SPINOZA AND CHRISTIAAN HUYGENS: THE ODD PHILOSOPHER AND THE ODD SYMPATHY OF PENDULUM CLOCKS[1]

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Abstract. In 1665, in a response to a question posed by Robert Boyle, Spinoza gave a definition of the coherence between bodies in the universe that seems to be inconsistent both with what he had written in a previous letter to Boyle (1661) and with what he would later write in his main work, the *Ethics* (1677). Specifically, Spinoza's 1665 letter to Boyle asserts that bodies can adapt themselves to another body in a non-mechanistic way and absent the agency of an external cause. This letter – *Letter 32* – seems therefore to be in clear contradiction with the metaphysical determinism that is an important and characteristic element of his philosophy.

This article suggests that the viewpoint expressed by Spinoza in *Letter 32* may have been inspired by a spectacular discovery made by Christiaan Huygens a few months prior, namely, the self-synchronization of pendulum clocks. As I argue in this article, this new, hypothesized link to Huygens' pendulum experiments may account for Spinoza's otherwise paradoxical answer to Boyle in *Letter 32*.

Keywords: Spinoza, Christiaan Huygens, Robert Boyle, pendulum clock, synchronization.

1. Introduction: Robert Boyle's question to Spinoza[2]

On the 10th of October 1665, Henry Oldenburg (1619-1677), then serving as Secretary of the Royal Society of London, sent a letter[3] to Robert Boyle (1627-1691) to inform his friend that he had just received a letter from a "certain odd Philosopher" who "lives in Holland, but no Hollander". Oldenburg attached an extract of that letter to his own wherein he added the following:

> In the same letter to Sir Robert [R. Moray], I took notice to him of what a certain odd Philosopher (whom you know better, then He, it being Signor Spinosa) hath very lately written to Me concerning M. Hugens, his transmigration into France, <his Penduls,> and his progress in Dioptricks etc. The same Spinosa expresses a very great respect for you, and presents you his most humble service, and is displeased, that the Dutch Statiners will,

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> in spight of our teeth, sell off one of their Lattin impressions of your History of Colors, before the Translation, made here, can be sent thither[4].

Being intrigued by what "signor Spinosa" had written in his letter on the relation between the parts and the whole in the universe, Robert Boyle encouraged the heterodox Jewish philosopher (via his friend Oldenburg) to continue philosophizing and asked him to transmit his views on how each part of nature accords with its whole, and how it coheres with other parts:

> Mr. Boyle joins with me in sending cordial greetings, and urges you to pursue your philosophising with energy and rigour. Above all, if you have any light to cast on the difficult question as to how each part of Nature accords with its whole, and the manner of its coherence with other parts, please do us the favour of letting us know your views[5].

2. Spinoza's answer

a. Two preliminary remarks

Spinoza (1632-1677) did not answer Boyle's question directly. However, before answering, he gives two specifications:

> When you ask for my views on 'how we know the way in which each part of Nature accords with the whole, and the manner of its coherence with other parts', I presume that you are asking for the grounds of our belief that each part of Nature accords with the whole and coheres with other parts. As to knowing the actual manner of this coherence and the agreement of each part with the whole, I made it clear in my previous letter[6] that this is beyond my knowledge. To know this it would be necessary to know the whole of Nature and all its parts. So I shall attempt to give the reasoning that compels me to this belief. But I would first ask you to note that I do not attribute to Nature beauty, ugliness, order or confusion. It is only with respect to our imagination that things can be said to be beautiful, ugly, well-ordered or confused[7].

Firstly, Spinoza highlights that he does not have any complete knowledge about the coherence between bodies in the universe. Adequate knowledge of a thing implies, according to the Dutch philosopher, a knowledge of the cause[8] of that thing. And the knowledge of that cause implies the knowledge of the cause of that cause, *ad infinitum*. As a consequence, knowledge of the nature of the relations between the parts, and between these parts and the whole, would imply knowledge of the entire, infinite causal chain of bodies which is, as he had already pointed out in his former letter, beyond his knowledge.

Secondly, Spinoza emphasizes that qualities such as beauty, ugliness, order and confusion are not intrinsic properties of bodies. He could have likewise added odors, tastes, sounds, touch, colors and harmony as he does in the appendix of the first part of the *Ethics* where he makes the same distinction[9]. For Spinoza, these extrinsic qualities are ideas of affections of the body which he calls in his main work "imagination" [*imaginari*][10]. By eliminating these extrinsic qualities from his discussion, Spinoza places himself on the level of what he calls "knowledge of the second kind"[11] in order to focus directly on the relationships between the parts of bodies in the universe. Indeed, according to the definition provided in the *Physical interlude*, the essential nature of a 'body-in-itself' is encoded in the ratios of the motion and rest of its constituent parts.

> When a number of bodies of the same or different magnitude form close contact with one another through the pressure of other bodies upon them, or if they are moving at the same or different rates of speed so as to preserve an unvarying relation of movement among themselves, these bodies are said to be united with one another and all together to form one body or individual thing, which is distinguished from other things through this union of bodies[12].

And these bodies are themselves part of a more complex body with its proper ratio. Ultimately, all bodies are part of nature regarded as a whole which is, as he clarifies in the same letter, characterized by its own invariable ratio[13].

b. Spinoza's paradoxical answer

After these preliminary remarks, Spinoza then offers a direct answer to Boyle's direct question:

> By coherence of parts I mean simply this, that the laws or nature of one part adapts itself to the laws or nature of another part in such wise that there is the least possible opposition between them. On the question of whole and parts, I consider things as parts of a whole to the extent that their natures adapt themselves to one another so that they are in the closest possible agreement. Insofar as they are different from one another, to that extent each one forms in our mind a separate idea and is therefore considered as a whole, not a part.[14].

This definition of the coherence between bodies in the universe is remarkable for several reasons. First of all, this definition is very different from explanations Spinoza gives on this same subject elsewhere in his works. Specifically, Spinoza asserts that the nature of bodies can adapt itself to other natures in a non-mechanistic way, and absent the agency of an external cause. As such, this definition appears to be in clear contradiction with Spinoza's radical, metaphysical determinism which is an essential and characteristic element of his philosophy. I will comment on these differences before proposing a solution for this apparent paradox.

Firstly, Spinoza's definition seems to be inconsistent with the explanation he would give in the *Physical Interlude* of his main work, the *Ethics*, which was published posthumously in 1677. In *lemma* 3 of that work, he writes:

> The degree of difficulty with which the parts of an individual thing or composite body can be made to change their position and consequently the degree of difficulty with which the individual takes on different shapes is proportional to the extent of the surface areas along which they are in close contact. Hence bodies whose parts maintain close contact along large areas of their surfaces I term hard; those whose parts maintain contact along small surface areas I term soft, while those whose parts are in a state of motion among themselves I term liquid[15].

Spinoza had already developed views similar to what he would express in the *Physical Interlude* as early as 1661/62. In letters known as the Boyle/Spinoza correspondence[16], written after Oldenburg's visit to Spinoza during the summer of 1661, Spinoza writes in *Letter 6* (December 1661) the following explanation:

> To understand the first question, it should be noted that bodies in motion never come into contact with other bodies along their broadest surfaces, whereas bodies at rest lie on other bodies along their broadest surfaces[17].

Thus in both the *Physical Interlude* (1677) and *Letter 6* to Boyle (1661) the coherence between the constituent parts of bodies is, in contrast to the explanation of *Letter 32* to Boyle (1665), conceived of in a purely mechanistic way. In other words, coherence is conceived of in terms of relative position, contact, and the motion and rest of the parts that constitute the whole[18].

