

Natural Law and Laws of Nature in Early Modern Europe

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Chapter 13

From Principles to Regularities: Tracing 'Laws of Nature' in Early Modern France and England

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Laws of Nature in the Seventeenth Century

The concept of laws of nature already had a long tradition in the seventeenth century, both in natural philosophy and legal thinking. 'Natural law' had long been treated as a specific type, juxtaposed beside divine and eternal law. In ancient and medieval natural philosophy, the talk of 'laws of nature' occurred – if rather rarely – in at least two different traditions. In astronomy and 'mixed mathematics', 'laws' counted as the central principles within a deductive system of theorems – a use still found in Copernicus and Kepler [GRABHOFF].² In theology, by contrast, with Ockham as prominent proponent, emphasis was put on divine voluntarism [ARMOGATHE], while the axiomatic character and the position within a larger system played no major role.³ Both in natural philosophy and juridical thought, the situation changed profoundly and rapidly in the second half of the seventeenth century. Within a few decades, the law-concept came into much wider use, and its meaning shifted and was significantly broadened. In this paper, I shall focus on natural philosophy and trace the use and meanings of the concept of 'laws' and related terms in both France and England.⁴ A few emblematic figures provided important stimuli for establishing and developing the concept of laws of nature.

One of the most influential programmes for a 'new science' was presented in Francis Bacon's 1620 *Novum Organum*. Bacon here used a concept of laws of nature that was closely connected to his idea of 'form' and was thus not more sharply defined than the latter.⁵ Rather than stressing theological considerations,⁶ Bacon emphasized

¹ I thank Lorraine Daston and Sophie Roux for many stimulating discussions.

² Ruby 1986; Schramm 1981; Grabhoff and Treiber 2002.

³ Oakley 1961a; Oakley 1981; Crombie 1994, I: 402–403.

⁴ For previous studies, see Zilsel 1942b; Schimank 1949; Needham 1956: chap. 18; Milton 1981; Steinle 1995; Roux 2001.

⁵ For example *Novum Organum* II, 5: 'leges fundamentales et communes, quae constituent Formas' (Bacon 1858: I, 232).

⁶ Thanks to Sachiko Kusukawa for pointing out that Bacon, in his *De Augmentis*, well included theological aspects; see Bacon 1858: I, 567. For the Royal Society, however, the *Novum Organum* would become far more important.

the analogy to the legal realm. He spoke of 'law and its paragraphs' and even drew a distinction between 'consuetudines naturae' – observed regularities in specific domains – and 'leges fundamentales et communes' that applied for a wide range of effects.⁷ The analogy to the 'common law' tradition, so important in England, is striking. It was largely based on 'customary' and 'municipal laws' and customs of particular regions were sometimes called 'laws of the land', with no reference to a commanding authority.⁸ Bacon – lawyer and politician, after all – dealt with those questions and acted as a proponent of authoritative legislation.⁹ In transferring these legal concepts to natural philosophy, he was careful to differentiate between different types of statements that played different roles and had to be established in different ways. 'Consuetudines naturae' could only be recognized by empirical means and were valid even without being derived from more general principles. 'Laws', by contrast, were central parts of a larger structure of argumentation. It is striking to realize that Bacon, being one of the few to draw an explicit analogy between natural philosophy and matters of legislation, did exactly *not* refer to the tradition of natural law, but to the separate common-law tradition, so prominent in England.

It was another author, however, who for the first time gave 'laws of nature' an absolutely central and prominent place within a system of natural philosophy. René Descartes, in his 1644 *Principia philosophiae*, launched the exposition of his mechanical system of the universe with three principles of how the state and motion of bodies were conserved and transmitted. He founded those principles on considerations about the immutability of God and called them 'regulae quaedam sive leges naturae' or 'règles certaines, que je nomme les loix de la nature'.¹⁰ As the careful wording indicates, Descartes was well aware of how unusual the concept was in this context. Moreover, he brought different traditions together here. Cartesian laws had both a quasi-axiomatic status within a deductive system and at the same time reflected the voluntaristic tradition: Descartes emphasized that God could have created different laws. It is significant, moreover, that Descartes reserved the law-concept for those three principles: no other theorem, rule or principle was called a 'law' in his system.

I shall not analyse the intricacies and background of Bacon's and Descartes' law-concepts in detail.¹¹ Rather, my procedure will be to take these two most influential seventeenth-century authors as starting points, and trace the further use of the law-concept until the end of the century. One should keep in mind here that it is one thing to have the concept of a certain type of statements, and another to call it 'laws of nature'. Concept and terminology of laws were not necessarily connected, and indeed have their own separate contexts and histories. The case of Galileo, who sometimes is regarded as indicating the historical transition from the search for

⁷ *Novum Organum*, II, 2 and 5.

⁸ See OED, s.v. 'law', sect. II, 14.

⁹ Pocock 1987: 103.

¹⁰ *Principia Philosophiae*, II, § 37–42: Descartes AT, VIII/1: 62 and IX/2: 84.

¹¹ For Bacon, see Steinle 1995 or Krohn 2001. For Descartes, see Loeck 1986; Knebel 1992; Steinle 1995; Roux 1999; Specht 2001.

causes to the search for laws, is instructive here.¹² While the type of statements he made about the fall of bodies may well fit into the concept that later was labelled 'law', he never talked of 'laws' in presenting his research.¹³ The idea of empirically based statements that express regular behaviour of things was certainly present in the early modern period, if not earlier. But it was not at all clear that, and why exactly, they should be called 'laws'. My study aims at illuminating that historical process.

