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## Exact experiences and mathematical deductions: physics according to Mariotte

### *Introduction*

In his *Histoire du ciel*, the Abbé Pluche opposes the epistemological commitments of a stubborn and dogmatic Descartes on one hand, and Edme Mariotte, the modest experimenter, on the other. Mariotte, unlike Descartes, admitted the necessity of carrying out experiments or observations, even if they lack the clarity of a mathematical reasoning:

"Oh ! que j'aime mieux la méthode de cet académicien aussi modeste que savant, & qui n'entreprend ou ne promet rien qu'il ne sente en son pouvoir. L'illustre Mariotte avait lu Descartes : mais il connaissait mieux les bornes de l'intelligence humaine, & l'usage de la géométrie. [...] Quand les connaissances claires lui manquent, il ne croit pas pour cela tout désespéré ou perdu. Il a recours à la certitude de l'expérience, & il se borne prudemment à se servir en chaque chose des effets observés pour lui tenir lieu de principe. Mais il est bien éloigné de penser qu'un seul principe le conduira comme Descartes jusqu'aux vérités les plus éloignées, et qu'aucune ne lui échappera. Pour aller toujours quelque peu en avant, il suit tant que faire se peut son procédé géométrique, mais il ne flatte point l'homme de pouvoir lier en un même tout des connaissances, pour ainsi dire, éparses, ni de pouvoir enseigner la physique comme la géométrie. La perfection de la physique consistera plutôt à recueillir ce que nos sens nous peuvent apprendre de la nature qu'à consulter ce que la raison nous dit"<sup>1</sup>.

There is nothing remarkable about highlighting Mariotte's experimental commitment<sup>2</sup>. Nor will one be surprised by the general idea that physics presents less certainty than mathematics: this is a frequent notion from the second half of the 17<sup>th</sup> century, found even among authors known as "rationalists" or "Cartesians"<sup>3</sup>. The only interesting questions are in

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<sup>1</sup> N.-A. Pluche, *Histoire du ciel*, 2 vols., Paris, frères Estienne, 1762, vol. II, chap. VIII, pp. 191-192.

<sup>2</sup> Leibniz to Tchimhaus, [late June 1682], in *Leibniz. Sämtliche Schriften und Briefe*, Preussische (later Deutsche) Akademie der Wissenschaften ed., Darmstadt (then Leipzig then Berlin), 1923 (afterwards AA), vol. II-1, p. 830: "Unter denen Academici wird M. d. H. den H. Abbé Mariotte den ehrlichsten und aufrichtigsten zu seyn finden. So hat er auch ein sonderlich talent die natur zu untersuchen, artliche experimenta auszufinden und deren ursachen zu errathen". D'Alembert, in his *Essai sur les éléments de philosophie*, Paris, Fayard, 1986, chap. XX, p. 178, mentions Mariotte alongside Boyle to show the extension of experimental physics. Condorcet, "Éloge de M. Mariotte", in *Œuvres*, 12 vols., Paris, Firmin-Didot frères, 1847, vol. II, p. 23, says of him that he was the "premier philosophe français qui se soit livré à la physique expérimentale. D'un côté, il étoit assez profond dans la géométrie pour savoir faire usage des découvertes des géomètres ; de l'autre, il avoit l'esprit assez philosophique pour ne tenter que les expériences qui pouvaient servir à faire mieux connaître la nature".

<sup>3</sup> See for example, J. Rohault, *Traité de physique*, 2 vols., Lyon, Claude Galbit, 1681 (hereafter *Traité de physique*), I, chap. III, § 3, vol. I, p. 22-23. Cf. and P. Perrault, *La mécanique des animaux*, "Avertissement", in *Œuvres diverses de physique ou de mécanique*, 2 vols., Leyde, Pierre Van der AA, 1721, vol. I, p. 331-332. P.-S. Régis, *La physique*, "Avertissement", in *Système de philosophie concernant la logique, la physique et la*

fact knowing specifically how Mariotte thematizes the function of observations, experiences and experiments in physics, why he considers that physical propositions are verisimilar, and what inspiration he may derive from the mathematical model.

To answer these questions, we will concentrate on the only work of Mariotte to deal not with physics, but with what we would call today "epistemology", or more precisely, "methodology", that is to say, the *Essai de logique*, published for the first time, anonymously, in 1678<sup>4</sup>. At times we will complete this study with passages from the *Œuvres de Mr Mariotte, de l'Académie Royale des Sciences, divisées en deux tomes, Comprenant tous les Traitez de cet Auteur, tant ceux qui avoient déjà paru séparément, que ceux qui n'avoient pas encore été publiez*, published in Leiden by Pierre Vander AA in 1717<sup>5</sup>.

Leaving aside here the question of the author of this work, we will show that, while the Abbé Pluche is right to note that Mariotte insisted on the specificity of physics, he also sought a certain inspiration in mathematics as to the way in which to lay out the propositions in a proof<sup>6</sup>. To do so, we will start off from the ontological distinction made in the *Essai* among three types of possibles; next we will show that the three types of propositions correspond to three types of knowledge, and, correlatively, that the main problem of physics is that it is impossible to establish in a certain fashion universal sensory propositions; we will next characterize the notion of principles of experience; finally, we will examine a bit systematically the relationship between mathematics and physics<sup>7</sup>.

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*morale*, 3 vols., Amsterdam 1691, repr. New York/ London 1970, Johnson Reprint Corporation, vol. I, p. 274-275, quoted and commented in S. Roux, "Le scepticisme et les hypothèses de la physique", *Revue de synthèse*, 4<sup>e</sup> s., n° 2-3, avr.-sept. 1998, p. 236-237.

<sup>4</sup> The first study on this *Essai de logique* is that of P. Brunet, "La méthodologie de Mariotte", *Archives internationales d'histoire des sciences*, 1<sup>ère</sup> année, 1947, p. 26-59. See in particular E. Coumet, "Sur l'*Essai de logique* de Mariotte", in *Mariotte savant et philosophe, († 1684). Analyse d'une renommée*, Paris, Vrin, 1986, p. 277-308, and S. Roux, "L'*Essai de logique* de Mariotte : une naturalisation de la méthode ?", *Recherches sur la philosophie et langage*, 26, 2008, to appear.

<sup>5</sup> In this article, we refer for the *Essai de logique* to the edition of A. Gabbey and G. Picolet, Paris, Fayard, 1992 (hereafter *EL*), and for all the other works, to the edition of 1717, available online thanks to the digitalization program of the SICD of the Universities of Strasbourg (hereafter OM). We can find very useful bibliographic indications, including on the unpublished texts of Mariotte, in E. Surgot, "Bibliographie des œuvres de Mariotte", in *Mariotte savant et philosophe*, p. 309-320.

<sup>6</sup> It is established that in the first part, Mariotte makes use, very often word for word, of a manuscript entitled *Les principes du devoir et des connaissances humaines* to which Roberval at least made a contribution, and which corresponds perhaps to a lesson he may have given in the presence of Mariotte in 1644 at the latest. It is B. Rochot, "Roberval, Mariotte et la logique", *Archives internationales d'histoire des sciences*, 6<sup>e</sup> année, 22, 1953, p. 38-43, who first pointed out the relation between the two texts. For their systematic comparison, see A. Gabbey, "Mariotte et Roberval, son collaborateur involontaire", in *Mariotte savant et philosophe*, p. 204-244. Although the present article does not make this comparison, we will note several variations between the two texts, by referring to the edition of the *Principes du devoir et des connaissances humaines* (hereafter *Principes du devoir*) provided by A. Gabbey and G. Picolet at the end of their edition of the *Essai de logique*.

