VIII, 139ff. and 143ff.

[58] *Ibid.* 139, l.29ff.

[59] *Ibid.* 197ff. and 288ff.

[60] *Ibid.* 266 Archimedes, Euclid, and Apollonius are referred to. The deductive expositions are given in the Latin, the experiments in the Italian, sections of the *Discorsi.* This is a survival of the social prejudice against manual labor. Respectable science deduces and uses the Latin language; experimentation is the business of vernacular speaking craftsmen.—*Ibid.* pp. 156-165ff. he discusses quantitatively, how the strength of a pillar depends on its breadth, weight, and length. The results are not called "laws", but are numbered as propositions and corollaries on the margin.

(*questo principio*).[61] It is significant that the modern English and German translations often speak of physical laws, when Galileo expresses himself differently. When the translator speaks of the most perfect laws of nature, Galileo only speaks of the "most orderly world" (*mondo ordinatissimo*) ; when the translator denies that anything can happen against the laws of nature, Galileo only says "against nature" (*contro a natura*).[62] Galileo came nearest to the law-metaphor when he discussed theological objections. A few years before the condemnation of the Copernican doctrine by the church he defended the rights of free investigation in a letter to Castelli (1613). The Holy Writ, he writes,[63] and Nature both originate in the Divine Word, the former as a dictation of the Holy Ghost, the latter as "an executor of God's orders" (*ordini di Dio*) —orders, not laws.

The law-metaphor originates in the Bible, but what was new in Galileo's investigation was not influenced by the Bible. It cannot be verified here that Galileo's concept of science sprung from the method of contemporary technology, since the verification would imply an analysis of the origin of modern natural science in general. The superior craftsmen of the sixteenth century, the artists and military engineers, were accustomed not only to experimentation, but also to expressing their results in empirical rules and quantitative terms. The substantial forms and occult qualities of the scholars were of little use to them. They looked for serviceable, and, if possible, quantitative rules of operation when they had to construct their lifting engines, machines, and guns. In the manuscripts of Leonardo da Vinci (about 1500) over and over again such quantitative rules of operation are given. They are usually formulated in the manner of cooking recipes: "If you want to know", Leonardo says explaining the drawing of a bent lever, "how much more than MB AM weighs, look how many times CB is contained in AD" etc.[63a] The mathematical function-

[61] *Ibid.* VIII, 152 l. 3ff., 13 and 16 (*Dialogo*).
[62] *Ibid.* VII, 43 l.6 (*Dialogo*) and VIII, 60 l.14 (*Discorsi*).
[63] *Ibid.* V, 282 l.30. Literally conforming his letter to the Grand Duchess of Tuscany (1615) *ibid.* 316 l.25.
[63a] Ravaisson-Mollien, *Les Manuscripts de Léonard de Vinci,* Paris 1891, vol. 6, Ms. 2038 fol 3r. On the other hand Leonardo, discussing the propagation of light, says in a more poetical and theological vein: "O marvellous Necessity . . . by a supreme and irrevocable law every natural action obeys

concept, applied to physical phenomena, appeared for the first time in the literature of mankind in a prescription for gunners. In 1546, eighteen years before the birth of Galileo, Tartaglia, in a booklet on gunnery, fortification, and applied mathematics, pointed out that an elevation of 25° gives a gun a certain range; if the elevation is 30° the range is "much greater", if 35° "greater", if 40° "somewhat greater", if 45° "a bit greater", if 50° "a bit smaller", if 55° "somewhat smaller" and so forth. One can make a table of the ranges, Tartaglia continues, and give it to the officer; the officer can tell the gunner how to level the gun, but the table itself can be kept secret, just as "the apprentices can carry out the prescriptions" according to the directions of the apothecary. Tartaglia was a quite poor, selfeducated mathematics teacher and adviser to gunners, architects, and merchants, ten pennies a question. He was not a university scholar but belonged with the superior artisans.[63b]

These quantitative rules of the early capitalistic artisans are, though they are never called so, the forerunners of the modern physical laws. Galileo set the investigation of functional relations between physical quantities as the main task for science.[64] The concept of physical law and its paramount scientific importance was perfectly familiar to him. But the term "law" was never used by him, since he cared more for his experiments than for the writings of the theologians and the *Corpus Juris*.

Stevin and Pascal proceeded in a way similar to Galileo's: both were entirely familiar with the concept without ever using the term "natural law". Stevin (1585 and 1608) views the mechanical problems with the eyes of an engineer. Still he explains important laws of statics (the mechanical advantage of the inclined plane, the principle of Archimedes) in the deductive way of Euclid, giving numbered definitions, postulates, and propositions.[65] Pascal

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thee by the directest possible process . . . thou by thy law containest all effects to issue from their causes in the briefest possible way" (*Codice Atlantico,* ed. Pinnati, Milan 1901, III, 1161).