Secondly, Spinoza writes in *Letter 32* (1665) that "the laws or nature of one part adapts itself to the laws or nature of another part in such wise that there is the least possible opposition between them" [*Per partium igitur cohaerentiam nihil aliud intelligo, quam quod leges, sive natura unius partis ità sese accommodat legibus, sive naturae alterius, ut quàm minimè sibi contrarientur*]. With this phrase Spinoza suggests that the parts of bodies have a kind of internal cause that makes it possible for the natures of these parts to adapt themselves spontaneously to the natures of other parts in order to form one and the same individual, physical entity. This explanation is not only very different from the purely mechanistic explanation in terms of contact, relative position, motion and rest that he had given in the two previous citations discussed above; clearly, the idea that "the nature of a part adepts itself to the nature of another part" [*se accommodat*] (an expression which Spinoza mentions several times in this letter[19]) is also in contradiction with proposition 28 of the first part of the *Ethics* which states that, "every individual thing, cannot exist or be determined to act unless it be determined to exist and to act by another cause which is also finite and has a determinate existence, and this cause again cannot exist or be determined to act unless it be determined to exist and to act by another cause which is also finite and has a determinate existence, and so *ad infinitum*." Likewise, according to proposition 6 of the second part of the *Ethics*, this external cause (which determines the action of a body) has to be another mode of the same attribute, in other words another body[20]. This is an important element of Spinoza's philosophy which the Dutch philosopher repeats several times in his *Ethics*. For instance, in the proof of the second proposition of the third part of the

Ethics, Spinoza writes, "the motion-and-rest of a body must arise from another body, which again has been determined to motion or rest by another body…" Obviously, this proposition seems to be violated in *Letter 32*. Indeed, according to Spinoza's metaphysics as expressed in the *Ethics*, the ratio of motion and rest of a body can only change via an affection of another mode of the same attribute. As a consequence, a body cannot adapt itself.

The formulation of Spinoza's views in *Letter 32* is not just of minor importance since it is well-known that the Dutch philosopher wrote very precisely. Moreover, exactly the same formulation can be found in the Dutch translation of *Letter 32* made by his friends following his death and appearing in the compilation *Nagelate Schriften* (1677):

> By zamenhanging der delen dan versta ik niets anders, dan dat de wetten, of de natuur van een deel zich in dier voegen naar de wetten, of natuur van 't ander schikt en voegt, dat zy op het minste tegen malkander strijden[21].

This translation also clearly expresses the idea that the laws [*de wetten*] or the nature [*de natuur*] of parts [*de delen*] adjust themselves [*zich voegen naar; zich schikken en voegen naar*] in such a way that there is the least possible opposition between them [*dat zy op het minste tegen malkander strijden*].

Lastly, it is important to take note of Spinoza's identification in *Letter 32* of the "laws of bodies" with the "natures" of the bodies [*leges, sive natura unius partis*]. In this letter, Spinoza writes that these laws adapt themselves to the laws or nature of another part in such a way that there is the least possible opposition between them. How are we to conceive these laws which Spinoza identifies with the nature of bodies? Which law could Spinoza possibly have had in mind when he wrote this? Spinoza had used the idea of the law of a body already in his *Letter 6* [22] to Boyle. In this letter, Spinoza makes clear to the author of [*The Origin of*] *Forms and Qualities* (1666) that Boyle's list of the most general properties of bodies was far too broad. Spinoza stresses that only "motion, rest and their laws" [*motus, quies, et eorum leges*] belong to the properties that bodies have in virtue of being a body of bodies. Under "laws", Spinoza probably means here his definition of a body or a physical individuality as given in the *Physical interlude* of the *Ethics*, namely, the ratio of motion and rest a body [*motûs, et quietis rationem*], or what he names in his *Short Treatise,* written in Dutch, a proportion [p*roportie*]. In other words, Spinoza intends by the term 'law', an expression to indicate the mutual relation between the parts of a body. In the first half the 17th century, the term "ratio" was often used by physicists such as Galileo and Huygens for what we call now "physical laws"[23]. However, at a first glance, it is unclear whether Spinoza had a particular law in mind when he wrote in *Letter 32* that the laws mutually adapt themselves.

It is of interest to note that Spinoza's definition in *Letter 32* is not only unclear to us now, but it was also unclear to Henry Oldenburg. Indeed, in Oldenburg's response to Spinoza (*Letter 33*, December 8, 1665), he begins by writing that he does not really understand Spinoza's theory.

> Your philosophical thoughts on the agreement of the parts of Nature with the whole on their interconnection are much to my liking, although I do not quite follow how we can banish order and symmetry from Nature, as you seem to do, especially since yourself admit that all its bodies are surrounded by others and are reciprocally determined both to exist and to act in a definite and regular manner, while at the same time the same proportion of motion to rest is preserved in them all. This itself seems to me good grounds for true order. But perhaps I do not here understand you sufficiently,[24][…]

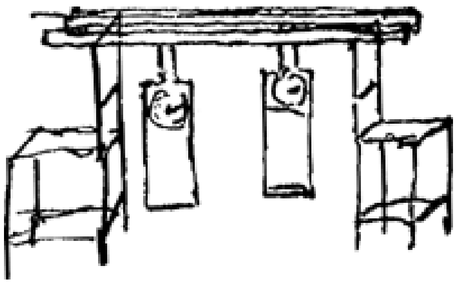
As Oldenburg makes clear in his reply, Spinoza's explanation in *Letter 32*[25] seems to be inconsistent with what he had written before, "since yourself admit that all its bodies are surrounded by others and are reciprocally determined both to exist and to act in a definite and regular manner…". Accordingly, then, the question arises as to how the paradoxical account of the coherence of parts given by Spinoza in *Letter 32* can be explained. The explanation given by Albert Rivaud[26], that Spinoza is referencing the concept of harmony between bodies in the universe, is unsatisfactory. Spinoza mentions the term "harmony" only once in the appendix of the first part of the *Ethics*, and even here, only to state very explicitly no such thing exists. Nor does Spinoza appeal to "harmony" elsewhere to explain any of his ideas. Clearly, we need to look for another explanation.

3. The hypothesis[27] of the sympathy of pendulum clocks

It is possible that that Spinoza's odd explanation in *Letter 32* (dated the 20th of November 1665) was inspired by a spectacular discovery made by the Dutch physicist Christiaan Huygens a few months earlier. At that time Spinoza was living in Voorburg, near the Huygens family residence at Hofwijck. The plague had broken out in the region in 1665 and Christiaan Huygens did not travel much during this period. According to *Letter 26*[28] "le juif de Voorburg"[29] visited the famous natural philosopher during this time and conversed with him on various topics, including natural philosophy[30].

What kind of discovery did Huygens make? Around the 22th of February 1665, while Christiaan Huygens was sick and lying in his bed, he observed that two pendulum clocks which were hanging in front of him started to beat in synchrony. He couldn't believe his eyes. Initially, he was unable to explain this phenomenon and referred to it as a "sort of sympathy" [une *espece de sympathie*]. He struggled not only with the 'what' but also with the 'how' and 'why' of this spectacular phenomenon. Why did the clocks mysteriously synchronize with each other? How could mechanical objects transmit an influence when they were not touching? What is the cause of this "odd kind of sympathy"?

Initially, Huygens was convinced that there could not be any other cause of the agreement of the clocks "*than an imperceptible agitation of the air which is produced by the movement of the pendulums."* However, a few days later he wrote with a pencil in the margin of his notes: *"causam hujus rei postea inveni ex communi fulcro"*. More precisely, on the first of March, he conducted some additional experiments and determined that, not the air, but rather the mechanical connection between the two clocks was essential for their synchronization:



> March 1. 10 in the morning. A preceded [B] by three seconds.
> For each clock, two chairs served as a support [Fig. 76][31], and the slight and entirely invisible motion of these chairs, excited by the agitation of the pendulums, was the cause of the aforementioned sympathy and it drove the pendulums to be always in consonance with opposing beats. For each pendulum, when it transits through its perpendicular, pulls its supports with it with maximal force. Therefore if pendulum B is at the perpendicular BD [Fig. 77] when A is only at AC, and B is moving left and A is moving right, then the suspension point of A is pushed to the left, and the vibration of pendulum A is sped up. And again, B has transited to BE when A is at the perpendicular AF, so at that moment the suspension of B is pushed rightward and, therefore, the vibration of pendulum B is slowed down. Again, B has arrived at the perpendicular BD when A is at AG, whence the suspension of A is pulled rightward and the vibration of pendulum A is sped up. Again B is at BK when A has returned to the perpendicular AF, and so the suspension of B is pulled leftward and, accordingly, the vibration of pendulum B is slowed down. And since whenever the vibration of pendulum B is slowed down, A is sped up, it is necessarily the case that they attain consonance with opposing beats, that is, A is borne rightwards and B leftwards simultaneously, and vice-versa. Whereupon they become unable to depart from this consonance since from the same cause they are continuously returned to the same condition. And when this happens, it appears that the supports remain still with hardly any movement, but if the agreement starts to become disturbed, even a little, then it is restored by a slight movement of the supports, and since this motion cannot be perceived by the senses, it is therefore no wonder that it provided the cause of our error[32].