<sup>7</sup> As the first part of the *Essai* corresponds closely to the *Principes du devoir*, what is said about the first text applies to the second; but as we will see, the use of the notion of principle of experience, at least insofar as it is fairly developed, is proper to Mariotte. "Principle of experience" is a word for word translation of the French "principe d'expérience". Note however that the French "expérience" refers both to "experience" and to

### *Ontology: the three types of possibles*

In the first part of the *Essai*, a first group of propositions relative to physics establishes an ontological distinction among three types of possibles:

i) Something is an intellectual possible "si la proposition qui assure qu'elle est impossible n'est pas une vérité première intellectuelle, ny comprise sous aucune vérité première intellectuelle"<sup>8</sup>. As expected, a first truth is a truth certain in and of itself, not derived from another truth, and an intellectual proposition is a proposition which can be judged true or false by reasoning alone<sup>9</sup>. The intellectual possible is thus determined by the fact that the proposition which denies it is false (this proposition consists in posing the impossible obtained by contradictory negation). We can make two remarks on this determination of the intellectual possible. First, in accordance with the strategy adopted by Aristotle in his *Metaphysics*, the possible is delimited by negation of the impossible<sup>10</sup>. But with Mariotte, contrary to what is found in Aristotle, necessity does not intervene, to the point where we have the feeling that his determination of the intellectual possible comes down to this tautology that the possible and the impossible are two contradictories. Second, although Mariotte seems ready to attribute possibility and impossibility to things as well as to propositions, the intellectual possible corresponds on the whole to what the medieval tradition has called, in opposition to the possible as a being in power, "pure possible", "absolute possible", or as in Duns Scotus, "logical possible"<sup>11</sup>.

ii) The natural possible is "ce dont les causes sont en la nature ; ce qui arrive d'ordinaire, et qui n'est pas au-dessus du pouvoir de la nature"<sup>12</sup>. There is obviously a relation of inclusion between all intellectual possibles and all natural possibles: "tout possible intellectuel n'est pas possible naturel ; mais tout possible naturel est aussi possible intellectuel"<sup>13</sup>. This relation of inclusion does not however indicate how to determine the subset of natural possibles. As is immediately detailed, to judge and determine "ce qui arrive d'ordinaire", comes down to identifying similarities: "une chose sera appelée naturellement

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"experiment"; moreover, Mariotte does not make any distinction between "experiment" and observation": the use of either "observation", either "experience" or "experiment" should not be overinterpreted in this paper.

<sup>8</sup> *EL*, 1<sup>st</sup> part, princ. 15, p. 20. *Les principes du devoir*, princ. 12-14 and 16, p. 182-183, speak of a "possible intelligible".

<sup>9</sup> *Ibid.*, princ. 2 and princ. 8, resp. p. 15 and p. 20.

<sup>10</sup> Aristotle, *Metaphysics*, D 12, 1019 b<sub>27-30</sub>.

<sup>11</sup> The analysis of the theory of modalities in the medieval period was renewed by S. Knuuttila, ed., *Reforging the Great Chain of Being. Studies of the History of the Modal Theories*, Dordrecht/ Boston/ London, Reidel, 1981. For some reserves and criticism of this analysis, see J. Schmutz, "Qui a inventé les mondes possibles ?", *Cahiers de philosophie de l'université de Caen*, 42, 2006, p. 9-45.

<sup>12</sup> *EL*, 1<sup>st</sup> part, princ. 19, p. 21.

<sup>13</sup> *Ibid.*, princ. 20, p. 22.

possible, quand une semblable a esté faite"<sup>14</sup>. We will come back to this: according to Mariotte, the judgments as to similarity and the inferences by analogy are, with causal links, the backbone of investigations in physics.

iii) The natural possibles are nonetheless not yet sufficiently specific for the events of our world; the proposition "in September, it may rain in Grenoble" expresses a natural possible, but it does not indicate that it will in fact rain on a given day or at a given time in Grenoble. In the terminology adopted by Mariotte, "tout possible naturel ne se réduit pas en effet"<sup>15</sup> — the other occurrences of the expression "réduit en effet" show that it is a synonym for "reduced to an act", "produced", "achieved", "made real"<sup>16</sup>. The natural possibles that, given the particular chain of cause and effect that make up the warp and woof of our world, have been reduced are what Mariotte calls the "possibles selon l'ordre de la nature"<sup>17</sup>. In this sense, our world is "un possible intellectuel réduit en effet"<sup>18</sup>.

This three-part division of possibles leaves several questions open. The first comes from a terminological surprise: why does Mariotte speak of *possibility* according to the order of Nature, and not, more simply, of reality or actuality? It is via Leibniz that we encounter some remains of the immense literature that in all likelihood constitutes the background for this terminological choice, and perhaps its conceptual implications<sup>19</sup>. In the context of the debates on grace in the post-Trentine theology, the Jesuits of the early 17<sup>th</sup> century came to distinguish three types of possibles<sup>20</sup>. Like that which we saw above, the first distinction is that of the *possibile physice*, the natural power, on one hand, and the *possibile metaphysique*, *logice* or *mathematice* on the other, which corresponds to what Mariotte calls the "intellectual possible" and is defined by the conceivability or the non-contradiction of terms. A second

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<sup>14</sup> *Ibid.*, princ. 21, p. 22.

<sup>15</sup> *Ibid.*

<sup>16</sup> *Les principes du devoir*, princ. 14, p. 182, use, as a synonym of "réduire en effet", "réduire en acte", a literal French translation of the Latin expression "*reducere ad actum*" which is frequently found in the later Scholastics which will be mentioned below.

<sup>17</sup> *EL*, 1<sup>st</sup> part, princ. 26, p. 23: "Il y a une suite de causes et d'effets en la nature, suivant laquelle les choses naturellement possibles se reduisent en effet, comme le Soleil fait élever l'eau en vapeurs, les vapeurs épaissies et condensées dans l'air retombent en pluye, la pluye fait croître les herbes, les herbes nourrissent les animaux, et ainsi de suite. On appellera possible selon l'ordre de la nature, ce qui doit se reduire en effet selon cette suite de causes".

<sup>18</sup> *Ibid.*, princ. 17, p. 21.

<sup>19</sup> See for example, *Essais de théodicée*, 1st part, §§ 40-41, and *Causa Dei*, §§ 14-17, in *Die philosophischen Schriften von G. W. Leibniz*, C. I. Gerhardt ed., Berlin, 7 vols., reprinted. Hildesheim, 1961 (hereafter GP), vol. VI, resp. p. 124-125 and p. 440-441. This connection with Leibniz indicates the existence of common sources, not a community of thought. Mariotte avoids the metaphysical waters: we do not find in Mariotte metaphysical mechanisms that would permit a move from intellectual possibles to the possible reduced to effect that is our world; the selection of our world was perhaps the result of a very wise choice, but also perhaps a result of chance.

<sup>20</sup> I rely on what follows on the work of S. K. Knebel, *Wille, Würfel und Wahrscheinlichkeit. Das System der moralischen Notwendigkeit in der Jesuitenscholastik 1500-1700*, Hamburg, F. Meiner, 2000, the knowledge of which I owe to Jakob Schmutz.

distinction is nonetheless added to the first, that of the *possibile physice* and the *possibile morale*, the former being the power of a being (in the moral and theological context concerned here, a person) of accomplishing or not accomplishing something, and the latter being this power insofar as it comes to be associated with extrinsic circumstances that favor a particular act, or with the difficulties that are an obstacle for it, in other words, this power as it is actualized<sup>21</sup>.

Two points are remarkable with regard to Mariotte's three-part division. First, the Jesuit theologians clearly see that the moral possible as they define it comes down to what happens *de facto*, and that to declare that an event is morally possible is simply to say that it occurs<sup>22</sup>. Second, among these people who speak of human sins, as in the *Essai* that speaks of physical substances, the analogy with dice is pregnant for capturing the difference between what is physically possible and that which is morally possible. It is physically possible with a die to roll a one, a two, a three, a four, a five, or a six; it is physically possible for a person to sin or not to sin; a substance has the physical possibility of acting in several manners depending on the substances in whose presence it is found. But in each case, only one possibility will actually occur<sup>23</sup>. All these connections make it very likely that Mariotte, following Roberval, is using a common source of conceptual distinctions set up in a theological context, and limiting himself to substituting the expression "possible selon l'ordre de la nature" for the expression "possible moral", which would have little relevance when dealing with elastic or luminous bodies. We imagine that the goal of dividing these types of possible in three is for Mariotte neither theological, nor metaphysic, nor moral: the second question is thus to understand how it can be used in the context of physics.

### *Theory of knowledge: the modality of propositions*

In fact, Mariotte wants to indicate the specificity of propositions arising from different disciplines, those of mathematics and physics, and determining what is the object of physics. Although he does not make it totally explicit nor systematic, it seems that he considered a correspondence among types of possibles, modalities of propositions, and types of knowledge. To anticipate what will now be described in detail, we can make the following table.

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<sup>21</sup> S. K. Knebel, *Wille, Würfel und Wahrscheinlichkeit*, p. 148-156.

<sup>22</sup> See the texts cited in *ibid.*, p. 154.