[63b] *Quesiti et inventioni* I, 1; "ten pennies" (scudi) *ibid.* III, 10.

[64] Galileo himself declared the problem of the curve of projection (which puzzled the gunners of the period) as the starting point to his study of the law of falling bodies. *Opere,* letter 2300 to Marsili (1632), XIV, 386.

[65] *Hypomnemata Mathematica,* 1608, vol. 4, *Statics.*

(1663) expressly rejects the doctrines of abhorrence of vacuum and of occult qualities.[66] He knows that all machines satisfy the principle of work, that the heights of two liquids in a communicating tube are inversely proportional to their densities, and discusses the principle of Archimedes—all this without ever speaking of laws.[67] Occasionally he mentions meteorological "rules" for the variations in the height of the barometer.[68] His ignorance of the law-metaphor is remarkable, since he was intently dealing with theological problems; his physical and his religious interests seem to have been separated by an impenetrable wall. The doctrine of natural law in the juridical meaning, however, was known and agreed to by him.[69]

9. Kepler seems to be the first naturalist who, occasionally, used the law-metaphor. His well known three laws of planetary movement, however, never are called laws by him. The first and second, given in his *Astronomia Nova* (1609), are paraphrased in long expositions;[70] the third, published in *Harmonices Mundi* (1619), once is called a "theorem".[71]

On the other hand Kepler frequently compares the inverse proportion of velocity and solar distance of a planet (which is the basis of his second law) to the analogous proportion between the force and arm of a balanced lever. And in this context he sometimes speaks of the "law", more frequently however of the "ratios", of the lever.[72] Sometimes he uses the term law as almost synonymous with measure or proportion. Once he draws a diagram in order to clarify the question "which laws are required" in representing a planetary orbit. Or he remarks that the earth receives "the laws of its celerity and slowness" in proportion to its approach to and its movement away from the sun.[73] Other passages are

[66] *Traitez de l'équilibre etc. Œuvres* (ed. Brunschvicg-Boutroux III, 224 and 254.
[67] *Ibid.* 163, 171, 178.
[68] *Fragments, Œuvres,* II, 520.
[69] *Pensées, Œuvres* XIII, 216 no. 294.
[70] III cap. 59f.
[71] V cap. 3 (*Opera,* ed. Frisch V, 280).
[72] *Astr. Nov., Opera* III, 391: *lege staterae; Epitome Astr. Cop. Opera* vol. VI, 373: quae sunt huius celeritatis et tarditatis leges et exempla? Exemplum genuinum est in statera.—Rationes staterae; *Astr. nov. Opera* III, 300, 390, 391 and *Ep. Astr. Cop., Opera* VI 405.
[73] *Astr. Nov. Opera* III, 315: quibus legibus opus sit ad . . . orbitam repraesentandam; *ibid.* 149: leges celeritatis et tarditatis suae accipere ex modulo accessus . . . et recessus.

nearer to modern terminology. He discusses the spread of forces from the sun and points out that the force diminishes either with the second or with the third power of the distance; this follows "from the very law of emanation", for the force, although being immaterial, is "not free from geometric laws".[74] The background of these expositions is formed by theological ideas. Kepler ends a long astronomical discussion with the remark that some "geometrical incertitude" is implied in the problem. "And I do not know", he adds,[75] "whether this is not repudiated by God himself, who, up to now, is always found (*deprehenditur*) to be proceeding in a mathematical way." From this the Pythagorean doctrine in Kepler's *Harmonices mundi* follows quite consistently, stating that God ordered the universe according to the principle of "geometrical beauty". In a letter to Fabricius (May 1605) Kepler reports that he has most laboriously treated the irregularities of the planetary movement "until they were at last accommodated to the laws of nature".[76] It can hardly be doubted that these laws of nature are nothing else than the divine principles of mathematical beauty.[77]

Kepler was at the same time a Pythagorean and a devout Protestant. His first work, the *Mysterium Cosmographicum* (1596), explained the solar system by means of the five Platonic bodies. His *Harmonices Mundi* (1619), which gave the third law among numerous mathematical relations without any physical importance, advocated the harmony of the spheres. He considered it his scientific task to reveal the mathematical order of the universe, to describe its beauty, and to praise God as its founder. Thus he changed the divine laws of the Bible into geometric prescriptions and used the term "law" almost as synonymous with ratio or proportion. He is distinguished from the numerous Neo-Pythagoreans of the late Renaissance by his care for empirical observation and his mathematical genius which succeeded in discovering the regularities in apparently most irregular phenomena. His interpretation of these laws, however, still is animistic. After having stated "the laws and quantity of the variation" of the planetary velocity, he

[74] *Ibid.* 303. [75] *Ibid.* 397. [76] *Opera* III, 37.