A few days later, Huygens informed his contact at the Royal Society [Moray] that he was mistaken about the cause of the phenomenon. The Dutch physicist clarified that the cause of the effect is the slight, small movements of the board that connects the two clocks. A cause which he had not noticed before on account of these motions "*being entirely insensible*".

> … My [clocks] go with a very high precision, especially after I found by experience that it's necessary to attach them to some beam or other unwavering thing, because unless this is so, the movement of the pendulum, notwithstanding the great weight of the box, gives a small movement to the entire clock which alters its precision and causes it to move more quickly in proportion as there is an excess. Thus I found that the cause of the sympathy of which I wrote in my last letter does not come from the movement of the air but from this aforementioned wavering, which being entirely insensible I had not noticed at the time. You must know, then, that our two clocks were each attached to a board 3-inches square and 4-feet long and placed on the same two chairs at a distance of 3-feet. This being so, and the chairs being capable of a slight movement, I can show that the pendulums must necessarily reach consonance within a short time and not depart from it thereafter, and that the beats must go contrariwise and not parallel as experience has already shown. Having arrived at the said consonance the chairs no longer move except only to hinder the clocks from deviating since as soon as they attempt to do this, that small movement puts them back as before.[33]

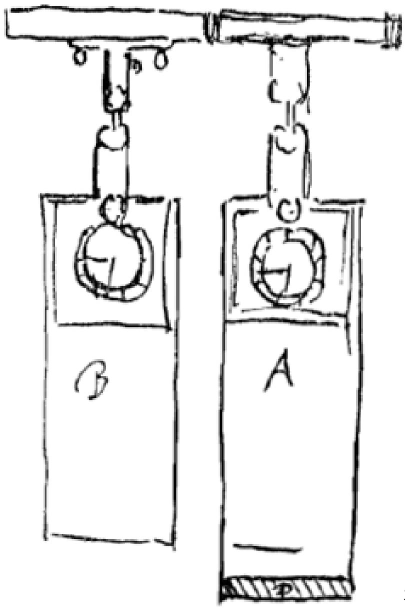
Huygens' explanation of the cause of "l'accord merveilleux" was by the end of March 1665 quite definitive and he specifies in his next letter to Moray that he had nothing to add to the explanation of the cause that he had given in his former letter:

> Although you might not plan to add anything to the Instruction I have sent you, it would nevertheless be necessary to adjoin an article touching on the suspension of the clocks, namely, that one must take care to attach them firmly with their screws to some beam of the vessel, and that on land, when getting them to agree, it is necessary likewise to seek such a suspension, one entirely fixed and unwavering, since without it one would not only have more trouble getting them to agree with each other, but having been in agreement on land, they would not be so at sea. For this is what I found by my observations (and, I can say, at my expense), that the movement of the pendulum, though of so little weight in comparison to the whole clock, also gives some movement to the body from which it is suspended if the latter is capable of the slightest wavering."[34]

Christiaan Huygens did not hide what he had observed from the world. On the contrary, as early as the 24th of February[35], he informed the Walloon mathematician René-Francois de Sluse (1622-1685) of his discovery [*de sympathia mirabili horlogiorum meorum recens detecta*]. And two days later, he wrote[36] to his father, Constantijn Huygens (1596-1687), to inform the famous poet and diplomat about what he thought to be a spectacular observation, and one which no one ever would have thought of [*un effet admirable, & auquel personne n'auroit jamais pû penser*]:

> … Having been forced to keep to my chambers for some days, which I occupied in making some observations of my clocks of a new design, I noticed an intriguing effect, and one which no one ever would have thought of. That is, that these two clocks, being suspended the one next to the other at a distance of one or two feet, keep a precision between them that is so exact that the two pendulums always beat together without ever varying. Having admired this greatly for some time, I finally found that it happened because of some sort of sympathy, such that by making the pendulums strike with mixed beats I found that within a half an hour they would always put themselves back into consonance and keep to it constantly afterwards for as long as I let them go. I then separated the one from the other, hanging one at one end of the room and the other fifteen feet from it; and then I saw that in a day there were 5 seconds of difference and that consequently their previous agreement had not come but from some sympathy which, in my opinion, cannot have any other cause than an imperceptible agitation of the air which is produced by the movement of the pendulums. The clocks are however enclosed in their boxes, which with all the lead which is inside, can hardly weigh less than a hundred pounds each. And the vibrations of the pendulums, when they are put in consonance, don't go such that the one is parallel to the other, but on the contrary, they approach and separate with contrary movements. Upon bringing the clocks close together again, I saw that afterwards the pendulums were put back into the same cadence. I moreover took a table-mat of three-feet per side, one-inch thick, which I put in between the two such that the bottom touched the floor, and it was so tall that it entirely covered the clocks and separated them in this manner one from another. But nevertheless the agreement remained as before, lasting entire days and nights, and even if disturbed by me, it reestablished itself in little time. I am now attempting to bring them together very precisely (being separated) and I will test to what distance the aforementioned sympathy extends, imagining, by what I have already seen, that it may well be up to five or six feet. But to have a better certainty of these things it is necessary, if it please you, to wait until I have examined them further and investigated the causes more exactly. But nevertheless, here two clocks are found which never deviate at all, which will seem incredible and yet it is entirely true. Never have any other pendulums, except this new invention, been able to do the same thing; and one can see by this how exact they are since it takes so little to keep them in perpetual accord."[37]

Moreover, on February 27 he sent a very similar letter[38] to Robert Moray to inform the fellows of the Royal Society (of which he had been an elected fellow since 1663) of his observations. In this letter he recommended that they discuss his spectacular discovery during one of the upcoming meetings of the Society. Huygens even proposed to attend the meeting in person to hear the reactions of the members and to respond to their questions.



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Robert Moray[40] (1609-1673) answered in a letter dated March 5[41]. However, he seemed to be less enthusiastic than was Huygens about the "sympathy of the clocks". On the contrary, Moray regarded the observed phenomenon as a disadvantage when considering the applicability of pendulum clocks for determining longitude at sea. Moray argued that "if any imperceptible movement of the air can cause" the sympathy, then these "irregular motions of the air could" also "make them deviate from their true exactness" for the determination of the longitude at sea. Furthermore, Moray suggested that Huygens should examine how far the pendulums can be separated from each other before losing their agreement. He likewise requests that Huygens examine whether it is possible to have sympathy between three or four clocks in the same way. Lastly, he promises to present the question at an upcoming meeting of the Royal Society.

> … It was indeed a very welcome surprise for our president [William Brouncker] and for me to learn about this new sort of sympathy which you have observed in your clocks. It will doubtless be good to discuss and we intend to speak about it at our first assembly. But it's possible that we won't deliberate on it until the assembly eight days later so that we may think before discussing it. Be this as it may, I'll do my part in communicating to you what is said about it if I find there is something worthwhile. But I will tell you that if it were not the case (as each of us knows that it is) that you are thoroughly capable of inventing on your own all the experiments necessary, both to penetrate further into this matter and to draw useful consequences from it, perhaps we could propose some for you to do on this subject. But inasmuch