Mid-century Terminologies

Among Descartes' contemporaries it was the French polymath Marin Mersenne who played a core role as communicator of scientific research throughout Europe. Mersenne deployed the concept of 'loy naturelle' or 'loy de nature' in a juridical and moral sense, when talking about the naturalness of Abraham having his concubines, for example.¹⁴ It is hence all the more significant that he never spoke of laws in questions of natural philosophy. The topic of falling bodies and of the trajectory of projectiles, widely discussed in the Mersenne circle of the late 1630s and early 1640s, is indicative. In those rare cases in which the statements discussed were labelled at all (usually they were not),¹⁵ the traditional terminology of mathematics prevailed, such as 'la proposition des chutes des corps pesants', the 'demonstration des chutes', or the 'mesure de la chute des graves'.¹⁶ Only in very rare cases was the terminology of laws used, always with explicit reference to Descartes. The young Christiaan Huygens, for example, alluded to Descartes' 'loy de la nature' by which bodies continued in their motion with the same speed.¹⁷ Descartes' terminology was adopted, but not transferred to other contexts or developed further.

A similar attitude can be observed in other mid-century publications that took up Descartes' ideas. The first and immediately problematic case was Henri de Roy (Henricus Regius), Professor of Medicine at the University of Utrecht who, as a propagandist for Descartes, nearly got expelled from his chair at Utrecht, but later distanced himself from Descartes with his 1646 *Fundamenta physices*, in which he placed Cartesian ideas within the context of scholastic metaphysics.¹⁸ But even then Regius maintained Descartes' talk of laws, presenting, for example, a conservation principle of matter under the label 'lex immutabilitatis naturae' or 'lex universalis' and deducing a principle of conservation of motion from it.¹⁹ Like Descartes, Regius did not speak of laws when it came to more specific propositions about light, planetary motions, or the earth. Similar observations hold for more straightforward accounts of

¹² Stilman Drake 1983: 143, even made Galileo speak of 'laws' in some fictive dialogue.

¹³ As already observed by Zilsel 1942b: 262–263; for the few exceptions, see Steinle 1995.

¹⁴ Mersenne 1624. See also Mersenne, *Correspondance*, 1932–88: IX, 372, for example.

¹⁵ Mersenne 1932–88: VIII, 232, 421, 696.

¹⁶ *Ibid.*: XIII, 126; XIV, 527 and 613.

¹⁷ *Ibid.*: XIV, 569.

¹⁸ Regius 1646; for Descartes' sharp reaction, see Descartes 1648: AT, VIII: 337–369.

¹⁹ Regius 1646: 7–8.

Descartes' ideas. In one of the earliest textbooks of Cartesian philosophy, published in 1653, the Paris writer Jacques Du Roure adopted the terminology of Descartes' *Principia* directly. When it came to motion, he presented the three general 'loix de la nature', and emphasized, against the Aristotelian tradition, that 'les pierres ... ne suivent pas moins les loix de la Nature lors qu'elles [*sic!*] montent, que lors qu'elles [*sic!*] descendent'.²⁰

Stimulated by Descartes' approach, Christiaan Huygens started to work on the motion and collision of bodies and finished an extended manuscript in 1656.²¹ It was structured along mathematical lines, with 'Hypotheses', 'Propositions', 'Demonstrations', and 'Lemmata'. Only once did Huygens speak of the 'laws according to which bodies impelled each other'.²² In his extended correspondence on the subject – with the Liège bishop René-François de Sluse, for example – the statements, if they were labelled at all, were called 'regles': 'Cartesii regulae circa corporum occursus', 'regulae impulsus', 'meae regulae', 'Axioma Cartesii de conservacione motus', and so on. Again only in rare cases did Huygens also speak of 'motus leges' or 'lois de mouvement'.²³ Huygens' terminology was not systematic and, like most others, he did not discuss his terminology explicitly. I take it as significant that Huygens, who relied so much on Descartes' ideas, was reluctant to adopt the talk of laws. In the rare cases in which he used it, moreover, he deviated from Descartes' (and his own early) use, speaking no longer of 'laws of nature' in general but, more specifically, of 'laws of motion'. But still 'laws' stood for highly abstract and most general principles, placed at the top of a deductive system.

In research fields pursued more independently of Descartes, the terminology of laws did not occur. Blaise Pascal, for example, did not talk of 'laws of nature' at all in his work on pneumatics and hydrostatics, conducted in the 1640s and 1650s. In his final synthesis, posthumously published in 1663, Pascal presented his deductive structure along the line of 'principes', with the 'principe de la Pesanteur de la masse de l'Air' as the most prominent case.²⁴ Pascal was, however, perfectly well acquainted with natural law in the juridical sense. In his *Pensées*, he talked about 'les lois naturelles communes en tout pays', contrasting them to the ever-changing laws and customs of particular regions. Although he regarded those natural laws as the best foundation of human societies, he doubted whether human reasoning, always corrupted, could ever achieve a full knowledge of them.²⁵ This sceptical stance might be the background for his refusing – *pace* Descartes – to use such a terminology in natural philosophy. Moreover, different research traditions come into play here. Hydrostatics and pneumatics had been treated in mathematical terminology ever since Archimedes. Simon Stevin had organized his 1586 *Beghinselen des*

²⁰ Du Roure 1653: 49, 50, 52; later, however, in Du Roure 1665, there was no talk of 'laws'. I thank Dan Garber for pointing me to Du Roure and Regius.

²¹ Posthumously published in 1703: Huygens, *Oeuvres*, 1888–1950: XVI, 30–91.