<sup>23</sup> The example of the dice throw appears in *EL*, 1<sup>st</sup> part, princ. 28, 42, 45, 97, resp. p. 23, p. 29, p. 30 and p. 110-112. For its use among Jesuit theologians (more sophisticated than those of Mariotte), see S. K. Knebel, *Wille, Würfel und Wahrscheinlichkeit*, in particular p. 380-437.

TYPES OF POSSIBLES	MODALITIES OF PROPOSITIONS	TYPES OF KNOWLEDGE
Intellectual	Intellectual and universal truths are certain.	Mathematics
Natural	There are no universal sensory truths. The principles of experience are plausible and provisional.	Physics
According to the order of Nature	Sensory and singular truths are certain.	Common sense

Let us detail and explain the contents of this table. The three types of possibles give rise to different types of propositions, which do not have the same modalities:

i) At the top of the table, the intellectual possible is the object of intellectual propositions, which can be judged true or false with certainty and by reasoning alone<sup>24</sup>. And, adds Mariotte, any intellectual proposition is universal; it is because of this universality that it is possible, starting from self-evident intellectual propositions, or intellectual first truths, to derive other truths which will serve in turn to prove yet others.

ii) At the other end of the chain, at the bottom of the table, the possible according to the order of Nature gives rise to singular sensory propositions, for example, "what I touch is hot", "what I see is a wood fire". A singular sensory proposition is true as long as the event to which it relates is a matter for the senses; in this light, it receives the title of "vérité première sensible", or "principe de connaissance sensible"<sup>25</sup>. Unlike a certain Cartesian Vulgate, here clarity and certainty are disassociated: a fact can be certain, and thus be held to be true, without being clear to the mind's eye. Hence the countless declarations in the *Essai* that insist on the fact that our masters in physics are experiments, and not reasonings — according to the words of Leibniz, we must prefer a Leeuwenhoek who tells us what he sees to a Cartesian who tells us what he thinks:

"Une expérience d'une heure, nous instruit souvent davantage que des raisonnements de plusieurs années ; et puis qu'il n'y a point d'autres démonstrations en Physique, que celles qui sont fondées sur des expériences certaines par des conséquences infaillibles qu'on en tire, soit qu'on y employe des propositions intellectuelles ou non ; il s'ensuit que lors qu'on peut avoir des expériences, il n'est pas

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<sup>24</sup> *EL*, 1<sup>st</sup> part, princ. 8, p. 18: "Proposition intellectuelle est une proposition qu'on peut juger vraie, ou fautive par elle-même, ou par le raisonnement, sans qu'il soit besoin de se servir des sens pour en avoir la certitude, mais seulement pour en entendre la signification [...]. Proposition sensible est celle qui ne peut être jugée vraie ou fautive, sans l'aide des sens".

<sup>25</sup> *Ibid.*, princ. 14 and 15, p. 20.

necessaire de chercher d'autres moyens pour prouver la verité des faits"<sup>26</sup>.

Hence also the need for a system of defense against those who would doubt the testimony of the senses, which we will not deal with here<sup>27</sup>. But a singular sensory proposition as such has no fecundity in the sciences, for one can derive nothing from it; one can simply repeat: "what I touch is hot", "what I see is a wood fire".

iii) The problem of physics as a science thus corresponds to the remaining row, the middle row of the table, and we now see the great interest presented for an epistemology of physics by the distinction between "natural possible" and "possible according to the order of Nature". The physicist cannot offer to guess what is the causal chain that makes up our world: a chain that is both total (since it constitutes the world) and particular (since another world could have been). What he seeks to know are certain natural possibles — localized causal chains that can be observed in various places —, or perhaps sensory propositions —singular, but susceptible to generalization. Not, for example, the causal chain that let this fire be extinguished by this water, but the attribution to water of the causal power of extinguishing fire<sup>28</sup>. Once acquired, this knowledge makes it possible to advance a conditional judgment of the type "if I pour the water contained in this bucket on this fire, the fire will be extinguished".

One must be a bit more specific than this, because a universal sensory proposition such as "all animals are alive", although true, is according to Mariotte without interest for science, insofar as, we are tempted to say, it is analytical, the concept of life being contained in the concept of animal. In the terms of Mariotte, and not those of Kant, a proposition of this type is said to declare the "essential qualities" of the thing; and contrary to the case in Kant, the essence is only that which gives its name to the thing<sup>29</sup>. The problem of physics as a science is thus, to recapitulate, establishing universal non-essential sensory propositions that describe certain natural possibles: what bodies are capable of when in the presence of other bodies. But while Kant will hold as established the existence of *a priori*, and thus absolutely certain,

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<sup>26</sup> *EL*, 2<sup>nd</sup> part, 3<sup>rd</sup> disc., p. 137. Also, "Préface", p. 122, and 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 97, p. 107, *passim*. See Pascal, *Traité de la pesanteur de la masse de l'air*, in *Œuvres*, ed. J. Chevalier, Paris, Gallimard, 1954 (hereafter *Œuvres*), p. 430-431, then p. 462: "dans la physique les expériences ont bien plus de force pour persuader que les raisonnements", "Les expériences sont les véritables maîtres qu'il faut suivre dans la physique", *passim*.

<sup>27</sup> On this point, see the last part of S. Roux, "L'Essai de logique de Mariotte : une naturalisation de la méthode ?".

<sup>28</sup> *Les principes du devoir* say that these propositions are "générales", and not "universelles".

<sup>29</sup> *EL*, 1<sup>st</sup> part, princ. 49, p. 27-28: "d'autant que le nom d'animal est donné à cause de la vie, en sorte que rien ne peut estre dit animal, s'il n'est vivant ; il faut de nécessité que tout animal soit vivant". The essential quality of a substance is defined as "celle sans laquelle elle n'auroit pas le nom qu'elle a" (*ibid.*, princ. 31, p. 24-25).



synthetic judgments, Mariotte deems that as a general rule, it is impossible to establish universal non-essential sensory propositions<sup>30</sup>.

There are two reasons for this impossibility. A relativistic starting position: we know things by means of the relation they have with our senses, and not as they are in and of themselves<sup>31</sup>. A nominalist starting position: things are singular, but our sensations are too gross and our terms too general to capture them<sup>32</sup>. Because two things are never totally alike, we always proceed by analogy and similarity. But in these conditions, our universal sensory propositions are at best merely plausible, their verisimilitude here meaning that these propositions are intended to be invalidated when the limits of the analogy and the similarity in question are reached<sup>33</sup>. Mariotte insisted on several occasions on the eminently provisional character of physics propositions and on the dissymmetry, already perfectly clear in the letter from Pascal to the Père Noël, that exists between the fact that a proposition must take into account all known experiments, and the fact that a single experiment suffices to refute this proposition<sup>34</sup>.

It is thus at this set point that, given the object of physics (natural possibles) and the way we have knowledge (by experience or single observation), it is impossible to establish in physics propositions in every point similar to mathematical theorems. But this is not the last word from the *Essai*: according to Mariotte, a pragmatic constraint applies to physics as in the field of action, so as to make us go forward, from one uncertain proposition to another<sup>35</sup>. What

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<sup>30</sup> The exception to this rule is the case when, all things being equal, we can invoke the principle of reason; see *infra*, note 67.

<sup>31</sup> *Ibid.*, princ. 30, p. 24: "La plupart des qualités naturelles ne nous paroissent que suivant le rapport que les substances ont à nous, et à nos sens; et si nos sens changeoient de disposition, elles nous pourroient paroître d'une autre sorte". See also Gassendi, *Dissertations en forme de paradoxes contre les aristotéliens. Livres I et II*, text established, translated, and annotated by B. Rochot, Paris, Vrin, 1959 (hereafter *Dissertations*), II, 6, p. 434 ff. As we show in the last part of S. Roux, "L'*Essai de logique* de Mariotte: une naturalisation de la méthode?", this relativism does not necessarily lead to a denial that sensations are a source of knowledge.

<sup>32</sup> *Ibid.*, princ. 33, p. 26: "Toutes les choses sont particulieres, et l'une n'est pas l'autre, quoy qu'elles ayent des noms communs de genre et d'espece". *Ibid.*, princ. 35, p. 26: "Nos sens ne discernent point avec exactitude les petites differences des choses entr'elles". See also Gassendi, *Dissertations*, II, 2, p. 278-289.