> as you are undertaking the pursuit of this, it is necessary to rely on you. I would only mention that I'd be pleased if you could know precisely to what extent it is necessary for the two clocks to approach each other in precision before this sympathy will appear; that is to say, whether 2, 3, 4 or some other number of seconds in 24 hours. Next, if 3 or 4 watches will be able to agree with each other in this way; and lastly, since when there is a difference of 2 or 3 seconds in 24 hours between the two clocks they do not fail but to come into accord, that you could learn which yields to the other, as apparently one rectifies the other. These differences can be observed, it seems to me, as well as the solution to that last difficulty, by comparing them to your large clock which strikes the seconds. For the rest, if any imperceptible movement of the air can cause this isochronicity, I fear that one would have reason to suspect that some irregular motions of the air could rather make them deviate from their true exactness which renders their vibrations equal. And since, in the end, the clocks which feel these movements can more easily stray than those which do not feel them at all, it follows that it would be better if the two clocks which are used at sea might not be in so well an agreement as otherwise, inasmuch as their difference being always the same, it serves just as well as if there weren't any at all. Instead, by keeping themselves always together, one cannot be so well assured that they do not lose any of their precision, since what is evident from your experiences is that whenever in reality they are 2 or 3 seconds away from being said to be both equally correct, that this does not hinder them from going equally fast when they are within one or two feet of each other.
>
> I have let myself go much further in this material than I thought when I set myself to write. But it is to justify what I said to you at the beginning that I interact with you without any manner of constraint. You will tell me that perhaps what I was just saying settles nothing to the disadvantage of the clocks with regards to their usefulness, and I shall well vouch this to you. You will always find that I do not but discourse in my usual way on whatever comes up in conversing with you. But, for fear lest I be soon interrupted as almost always happens to me, I leave this material aside for the present, to be taken up again another time, and I go to see what I have to say to you about the other passages in your letter.[42]

As the *Journal Book of the Royal Society* shows, they did discuss the question during their meeting on the first of March (which corresponds to March 10 in the Gregorian calendar). The minutes of the Royal Society make clear that it was decided during this meeting that the president (the mathematician William Brouncker) and Robert Hooke (1635-1703) would devise and conduct some experiments to determine whether the cause of the odd sympathy was the "agitation of the air" or a "magnetical cause."[43]

> It was thought proper hereupon, 1. That the said instructions should be compared with those of the president, to have them printed in English. 2.

> That the president and Sir Robert Moray should be desired to think upon and make some experiments, to find out upon what account this pretended sympathy should happen; whether from a magnetical cause, or from the agitation of the air; and, among other things, to observe whether pendulums, that go alike in any clock-work, go together, hanging near to one another; as also whether three or four watches do the same, that two do.

Oldenburg was present[44] at this meeting so that we may assume that he knew of the "sympathie des horloges" at the moment that he and Boyle addressed their question concerning the coherence between the bodies to Spinoza. Robert Boyle was certainly present during the meetings of 15 and 22 February and 15 March 1665[45] but it is uncertain whether he was also present the 1st and 8th of March[46]. However, Boyle must have been informed if he was not present, given the fact that he was interested in the pendulum clock. Remember that Boyle conceived nature as one giant pendulum[47]. And the correspondence between Oldenburg and Spinoza in this period shows that Oldenburg's circle was very interested in Huygens' project with the pendulum clocks. The secretary of the Royal Society asked repeatedly information about Huygens' advancements.

Within a month after Christiaan Huygens (1629-1695) made his observations, he had already informed the leading philosophers in Holland and Britain about his amazing discovery. Soon thereafter, news of his discovery was enthusiastically received in other countries as well. As Huygens relates in his letter[48] to R. Moray, in France they even published his letter in the *journal des savants* on the 16th of March 1665 without his permission after his father had transmitted his letter to Jean Chapelain: "At *Paris there has been a rush to put my observation in the weekly journal without my knowledge, concerning which I was not very pleased."* Chapelain (1595-1674), however, was not able to prevent the publication of Huygens' letter upon learning that Christiaan had changed his view on the cause of the harmony of the clocks. Accordingly, he wrote a note in the next edition of the *Journal des Savants* (March 23rd) explaining that not "la sympathie de lair" was the cause of the harmony, but rather "une impression secrette des pendules."[49]

Consequently, it is not unreasonable to assume that Spinoza was informed about this spectacular phenomenon since (as his *Letter 26*[50] to Oldenburg makes clear) he visited Huygens in that period and discussed with him scientific matters. Moreover, as Huygens' notes of his observations reveal, he was still actively engaged in studying the phenomenon of the "sympathy" after March 1665, certainly throughout April but also later, even during the month of November, the month Spinoza wrote his *Letter 32*.[51]

Thus Boyle and Oldenburg, and quite likely Spinoza as well, were aware of Huygens' discovery of "the sympathy of pendulum clocks" when they corresponded. And it is thus possible that they may have had this phenomenon in mind when they discussed parts which adapt themselves to form a new physical individuality absent the agency of an external cause.

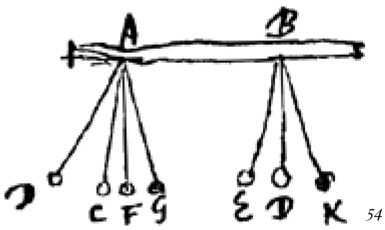
4. The synchronization of Huygens' pendulum clocks

In his correspondence with Christiaan Huygens, which was conducted in French, Robert Moray (1609-1673) uses the term "*isochronicity*" [*isochroneité*] when referring to the sympathy between the pendulum clocks. Huygens uses terms such as "*la concordance*", "*la concorde*" and "*la consonance*" in order to describe the phenomenon he had observed. However, in modern parlance, this phenomenon would be described as an example of "synchronization". But what does this term mean exactly?

Synchronization is an adjustment of the rhythms of oscillating objects due to a small interaction[52]. This definition implies several important elements. First of all, there must be oscillating objects, such as pendulums, which each have an internal source of energy that is transformed into a stable, oscillatory movement. Thus, what is known as "resonance" describes a phenomenon that is different than synchronization since synchronization is about systems which have a rhythm of their own which is mutually adjusted.

Secondly, there should be a form of interaction between the systems. However, this interaction has to be "small" so that the systems don't completely lose their autonomy. Furthermore, in the case of a connection that is too rigid, there would be no interaction because in that scenario the movements would not be mutually transmitted. In that case, the clocks would not "talk" to each other; they would not "feel" each other. In the example of Huygens' clocks, the interaction was realized through the wooden beam which connected the two pendulums clocks, as he illustrated in the drawings which he added to his explanation.

Thirdly, there should be an adjustment of the rhythms due to some sort of interaction. Each pendulum has its characteristic, or natural frequency. However, when both pendulums are coupled via a supporting structure, such as a common supporting beam, they adjust their frequencies so that they start to oscillate with a common frequency, provided that the supporting beam can transmit suitable perturbing vibrations and provided that the difference between the frequencies of the uncoupled oscillators was not too large. During the process of synchronization, the motion of each pendulum is conveyed through the structure to the other pendulum. However, the synchronization of the clocks can appear in different forms. The pendulums can move in the same directions (in-phase) or alternatively in opposite directions (anti-phase). Huygens observed the latter possibility: "the vibrations of the pendulums, when they are put in consonance, don't go such that the one is parallel to the other, but on the contrary, they approach and separate with contrary movements."[53]



[54]

It is important to note that synchronization is not a state. On the contrary, it is a dynamic, equilibrium process[55]. Nowadays, this phenomenon can be perfectly well illustrated with metronomes[56] placed upon a thin board that is isolated from a table using, for example, empty soda cans. The synchronization takes place with two or more metronomes which were initially in motion but which need not be in phase. Additional metronomes can be added which, after a brief time, will also start to synchronize. Even if the synchronized system is disturbed (for example, by touching one of the metronomes to block its motion), the synchronization will spontaneously restore itself after a suitable interval. In sum, the pendulums have the capacity to adapt themselves so that they form a unity. As Kurt Wiesenfeld puts it, "The phenomenon of spontaneous mutual synchronization offers perhaps the most primitive example of emergent behavior"[57].

Interestingly, meanwhile, Bennett *et al.*[58] from The Georgia Institute of Technology have reconstructed Huygens' clocks and re–examined the 350–year–old synchronization in modern experiments. This research has confirmed that, in principle, Huygens' analysis was correct. As Huygens had suggested, the antiphase synchronization he observed was the result of the weak communication between the two similar, heavy, oscillating pendulums clocks via the board. As Huygens' drawings illustrate, the clocks were attached to a common supporting beam which itself was supported on the backs of two chairs.