²² *Ibid.*: XVI, 33.

²³ *Ibid.*: II, 79, 115.

²⁴ Pascal 1663; reprinted in Brunschvigg and Boutroux 1904–14, see III: 194, 281.

²⁵ Pascal 1670: §60, p. 53.

waterwichts with definitions, postulates, explications, and propositions,²⁶ and both Galileo and Torricelli had worked in the same spirit. That tradition in hydrostatics, on which Pascal's studies were essentially based, provided no stimulus whatsoever to introduce a concept of laws of nature.

When the Paris writer and Royal historiographer Charles Sorel published, in 1664, a book-length review of philosophical books in France, he included natural philosophy. He discussed Descartes as most prominent in departing from the scholastic tradition, and mentioned Du Roure's work as being much in Cartesian spirit (even as belonging to the Cartesian 'sect').²⁷ But, though Sorel spoke well of 'loix de la nature' as moral laws,²⁸ such a terminology was absent in the natural philosophy part. Sorel's presentation illustrates a general reluctance to use law-talk in France.

In mid-seventeenth-century England, the situation was more complex. The group of philosophers who aimed at reforming natural philosophy was not yet widely visible. Descartes' impact was strong, though not immediate; likewise his concept of laws of nature filtered in only slowly. When Henry More, then a young cleric in Cambridge who had welcomed Descartes' approach enthusiastically, corresponded with Descartes in 1649 on physical questions of the *Principia*, the talk of laws occurred rarely, and then only with explicit reference to Descartes.²⁹ A quite different account, by contrast, can be seen in the writings of Walter Charleton, physician to King Charles II, and talented expositor of philosophical systems. Entirely devoted to Helmontian chemistry in his youth,³⁰ Charleton turned his perspective in the 1650s towards a mechanistic approach. In his 1654 defence of Epicurean atomism, explicitly based on Pierre Gassendi [WILSON],³¹ he often used the terminology of laws, in a shifting and varied manner. In contrast to Descartes, whose law-talk he knew well and quoted explicitly, Charleton's 'Laws of Nature' were statements about causality, and how it acted in natural processes: namely merely mechanically by motion, and only between contacting bodies. Charleton also had 'Fundamental' or 'Universal Laws of Motion', stipulating how the motion of macroscopic bodies depended on those of the constituting atoms.³² In other passages, by contrast, his use of 'Lawes' pointed to something like generalized observations and was almost indistinguishable from his concomitant use of 'Rule'. In a section on the loadstone, Charleton even spoke of 'Laws of Magnetick Energy', 'Laws and Experiments Magnetical', and 'Laws of Magnetical Attraction'.³³ Significantly enough, moreover, Charleton used still another term here, without further explication. He labelled statements such as the assertion that armed magnets held stronger than unarmed, that the strength of a magnet was not necessarily related to its bulk and volume, or that each of the two pieces of a cut magnet showed its own polarity, as 'Observables'. And he even ascribed some

²⁶ Stevin 1586.

²⁷ Sorel 1664: 33.

²⁸ *Ibid.*: 47, 50.

²⁹ Descartes AT, V: 385. For More, see Hall 1990 or Crocker 1990.

³⁰ Kargon 1966.

³¹ Gassendi 1649.

³² Charleton and Gassendi 1654: 445, 343, and 270, 435.

³³ *Ibid.*: 343, 348, 388, 391, 397.

explanatory power to that sort of generalized observations in stating that all effects of magnetic attraction could 'conveniently be referred to' those observables.³⁴

Vague and unexplicated as Charleton's separation of 'laws' and 'observables' remained, it is clear that he drew from sources other than Descartes. Strikingly enough, there was nothing parallel to Charleton's terminology in Gassendi, of whose study Charleton gave a more or less close paraphrase,³⁵ nor in William Gilbert's work on magnetism, to which Charleton often referred.³⁶ It was rather Bacon (whom Charleton praised repeatedly) who served as an important model here, with his talk of laws of particular realms of phenomena rather than of nature in general. As a sort of blend between Baconian and Cartesian uses, the law-concept in England became wide and vague at the same time. The talk of laws in natural philosophy differed substantially between France and England already in the 1650s.

Expanding the Law-talk: the Early Royal Society

The situation of natural philosophy changed drastically from the 1660s on. In England, the foundation of the Royal Society in 1660 attracted public attention to the new approaches, with all the various effects attendant upon publicity. As to the law-concept, the case of Henry More is most instructive. Fellow at Christ's College in Cambridge, More had become a famous writer, defending the new approaches of natural philosophy against suspicions of atheism, and was early elected Fellow of the Royal Society in 1662. In the late 1660s, his attitude to the law-concept changed drastically. In contrast to his former reluctance, he not only fully adopted Descartes' use, but also extended it widely. In his pro-Cartesian *Epistola ad V.C.* of 1664, he spoke not only of 'leges Naturae', but also of 'leges mechanicae', 'leges motus', 'Materiae Motusque Leges', and even of 'Magnetismi leges', as he did in his very popular *Enchiridion Ethicum* of 1667.³⁷ Despite his fierce opposition to Epicurean atomism, so strongly promoted by Charleton, the latter's study provided a direct and main source for More's talk of laws. The concept even survived More's anti-Cartesian turn of the late 1660s. In the very subtitle of one of his main anti-Cartesian texts, the 1671 *Enchiridion Metaphysicum*, More announced his intention to 'consider' ('expendere') natural phenomena with respect to 'Leges Cartesii Mechanicas', but at the same time to demonstrate the 'Vanitas' and 'Falsitas' of Descartes' attempt at explaining the universe by purely mechanical causes. His explicit opposition to mechanistic explanations contrasts with his neutral stance with respect to laws. In the text of the work, More mentioned 'leges mechanicae' in many places.³⁸

More set important signals for the talk of laws in the Royal Society. He never participated, however, in what was to become the Society's central programme:

³⁴ Charleton and Gassendi 1654: 388, 393–397.