<sup>33</sup> *Ibid.*, princ. 47, p. 30-31: "il est vray-semblable que les causes qui auront du rapport entr'elles feront des effets ou semblables, ou qui auront du rapport entr'eux, et seront proportionnés à leurs causes". At this period, the great question of the Academicians with regard to analogy is to determine if there exists in plants a circulation of sap analogous to that of blood, whose existence in animals had been established by Harvey. General functional similarities support this analogy, but the absence of a motor in plants that would have the same function as the heart in animals is a problem: Mariotte and Claude Perrault would long wonder what could make sap rise. On these questions, see A. Stroup, *A Company of Scientists: Botany, Patronage, and Community at the Seventeenth-Century Parisian Royal Academy of Sciences*, Berkeley, University of California Press, 1990, p. 118-144.

<sup>34</sup> *Ibid.*, princ. 46, p. 30: "[...] comme, si on a veu de l'eau éteindre du feu, on tiendra pour vray-semblable que tout eau éteindra tout feu dans la quantité suffisante, jusques à ce que le contraire paroisse par une vérité premiere sensible [...]". *Ibid.*, princ. 53, p. 35: "Une hypothese d'un systeme est plus vray-semblable que celle d'un autre, lors qu'en le supposant, on rend raison de toutes les apparences, ou de plus grand nombre d'apparences, plus exactement, plus clairement, et avec plus de rapport aux autres choses connues; mais s'il y a une seule apparence qui ne puisse convenir à une hypothese, cette hypothese est fausse ou insuffisante".

<sup>35</sup> *Ibid.*, princ. 41, and 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 1, resp. p. 28-29 and p. 90.

remains is thus to determine how to carry out for the best the management of the uncertain in physics.

### *Epistemology of physics: the principles of experience*

With a few nuances, some found in our notes, everything we have said until now is found in Roberval's *Principes du devoir*. The specific contribution of the *Essai* is in the notion of principle of experience — at least if we understand by "notion" something a bit developed — and in the way Mariotte thematizes the relation between deduction in physics and deduction in mathematics. For the sake of terminological simplicity, in the following we will speak of "principles of experience": this is the expression used in the titles of the paragraphs of the treatises, while in the body of the texts of the treatises as well as in the *Essai*, Mariotte at times calls the propositions in question "principles of experience", and at others "natural maxims", and at yet others "laws of nature", "rules of nature", "natural principle", "fundamental propositions" (they found later propositions), or even "second principles" (with respect to first sensory truths)<sup>36</sup>.

Not only does their name vary, but the propositions given as examples given are troubling for us, since at first glance they do not appear to be of the same epistemological categories. Some express fairly common observations ("le fer se meut vers l'aimant", "un rayon lumineux pénétrant dans le verre produit diverses couleurs"), some refer to more scientific observations, at least insofar as they use a scientific terminology ("chaque corps a un 'centre de pesanteur'"), some correspond to what we would call laws ("l'angle de réflexion d'un rayon lumineux est égal à celui de son incidence"), while others are statements we would qualify as metaphysic ("la nature ne fait rien de rien, et la matière ne se perd point", "il n'est point de matière sans quelques qualités apparentes ou réelles")<sup>37</sup>.

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<sup>36</sup> This terminological inconsistency is noted by E. Coumet, "Sur l'*Essai de logique* de Mariotte", p. 290-291. It is sufficient to refute the distinction proposed by P. Brunet, "Sur la méthodologie de Mariotte", p. 41-51, between experiments, causes, laws, and hypotheses. There is an indisputable desire for syncretism with Mariotte: "natural first causes" or "natural principles naturels" are expressions found in the *Principes du devoir*, p. 194; "maxims" and "rules of nature" are found in Pascal, for example, in the *Expériences nouvelles*, in *Œuvres*, p. 368-369, or in the *Traité de l'équilibre des liqueurs*, in *ibid.*, p. 413. For the use of the expression "law of nature" in the classical period, see S. Roux, "Les lois de la nature au XVII<sup>e</sup> siècle : le problème terminologique", *Revue de synthèse*, 4<sup>e</sup> s., n<sup>o</sup> 2-3-4, avr.-déc. 2001, p. 531-576. For a general presentation of metaphysical controversies on laws of nature at the same period, see S. Roux, « Controversies on Legality (1680-1710) », in *Natural Law and Laws of Nature in Early Modern Europe*, L. Daston et M. Stolte eds., Aldershot, Ashgate Publishing Ltd., 2008. For a comparison between the notion of laws of nature in France and England, see F. Steinle, "From principles to regularities: tracing 'laws of nature' in early modern France and England", in *ibid.*

<sup>37</sup> *EL*, 1<sup>st</sup> part, princ. 49-50, and 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 32-33, p. 91-92, p. 96, p. 107. The presence of statements such as "Nature does nothing in vain" is all the more troubling as they are supposed to depend on exact observations (p. 92): what exact observation could show that Nature does nothing in vain?

This terminological inconsistency and this choice of epistemological indifference, which we also find in Mariotte's treatises, do not prevent the constitution of a fairly consistent notion of principle of experience. As far as we are able to give a systematic turn to the statements of the *Essai*, here are the characteristics of this notion, which will allow us to understand how what we have just called the management of the uncertain takes place in physics:

i) With regard to the genesis of principles of experience, Mariotte proposes nothing that resembles the logics of induction found, for example, in Francis Bacon or John Stuart Mill. To limit ourselves to a discussion on the 17<sup>th</sup> century, we know the main tenets of the empiricist epistemology of Bacon's physics. According to Bacon, Aristotelian physics failed because its foundations were unsound: the first principles were not the result of a scientific enquiry, but were supposed to arise from things spontaneously, even with no particular attention being paid to them. To build a new physics, science must take on the question of its bases and set up procedures that allow for the extraction of new principles from experience, principles that will be all the more certain because their extraction is more gradual. These are the procedures that Bacon brings together under the term of induction, whence his tables of presence, absence, and degree. And as for the principles whose extraction they are supposed to allow, it has often been observed that they are forms, taken in the absolute senses<sup>38</sup>.

Mariotte proposes no reflection on the various forms of experience with which one can deal in physics<sup>39</sup>. He says nothing about observations, experiences or experiments that found the principles of experience, other than that they must be "exact", without us really knowing what this adjective refers to, nor what allows us to measure or at least estimate a greater or lesser degree of exactitude. The frequency of this adjective is such that we could say that it is a sort of Homeric epithet without any fixed meaning<sup>40</sup>. In addition, Mariotte condemns the Baconian pretension of isolating the principles of experience according to well-defined

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<sup>38</sup> Bacon, *Novum organon*, I 19 to 22, 100, 105, in *The Works of Francis Bacon*, J. Spedding, R. E. Ellis and D. D. Heath eds., 14 vols., London, Longman, 1857-1874 (hereafter *SEH*), vol. I, resp. p. 159-161, p. 203, p. 205-206. *Passim*.

<sup>39</sup> But see Rohault, *Traité de physique*, "Préface", vol. I, p. v.

<sup>40</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 92: "pour parvenir à la connaissance de ces maximes naturelles ou principes d'expérience, il faut faire plusieurs observations exactes". *Ibid.*, p. 97: "ces expériences sont souvent très difficiles, tant pour la dépense que pour le travail et l'exactitude". *Ibid.*, p. 103-104: "[...] il faut avoir une connaissance exacte de ces expériences [...] on en examinera exactement toutes les apparences [...] plusieurs observations exactement faites". *Ibid.*, 4<sup>th</sup> disc., art. 1, p. 156: "[...] plusieurs expériences exactes [...]". *Ibid.*, art. 2, p. 164: "[...] il faut donc examiner avec beaucoup d'exactitude ces questions de fait". *De la percussion*, in OM, vol I, p. 113: "[...] J'ai fait plusieurs expériences [...] dont voici les plus exactes". *Du chaud et du froid*, in OM, vol. I, p. 193: "Ces observations, qui ont été faites avec beaucoup d'exactitude [...]". *De la nature des couleurs*, in OM, vol I, p. 197: il "est impossible d'établir aucune science dans les sciences naturelles que par des expériences exactes". *Ibid.*, p. 201: "[observations] exactement faites avec des personnes fort intelligentes". *Ibid.*, p. 304: "expériences [...] faites avec beaucoup d'exactitude".

procedures, noting once and for all that "on ne peut donner des regles certaines et infaillibles pour les trouver"<sup>41</sup>. And yet he does use the term "induction"<sup>42</sup>. But this is in neither the Baconian sense of a methodical procedure, nor an enumeration or a counting, which Bacon qualified as puerile, but which can be found in Descartes for problems where it is important to review all cases so as to be sure of identifying all possible solutions<sup>43</sup>. With Mariotte, the term "induction" is simply a synonym for the term "expérience", with which it is often paired: what is known "par expérience ou par induction" is what is directly apprehended by the senses<sup>44</sup>.