Kurt Wiesenfeld and Michael Schatz[59] further determined that the cause of the anti-synchronized motion of Huygens' clocks was friction as Huygens had described. The Dutch physicist had put weighs in the clocks so that they could be used in a stable way on ships. As Huygens originally postulated, the swinging of the pendulums gives rise to small, frictional forces from the supporting beam. If the pendulums are moving in the same direction, they nudge the beam in the other direction which causes friction that damps out that motion. Conversely, if the two pendulums are moving in opposite directions, the forces they exert on the beam are cancelled out. So over time, the anti-phase synchronization wins over the in-phase synchronization[60]. Kurt Wiesenfeld and Michael Schatz argue that in Huygens' conditions this was only possible outcome given the fact that the ratio of the weighs of the pendulums and their cages was narrow[61].

Huygens was also correct in that he had observed something very exceptional for the very first time. Indeed, historians consider him to be "the first scientist who observed and described the synchronization phenomenon"[62]. Moreover, he was also correct in realizing that it could be a very important phenomenon. Meanwhile, scientists have discovered that synchronization is widespread in nature and is very important not only for physics but also for medicine, biology, technology and many other fields[63]. For instance: insulin oscillations, the menstrual cycle, the sleep-wake cycle and all other circadian rhythms[64] (in plants, animals, fungi, and cyanobacteria) are examples of phenomena for which synchronization may be essential.

5. Resolving the paradox

It is possible that Spinoza may have been inspired by this phenomenon, and that this might provide context for his otherwise paradoxical assertion in *Letter 32* that the "laws or nature of one part adapts itself to the laws or nature of another part in such wise that there is the least possible opposition between them." Without this connection to Huygens' discovery, it is difficult to find another interpretation that would allow us to resolve the manifest paradox in Spinoza's explanation.

First of all, it is important to note that Spinoza wrote his explanation in the immediate aftermath of Huygens' discovery. At this time, they both lived in Voorburg, and there is historical evidence that Spinoza visited Huygens[65]. As Huygens' notes[66] show, during that period Huygens was still conducting experiments to understand the sympathy of his clocks in greater depth[67]. Accordingly, it is reasonable to assume that Huygens informed Spinoza about his observation which he had also made public to the entire scientific world of that time. This connection could help provide context for the discontinuity in Spinoza's explanation of the coherence between bodies.

Secondly, the hypothesis of synchronization provides a suggestive example of how the parts of a body can adapt themselves, since during the process of synchronization the pendulum clocks adapt themselves to form one physical individuality or a body. In other words, the pendulum clocks form one unity, guided by one and the same mutual relation of a physical nature, without violating Spinoza's mechanistic ideas. Indeed, in his letter of the 27 February 1665, Huygens wrote to Moray that once synchronized, the clocks behaved as if they were one clock, one unity: "elles s'accordent aussi longtemps qu'on veut sans s'ecarter l'un de l'autre de la moindre partie d'une seconde, et sans meme changer de battement, mais demeurent perpetuellement a sonner toutes les vibrations ensemble, comme si c'estoit une seule horloge."[68]

Martial Gueroult[69] claimed already in the 1970s that Spinoza conceived the simplest bodies [*corpora simplicissima*] as simple pendulums, arguing that this model is compatible with all the axioms and lemmas[70] of the *Physical interlude* treating the simplest bodies. However, for Gueroult, it was not the pendulum as such which is important here but rather the kind of motion which is typically represented by the pendulum, namely, what is known today as harmonic oscillation. Indeed, just like single pendulums, the simplest bodies are either in motion or at rest (*axiom 1*); each can move at varying speeds (*axiom 2*); and they are distinguished from one another in respect of motion-and-rest, quickness and slowness, and not in respect of substance (*Lemma 1*). According to Huygens' formula describing the period of a pendulum, the oscillating time depends only upon the local gravitational acceleration and the length of the pendulum and not on the mass, nor the material, of the oscillating bodies. Furthermore, the simplest bodies agree in certain aspects (*Lemma 2*) just like pendulums and their motion or rest must be determined by another body. In other words, just like pendulums, simplest bodies cannot oscillate on their own (*Lemma 3*); rather, they must be set in motion or rest by an external cause. Hence Gueroult concludes that the *corpora simplicissima* should be conceived as corpuscles that are in in perpetual vibration and the nature of their vibration constitutes the fundamental essence of their individuality.[71]

However, when Martial Gueroult applies the model of the pendulum to complex bodies, he only occasionally mentions the term "synchrone" in the context of his pendulum hypothesis. Moreover, the French commentator uses this term in a completely different sense than we use it here. Gueroult's hypotheses is based on the principle of isochronism rather than on the principle of synchronism. For Martial Gueroult, "syncronicité" is about the relation between a complex pendulum and the individual pendulums that can be associated with each length of a complex pendulum[72]; moreover, all complex pendulums are ultimately part of the giant pendulum otherwise known as nature. By contrast, the model that is applied in this article is of synchronization between physically distinct pendulums that synchronize via weak contact. These divergent definitions of "syncronicité" constitute a significant difference between Gueroult's hypothesis[73] and the argument presented here.

Third, the paradigm of synchronization would explain why Spinoza speaks about "the laws" which adapt themselves. Huygens' pendulum clock was based on the principle of isochronism of a single pendulum. Actually, it was not Huygens but Galileo Galilei (1564-1642) who discovered this principle. Amazingly, Gueroult never mentions Galileo's name in his monumental work. However, as the Dutch Huygens scholar Vincent Icke[74] puts it, it was Huygens who expressed the idea for the first time in the form of the first modern, mathematical formula in theoretical physics – in other words, as a modern, physical law.

It is interesting to note that it was also Galileo who, in 1637[75] near the end of his life, conceived for the first time the idea of constructing a clock based on the isochronism of the pendulum. This is attested by Galileo's last student and first biographer, Vincenzo Viviani (1622-1703), in his biography[76] of his master entitled *Racconto istorico della vita di Galileo Galilei* (1717). Viviani would later even go so far as to accuse Huygens of stealing this idea.[77]

According to the pendulum-law, each pendulum has his own proper frequency or proper oscillating time (period). In other words, the frequency (or period) can be conceived of as the nature of the oscillation. Before synchronization, the pendulum clocks are moving with slightly different frequencies. During the process of synchronization, however, the pendulums adapt themselves in the sense that they slightly alter their own frequency to adapt a common frequency. The rhythm of an oscillation is characterized by the period (or frequency) of the oscillation[78]. This period is given by the pendulum-law which Huygens made famous. In this context, then, it can make sense to state, as Spinoza did, that the laws adapt themselves when their rhythms (their natures) adapt themselves (that is, adjust their frequencies) in order to synchronize and obtain a common frequency which identifies the unity as a whole composed of individual oscillators.

6. Why Spinoza did not mention the sympathy of the pendulum clocks

As I have shown, it is likely that Spinoza was aware of and inspired by Huygens' discovery of the synchronization of pendulum clocks. However, one could challenge this hypothesis by asking: Why did Spinoza not mention the "the odd sympathy of the clocks" more explicitly if it played a significant role in his explanation of 1665? The answer to this objection may be that Spinoza uses the words "sympathy" and "clock" only very rarely. Why?

Firstly, the main reason why he does not use the term "sympathy" may be that Spinoza categorically denied the existence of obscure qualities such as "sympathy" and "antipathy". As a consequence, he tried by all means to avoid the use these terms. Already in his interpretation of Descartes' *Principia*, which he had published in 1663, Spinoza added a scholium stating that all "fictions about Sympathy and Antipathy must be rejected as false" [*Quare omnia illa figmenta de Sympathiâ, et Antipathiâ, ut falsa, sunt rejicienda*.]:

> Because the parts of matter are in reality distinct from one another (Art. 61 Principia Part I), one can exist without another (Cor. Prop. 7 Part I), and they do not depend on one another. So all those fictions about Sympathy and Antipathy must be rejected as false. Furthermore, because the cause of an effect must always be positive (Ax. 8 Part I), it must never be said that a body moves to avoid there being a vacuum. It moves only through the impulse of another body [*ne detur vacuum : sed tantùm ex alterius impulsu*]."[79]

And later, in his *Ethics* (1677), Spinoza comes back to this subject arguing that, "the writers who first introduced the terms 'sympathy' and 'antipathy' intended them to mean certain occult qualities,"[80] before giving these terms a completely different meaning in the context of his own discussion of emotions. As he highlights already in chapter 6 of second part of his *Cogitata Metaphysica,* for Spinoza "in matter there is nothing but mechanical structures and their operations."