³⁵ What Charleton called 'General Laws of Nature', for example, had been discussed by Gassendi as 'modus agendi & patiendi': Gassendi 1649: 348.

³⁶ Gilbert 1600.

³⁷ More 1679, reprint 1966, vol. II, 1: 109, 110, 112, 113; for example, More 1667: 38.

³⁸ More 1671: 246, 248, among others; English translation by Jacob, More 1995.

an 'experimental philosophy' in a Baconian understanding.³⁹ That programme, with its empiristic and inductivistic ideal, differed essentially from the Cartesian, rationalistic approach. Beyond that programmatic claim, however, the Royal Society was extremely heterogeneous, and indeed some of the approaches did not have much to do with the Baconian ideal. That heterogeneity was reflected in the development of the concept of laws of nature.

In the late 1660s, the collision of bodies became an important topic in the Royal Society, and it was in this context that the talk of laws visibly crystallized, already when Henry Oldenburg, the Society's secretary, proposed in 1667 'that the experiments for making out a theory of the laws of motion ... should be prosecuted'.⁴⁰ In the correspondence between Oldenburg, Huygens, Wren, Wallis, Neile and Gregory, 'laws of motion' were mentioned again and again, in most cases equivocally with 'principles of motion', 'rules of motion', 'rules & axioms' or the like. The background stimulus of the whole enterprise clearly showed up in references such as 'the Lawes of Motion, given by Des Cartes, (divers ingenious Mathematicians looking upon them, as false)'.⁴¹ Cartesian or not, the collision of bodies was fundamental within every mechanical philosophy. The law-talk also was used in the published papers in the *Philosophical Transactions*, with titles such as John Wallis's 'Summary Account ... of the General Laws of Motion' or Christopher Wren's 'Lex Naturae de Collisione Corporum'.⁴² Wallis spoke of 'principia de motibus' interchangeably with 'Generales Motuum Leges'. These laws were fundamental principles, even kinematic ones, such as the statement that something which moves in the period T along the distance L would move along the distance nL in the period nT. In Wren's paper, the 'Lex Naturae' stated that in collisions the loss of motion (combined from the bulk and velocity) of one body was equal to the gain of motion in the other. Wren used the law-concept for quite particular cases, comparable to the level of Descartes' seven 'rules' of collision. This points to a significant expansion of the terminology: Descartes had been most careful *not* to call those rules 'laws'. The discussion of the collision of bodies was the first in which the talk of laws was broadly used, first in England, but soon all over Europe.

Not all contributors, however, showed the same usage. While Oldenburg, Wren and Wallis used the terminology of laws quite freely,⁴³ Huygens, the only one with strong commitments to Cartesianism, remained reluctant. Almost without exception, he responded to Oldenburg's talk of 'loix du mouvement' by speaking of 'regles et theoremes' or the like. His contribution to the competition, submitted in French in early 1669, had the title 'Regles de mouvement', and in the whole paper law-talk occurred only once.⁴⁴ When Oldenburg published a Latin translation of Huygens'

³⁹ Sprat 1667; Hunter 1989.

⁴⁰ Council meeting of 16 January 1667: Birch 1756–57: II, 140. See Hall 1981: 189–191.

⁴¹ Oldenburg 1965–86: V, 103, 117, 125, 341, 358, among others. For a compilation of relevant passages, see Graßhoff and Treiber 2002.

⁴² Wallis 1669; Wren 1669: 867.

⁴³ Oldenburg 1965–86: V, 103, 117, 358.

⁴⁴ Huygens 1669; reprinted in Huygens 1888–1950: XVI, 179–181.

text, he mainly adopted Huygens' terminology of rules, principles and propositions. Significantly enough, however, he changed terms in the very title and presented Huygens' treatise as 'A summary account of the *Laws of Motion*'.⁴⁵ It is difficult to imagine that Oldenburg did not register these changes. He was determined to give the law-concept a more prominent place than Huygens.

Discussion of laws occurred also in other fields. John Wallis, in a 1666 paper on tides, considered how the motion of particular bodies should be explained from '*Mechanick Principles*'; that is, 'according to the *Laws of Motion* and *Statick Principles*'. One of those principles was 'that a Body in motion is apt to continue its motion, and that in the same degree of celerity, unless hindered by some contrary Impediment'. Another 'Law of *Staticks*' stated that the common centre of gravity of two bodies was always on the line between them.⁴⁶ By means of principles of this kind, Wallis aimed to account for the observed regularities of tides, which themselves were not called 'laws', but tidal 'periods': daily, mensual and annual. These regularities were not called laws: they were rather to be explained by laws. In yet another field – hydrostatics – Robert Boyle often spoke of the 'Principles and Laws of Hydrostaticks' or the 'known laws of hydrostaticks'.⁴⁷ He also mentioned 'optical laws', 'mechanical laws' and 'magnetical laws', or even the 'laws of refraction'. Like Wallis and Wren, he used the terms 'Principle' and 'Law' synonymously, oftentimes even with 'rule'.⁴⁸ A similarly broad use can be seen in the work of the young Isaac Newton. In his early (unpublished) research notes on collision, he adopted Wallis's and Wren's use of 'Laws of motion'.⁴⁹ Likewise he spoke, in his 1672 paper on light and colours, of the 'received laws of refraction', but also called them 'Hypotheses'.⁵⁰ In the long controversy following this publication, the term 'Laws of Refraction' was used by all parties synonymously with 'rule of refraction'.⁵¹ Even earlier, Erasmus Bartholin, in presenting the extraordinary refraction of the Iceland spar, had spoken of the 'ordinary Laws of Usual Refraction'.⁵² Again recall the fact that Descartes had been eager *not* to call the sine-relation a 'law'. In London, the talk of laws embraced not only many more subject fields than in France, but also lower-level principles.