[77] In his *Ad Vitellionem Paralipomena* (1604, *Opera* II) he gives many optical laws (not yet the law of refraction). The term "law" is never used; they are numbered as propositions and corollaries in the manner of Euclid.

raises the question "whether the laws are such, that they probably can be known to the planet". He explains extensively that the movement of the planet probably results from the "wrestling" of its animal and its magnetic faculty, the "mind" of the planet perceiving a certain angle and reckoning its sine. This sense-perception without eyes does not seem impossible at all to him. For an analogy he refers, on the one hand, to the sublunar bodies adjusting their behavior to the stars and, on the other, to his own mother who has born all of her children under the same constellation without making use of eyes.[78] Obviously Kepler's concept of law is quite near to astrology.[79]

The concept of natural law occurs fully developed in Descartes. In his *Discours de la Méthode* (1637) Descartes starts the short exposition of his new philosophy of nature with the declaration that he has found "laws which God has put into nature". God has impressed the ideas of them on the human mind in such a way, that their universal validity cannot be doubted.[80] In the following[81] it is explained that God, after the creation of matter, let nature develop from chaos in accordance to these laws. Even if God had created several worlds the "laws of nature" (*loix de la nature*) would be valid in all of them. The laws themselves, however, are not given in the *Discours*. When discussing the circulation of the blood Descartes only mentions that "the rules (*règles*) of nature are identical with the rules of mechanics".[82] As an appendix to the

[78] *Astr. nov.* cap. 57 (*Opera* III, 392-397); Cf. *ibid.* cap. 39 pp. 317-320. The astrological passage p. 319.

[79] The question how the planets manage to move regularly results from the elimination of the solid spheres by Tycho Brahe, as Kepler himself states (*ibid.* p. 319). The same problem had been discussed a few years before (1591) by Patrizzi (*Nova de Universis Philosophia,* Pancosmia 12; 2nd. ed. Venice 1593, fol. 91 col. 3). Though Patrizzi does not speak of laws and contrasts only the "order of the world" to chaos, he is quite near to an embryonic concept of natural law. Like Kepler he refers to the *animae rationales* of the stars obeying "God's providence" and compares them to manoeuvring soldiers, obeying the order of the officer. God corresponds in this metaphor to the officer and the natural laws to his orders.—Patrizzi's military metaphor reveals the importance of social changes for the history of ideas. He himself gives ancient Spartans and Macedonians as examples. A medieval author, however, could not have thought of the military metaphor, since battles in the feudal period consisted of a multitude of duels with very little discipline. Obviously Patrizzi is inspired by the new infantry tactics which, in early capitalism, had developed from the armies of Swiss mercenaries.

[80] Disc. 5 (*Œuvres,* ed. Adam-Tannery, VI 41).

[81] *Ibid.* 42f. *cf.* 45 l. 11ff.

[82] *Ibid.* 54 l. 26f.

Discours Descartes published his *Dioptrique*. There the laws of reflexion and (for the first time) of refraction are discussed. In connection with the latter the term "law" is used too.[83]

The *Principia Philosophiae* (1644) is the new work announced in the *Discours*. There Descartes explains in the second book[84] that the product of mass and velocity remains constant in nature, since God and his operations are perfect and immutable. "And from this immutability of God", Descartes continues, "some rules or laws of nature which are the causes . . . of the various motions, can be understood."[85] He gives three laws, the first and second expressing the law of inertia, the third stating that in every impact "one body gives as much of its movement to the other as it loses". They are alternately and repeatedly called laws and rules. The immutability of God and his operations and the creation of the world are mentioned several times.[86] In order to make quantitative calculation of movement possible Descartes adds seven "rules" of impact which, however, are partly incorrect.[87] He closes the section with the remark that in his opinion no other "principles of physics" are necessary in the explanation of all phenomena in nature.[88] Being a mechanist, he believes he has exhausted not only all mechanical but all physical laws by his enumeration.