It is interesting to note that Oldenburg and Boyle likewise avoided using the terminology "sympathy of pendulum clocks" in their correspondence with Spinoza. The reason for this might be that from the start, the Royal Society expelled implicitly all kind of "magic" from their discussions and writings. Huygens could make impossible things happen with his clocks. His clocks had a quality which seemed to be too wonderful to be real. What Huygens did was thus per definition magic and was initially presented by him as such in his correspondence. The harmony of his clocks had appeared as if by magic. This could be the reason why the Royal Society did not discuss the question for a longer period even though history would prove that synchronization is an important principle in science. Huygens' phenomenon was only discussed between the end of February and the end of March 1665. This magical aspect, and the fact that the synchronization was considered a disadvantage for the use of the clocks at sea, was responsible for the fact that the harmony of clocks is not mentioned in the minutes after March 1665 and does not appear subsequently in the correspondence of any of the fellows of the Royal Society[81].

A second reason why neither Spinoza nor Oldenburg mentioned the term "sympathy" may be because shortly after Huygens' discovery, the Dutch physicist determined that the supposed "sympathy" was no sympathy at all. Indeed, the sympathy of clocks was defined at that time in the *Journal des savants* as an effect which was caused by imperceptible agitation of the air : "on en attribuoit la cause à un espece de sympathie ; c'est-à-dire une agitation imperceptible de l'air, qui faifoit que les pendules se mettoient d'elles-mesmes à la concordance."[82] However, as explained above, shortly after his first observation Huygens determined that it was not the air but a communication via a vibrational connection between the two clocks which was responsible for their synchronization. So what was considered initially to be sympathy turned out to be something else, namely, a mechanical process.

A third reason why Spinoza does not mention the "sympathy of pendulum clocks" may be that he mentions the term "clock" only very rarely. As his *Letter 41*[83] to Jarig Jelles makes clear, Spinoza did employ a pendulum clock for time measurements. But contrary to many of his contemporaries such as Descartes[84] and Boyle[85], Spinoza did not apply the metaphor of the pendulum clock in an explicit way in his philosophy. He mentions the pendulum clock only rarely in his proto-*Ethica*, the *Short Treatise* (ca. 1660). Moreover, this metaphor disappears in the corresponding text in the *Ethica*, illustrating an evolution in his writings.

In the *Short Treatise* (ca. 1660), Spinoza explains that in contrast to the parts of a clock and the parts of water as such, there are no parts of extension which can be conceived, understood, or exist without the whole. These kind of parts, Spinoza argues, are only "things of reason" [*wezens van reeden*] not true, real entities [*waare of daadelyke wezens*].

> To this we reply: (1) that "part" and "whole" are not true or real entities, but only "things of reason; and consequently there are in Naturel neither whole nor parts. (2) A thing composed of different parts must be such that the parts thereof, taken separately, can be conceived and understood one without another. Take, for instance, a clock which is composed of many different wheels, cords, and other things; in it, I say, each wheel, cord, etc., can be conceived and understood separately, without the composite whole being necessary thereto. Similarly, also in the case of water, which consists of straight oblong particles, each part thereof can be conceived and understood, and can exist without the whole; but extension, being a substance, one cannot say of it that it has parts, since it can neither diminish nor increase, and no parts thereof can be understood apart, because by its nature it must be infinite[86].

In the corresponding passage from the first part of the *Ethics*, more precisely in E1p15s, Spinoza explains the same idea. However, as counter-example he only speaks of water this time, not of the clock. The example of the pendulum clock has thus disappeared completely from his explanation:

> For example, we conceive water to be divisible and to have separate parts insofar as it is water, but not insofar as it is material substance. In this latter respect it is not capable of separation or division. Furthermore, water, qua water, comes into existence and goes out of existence; but qua substance it does not come into existence nor go out of existence [*corrumpitur*]. I consider that in the above I have also replied to the second argument, since this too is based on the supposition that matter, insofar as it is substance, is divisible and made up of parts[87].

Why did Spinoza eliminate the example of the pendulum clock when clarifying his ideas in the *Ethics*? It is likely that the Dutch philosopher skipped this example because the clock is an example of a man-made machine constructed for a certain purpose. And this is precisely the kind of anthropomorphic concept of extension that Spinoza categorically rejects in the appendix of his *Ethics*. Clearly, presenting a body (and nature as a whole) as a pendulum clock would have risked violating Spinoza's divine anti-finalism[88].

These reasons provide possible explanations as to why Spinoza eliminated the metaphor of the clock from his discussion. In his *Short Treatise*, Spinoza was still strongly under the influence of Descartes; by contrast, in the *Ethics*, which contains Spinoza's philosophy of nature in its most developed form, the example of the man-made clock disappears.

All the same, we should not conclude from this that the pendulum did not play a role in the development of Spinoza's philosophy. On the contrary, although Spinoza did not use the pendulum clock as a model for a body or for nature in general, the physics of the pendulum nevertheless played an important role in his thinking in the *Short Treatise* as well as in the *Ethics*. Indeed, the idea of a pendulum oscillator may very well be the foundation for the concept of a *ratio* of a body of the *Short Treatise* (ca. 1660):

> 12. As soon, then, as a body has and retains this proportion [which our body has], say e.g., of I to 3, then that soul and that body will be like ours now are, being indeed *constantly subject to change*, but to none so great that it will exceed the limits of 1 to 3; though as much it changes it changes, so much also does the soul always change.

When Spinoza mentions the proportion or *ratio*, the numbers he gives do not indicate an exact, geometrical proportion but rather indicate the limits [*niet zo groot dat ze buijten de palen van 1. tot 3. Gaat*] of a continuous, steady change of motion [*gestadig verandering*] as the original text, written in Dutch, reveals clearly:

> 12. Zoodanig een lichaam dan, dese zijne proportie, als *e.g.* van 1. tot 3, hebbende en behoudende, zo zal de ziel en 't lichaam zijn gelijk het onze nu is zijnde wel gestadig verandering onderworpen, maar niet zo groot dat ze buijten de palen van 1. tot 3. gaat; dog zo veel het verandert, zo veel verandert ook telkens de ziel.

Consequently, as several Spinoza scholars[89] have argued, the proportion or *ratio* does not designate an exact number but rather the amplitude of an oscillation of a swinging object such as the pendulum. Obviously, this idea is in the text although Spinoza does not mention the pendulum explicitly. However, in the citation above, the swinging is not just a physical principle. Indeed, Spinoza speaks not exclusively of body here but also of a mind. So there is an oscillation of the physical as well as the psychological. Or perhaps it is more correct to say that synchronization is on the level of attribute-neutral which is expressed through the two attributes of Thinking and Extension.

7. Conclusion

In sum, the spectacular observations made by Christiaan Huygens in February 1665 of self-synchronizing pendulum clocks may provide a context within which to understand Spinoza's otherwise paradoxical *Letter 32* to Henry Oldenburg from November 1665. In this letter, Spinoza appears to imply that bodies can adapt themselves to another body in a non-mechanistic way, and absent the agency of an external cause – a claim that is completely contradictory with the metaphysical determinism that is an important and characteristic element of Spinoza's philosophy.

Huygens was the first to observe the phenomenon of synchronization in two pendulum clocks. Synchronization is a phenomenon whereby oscillators that are appropriately coupled together will adjust their oscillations so as to exhibit a synchronous motion that is regulated by weak impulses communicated through their mutual coupling. Thus, the synchronized oscillators appear to behave as if they had spontaneously adapted themselves [*se accommodat*] to each other without any corporeal contact. They appear to act as if they "feel each other" or "communicate which each other" at a distance. Consequently, despite his strongly mechanistic worldview, Huygens initially referred to this phenomenon as "the sympathy of clocks", which seems to suggest a kind of action-at-a-distance as a result of a hidden, or 'occult', quality inherent in the clocks.

Huygens did not hide his discovery. On the contrary, he directly notified his father and the fellows of the Royal Society. Moreover, his discovery was published only a few weeks later in the first scientific journal, the *Journal des Savants*. Consequently, within the space of a month, the entire *République des lettres* was made aware of this odd phenomenon. Therefore, it is not unreasonable to assume that Spinoza was likewise aware of Huygens' observations, all the more so since, according to *Letter 26* (1665), the Dutch philosopher visited Huygens in Voorburg during that time.