⁴⁵ Huygens and Oldenburg 1669; original emphasis. See also the alphabetic index of the volume.

⁴⁶ Wallis 1666: 264, 268, 272.

⁴⁷ Boyle 1666a, cf. Boyle 1772 II: 742–745; or Boyle 1663, cf. Boyle 1772 II: 36; or *Philosophical Transactions*, 1 (1666): 233–234. See also the review in *Philosophical Transactions*, 1 (1666): 174.

⁴⁸ Boyle 1674 and Boyle 1671, cf. Boyle 1772: IV, 68, 69, 71, 72, and III, 430.

⁴⁹ Herivel 1965.

⁵⁰ Newton 1672a: 3076–3077; Newton 1958: 48–49.

⁵¹ *Philosophical Transactions*, 7 (1672): 4081, 4089, or 9 (1674): 218, 501; Newton 1958: 79, 81, 149, 152.

⁵² Bartholin 1670: 2045.

New Meanings

Along with that gradual expansion of the law-talk, however, a shift in meaning occurred that perhaps was barely noticed. Robert Hooke, in his 1665 *Micrographia*, not only named the sine-relation in optical refraction the 'law of refraction' (and was probably the first to do so), but also emphasized that he had found the law 'experimentally'.⁵³ That was a new perspective indeed. Empirically established regularities had not been called 'laws' before. Even more distinctly, Hooke mentioned, in discussing his newly invented baroscope, the 'very odd laws' of the change of the pressure of the air.⁵⁴ Again, he had in mind empirical regularities, those moreover, which he could not (yet) situate within a larger deductive system. To call them 'laws' was to turn round the Cartesian use. No longer were laws the central principles, but the particular phenomena and regularities which traditionally were to be derived from them: no longer the traditional *explanans*, but the *explanandum*! The position of 'laws' within the explanatory structure had been turned upside down here.

Oldenburg, in reviewing Hooke's book, took up his law-talk unchanged.⁵⁵ Later on, in a paean to the usefulness of the new natural philosophy, he even mentioned, 'an Instrument to measure the Refractions of Liquors of all kinds, for establishing the Laws of Refraction'.⁵⁶ That laws could – and perhaps should – be established by *instruments*, indicates the change of perspective most strikingly: such an idea would have been unthinkable in Descartes. And when Newton, in discussing optical theory, raised the problem 'What is the Law according to which each ray is more or less refracted?'⁵⁷ he did not have the sine-relation in mind, but rather a regularity describing how different colours were refracted – we call it a dispersion-rule. He was fully aware that such a relation could only be found empirically – any explanation from general principles was far away. It is instructive that Newton, after discussing the diverse refrangibility of rays, asked himself 'Where that diversity originates: In some uncertain and irregular cause, or in a certain law [certâ lege] according to which any ray is inclined to suffer a determinate refraction?'⁵⁸ The contraposition of an 'uncertain and irregular cause' and a 'certain law' reveals much about what laws had come to mean. Empirical regularities obtained the status of laws if they represented a *distinct* and *regular* outcome. Not only were they not principles in a Cartesian sense, but their status as 'laws' did not even depend on inclusion in deductive systems; it was secured by their certainty and regularity alone – a point that philosophers of law would quickly take up [MOHNHAUPT].

Neither Newton nor Hooke, however, were consistent in their terminology, nor were they inclined to discuss it in its own right. And it is not even clear whether they realized how significant a step they had taken: the new use could appear as just another step within the ongoing broadening of the terminology. Boyle was more

⁵³ Hooke 1665: preface, p. xxv in my counting. Ruby 1986 (reprint p. 297) ascribes the term 'lex refractionis' already to Roger Bacon, but gives no reference.

⁵⁴ Hooke 1665: preface, p. xiv in my counting.

⁵⁵ *Philosophical Transactions*, 1 (2) (1665): 31, 32.

⁵⁶ *Philosophical Transactions*, 4 (1669): 894.

⁵⁷ Newton 1672d; Newton 1958: 93.

⁵⁸ Newton 1672c; Newton 1958: 100. Also Newton 1672b: 5093.

reflective here. Probably as a response to what he realized as a shift of meaning, he discussed the concept of laws of nature explicitly, and introduced a whole scale of laws. At the one end, there were the 'fixt laws of nature, or rules of action and passion among the parcels of the universal matter',⁵⁹ being general rules with broad scope. At the other end, he found empirical regularities, which he compared to 'municipal laws ... that belong to this or that particular sort of bodies'. While only the former were really 'laws of nature, more properly so called', he called the latter ones also 'customs of nature'.⁶⁰ Boyle took up here, in verbal translation, Francis Bacon's distinction between 'consuetudines naturae' and 'leges fundamentales et communes'. While Bacon had restricted his concept of laws to the latter statements, Boyle included even the 'customs of nature' within a now much more capacious concept of law.