Descartes discusses natural laws in a few more places. In the third book of the *Principia* he states that it is a "law of nature" that all bodies moving in circles try to recede from the centre.[89] He immediately explains that he does not intend to ascribe minds to moving bodies by this statement and thus shows how carefully he avoids the vitalistic concepts of the middle ages.[90] A quantitative determination of the centrifugal force, however, is not yet given. Near the end of the work he states, summarizing, that it has discussed "what must follow from the mutual impact of the bodies according to mechanical laws, confirmed by certain and everyday experiments".[91] His laws or rules of impact are discussed

[83] *Œuvres* VI, 100 l. 27f. The law of refraction was discovered by Snell in 1621 and first published by Descartes.
[84] *Princ. II* §36. *Œuvres* VIII 61.
[85] *Ibid.* II §37 (p. 62). In the *Discours* also Descartes had stated that his laws of nature are derived from no other principle but God's perfection (VI 43 l. 5).
[86] *Ibid.* II §§37-42.
[87] II §§45-52.
[88] II §64.
[89] III §55.
[90] III §56.
[91] IV §200.

frequently in his correspondence, among others in a letter to Christian Huyghens.[92]

Descartes was a consistent mechanist. Convinced that in the last analysis all physical phenomena consist in movement and impact, he strictly denied any teleological, anthropocentric, or animistic explanation of nature. The soullike substantial forms of the Scholastics were discarded by him. On the other hand he was a devout Catholic. Adapting the traditional ideas of God and soul to the new mechanistic science, and stressing the idea of indestructibility, he created a new concept of substance, able to cover both matter and mind. To substantial souls he clung as firmly as he eliminated all soullike components from the physical world. Thus he introduced into human thinking a dualism of matter and mind, of outer and inner world, which in similar rigor had nowhere and never before existed. There is hardly any other philosopher as characteristic of the modern era and Western culture as is Descartes.[93] When we compare with other cultures and omit details, all modern Western philosophers appear more or less as Cartesians, since all of them deal with the mind-body-problem and the problem of the external world. At the end of the nineteenth century only, since the breakdown of mechanistic physics (and with the fading of religious orthodoxy), the influence of Cartesian metaphysics is beginning to decline.

The Cartesian concept of the world combined the basic ideas of the Bible and the new physics. By the same combination of ideas he became the most important pioneer of the concept of natural law which influenced the thinking of the modern era as strongly as his dualism. Like Galileo, he took over the basic idea of physical regularities and quantitative rules of operation from the superior artisans of his period. And from the Bible he took the idea of God's legislation. By combining both he created the modern concept of natural law.[94] Galileo understood the scientific importance of the

[92] "Laws" and "rules" alternately; No. 114 to Huyghens (II, 50); No. 371 to Clerselier (IV, 183ff.); No. 179 to Mersenne (IV, 396); No. 514 Burman (VI, 168); No. 566 to Morus (VI, 405).

[93] *Cf.* Edgar Zilsel, *Problems of Empiricism,* Encyclopedia of Unified Science, II/18, Chicago 1941, §3.

[94] The relations of Descartes to contemporary technology recede to the background in his writings. Yet in his *Discours* he stresses the utility of his principles and refers to the "various crafts of our artisans" (*Œuvres*

interdependence of physical quantities at least as clearly as Descartes and made use of more and of more complicated mathematical functions. But the law-metaphor was unknown to him. Kepler did speak of laws, but his law-concept was too animistic to influence rising physics greatly. Descartes only combined the law-metaphor with a mechanistic concept of natural law. His influence both on philosophy and on physics can be in Spinoza, in the physicists of the Royal Society, and in Newton.

10. Spinoza gives a chapter on divine law in his *Tractatus Theologico-Politicus* (1670). In this he distinguishes the laws "depending on necessity of nature" from the laws resulting from human decrees. As an instance of the former he gives the principle of the conservation of the quantity of motion following Descartes. He amplifies, however, the extent of the Cartesian law-concept from physics to psychology by adding the law of association by contiguity (as it is called today). Moreover he stresses universal determination: "everything is determined", he says, "by the universal laws of nature."[95] This idea is emphatically repeated in the chapter on miracles. The immutable and universal laws of nature are mentioned again and again and are expressly identified with the "decrees of God". Miracles which apparently contradict them are denied and explained by human ignorance.[96] The opposition of "natural law" and miracle, repeated in the following period over and over again, apparently occurs here for the first time. In the *Theologico-Political Treatise* Spinoza is still trying to hide his pantheism. He speaks, therefore, of the decrees of God in a rather ambiguous way. Since he did not believe in God's personality, however, he noticed, in contrast to Descartes, that application of the term "law" to physical things is based "on a metaphor (*per translationem*)".[97] Possibly this insight was also influenced by Suarez, who was known to Spinoza.

VI 62). The Cartesian dualism presupposes the New Testament (concept of soul), his law-concept the old (God, the lawgiver).

[95] *Tract. Theol.-Pol.* cap. 4. *Opera* (ed. Vloten-Land in 4 vols., The Hague 1914) II 134.

[96] Cap. 6 (*ibid.* 156-170 passim).