But is not this confidence in the certainty of the senses naivety in the second half of the 17<sup>th</sup> century, when any self-respecting natural philosopher would make the distinction between intrinsic properties of bodies and the way they appear to us<sup>45</sup>? In fact, Mariotte admits this distinction: he declares in passing that most qualities arise from variously disposed matter<sup>46</sup>. But this does not lead him to doubt the knowledge given by sensory appearances, as his goal is simply to set out the proper scientific usage of these appearances. He thus notes that the thesis that sensory qualities exist as we perceive them in things is not a radical illusion:

"Quoy que nous soyons détrompez des faux jugemens du vulgaire, touchant les sensations, il ne faut pas laisser d'en parler comme les autres ; et il ne faut pas s'obstiner à combattre les apparences naturelles que nous donnent les sens. Ainsi nous dirons que le feu est chaud, que le Soleil est lumineux, que le sucre est doux, que la neige est blanche, que les cloches sonnent, qu'un Luth produit une agréable harmonie, etc."<sup>47</sup>.

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<sup>41</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., p. 89.

<sup>42</sup> Pace C. Salomon-Bayet, *L'institution de la science et l'expérience du vivant. Méthode et expérience à l'Académie royale des sciences*, Paris, Flammarion Science, 1978, p. 84, declares that the term "induction" is not found in Mariotte.

<sup>43</sup> For the puerile character of induction understood as enumeration according to Bacon, see *Novum organon*, I 69 and 105, in SEH, vol. I, p. 179 and p. 205-206. We frequently encounter the idea that the impotence of induction comes from its inability to be an exhaustive enumeration; see for example, Gassendi, *Dissertations*, II, 5, art. 5, p. 414-419. For the Cartesian use of the term "induction" as a synonym for "dénombrement", first with regard to mathematical problems, then by a problematic extension, in physics contexts, see *Regulae ad directionem ingenii*, 7 and 11, in *Œuvres de Descartes*, C. Adam and P. Tannery eds., new presentation by B. Rochot and P. Costabel, 11 vol. Paris, Vrin, 1964-1974 (hereafter *AT*), vol. X, resp. p. 388-389 and p. 408; to Mersenne, 27 juillet 1638, in *AT*, vol. II, p. 254; *Principia philosophiae*, IV 145, in *AT*, vol. VIII-1, p. 284.

<sup>44</sup> *EL*, 1<sup>st</sup> part, princ. 9 and 2nd part, 2<sup>nd</sup> disc., art. 2 and art. 3, resp. p. 18, p. 89, p. 110.

<sup>45</sup> With regard to this distinction, see S. Roux, *La philosophie mécanique (1630-1690)*, unpublished doctoral thesis, EHESS, 1996, p. 43-96, 159-212, *passim*.

<sup>46</sup> *EL*, 1<sup>st</sup> part, princ. 29, p. 23: "La plûpart des qualités naturelles ne sont autre chose que des dispositions de la matiere à faire et recevoir de certains effets ; ainsi une corde de luth frappée produit le son par le mouvement qu'elle imprime en l'oreille, quoy qu'en la corde il n'y ait aucun son ; mais seulement un mouvement", followed by the princ. 30 cited *supra* note 31. See also *Traité des couleurs*, in *OM*, vol. I, p. 196: "La plupart des hommes n'hésitent point à dire que le soleil est lumineux, que le feu est chaud, que les cordes de luth ont un son agréable ; et cependant ces choses n'agissent sur nous que par quelques mouvements, tout le reste de leurs apparences vient de nous et nous doit être entièrement attribué".

<sup>47</sup> *EL*, 2<sup>nd</sup> part, 4<sup>th</sup> disc., art. 1, p. 155-156.

Mariotte poses the question of knowing how to speak and what to say, but, if one must continue to speak like the common people, it is not due to a polite respect for propriety, nor to a reliance on a conventional idea that our sensations have their own finality, that is, the preservation of our bodies<sup>48</sup>. Rather, it is because common sense is right: while fire contains no real quality corresponding to what we experience as heat, it is a sensory truth that fire is hot for an animal organism like ours, and that it contains what is needed to cause this sensation. That the sensory truths are truths that depend on our sensory organs does not make them lesser truths: they are simply truths that express relations, as, for example, when we say that fire softens wax. Thus Mariotte sails between the two shoals that would prohibit the establishment of a science of phenomena: either taking all appearances as realities (whereas the qualities that appear to us are not identical to the qualities truly possessed by the things), or considering that appearances are all unreal (for qualities to appear to us, things must truly have the qualities capable of producing them)<sup>49</sup>.

To recapitulate this first point while playing a bit on words, the *Essai* places observations, experiences and experiments at the foundation of physics, without making them the object of a foundationalist inquiry: he does not go beyond the tautological affirmation that the principles of experience come from experiences, that this origin makes for their certainty, and that this certainty is not affected by the distinction between real and apparent qualities. In fact, in his longer and more complex treatises, the *Traité de la percussion* and *De la nature des couleurs*, Mariotte formulates principles that he relates to various experiences and from which he then deduces the consequences that correspond to other observations or experiences<sup>50</sup>. Things are however never as simple as one would like. Before even the principles of experience, these treatises refer to "suppositions", for example, the principle of inertia in mechanics, or the laws of reflection and refraction in optics. To be sure, all physicists of the time did not agree as to the status of the principle of inertia, with some following Descartes and deriving it from general metaphysical principles such as

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<sup>48</sup> We find this idea in *Du chaud et du froid*, in OM, vol. I, p. 184: "[...] ils [nos sens] ne sont pas disposés pour nous faire connoître les choses en elles-mêmes, mais seulement telles qu'elles sont à notre égard, afin que nous puissions éviter celles qui nous sont nuisibles, et nous servir de celles qui sont propres à notre conservation". I call it "conventional" in the sense that it can be reconciled, for an author such as Malebranche, with the thesis that sensations offer no knowledge as such as to what are bodies. Here as elsewhere, the readers of Descartes choose the position that suits them in the broad spectrum he opened, with Mariotte and Malebranche being here at the two extremities.

<sup>49</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, and 2<sup>nd</sup> part, 4<sup>th</sup> disc., art. 1, resp. p. 94-95 and p. 143 ff.

<sup>50</sup> The first proposition of the *Traité de la percussion* explains how to build a machine to carry out experiments, after which the experimental foundation of each proposition is highlighted: "Cette proposition se prouve facilement par l'expérience" (prop. 2 a,d prop. 3, in OM, vol. I, resp. p. 9 and p. 10); "on en peut voir l'expérience" (prop. 2, p. 9); "On connaîtra la vérité de cette proposition par l'expérience" (prop. 5, p. 12), *passim*. He is less heavy-handed in the *Traité des couleurs*. There is a remarkable, but not exceptional, way of doing: we can already find it in the *Expériences nouvelles* and the *Traité de la pesanteur de la masse de l'air* of Pascal.

"nothingness has no properties", "any change of a subject has an outside cause", while others discuss it under various names (hypothesis, axiom, law) as an initial principle without declaring what type of justification it is subject to — not to mention the case of Roberval, whose refuses this status because it cannot be confirmed experimentally, as bodies in our world do not continue their movement indefinitely, but rather, come to a stop<sup>51</sup>. We must nonetheless recognize that nothing in Mariotte's epistemology authorizes a distinction between "principles of experience" and "suppositions", all the more so as in the *Traité des couleurs*, he explains that the priority sometimes attributed to the laws of reflection and refraction comes not because they are more worthy than the other principles of experience, but simply because they are more experimentally accessible than them — which seems to indicate that, contrary to Roberval, he did not mean by "supposition" a principle which cannot be confirmed experimentally<sup>52</sup>.

ii) To speak of *principles* of experience is to make use of a convenient fiction: it could lead one to believe that it is a matter of absolute principles, of first causes, but this is not the case — these are the stopping points which one must admit pragmatically to get around the problem of the incompleteness of the causal inquiry. Contrary to what happens in mathematics, a good deal of physics is, according to Mariotte, the identification of causal chains<sup>53</sup>. But the process of causal inquiry is always impaired by its incompleteness. First, multiple causes are almost always required to produce an effect<sup>54</sup>. Second, even if we suppose that a single cause suffices to produce a given effect, and even if we know this cause, we must

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<sup>51</sup> The "Cartesian" position can be found, for example, in J. Rohault, *Traité de physique*, I, chap. XI, §§ 1-3, vol. I, p. 69-71 or P.-S. Régis, *Système de philosophie. Physique*, book I, 2<sup>nd</sup> part, chap. 9, vol. I, p. 323 (which also presents several pages later the description of Mariotte's machine). For several remarks on the status of the first principles according to Newton and Huygens, see S. Roux, "Les lois de la nature au XVII<sup>e</sup> siècle", p. 561-565. For the position of Roberval, see his letter to Torricelli, Jan. 1646, in M. Mersenne, *Correspondance du P. Marin Mersenne, religieux minime*, P. Tannery, C. de Waard, and A. Beaulieu eds., 17 vols., Paris, Éditions du CNRS, 1932-1988, vol. XIV, p. 17: "*Motu quidem recto concedimus, at motu aequabili; unde hoc? Equidem in omnibus omnino mobilibus projectis experientia constantissime huic assertioni repugnant*". Twenty years later, he maintains this position, as is indicated by Huygens, in *Œuvres complètes de Christian Huygens*, Société hollandaise des sciences ed., 22 vol., La Haye, 1888-1950, vol. XVIII, p. 452-453, p. 456, *passim*.