This may explain the context within which Spinoza wrote, "I consider things as parts of a whole to the extent that their natures adapt themselves to one another so that they are in the closest possible agreement." This assertion seems not only to represent a discontinuity in his views on the nature of the relations between bodies but also – and more importantly – it seems to be inconsistent with his metaphysical determinism. However, the paradigm of the synchronization of bodies explains that bodies can "adapt themselves" to other bodies. Moreover, the effect is completely explainable in terms of the mechanistic model of the collision of bodies so that the phenomenon is entirely compatible with Spinoza's mechanistic views and his concept of the causality of bodies. Furthermore, this hypothesis allows us to explain why Spinoza speaks of "the laws" which adapt themselves. It is likely that he had Huygens' law of the pendulum in mind. By this line of reasoning, each pendulum has its own natural frequency, its own law, so to speak, which adapts itself slightly during the process of synchronization to the law of other pendulums in order to form one law, that is, one whole united by a mutual relation of motion-and-rest.

References

[1] In this article, all translations from Christiaan Huygens' correspondence are from Alex Boxel. These translations can be found on the following site: *http://idolsofthecave.com*

Abbreviation applied for Christiaan Huygens'work: OCH - Huygens, Christian. *Œuvres Complètes de Christiaan Huygens* (Publ. par la Société hollandaise des sciences) (La Haye: M. Nijhoff, 1888-1950).

[2] All translations from Spinoza's works in this article are from Samuel Shirley. The abbreviations applied for Spinoza's works: E – *Ethics (Ethica)*; *CM –Metaphysical Thoughts* (*Cogitata metaphysica*); *PPC–Descartes's Principles of Philosophy* (*Principia Philosophiae Cartisianae*); *Letters (Epistolae); KV–Short Treatise on God, Man and his Well-being (Korte Verhandeling van God de Mensch en deszelfs Welstand); TP–Political Treatise (Tractatus-Politicus) and TTP–Theological Political Treatise* (*Tractatus Theologico-Politicus*).

Passages in Spinoza's *Ethics* will be referred to by means of the following abbreviations: a (axiom), ap (appendix), c (corollary), d (demonstration), def (definition), p (proposition), le (lemma) and s (scholium). For instance: E2p16c2 = Part 2 of the *Ethics*, proposition 16, corollary 2.

[3] *Letter 30* of Spinoza to Oldenburg. Cf.: Spinoza, B. *Complete Works*, Eed. M. L. Morgan and tran. S. Shirley (Indianapolis: Hackett, 2002), 844.

[4] Boyle, R., *The correspondence of Robert Boyle,* ed. M. Hunter, A. Clericuzio and L.M. Principe (London: Pickering & Chatto, 2001), 550.

[5] Spinoza, B.,, *Complete works*, 846.

[6] Spinoza refers here to letter 30 (autumn 1665).

[7] Spinoza, B., *Complete works*, 848.

[8] Spinoza, B., E1a4.

[9] See also Spinoza's letter 54 (1674) to Hugo Boxel. Cf. Morgan, M.L., *Spinoza Complete works*, 899.

[10] Spinoza, B., E2p17c.

[11] Spinoza, B., E2p40c2.

[12] Spinoza, B., *Complete works*, 253.

[13] Spinoza, B., *Complete works*, 849.

[14] In the original text we read: "Per partium igitur cohaerentiam nihil aliud intelligo, quàm quòd leges, sive natura unius partis ità sese accommodat legibus, sive naturae alterius, ut quàm minimè sibi contrarientur. Circa totum, et partes considero res eatenus, ut partes alicujus totius, quatenus earum natura invicem se accommodat, ut, quoad fieri potest, inter se consentiant, quatenus verò inter se discrepant, eatenus unaquaeque ideam ab aliis distinctam in nostrâ Mente format, ac proinde, ut totum, non ut pars, consideratur. Ex. gr. cum motûs particularum lymphae, chyli, etc. invicem pro ratione magnitudinis, et figurae ità se accommodant, ut planè inter se consentiant, unumque fluidum simul omnes constituant, eatenus tantùm chylus, lympha, etc. ut partes sanguinis considerantur : quatenus verò concipimus particulas lymphaticas ratione figurae, et motûs, à particulis chyli discrepare, eatenus eas, ut totum, non ut partem, consideramus." From: Spinoza, B., *Opera.* 4 volumes., ed. C. Gebhardt (Heidelberg: Carl Winter Verlag, 1972 (1925).

[15] Spinoza, B., *Complete works*, 253.

[16] The correspondence between Baruch Spinoza and Henry Oldenburg is composed of 17 letters from Oldenburg to Spinoza and 10 from Spinoza to Oldenburg. This correspondence was between 1661 and 1676 with hiatuses between 1663 and 1665 and between 1665 and 1675. What is known as the 'Spinoza-Boyle' correspondence forms a part of this larger whole and consists of the letters 6, 11, 13 and 16 written between 1661 and 1663.

[17] Spinoza, B., *Complete works*, 849.
[18] Cf. Rivaud, A., "La physique de Spinoza," *Chronicon Spinozanum* 4 (1924-1926): 24-57.
[19] The only places Spinoza uses the verb "*accommodare*" or any variation of it in the *Ethics* are: the corollary of proposition 4 of E4 and, consequently, the appendix of E4, and proposition 7 of E5.
[20] See also the proof of lemma 3 of the *Physical Interlude* of the second part of the *Ethics*.
[21] Vyftiende Brief, in: Spinoza, B., *De Nagelate schriften van B.D.S.* (Amsterdam: J. Riewertsz, 1677), 495.
[22] Spinoza, B., *Complete works*, 773.
[23] Cf. Zilsel, E., "The Genesis of the Concept of Physical Law," in *The Social Origins of Modern Science*, ed. D. Raven, W. Krohn and R.S. Cohen (Dordrecht: Kluwer, 2000), 96-121.
[24] *Letter 33* from H. Oldenburg to Spinoza, London, 8 December 1665. Cf. Morgan, M.L., *Spinoza Complete works*, 851-852.
[25] *Letter 32* from Spinoza to H. Oldenburg, London, 20 November 1665.
[26] Cf. Rivaud, A., (1924-1926), 24-57.
[27] This hypothesis is new since she has not been examined yet in existing publications that treat Spinoza and the pendulum such as: Chareix, F., "Le bal des pendules: Spinoza et Leibniz face à la mécanique théorique de Huygens," in *Spinoza et Leibniz*, ed. P.F. Moreau, et al., ch. XII. (Paris: PUPS, 2014); Gullemeau, E., "El paradigma pendular en la teoría spinozista de los afectos," in *El gobierno de los afectos en Baruj Spinoza*, ed. E. F. García and M. L. de la Cámara García (Madrid: Trotta, 2007), 93-106 and Parrochia, D., "Physique pendulaire et modèles de l'ordre dans l'Éthique de Spinoza," *Cahiers Spinoza* 5 (1984-85): 71-92.
[28] *Letter 26* of Spinoza to Oldenburg from May 1665. Cf.: Morgan, M.L., *Spinoza Complete works*, 838.
[29] Christiaan Huygens uses this expression in his letter 1606 to his brother Constantijn Huygens of 14 October 1667.
[30] Cf. Israel, J., *Radical Enlightenment* (Oxford: Oxford University Press, 2001), 246-252; Keesing, E., "Les frères Huygens et Spinoza," *Cahiers Spinoza* 5 (1985): 109-128; Klever, W., "Spinoza en Huygens. Een geschakeerde relatie tussen twee fysici," *Gewina* 20 (1997): 14-31. Nadler, S., *Spinoza: A Life* (Cambridge: Cambridge University Press, 1999), 221-222; Vermij, R., "Instruments and the Making of a Philosopher. Spinoza's Career in Optics," *Intellectual History Review* 23/1 (2013): 65-81 and Van Bunge, W., et al., eds, *The continuum Companion to Spinoza* (NewYork: Continuum, 2011), 16-24.
[31] Drawing from Chr. Huygens, (OCH XVII 185, Fig.76).
[32] OCH XVII, 185.
[33] Letter N° 1345 de Christiaan Huygens to Robert Moray (6 March 1665), trans. A. Boxer.
[34] Letter N°1362 de Christiaan Huygens to Robert Moray (27 March 1665), trans. A. Boxer.
[35] Letter N°1333 de Christiaan Huygens to R.F. de Sluse (24 February 1665), trans. A. Boxer.
[36] Letter N°1335 de Christiaan Huygens to his father Constantyn Huygens (26 February 1665), trans. A. Boxer.
[37] Cf. Letter N°1335 de Christiaan Huygens to his father Constantyn Huygens (26 February 1665), trans. A. Boxer.
[38] Letter N°1338 de Christiaan Huygens to Robert Moray (27 February 1665), trans. A. Boxer.
[39] Original drawing by Christiaan Huygens (Cf. OCH XVII 183).
[40] Letter N° 1348 de R. Moray to Christiaan Huygens (6 March 1665), trans. A. Boxer.
[41] This is the date according to the Gregorian calendar which was different than the old Julian calendar which was applied in England. The result was that during this time England was 10 days behind most of continental Europe.
[42] Letter N° 1348 de R. Moray to Christiaan Huygens (6 March 1665), trans. A. Boxer.