[97] Cap. 4 p. 135.—In his first work (1663), the *Renati Des Cartes Principia Philosophiae,* he gives the Cartesian seven "rules" of motion (II, prop. 24-31). In the annexed *Cogitata Metaphysica* he often speaks of the "decrees" of God (I, cap. 3).

The determinist explanation of mental phenomena is carried out in Spinoza's *Ethics*. The famous preface to the third part begins with the statement that human affects too "follow the common laws of nature". Alluding to the origin of the term "law", Spinoza explains that man in nature does not form a state within the state and expressly denies Descartes' doctrine of free will. Actually "the laws and rules of nature, according to which everything happens and is transformed, are the same everywhere and always". Therefore he will deal with human behavior in a strictly causal way without any valuation—a modern author would have said, in the manner of the natural sciences. Since Spinoza, however, considered the deductive method of Euclid the most scientific, he says he will treat human actions as if the question were of lines, planes, and bodies. In the following this program is carried out *more geometrico*. Yet Spinoza is, of course, not able to give quantitative laws of psychology. The laws of nature are occasionally mentioned in later sections also of the *Ethics* and in his correspondence.[98] One passage is interesting, since it occurs in a letter to Oldenburg, the secretary of the Royal Society, and since it expressly states that all physical processes follow "the laws of mechanics". Like Descartes and virtually all physicists of the period he is a consistent mechanist.

On the whole Spinoza has taken over the theistic concept of natural law from Descartes and has reinterpreted it in a pantheistic way. At the same time he has extended it to the province of mental phenomena. His ethical ideals being entirely Stoic, he is a determinist. Yet his determinism is neither magic nor theological but mechanistic, as it is in Hobbes and as it became in the natural sciences of the following period. Spinoza is the first author combining general metaphysical determinism with the modern concept of natural law.

In 1638, six years before publication of his *Principia,* Descartes had written to the young Christian Huyghens on his laws of impact.[99] With these "laws" or "rules" Huyghens occupied himself in various manuscripts for many years, since he noticed the incor-

[98] *Ethics* 4, app., cap. 6f.—Letter no. 13 (to Oldenburg, *leges mechanicae*). Cf. letters no. 31, 33, 42.

[99] *Cf.* above footnote 92. Huyghens was then 19 years old.

rectness of Descartes' statements. He discovered the conservation of kinetic energy in elastic impacts and published his results in a letter to the *Journal des Scavans, Sur les régles du mouvement dans la rencontre des corps* (1669). After his death a treatise of his on the same subject *De Motu corporum ex percussione* appeared in his *Opuscula Postuma* (1703). In all these papers the laws of impact are alternately called "rules" and "laws".[100] A Latin translation of his letter to the *Journal des Scavans* was published also in the *Philosophical Transactions* (1669), the new journal of the newly founded Royal Society. In the brief English introduction Oldenburg, the secretary of the Society, speaks alternately of the "laws" and of the "rules" of motion.[101]

On the same problem two Latin papers of Wallis and Christopher Wren had appeared one year before (1668) in the *Philosophical Transactions*. The whole discussion was started by the Royal Society. Wallis' paper has the title *A summary account given by Dr. John Wallis of the General Laws of Motion.* Wren's article is called *Lex naturae de Collisione Corporum.*[102] As these papers show, the term "law" first became customary among physicists with the laws of impact. In this the influence of Descartes is obvious, though the papers of Huyghens, Wallis, and Wren, no longer contain theological remarks. Possibly the terminology of the *Transactions* was influenced also by Spinoza, the friend of Oldenburg. The first volumes of the *Transactions* occasionally speak of natural laws in other contexts too. They report on a paper of a French Gentleman, Mr. Auzout, who believed he had found laws of cometary movement.[103] And they mention "odd laws" of variation of the barometer and the "laws of refraction" in optics.[104]

The last two passages refer to two new physical instruments

[100] Huyghens, *Œuvres Complètes* (ed. Soc. Holl. d. Sc.) XVI 95 (ms. of 1652), 104 (ms. of 1654), 139 (ms. of 1656), 181 (letter to the Journ. d. Sc.), pp. 33, 91 (de motu corp.).—In his *Horologium Oscillatorium* (Ibid. XVIII 69ff.) and his *De vi centrifuga* (ibid. 366ff.) the term "law" is not used, though important physical laws are stated for the first time.

[101] *Phil. Trans.* IV (1669), 925.—The Royal Society was founded in 1663; the *Trans.* appeared first in 1665.

[102] *Ibid.* III (1668) 864ff.

[103] *Phil. Trans.* I 4. Auzout speaks of "laws" also in his French pamphlet on the comet of 1664/65, printed in 1665 in Paris (pp. 1 and 7).—He believes that the comet in question moves in a circle. He is proud of having found this hypothesis upon three observations only (*Phil. Trans.* I 19).