<sup>52</sup> *Traité des couleurs*, in OM, vol. I, p. 231: "On pourrait objecter que ces principes [les principes d'expérience que Mariotte s'apprête à énoncer] ne sont pas d'égale dignité à ceux-ci [les lois en question]. [...] Mais on peut répondre que la vérité de ces deux derniers principes n'est connue que par les observations qu'on en a faites, et que le seul avantage qu'ils ont, est qu'ils sont plus simples, et que les expériences en sont plus aisées à faire".

<sup>53</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 1, p. 71: "Quelques-uns ont dit que les choses estoient bien prouvées, quand elles estoient prouvées par leurs causes; ce qui est vray à l'égard des choses naturelles: mais à l'égard des propositions de Geometrie, ou des autres sciences intellectuelles, il n'est pas nécessaire de prouver pourquoy la chose est ainsi, mais seulement qu'elle est ainsi". The importance of the causal inquiry is clear in the first part of the *Essai*: principles 18-19, 23-27 and 46-49 deal with the relation between causes and effects.

<sup>54</sup> *Ibid.*, art. 2, p. 98: "[...] pour l'ordinaire, il y en a plusieurs [causes] qui concourent à la production d'une effet, et y contribuent diversement; d'où il suit qu'il est impossible de bien expliquer la plupart des effets, puis qu'on ignore la plupart de leurs causes [...]". *Ibid.*, art. 3, p. 111: "[...] la Physique est difficile à cause qu'il faut souvent chercher plusieurs causes pour expliquer un effet naturel [...]".

wonder what is the cause of the cause, and so on. And this does not take into account the fact that there are often causes that impede each other<sup>55</sup>. In this way, treating principles as if they were genuine causes, even if we know this not to be the case, is a means of avoiding a vain infinite causal regression:

"Lorsqu'en recherchant la suite des causes pour expliquer, et rendre raison de quelques effets naturels, on en trouve une dont on ne peut donner aucune cause qui soit certaine et évidente, on s'en servira comme d'une cause première naturelle pour prouver et expliquer ces effets ; et la proposition qui enoncera la vérité de cette cause, servira de principe pour prouver les effets qu'elle produit ; pourvu que cette proposition soit reconnue véritable par plusieurs expériences, sans qu'aucune n'y contrevienne. [...] La raison est, que puisque par le vingt-quatrième principe nous ne pouvons aller à l'infini dans la recherche des causes naturelles, nous devons nous arrêter à la plus éloignée qui nous paroît certaine et évidente, lors qu'elle peut rendre raison de plusieurs effets"<sup>56</sup>.

The principles of experience also avoid a deceptive dodge to the problem of incompleteness of causal inquiry, that dodge being to seek to explain the principles of experience in terms of elements judged elsewhere to be ontologically prior<sup>57</sup>. The examples used by Mariotte in the *Essai* show that he is thinking primarily of the attempt to reduce phenomena to movements of corpuscles, which was the great question for Cartesians of his time<sup>58</sup>. In his treatises on physics, he also takes aim at the chemists of the Académie, who,

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<sup>55</sup> *Ibid.*, 1<sup>st</sup> part, princ. 27, p. 23: "Il y des causes naturelles qui s'empeschent les unes les autres ; mais les effets se font suivant les plus fortes [...]". *De la nature des couleurs*, in OM, vol I, p. 305: "Mais parce qu'il y a quelquefois des Régles générales ou loix de la nature qui empêchent les effets les uns des autres ; lorsqu'on trouvera quelque effet différent des effets ordinaires, il faudra chercher quelques autres Régles qu'on puisse appliquer à cet effet, car alors il dépendra de deux ou trois causes, et on tâchera de l'expliquer par deux ou trois Régles".

<sup>56</sup> *Ibid.*, princ. 49, p. 31-32. Princ. 24, p. 22, hesitates between an ontological affirmation and an epistemological restriction: "Il n'y a pas en mesme temps une subordination infinie de causes naturelles d'un mesme effet ; mais chaque effet a une ou plusieurs causes premières, ou du moins, on ne peut aller à l'infini dans la recherche des causes naturelles d'un mesme effet". See also princ. 50, p. 33. In contrast, see Pascal, *Pensées*, Ch. 352, Br. 72, in *Œuvres*, p. 1110: "[...] toutes choses étant causées et causantes, aidées et aidantes, médiates et immédiates, et toutes s'entretenant par un lien naturel et insensible qui lie les plus éloignées et les plus différentes, je tiens impossible de connaître les parties sans connaître le tout, non plus que de connaître le tout sans connaître particulièrement les parties".

<sup>57</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 97: "La troisième [cause du peu de progrès qu'on a fait jusques à présent dans la science des choses naturelles] est, que plusieurs philosophes s'attachent avec un grand soin à chercher les causes des principes d'expérience, quoiqu'ils soient suffisants pour expliquer beaucoup d'effets naturels selon la proposition quarante-neuvième ; au lieu d'en tirer plusieurs belles conséquences, et d'imiter en cela les géomètres qui ne cherchent point à prouver les premiers principes dont ils se servent, mais qui s'attachent à en tirer plusieurs belles conséquences". Leibniz also speaks of "principles of experience" and compares their use in physics to the use of undemonstrated axioms in geometry (*Nouveaux essais sur l'entendement humain*, IV 12 § 10, in GP, vol. V, p. 435). But Leibniz explicitly criticizes Mariotte: he states that one must not renounce one's own genius or censure those who seek causes or those who try to demonstrate everything, as was the case, he adds with a bit of perfidy, of Roberval (Leibniz to Mariotte, July 1676, in AA, vol. II-1, p. 422).

<sup>58</sup> *EL*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 103: "[...] il vaut bien mieux se contenter d'une belle et ample histoire des principaux effets de la nature, connus par des expériences certaines, quoy qu'on n'en sçache pas toutes les causes, que de perdre son temps à vouloir établir de fausses hypothèses pour tâcher d'expliquer les plus

following Samuel Cottureau Duclos and Claude Bourdelin, had attempted to carry out a chemical decomposition of plants by distillation, in a reductionist perspective, even if the elements at stake were not those of the Cartesians, but rather salt, sulfur, and mercury, along with the Aristotelian elements<sup>59</sup>. Against all of these parties, Mariotte's position ultimately comes down to the fact that the causal function that a principle can fulfill in an explanatory system does not require that one identifies the elements that one supposes to be ontologically prior. These also applies in a field such as optics, where the hypotheses in presence, for Mariotte primarily those of Descartes and Newton, with Grimaldi and De Chales mentioned in passing, were associated with theories of matter<sup>60</sup>.

This position can evoke what we might, to be brief, call Robert Boyle's theory of intermediate causes. Taking the defense of scientists supposed to be close to experience, in particular physicians and chemists, against a speculative corpuscularism according to which no explanation of natural philosophy can be rational unless it assigns certain corpuscles as causes of phenomena, Boyle asserted that it is not dishonorable to propose explanations that call on more familiar properties, ones that in any case are easier to observe than corpuscular properties; depending on the text, he calls them "theories, notions, and intermediate rules", "subordinate principles", "subordinate causes", or "intermediate causes"<sup>61</sup>. The task of speculative minds and that of experimenters would in this way be complementary: one would

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difficiles, comme le ressort des corps, la vertu de l'aymant, etc. et faire ensuite une infinité de faux raisonnemens, qui empeschent l'avancement de la Physique".