The Paris Academy: Laws and 'principes d'expérience'

In Paris, as in England, the situation for research in natural philosophy changed dramatically in the 1660s. With the foundation of the Académie Royale des Sciences in 1666, experimental research received a firm institutional backing and, with royal patronage, a widely acknowledged reputation. The academy quickly developed into France's centre for conducting research and exchanging natural philosophical results. Even in those changing times, the talk of laws remained as rare as before, both in books and in the early volumes of the *Journal des sçavans*. As one of the rare cases, the astronomer Auzout opened a treatise on comets with the remark that the motions of comets had been regarded as too irregular as to be captured 'sous des Loix'.⁶¹ Even Cartesian writers were reluctant. Gerard de Cordemoy, in his 1666 study on the relation between mind and body, mentioned the 'loix de la nature' at only one place, directly adopting Descartes' terminology.⁶² The same holds for Rohault's famous Cartesian textbook *Traité de physique* (1671).⁶³ Both the rare use and the specific meaning of the law-concept still directly reflected the Cartesian approach. As already mentioned, this held even for Christiaan Huygens – soon to become one of the academy's most prominent members – and his work on the collision of bodies. In his survey article of 1669, even statements such as the conservation of the overall motion ($m \bullet v$) in collision (§5), or the conservation of the sum of $m \bullet v^2$ (§6), were called 'règle', 'proposition' or 'principe'. Only in one case did Huygens use the term 'loy admirable de la Nature',⁶⁴ referring to the extremely general principle that the motion of the common centre of gravity of colliding bodies was not affected by the collision.

⁵⁹ Boyle 1663; Boyle 1772: II, 37.

⁶⁰ Boyle 1686: sect VII, §II; Boyle 1996: 107; cf. Boyle 1772 V: 217. Printed in 1686, the book had already been drafted in 1665–66. See also McGuire 1972.

⁶¹ Auzout 1665/6: first page of the preface. The law-talk did not occur elsewhere in the study. Oldenburg adopted the terminology immediately: Oldenburg 1665: 4.

⁶² Cordemoy 1666, reprinted Cordemoy 1968: 125.

⁶³ Rohault 1671: vol. I, chap. 11 (p. 69 in the fourth edition of 1681).

⁶⁴ Huygens 1669; reprinted 1888–1950: XVI, 181.

Among Huygens' fellow academicians, it was probably Edme Mariotte who worked most extensively in experimental natural philosophy – Condorcet would later praise him as the one who brought experimental physics to France. In Mariotte's early writings,⁶⁵ there was no talk whatsoever of laws of nature. Even when he studied the collision of bodies (1673) and referred to Descartes and 'some other modern writers', doubtless Wren, Wallis and Huygens, he did not adopt the talk of laws, but used – significantly enough, and much like Huygens – the fine-grained terminology of mathematics: Règle, Proposition, Lemme, Problème.⁶⁶ Being more attentive than others to discriminating different types of statements, he introduced, however, a special type of propositions under the name of 'Principe de l'expérience'. The statement that weights, when they fell on a support, made a larger impact than when they rested, provided an illustrative example.⁶⁷

Five years later, in his *Essay de Logique*, Mariotte presented a systematic account of those 'Principes'. Among all propositions about the sensible world, he divided those that could be proved by direct induction ('verités premières sensibles', such as the statement that fire is hot), from those that could only be argued for by means of certain 'principes', be they 'intellectual' (as in mathematical reasoning) or 'sensibles'.⁶⁸ The latter ones were central for empirical research. Mariotte called them 'Maximes ou règles naturelles, ou principes d'expérience' and mentioned, on the one hand, very general statements such as the rectilinear propagation of light, the unequal action of equal weights at unequal distances at the balance, the motion of iron towards magnets and the heating effect of friction, but also, on the other hand, specific regularities such as the refraction of light from air into water towards the perpendicular or the proportionality of compression and weight of the air (later called 'Mariotte's law').⁶⁹ Most of those empirical generalizations (as we would call them) were supported by experiment and not embedded in a larger theoretical framework. Mariotte knew well, moreover, that statements of this type were sometimes called 'laws of nature' by his contemporaries. In one case, referring to a relativity principle in collision (of Huygens' type), Mariotte even explicitly spoke of 'un principe d'expérience, ou loy de la nature'.⁷⁰ Already earlier, in presenting his famous proposition on pneumatics in 1676, he had introduced it as 'une règle certaine ou loi de la nature'.⁷¹ It is important to note that the reliability of the statement rested on experiments, carried out by Mariotte and the instrument-maker Hubin, and that there was no explanation provided from principles such as the microscopic properties of air. Mariotte did indeed aim at such an 'explication' in the long run, but admitted that, for the time being, it could not be achieved.⁷² The status of the proportionality

⁶⁵ Mariotte 1666; Mariotte 1923.

⁶⁶ Mariotte 1673: 28, 239, 280.

⁶⁷ 'second principe d'expérience': *ibid.*: 267, cf. 179.

⁶⁸ Mariotte 1678; reprinted Mariotte 1992: 89–90.

⁶⁹ *Ibid.*: 91–93, 127, 132.

⁷⁰ *Ibid.*: 99; cf. Mariotte 1686: 79.

⁷¹ Mariotte 1923: 8.

⁷² *Ibid.*: 38. Opposing the idea that the expansion of air was caused by increasing distance between its particles, he favoured an analogy to the behaviour of cotton wool, an

as a 'principe d'expérience', however, remained unaffected by the lack of a 'deeper' explanation.