[104] *Phil. Trans.* I 31f.

of the eminent microscopist and experimentalist Robert Hooke and are almost literally taken from the preface to his *Micrographia* (1665). Hooke was Curator of the Society and had to prepare the experiments for their meetings. He discovered the so-called law of Hooke, stating that the stress of an elastic body is proportional to its strain. In his *Lectures de Potentia Restitutiva* (1678) he calls it a "Rule or Law of Nature".[105] This is the first time that a physical law, referred to in modern textbooks under the name of its discoverer, is called a law by the discoverer himself. As early as in 1662 Hooke used the term "law" occasionally also in his notes on his experiments on Boyle's law.[106]

Sir Robert Boyle was among the eminent members of the Royal Society. He published his law (the volume of a gas is inversely proportional to its pressure) in his *Defense of the doctrine touching the Spring and Weight of the Air* (1660) without using the term "law". It is always called a hypothesis by him.[107] On the other hand he frequently speaks of natural laws in his theological writings. In his *Free inquiry into the vulgarly received Notion of Nature* (composed in 1666) he declares the term "law", when applied to inanimate things, "an improper and figurative expression", explaining this at great length.[108] In the explanation he strangely assumes that the law-metaphor ascribes teleological tendencies to physical objects. When an arrow, shot by a man, he says, moves towards the mark, "none will say that it moves by a law but by an external . . . impulse".[109] Nevertheless he himself speaks in what follows very often of the "laws of motion prescribed by the author of things".[110] He confesses to belong to the "modern naturalists and divines", explaining the phenomena through "physico-mechanical principles and laws". Animistic interpretations of nature, therefore, are combatted by him, but he immediately adds that "sometimes" there are miracles.[111] The paper contains numerous biblical quotations and a long polemic against Descartes.[112] It is significant that twenty-one years before the pub-

[105] Reprinted in R. T. Gunther, *Early Science in Oxford,* Oxford 1938, VIII 334 and 336.
[106] *Ibid.* VI 83.
[107] *Works* (ed. Birch) I 158, 162.
[108] *Ibid.* V 170ff.
[109] P. 171.
[110] P. 177, *cf.* pp. 194, 225, 251, 252.
[111] P. 215.
[112] P. 242.

lication of Newton's *Principia* the memory of the metaphysical character and theological origin of the concept of natural law is completely alive in a treatise of a physicist of the Royal Society.

Newton's *Philosophiae Naturalis Principia Mathematica* (1687) has definitely made the term "law" a familiar component of the scientific vocabulary. Particularly his famous three "laws of motion", given at the beginning of the work,[113] were taken over by all physicists of the following period. The reference to Wren, Wallis, and Huyghens, and their laws of impact, in this section[114] reveals the origin of the terminology. The term "law" is applied by Newton also to his gravitation-formula. The "laws and measures of gravitation" appear as early as in the preface. And at the end of the *Principia,* just after the famous refusal to invent hypotheses about the cause of gravitation, Newton states: "it is sufficient that actually gravitation exists and acts according to the laws given by us."[115] In several problems the mathematical and formal side is conspicuous in his concept of law. He looks for "the law of the centripetal force", given the orbit of a moving body. In one special case the solution is: the force is proportional to the distance from the center. On the other hand a different "law" (the law of gravitation) results, if other orbits are given.[116] Here "law" is obviously almost synonymous with "proportionality" without any tinge of metaphysics.

Still theological components have not vanished in Newton's physics. Though he never mentions the divine origin of the natural laws, he declares that only creation of the world by an intelligent Entity can explain the remarkable coincidence of the directions and planes of the planetary movements. The planets stay in their orbits "by the laws of gravitation, but they could not, initially, receive the regular position of the orbits by these laws".[117] There

[113] *Opera* (ed. Harsley) II. 13ff. They state, as is generally known, the principle of inertia, the proportionality of force and change of momentum, and the equality of action and reaction. The section is named *"Axioms or Laws of Motion"*.

[114] P. 23. As in Descartes, Wren, Wallis, and Huyghens, the laws of impact are alternately called "laws" and "rules".

[115] *Opera* III, 174. His third letter to Bentley says: "Gravity must be caused by an agent acting constantly according to certain laws" (IV 438).

[116] I, sect. 2 prop. 10, probl. 5. *Cf.* I sect. 3, prop. 11, probl. 6, and prop. 12f.