<sup>59</sup> *De la végétation des plantes*, in OM, vol. I, p. 146: "J'avoue donc ici [lorsqu'il s'agit des principes des plantes] nettement mon ignorance, et que dans la recherche que j'ai faite de ces causes particulières je n'ai rien découvert qui me pût satisfaire et qui eût la moindre apparence de certitude. C'est pourquoi je conseille aux savants de ne pas se tourmenter à les rechercher, soit par la Chimie, soit par les raisonnements qu'ils pourraient fonder sur l'hypothèse commune du chaud, du froid, du sec et de l'humide, ou sur celle de l'acide et de l'alcali, etc., mais de s'arrêter seulement à ce que les observations et les expériences de plusieurs siècles nous en ont pu faire découvrir". The attempt to chemically decompose plants made by Academicians and *De la végétation des plantes* are analysed in C. Salomon-Bayet, *L'institution de la science et l'expérience du vivant*, resp. p. 54-66 and p. 81-84, but see in particular A. Stroup, *A Company of Scientists*, p. 89-102.

<sup>60</sup> *Traité des couleurs*, in OM, vol. I, p. 228: "Pour ne pas m'embarrasser dans de semblables difficultés [Mariotte vient de discuter les différentes hypothèses, et de montrer qu'aucune ne s'accorde avec toutes les expériences disponibles], je n'ai pas voulu entreprendre d'établir ici quelque hypothèse douteuse et obscure, mais seulement de donner quelques règles générales, ou principes d'expériences, qui puissent s'accorder à toutes sortes d'observations". The theories of color in presence are studied in M. Blay, *La conceptualisation newtonienne des phénomènes de la couleur*, Paris, Vrin, 1983.

<sup>61</sup> For the texts of Boyle, see in particular *Royal Society Boyle Papers*, IX, f. 28 and f. 40, cited by L. Laudan, *Science and Hypothesis. Historical Essays on Methodology*, Dordrecht/ Boston/ London, Reidel, 1981, p. 35-36, and *An Examen of Mr. T. Hobbes his Dialogus Physicus de Natura Aeris*, in *The Works of the Honourable Robert Boyle*, T. Birch ed., 6 vols., London, 1772, here in the reprint Hildesheim / New York, Georg Olms, 1966 (hereafter TB), vol. I, p. 199. For the analyses of these texts, see L. Laudan, *op. cit.*, p. 27-58, and A. Chalmers, "The Lack of Excellency of Boyle's Mechanical Philosophy", *Studies in History and Philosophy of Science*, 24, 1993, p. 556-560.



need to make space for more experimental inquiries, while maintaining the ideal of the reduction to corpuscular properties — even if this achievement is indefinitely postponed<sup>62</sup>.

If the position of Mariotte can recall that of Boyle, it is because the terms of the problem are identical: on one hand, explanations establishing functional dependencies between phenomena, on the other, explanations that reduce phenomena to ontologically prior elements. But contrary to Boyle, Mariotte does not consider the reduction of phenomenal properties to corpuscular properties as an ideal. As we have seen, while he declares that most qualities arise from variously arranged matter, this is to delimit two excesses in the use of sensory experiences. In so doing, he does not prejudge the ontologically prior elements of the physics yet to come. And as such, the principles of experience are not only provisional, intermediate, and subordinate with regard to an ontology, whether corpuscular or chemical, which might be considered as otherwise established: these are simply the stopping points blazed to avoid getting lost one way or another in the forest of causes.

iii) In recapitulating the preceding, Mariotte manifests a certain form of indifference as to the origin of propositions and the enterprise of ontological reduction: to be a principle of experience, a proposition does not have to undergo a genetic test defining its empirical origin, nor present a certificate attesting that its terms can be reduced to supposedly ontologically correct elements. But one is tempted to wonder what, in these conditions, can be the function of a principle of experience in the edifice of knowledge, and how one can recognize that a principle of experience properly fulfills its function? In fact, it is necessary and sufficient that it fulfills the same function as a first cause in the deductive machinery, that is to say, that it allows for the deduction of a certain number of propositions corresponding to effects attested to elsewhere.

At this point, two interpretations are possible. According to the first, the most moderate and in our minds, the most correct, Mariotte did not give up the idea that a large part of physics inquiries involves establishing real links of causality between phenomena and that physics treatises should, as much as possible, represent these links in the logical chain of principles and consequences<sup>63</sup>. We can thus (it would lead to the second interpretation) emphasize passages that are more pragmatic or skeptical, which could lead to the idea that the physicist is indifferent to the weight of reality of the principles he supposes; and so it is, in the passages that discuss the notion of system of a thing, already put forward by Roberval, a

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<sup>62</sup> For a systematic comparison of Descartes, Mariotte and Boyle on this point, see S. Roux, *La philosophie mécanique (1630-1690)*, p. 215-233.

<sup>63</sup> The *Traité de la percussion*, in OM, vol. I, p. 14, notes in passing that the order of propositions is not the same as the "ordre de la nature", that is to say, the effective chain of causes in Nature.

system being a hypothesis that takes into account known experiments<sup>64</sup>. But, besides the fact that the notion of systems is quite widespread in the epistemology of the 17<sup>th</sup> century, this interpretation does not pay justice to most of Mariotte's texts, which are resolutely realistic and causalistic, while giving itself an air of radicality on the cheap.

Whatever the interpretation chosen, we cannot avoid a problem. The idea of proceeding in physics as in mathematics, in particular by deduction, is as old as the mixed sciences of the Aristotelian tradition. But in the mixed sciences, the principles from which one starts are principles formulated so as to make deductions possible. How can one obtain principles of experience that meet this condition? Experiments may have the evidence of facts, but this does not suffice for the principles that are drawn from them to be structured so as to be fertile in deductions. As with regard to what makes for the exactitude of an experiment, Mariotte is silent as to that which would allow us to recognize a principle of experience: once again, it is the testing of facts that seems to decide the issue — there are some principles of experience that are fertile, while others are not. We must keep the former and forget the latter. But might there not on top of this be obstacles that prohibit by principle the parallel between deduction in physics and in mathematics?

### *Physics and mathematics*

Perhaps we must take up the question at a higher level, or in any case, more systematically. As is well-known, the program was made in the 17<sup>th</sup> century of a method that was inspired by the experiment carried out in a given field, that of mathematics, as to what made for a fertile reasoning. This program, or this dream, took a variety of forms, depending on whether one sought to take from mathematics an ontology, or specific reasoning procedures, or a "spirit", the most impalpable of all — and of course, depending on the type of mathematics considered. Ultimately the fact remains, that among a certain number of authors, that what takes the place of logic as *organon* or commonality among sciences and that that constitutes the model which should inspire the method, is mathematics.

As we have seen, Mariotte insists on the role that experience plays in physics. But he is far from being a partisan of an experimentalist physics, if by that we mean one that would be

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<sup>64</sup> *EL*, 1<sup>st</sup> part, princ. 2, p. 34: "On appellera systeme d'une chose, la façon dont on suppose qu'elle est pour expliquer ses effets, signes et apparences, et en rendre raison". *Ibid.*, 2<sup>nd</sup> part, 2<sup>nd</sup> disc., art. 2, p. 96: "Pour ce qui est de sçavoir comment une chose agit, et reçoit les actions externes ; il faut par le moyen de ses diverses apparences, établir un Systeme [...]. Quoy qu'on ne soit pas assuré de la verité d'un système, on ne laissera pas de s'en servir, si l'on peut expliquer et prévoir par son moyen les effets qu'il est important de sçavoir" Naturally, a system will be defective if it does not take into account all appearances, see *ibid.*, p. 97, and 4<sup>th</sup> disc., art. 1, p. 162.

defined by a systematic opposition to mathematics<sup>65</sup>. He first notes that sensory propositions need the support of intellectual propositions, and what occurs to him then is the role in physics of measurement and demonstrations of elementary geometry<sup>66</sup>. It even happens, exceptionally, that the physicist is able to form, exactly as does the mathematician, an intellectual proposition; this is the case in particular when, all things being equal, one can form an intellectual proposition with regard to sensible dimensions, as does, for example, Archimedes for the principle of the lever<sup>67</sup>. Thirdly, and Mariotte here complies with a thematicization of the relation between physics and mathematics that one traditionally finds in mixed sciences, he highlights the fact that, if mathematical objects are formed by abstraction, we can conversely move from these objects to sensory things by a process qualified as "ajustement à la matière"; the examples he gives in this context are taken from optics, with the abstract angle adjusted to matter when he is considered, for example, concretely as an angle between two rays of light<sup>68</sup>.