Mariotte thus provides a peculiar picture concerning law-talk. On the one hand, he was probably the first to introduce a proposition, established by himself, as a 'law of nature', thus emphasizing and furthering that terminology. On the other hand, he remained very reluctant in general to speak of laws.⁷³ Finally, he introduced a category – the 'principes d'expérience' – as a sort of empirical generalization, and he explicitly connected this type of statements – that had exactly not been named 'laws' by Descartes – to the now much broadened talk of 'laws'. His approach forms a unique attempt to keep these meta-concepts somewhat sharp, in contrast to what he realized to be widening usages, particularly in England

Metaphysics and Theology

The concept of laws had, of course, many connotations, some of which raised serious problems. Boyle registered them explicitly:

I must freely observe that, to speak properly, a law being but a notional rule of action according to the declared will of a superior, it is plain that nothing but an intellectual being can be properly capable of receiving and acting by a law. For if it does not understand, it cannot know what the will of the legislator is, nor can it have any intention to accomplish it, nor can it act with regard to it, or know when it does, in acting, either conform to it or deviate from it.⁷⁴

Such an observation made it necessary to explicate the status of those 'laws' and the mode in which they – or their 'author' – were considered to affect the workings of nature. In Boyle's account, the world, once created by God, would run purely mechanically on its own, 'according to mechanical laws' ordained by God.⁷⁵ Given this state of affairs, it appears surprising, however, that Boyle himself used and even propagated the terminology of laws. He argued that the analogy between 'regular motions of inanimate bodies' and the lawful acting of people led many (including himself) to use the notion of laws, 'for brevity's sake or out of custom' – a custom that he obviously observed when looking around in the Royal Society milieu. But he hastened to emphasize that such a talk was only metaphorical: what was really acting in natural processes was just brute inanimate matter and mechanic causes [WILSON].

idea probably taken from Pascal (without mentioning his name): *ibid.*, 47–48; cf Pascal 1663 in Brunschvigg and Boutroux 1904–14: III, 197–198.

⁷³ This also holds for his posthumously published study on hydrostatics and –dynamics: Mariotte 1686: 74, 76, 79, 85, 113.

⁷⁴ Boyle 1996: 24–25, or Boyle 1772: V, 170–171. The quoted passages were added in 1680.

⁷⁵ Boyle 1674; Boyle 1772: IV, 68–69. See also Boyle 1666b; Boyle 1772: III, 48.

Boyle here reacted to the Cambridge philosopher Ralph Cudworth who – much opposed to Descartes' mechanistic philosophy – conceived God's rule of nature in term of 'laws' and proposed a verbal interpretation:⁷⁶

Though it be true that the Works of Nature are dispensed by a *Divine Law and Command*, yet this is not to be understood in a *Vulgar Sence*, as if they were all effected by the mere Force of a *Verbal Law or Outward Command*, because Inanimate things are not *Commandable* nor *Governable* by such a *Law*; ...

Whereas Boyle and Cudworth concurred in this point, Cudworth, in strictly voluntaristic mood, proceeded to very different consequences:

and therefore besides the Divine Will and Pleasure, there must needs be some other Immediate *Agent* and *Executioner* provided, for the producing of every Effect.⁷⁷

Cudworth had in mind a 'Plastick Nature' here, acting as mediator between God's will and brute matter. Much in the same vein, Henry More had argued for the existence of an immaterial substance – the 'spirit of nature'. Boyle did his best to argue against those hylozoist positions, proposing a view of mechanistic action [WILSON].⁷⁸ Their dispute, pointing to the metaphysical and theological problems of law-talk, was quickly taken up in France, as Sophie Roux discusses in detail [ROUX]. But those problems did not stop the rise of the terminology in all its ambiguity and anthropomorphism.

Towards the End of the Century

In the last decade of the seventeenth century, talk of laws became increasingly common. Whereas in the early years of the *Philosophical Transactions* and the *Journal des Sçavans* the term occurred rather rarely, many papers later inserted it into their very titles. A significant landmark was the publication of Newton's *Principia* in 1686. Although seldom read in detail, the work became an icon of the 'new' natural philosophy. At the outset of the book, Newton placed his three 'Axiomata, sive Leges Motus', as a deliberate response to Descartes' three 'Laws of nature'. But the concept was also present in many other places, and with other meanings. Newton mentioned the 'laws of planetary motions', 'of the oscillating pendulum', 'of condensation' of an elastic fluid, or 'of gravitation'.⁷⁹ The whole spectrum of uses was present in the widely visible work of one author. At the same time, it became clear how fuzzy the concept had become. 'Laws' could mean axiomatic principles, or more or less empirically established regularities, or anything in between. Nor was

⁷⁶ I thank Andreas Hüttemann for pointing me to Cudworth. For more details, see Hüttemann 2001.

⁷⁷ Cudworth 1678: 147; original emphasis.

⁷⁸ Cf. Oldenburg's summary, *Philosophical Transactions*, 7 (92) (1673): 5198–5199.