[117] *Lib.* 3, scholium generale (III 171).

follows a long exposition, explaining with classical and biblical citations and a footnote on the etymology of the word "God", that everything is in God. Altogether in the *Principia* theology has retreated from the laws to (as the modern physicist would put it) the initial conditions. However, Newton would have certainly admitted, if he had been asked, that the laws too were established by God. Of course Newton knew also Descartes. It cannot be explained, as he states, by Cartesian vortices "that the movement of the comets follows the same laws as the planets".[118]

Newton realized the novelty and scientific importance of the concept of physical law. He starts his work in the preface with the statement: "the modern scientists, omitting the substantial forms and the occult qualities, have undertaken to explain the phenomena of nature by mathematical laws." The essential point of the modern scientific method is explained here with surpassing clarity. And he concludes his work regretting the imperfect state of knowledge in the fields of cohesion, nerve activity, and electricity. It is not yet known, he writes, "by which laws" these phenomena must be explained. Thus the first and the last sentence of the *Principia* deal with natural laws. Still the term "law" occurs more rarely than in a modern textbook on physics. It does not occur at all in his *Lectiones Opticae* and his *Opticks,* not even in the sections on reflexion and refraction.[119]

We need not trace the origins of our concept further. Whoever knows the immense influence exerted by Newton's *Principia* on the science and even the whole literature of the following period, will not be surprised at the rapid spread of the idea of natural law in eighteenth-century physics, philosophy, and deistic theology. The concept was simply taken over in the shape in which it appears in Newton. As a consequence, the physical meaning of the term "natural law" gradually displaced the juridical. Voltaire, who contributed most to the popularization of Newton's ideas on the continent, is already entirely familiar with the idea that nature is governed by laws, successfully investigated by scientists.[120] No

[118] *Ibid.*, 170.

[119] *Opera* III, IV.

[120] *Elements de la philosophie de Newton* (1738) 3, 1: (*Œuvres,* Firmin Didot, V, 721), les lois de l'attraction; 3, 3 (p. 726): lois de la chute de corps trouvées par Galilée; 3, 5 (p. 730): lois de la gravitation, règles de

doubt Newton's *Principia* (1687) is the turning point in the rise of this idea. Whereas Locke's *Essay concerning Human Understanding* (1690) does not yet know the concept of natural law in its physical meaning, it already is a matter of course in Berkeley's *Treatise concerning the Principles of Human Knowledge* (1710). In 1655 Hobbes' *De Corpore* does not speak of laws. In 1642 his *De Cive* and in 1645 his *Leviathan* discuss natural law in its juridical meaning only.[121] In 1748, on the other hand, Montesquieu's *L'esprit des lois* dedicates the first chapter to physical laws.

11. Finally, we must try to give an explanation of the development described. Why has it taken place in the way and at the time given? We cannot explain here why at the time of Galileo the idea of mechanical regularities arose. This explanation exceeds our present task, since it is linked with the much more general problem of the origin of experimental science and the quantitative spirit, and will be attempted at another place. Here it may be indicated only that in all civilizations experimentation originates in handicraft. In the period of nascent capitalism experimenting artisans began to look for quantitative rules of operation. The roots of these mechanical rules, therefore, must be searched for in the sociological and technological conditions of handicraft in the early modern era. They rose to science in Galileo.[121a]

However, why were these mechanical regularities eventually interpreted as divine laws of nature? This is not a mere question of terminology. Without the metaphysical components, contained in the law-metaphor, they could hardly have obtained their scientific and philosophical impetus. Reference to the strength of religious tradition does not give a sufficient answer to our question. The idea of laws, given by God to nature, does not occur in all religions. It is lacking in ancient Egypt,[122] and special investigations would be required to decide whether similar ideas were known

Kepler. *Essai sur la nature du feu* 2, 3, (ibid. p. 776): eight "laws". His *Dictionnaire Philosophique* (1764), however, gives the juridical meaning only s.v. "loi naturelle" (VIII 21ff.).

[121] Locke, *Essay* 1, 3 §13, mentions the juridical meaning only. Berkeley, *Principles* §30. Hobbes, *De Cive* cap. 2-4, *Leviathan* I, chap. 14f., II chap. 26.

[121a] *Cf.* Edgar Zilsel, "The Sociological Roots of Science," *The American Journal of Sociology* XLVII (1942) 545 ff.

[122] *Cf.* §2 footnote 4.

in Persia and India. In Babylonia with its Hammurabi code and in the Old Testament with its abundance of ritual and other law it has developed, but everyone who knows how in Christianity different ideas were emphasized or receded to the background in different periods, will not doubt that the divine commands to nature in the *Book of Job* could have easily stayed uninfluential in the history of ideas. In fact God's "eternal law", as we have met with it in Thomas Aquinas, was not a leading idea of medieval Catholicism. The idea of divine providence certainly was important, as far as human fates were concerned, since it gives consolation and hope. As far, however, as it implies eternal laws of nature, it was confined to being mentioned by learned theologians. The Middle Ages perceived the reign of God much more in miracles than in the ordinary course of nature. Comets and monsters were of greater moment to medieval piety than the daily sunrise and normal offspring. How was it that in the modern period the idea of God's reign over the world shifted from the exceptions in nature to the rules?