Lastly, and this is our main point, the chains of mathematical proofs constitute models as to the fashion in which reasonings should be laid out in physics<sup>69</sup>. Mariotte is thinking here mainly of the fact that one can provide proofs in physics as in mathematics, by understanding "preuve ou demonstration" as "le discours par lequel on connoît la connexité d'une proposition douteuse, avec des propositions certaines et infaillibles"<sup>70</sup>. As we have seen, the principles of experience are supposed to be the starting points for these proofs. But — here again, pragmatism intervenes —, proofs are rarely "by continuous reasoning", that is to say, they do not show all the connections needed to go from one proposition to the next: they work rather "by citation"<sup>71</sup>. Proving a proposition "by citation" is simply proving it by referring to other propositions already established, so as to avoid having to go all the way back to first

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<sup>65</sup> Pace C. Salomon-Bayet, *L'institution de la science et l'expérience du vivant*, p. 90, p. 97, *passim*, who in her desire to insist on the specificity of the natural sciences according to Mariotte, at times allows herself to say that he removes from mathematics its role as a model. We will follow the "Avis au lecteur" in the 1717 edition, in OM, vol. I, n.p.: "les démonstrations de mathématique et les raisonnemens fondés sur les expériences [sont] les seuls fondemens sur lesquels on puisse bâtir quelque chose de solide et de vrai en matière de physique, comme il [Mariotte] le dit très bien dans son *Essai de logique*". See also A. Stroup, *A Company of Scientists*, p. 222. The position described by Salomon-Bayet does exist, for example in Boyle, as when he opposes physics demonstrations and mathematics demonstrations of the principle of Archimedes (*Theodicina hydrostatica. An Essay*, in TB, vol. V, p. 460).

<sup>66</sup> *EL*, "Préface" and 2<sup>nd</sup> part, 2<sup>nd</sup> disc., resp. p. 14 and p. 61.

<sup>67</sup> *Ibid.*, art. 2, p. 93: "On ne peut prouver un effet naturel par les seuls principes intellectuels, si ce n'est lorsque tout est égal de part et d'autre ; car en ce cas l'expérience n'est pas nécessaire : comme, cette demande d'Archimede, *les poids égaux en distance pèsent également*, peut passer pour un principe intellectuel ; car où prendroit-on l'inégalité, et d'où pourroit-elle proceder, puisque tout est pareil de part et d'autre ?".

<sup>68</sup> *Ibid.*, p. 90-91, p. 93-94. Mixed sciences are expressly mentioned at the end of this article, p. 107.

<sup>69</sup> *Ibid.*, p. 61.

<sup>70</sup> *Ibid.*, 1<sup>st</sup> part, princ. 4, p. 17.

<sup>71</sup> *Ibid.*, 2<sup>nd</sup> part, 3<sup>rd</sup> disc., p. 127: "Lorsque les propositions sensibles douteuses sont éloignées des principes d'expérience, et des autres propositions qui peuvent servir à les prouver, il faut prouver les dernieres par la citation des premieres, de la mesme maniere qu'on prouve celles de Geometrie et d'Arithmetique".

principles each time a new proposition has to be demonstrated. So far there is an analogy between the practice of citation in mathematics and in physics. But Mariotte quickly marks the limits of this analogy<sup>72</sup>.

Indeed, in mathematics, there is, so to say, no remainder, insofar as we consider that a proposition is established if we have read the proof somewhere. In physics, however, something always escapes us, because reading a description of an experiment or deciphering observation notes, is not the same as carrying out this experiment or making these observations oneself and in person:

"Mais les experiences sur lesquelles sont fondées les principes ou regles de la nature, ne peuvent estre mises sur le papier, comme on y met les lignes et les figures de Geométrie, et on a souvent beaucoup de peine à concevoir comment elles ont esté faites : mesme il y en a, qu'un seul homme ne peut faire, comme d'observer quels vents regnent en mesme temps dans la France et dans la Pologne ; si le flux et le reflux de la mer se fait à la mesme heure aux costes d'Espagne et de l'Amerique.

Voicy ce qu'on pourra observer.

"Il faut enseigner de quelle sorte on a fait les experiences, avec quelles personnes, avec quelle exactitude, de quels instruments on s'est servy, etc. et écrire ces expériences par ordre [...]. On y ajoutera des figures, si les expériences sont difficiles à comprendre ; mais ces principes d'expérience ne seront principes qu'à ceux qui auront fait les mêmes observations ; et seront seulement vraisemblables aux autres, estant examinées [sic] selon les propositions 51, 52"<sup>73</sup>.

In the case of mathematics, as in the case of physics, proof by citation leads one to take into account the intersubjective dimension of science: for both, one relies on the results of other scientists to go a bit farther. But, according to the first part of the text we just quoted, while the book of mathematics holds transparent demonstrations that, at least ideally, anyone is able to reactivate within oneself, the passage from a first-person observation to a few lines on paper generates an obscurity and a confusion that are difficult to overcome. Mathematical figures designate only themselves, in any case, nothing of the things of this world, whereas the figures in a book of physics are supposed to represent bodies, natural phenomena, or artificial set ups. Whence the incessant risk of confusion when one attempts to return to these bodies. We are of course tempted to see in these lines the testimony of the difficulties that an experimenter like Mariotte had in transmitting the experiments he had carried out.

In the second part of the text quoted, Mariotte gives a series of rules that he presents as facilitating the proper transmission of experiments. In fact, he is responding to another

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<sup>72</sup> On what follows, see also E. Coumet, "Sur l'*Essai de logique* de Mariotte", p. 302-304.

<sup>73</sup> *EL*, 2<sup>nd</sup> part, 3<sup>rd</sup> disc., p. 127. The difficulty of putting experiments down on paper is also mentioned as the fourth of the six causes for the lack of progress of the sciences, see *ibid.*, p. 97: "lorsque quelqu'un veut prouver par écrit quelques propositions touchant les causes de quelques effets, il ne peut faire voir sur le papier les expériences sur lesquelles il a fondé ses raisonnements".

question at the same time, that of the conditions in which an experiment can be accredited. It is not merely a question of knowing how to write an experimental report so that another physicist can effectively appropriate this or that experiment as if he had done it himself, but rather of knowing how to write this report so as to convince the community of physicists to accept as worthy of credence the experiments done. The rules that Mariotte thus formulates are common enough to the period: have quality witnesses, be precise in narrating the experiments, make use of figures<sup>74</sup>. He more or less follows these rules in his treatises: we have noted that he so often qualifies his experiments as "exact" that the adjective has no determined meaning. In practice, nonetheless, the material precision with which he reports his experiments is quite far from the idealized descriptions found, for example, in certain texts of Pascal<sup>75</sup>. On the other hand, Mariotte is rather evasive as to his witnesses: he usually mentions the presence of "personnes fort intelligentes", and sometimes the active intervention of "sieur Hubin"<sup>76</sup>. Perhaps we can find the explanation for this lack of precision in the propositions 51 and 52 to which he refers: when an experiment is carried out before several witnesses, it must be held as true; when one person carries out the same experiment several times, it must be held as plausible<sup>77</sup>.

And in the end, plausibility is all that Mariotte ever asked of physics.

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<sup>74</sup> The study of these questions was launched by the bestseller by S. Shapin and S. Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life*, Princeton, Princeton U.P., 1985.

<sup>75</sup> On the use of the adjective "exact", see *supra*, note 40. On the idealized character of experiments in Pascal, see A. Koyré, "Pascal savant", in *Études d'histoire de la pensée scientifique*, Paris, Gallimard, 1973, p. 362-389.

<sup>76</sup> Hubin was an enamellist and a manufacturer of instruments prized by Academicians like Huygens and Mariotte; he is the author of *Machines nouvellement exécutées et en partie inventées par le sieur Hubin emailleur ordinaire du roy. Première partie, ou se trouvent une clepsydre, deux zymosimètres, un peze-liqueur, & un thermometre. Avec quelques observations faites à Orleans, sur les qualitez de l'air, & particulièrement sur sa pesanteur*, Paris, Jean Cusson, 1673, which we have not consulted.

<sup>77</sup> *EL*, 1<sup>st</sup> part, princ. 51, p. 127.

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