⁷⁹ Newton 1972: 54, 428, 521, 569, 577, 759. For details, see Steinle 1995.

the terminology consistent: for example, Newton called Kepler's three discoveries both 'laws' and 'Phaenomena'.⁸⁰

Newton set an example for many. Edmond Halley, in his review of the *Principia*, fully adopted Newton's terminology in all its variations.⁸¹ That was significant since Halley, in his previous articles on different fields, had never talked of laws, but had preferred a language of mathematical structures: Propositions, Corollaries, Lemmata, and so on. The use quickly went beyond the academic realm, moreover. In his popular sermons against atheism in the early 1690s, the cleric Richard Bentley spoke of 'Laws of Nature', 'laws of motion', 'Laws of Vegetation and Life', 'Laws of mechanism', and so on.⁸² Newton, who had provided Bentley with all necessary astronomical information, applauded. From the 1690s on, the notion was firmly established both in England and elsewhere.⁸³ Even the formerly reluctant Huygens used it more freely now, as his 1690 review of his researches in collision and centrifugal force strikingly shows.⁸⁴ In the prominent debates between Malebranche, Leibniz and Newton, the terminology of laws was ubiquitous [ROUX]. And in Pierre Regis's 1691 important Cartesian textbook, talk of laws was much in evidence, both as 'loy de la nature' and 'loix de mouvement', indicating a significant widening of Descartes' use.⁸⁵ Moreover, Regis intensely treated the natural law in the juridical meaning and emphasized a terminological separation between 'loy de la nature' (for natural philosophy) and 'loy naturelle' (for the moral realm).⁸⁶ Together with the English bishop Richard Cumberland [TREIBER], he was one of the very few to bring these two law-concepts together explicitly.

It is indicative that many of the great successes of the 'new sciences' in the seventeenth century came to be called 'laws' late in the century. Both Descartes and Snellius had introduced the sine-relation in optical refraction as a 'proposition', but Hooke, in 1665, referred to it as the 'law of refraction'.⁸⁷ Galileo had never used law-talk in presenting his research, but Boyle, in 1674, spoke of the 'laws of acceleration of heavy bodies descending'.⁸⁸ Kepler had presented his three famous results (1609 and 1615) as 'propositions', but Newton called them the 'laws of planetary motions, detected by Kepler' in 1686.⁸⁹ Boyle had introduced the inverse proportionality between pressure and volume of gases as a 'Hypothesis' (1662),⁹⁰ but by the end of the century the statement had been dubbed 'Boyle's law' in England. Only Mariotte, in 1676, had been the first to call a proposition established by himself a 'law of nature', and he was quickly followed by Hooke with the proportionality between the

⁸⁰ Newton 1972: 556–63 and 569.

⁸¹ Halley 1687: 291, 292, 295.

⁸² Bentley 1693a; Bentley 1693b; cf. Newton 1958: 348, 368, 369, 387, 388.

⁸³ Zilsel 1942b: 270–273; Roux 2001: 565–566.

⁸⁴ Huygens 1888–1950: XVI, 202–208.

⁸⁵ Regis 1691: I, 362–389.

⁸⁶ *Ibid.*, III, chap. 7 of the first book on morals.

⁸⁷ Hooke 1665: preface, p. xxv in my counting.

⁸⁸ Boyle 1674; Boyle 1772: IV, 71.

⁸⁹ *Principia* III, prop. 4, scholium: Newton 1972: 569.

⁹⁰ Boyle 1662: 50, 58; in Boyle 1999: III, 50, 58.

elongation and restituting force of a spring.⁹¹ Within half a century, the concept of laws of nature had been given a firm and visible place in natural philosophy. It was no longer debated, but could be used without further explanation or justification. At the same time, it had lost all sharpness, and the broadness of its meanings – from a-priori insights to empirical regularities – allowed the most divergent writers to invoke its authority.

Laws of Nature and the Rise of the New Sciences

The general picture becomes more differentiated by specific characteristics of, and differences between the developments in France and England. Not only was law-talk much more reluctantly used in France than in England, but the terminology was also much less varied. Whereas in France 'loix de la Nature' were taken in a nearly uniform sense, there was an abundance of more specific 'laws' in England, such as 'mechanical', 'magetical', 'optical' laws, and laws of 'motion', of 'collision', of 'refraction', of 'gravitation', of 'falling bodies', of 'the change of air pressure', of 'the oscillating pendulum', and of 'planetary motions'. Finally, the epistemic roles of 'laws' tended to be more sharply defined in France. There was either the Cartesian notion of a-priori laws, or (if much more reluctantly) the understanding of laws as generalized empirical results, a notion that was explicitly discussed and preferably treated under the term 'principes d'expérience'. In England, by contrast, the epistemic status of laws was barely discussed, but at the same time varied widely, from axiomatic statements with the character of definitions, to empirical regularities with rather restricted scope, and everything in between.

What is the background of such a remarkable development? Newton himself suggested a first clue by emphasizing that new concepts were needed in order to indicate causation after substantial forms had been discarded.⁹² But that can only be a part of the story. Not everyone identified causality with laws, and there had been obvious alternatives to the talk of laws. Wider historical perspectives must be included here. It is significant that it was exactly the protagonists of new approaches to natural philosophy who propagated a wider use of the law-concept. However, the settings in which those programmes began to work varied widely. In England, the activities of the Royal Society were challenged and attacked from early on, and from different angles. In response, many of the early papers were framed as apologies – some of the already cited quotes from Oldenburg are illustrative here.⁹³ Thomas Sprat's 1667 *History of the Royal Society* – commissioned by the Royal Society expressly for the purpose of gaining public support – was full of considerations showing the usefulness of the new experimental philosophy.⁹⁴ One of the most serious questions was that of the relation of those new sciences to religion and divine authority. Fellows felt compelled to show that experimental philosophy was supportive of rather than dangerous to religion. The cleric and FRS Samuel Parker

⁹¹ Gunther 1923: VIII, 333–334, 336.

⁹² *Principia*, Auctoris Praefatio, in Newton 1972: 15.

⁹³ Hunter 1989; Hunter 1990.

⁹⁴ Sprat 1667; cf. Wood 1980.