The expressions "reign over the world" and "law of nature" spring from a comparison of nature and state. Is it not almost a matter of course that the concept of the divine reign changed with changes in the structure of the state? In the feudal state of the middle ages government and law differed entirely from the corresponding institutions of the modern era. Thomas Aquinas lived in a period when Italian feudalism was already disintegrating under the influence of the rising money economy. Yet he mentions traits of human law, in his discussion of eternal and natural law, which would hardly fit the physical laws of modern science. There are, he says, "special laws" for the various estates of society; to priests it is "law" to pray, to princes to govern, to soldiers to fight.[123] This would still agree with physical laws: the laws of mechanics differ from the laws of electricity. But Thomas thinks the individual can occasionally change his estate and "law" by order of his lord; *e.g.,* a "soldier" (a nobleman) can be turned out of the "army" (of nobility) and can become subject to rural or mercantile law.[124]

[123] *Summa Theologica* II, 1 qu. 95, art. 4, resp. 2.
[124] *Ibid.* qu. 91, art. 6 resp.

To this there is no analogy in modern physics. The "laws" Thomas is here speaking of are, obviously, the bonds of feudalism, varying according to the estate of the individual. They are not based on statute law but on sacred tradition and do not derive from rational regulations of a legislator. Which paragraph of which code orders the prince to rule and the priests to pray?

The feudal state was an extremely loose organization. The bonds by which it was tied together were irrational and considered a matter of course. If the prince issued regulations they were most frequently privileges given to single noblemen, monasteries, and towns, corresponding rather to exceptions than to rules. The medieval interpretation of nature seems to correspond to this organization of the state: the Lord does miracles, they are noteworthy; the regular course of nature, on the other hand, is sacred but a matter of course. At any rate the idea of a comprehensive multitude of rational physical "laws" could not have arisen in feudalism, even if the corresponding physical facts had been known.

It is generally admitted that the Stoic doctrine of the one *Logos* ruling the universe is correlated with the rise of monarchies after Alexander the Great. The analogy might hold for the modern concept of natural law. It will be remembered that Patrizzi had explained the orderly course of the stars by comparing them to soldiers obeying the command of their officers:[125] the loose knightly armies of feudalism had been displaced by the mercenary armies of early capitalism with their rational discipline. The application of the law-metaphor to physical phenomena has probably been produced by the analogous change of the entire state. Money economy disrupted the bonds of feudalism and traditionalism, made rational regulations and statute law necessary, and increased immensely the power of the prince. Even in England, where Roman law was not introduced, this process took place under the Tudors; it reached its peak, however, in seventeenth-century absolutism on the continent. It is not a mere chance that the Cartesian idea of God, the legislator of the universe, developed forty years after Bodin's theory of sovereignty. Perhaps it is not even a coincidence

[125] *Cf.* §9 above, footnote 79.

that both thinkers were French: France was the native country of centralized absolutism. At any rate the doctrine of universal natural laws of divine origin is possible only in a state with rational statute law and fully developed central sovereignty. Possibly the change in the structure of the state also gives the explanation why the metaphorical character of the term "law", when applied to unreasonable beings, was not noticed before Suarez.[126] Under feudalism even animals and things could be summoned and punished. Thomas hardly thought of legal actions against animals, when discussing God's eternal law; but only rational statute law is, with necessity, restricted to rational beings. Man is a social being. He seems to be inclined to interpret nature not only according to the needs but also after the pattern of society. Yet one difficulty in our sociological explanation must be mentioned. How could medieval theologians speak of the legislature of God, when the power of the prince was very limited? The idea, however, had not originated in feudalism. It had been conceived under entirely different sociological conditions. Its authors were Jews who had outgrown their past of Bedouin clan-organization centuries ago, and its sociological pattern was the despotism of ancient oriental states. The idea could be preserved in a rudimentary form through two thousand years, even through a period in which it did not fit the sociological conditions, till it awoke to new life in early capitalistic absolutism. This fact, and there are numerous analogies, is very important for the theory of history. Ideologies are extremely conservative. They never can be explained by present conditions alone, but mirror the whole past too. At any rate historical problems are very complex. Even if this sociological explanation should be falsified by future investigations, the material here collected on the genesis of the concept of physical law remains.

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[126] After Suarez (1612) this insight was to be found in Spinoza (1670) and Boyle (1666). In Thomas (about 1270) it is still lacking.