[43] Journal Book of the Royal Society vol. 2 (JBO/2), meeting of 1 March 1664/5, 289 – 292.
[44] Cf. Birch, T. *The History of the Royal Society of London for Improving of Natural Knowledge from Its First Rise, in which the Most Considerable of Those Papers Communicated to the Society, which Have Hitherto Not Been Published, are Inserted as a Supplement to the Philosophical Transactions*, vol. 2 (London: A. Millar in the Strand, 1756), 18.
[45] Birch, T. *The History of the Royal Society*, 15-17, 22-3.
[46] Birch, T. *The History of the Royal Society*, 19-20.
[47] Cf. Boyle, R., *A Free Enquiry into the Vulgarly Received Notion of Nature*, ed. E. B. Davis and M. Hunter (Cambridge: CUP, 1996), 40.
[48] Letter No. 1362 de Christiaan Huygens to Robert Moray (27 March 1665), trans. A. Boxer.
[49] OCH XVII, 187.
[50] Spinoza, B., *Complete works*, 838.
[51] OCH XVII, 187, note 3.
[52] Cf. Pikovsky, A., M., Rosenblum, M. and J. Kurths, J, *Synchronization: A universal concept in nonlinear sciences* (Cambridge: Cambridge university press, 2001), 8-14.
[53] Letter N° 1335 of Christiaan Huygens to his father Constantijn Huygens (26 February 1665), trans. A. Boxer.
[54] Drawing from Chr. Huygens, (OCH XVII 185, Fig.77).
[55] Bennett, M., M. F. Schatz, H. Rockwood & K. Wiesenfeld. “Huygens's clocks”, *Proceedings of the Royal Society A*458 (2002): 563-579.
[56] Pantaleone, J., “Synchronization of Metronomes,” *American Journal of Physics* 10 (2002): 992-1000.
For a simulation of this experiment, please visit the site of the Harvard Natural Sciences Lecture Demonstrations at: *https://www.youtube.com/watch?v=Aaxw4zbULMs,* cited 29.30.2017.
[57] Wiesenfeld, K. and D. Borrero-Echeverry, “Huygens (and others) revisited,” 047515.1.
[58] Cf. Bennett et al., (2002): 563-579 and Czolczynski, K., et al., “Huygens’ odd sympathy experiment revisited,” *International Journal of Bifurcation and Chaos* 7 (2011): 2047-2056.
[59] Cf. Bennett et al., (2002).
[60] Cf. Klarreich, E.G., “Huygens’s clocks revisited,” *Americain Scientist, Sigma Xi*, The Scientific Research Society 90(4) (2002): 1.
[61] Cf. M. Bennett et al., (2002): 563-579 and Czolczynski , K. et al., (2011): 2047-2056.
[62] Pikovsky, A., (2001), 1.
[63] Cf. Blekhman, I.I., *Synchronization in Science and Technology*, American Society of Mechanical Engineers (New York: ASME Press, 1998) and Aschoff, J., ed., *Circadian Clocks* (Amsterdam: North Holland Press, 1965).
[64] Cf. Aschoff, J., (1965) and Koukkari, W.L. and R.B. Sothern, *Introducing Biological Rhythms* (New York: Springer, 2006).
[65] Cf. Letter 26 of Spinoza to Oldenburg.
[66] OCH XVII, 186-187.
[67] OCH XVII, 187, note 3.
[68] OCH XVII, 187, note 3. .
[69] Gueroult, M., *Spinoza II: L’âme* (Paris: Aubier, 1974), 159-165.
[70] Axioma 1 and 2, and lemma 1, 2 after Ep13s.
[71] Gueroult, M., (1974), 161.
[72] Gueroult, M., (1974), 173.
[73] For Gilles Deleuze’s critical comments on Gueroult’s hypothesis, see:
Deleuze, G., “Cours Vincennes: the actual infinite-eternal, the logic of relations - 10/03/1981. Confrontation with Gueroult's commentary”, [online] Available webdeleuze.com, cited 29.02.2017.

[74] Cf. Icke, V., *De ruimte van Christiaan Huygens* (Groningen: Historische Uitgeverij, 2009) and Icke, V., *Christiaan Huygens in de onvoltooid verleden toekomend tijd* (Groningen: Historische Uitgeverij, 2006).

[75] Galilei, G., Letter 3496, Galileo to Laurens Raeal (5 June 1637), in *Le opere di Galileo Galilei*ed. A. Favaro, Vol. XVII 100-3 (Florence: Tipografia Barbèra, 1890-1909).

[76] See also Viviani's letter to Leopold de' Medici (1617-1675) dated August 20, 1659.

[77] Cf. Whitestone, S.,. "Christian Huygens' Lost and Forgotten Pamphlet of his Pendulum Invention,"*Annals of Science* 1 (2012): 91-104.

[78] Cf. Pikovsky, A., M. Rosenblum, M. and J. Kurths, (2001), 9-14.

[79] Spinoza, B., PPC II 8s.

[80] Spinoza, B., E3p15s.

[81] The main affair of the sympathetic clocks is discussed in 5 letters (No. 1335, No. 1338, No. 1345, No. 1348, and No.1362) and two times in the minutes of the Royal Society from 1664/5.

[82] Journal des savants, XII, Lundi 23 Mars, M.DC. LXV, 161-162.

[83] "In order to measure the time, not having a pendulum clock to hand, I made do with a bent glass tube, […]", (Letter 41 from Spinoza to Jarig Jelles, 5 September 1669). Cf. Spinoza, B., *Complete works*, 867-868.

[84] Cf. Descartes, R., *Œuvres de Descartes*, ed. C. Adam et P. Tannery (Paris: Vrin, 1964-1974), XI, 199-121.

[85] Cf. Robert Boyle's definition of Mechanical Philosophy in the preface of "Some specimen of an attempt to make chymical experiments Useful to Illustrate the Notions of the corpuscular philosophy" in *Certain Physiological Essays* (1661) and in the Latin version of this work published in the same year under the title: *Tentamina quædam physiologica diversis temporibus & occasionibus conscripta*. Henry Oldenburg sent this Latin text to Spinoza on 11/21 October 1661,cf. Spinoza, B., *Complete works*, 767-768.

[86] Cf. *Short Treatise*, I cap. II,cf. Spinoza, B., *Complete works*, 44.

[87] Spinoza, B., *Complete works*, 227.

[88] Cf. Jonas, H., "Spinoza and the Theory of Organism," *Journal of the History of Philosophy* 3 (1965): 43-57.

[89] See not only M. Gueroult but also and more recently Zourabichvili, F., in *Spinoza – Une physique de la pensée* (Paris: Puf, 2002) 53: "C'est bien ce que Spinoza a en vue lorsqu'il donne son exemple : le corps peut être soumis "à un changement constant mais non à un si grand qu'il dépasse la limite de 1 à 3 . " Le rapport ne désigne donc pas l'équilibre de deux quantités mais l'amplitude d'une oscillation : le rapport entre un maximum de repos et un maximum de mouvement, et « si d'autres corps agissent sur le nôtre si puisement que la proportion de 1 à 3 de son mouvement ne puisse subsister, alors c'est la mort. "