Christiaan Huygens and the Scientific Revolution

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1 Introduction

Christiaan Huygens, who lived from 1629 to 1695, is without doubt the most important Dutch physicist of the 17^{th} century. He was widely recognised in his own age as one of the leading scientists, as shown by the fact that the newly founded *Académie Royale des Sciences* appointed him as their leader. Why was Huygens so important? What place ought we assign to his works and thoughts in the development of science in the so-called 'scientific revolution'?

In this short essay I will focus on two aspects on Huygens' work: his concrete scientific discoveries, and his methodology. It will become clear that his discoveries were many and important, thus justifying the assertion that he is one of the key figures of the scientific revolution. The analysis of the way Huygens worked and his views on the method of science will clearly show how he fits into the ever changing practice of 17^{th} century science.

2 Huygens' scientific discoveries

Christiaan Huygens contributed to many fields of physical and mathematical research. Heavily influenced by Descartes, whom he met a few times in his youth, he became interested in the laws of motion governing colliding bodies. Experiments soon brought him to the conclusion that the laws Descartes had written down for these phenomena in his *Principles of Philosophy* were in fact incorrect. Descartes had assumed that motion, conceived of as a scalar quantity, was conserved. Huygens showed that this was incorrect, and deduced the true laws of inelastic collision. He furthermore recognised that not motion, but linear momentum – that is, motion conceived of as a vector quantity – was conserved in collisions of inelastic bodies, so although he did not write this down in modern physical and mathematical concepts, Huygens can be seen as the discoverer of the first true conservation law.

An ongoing, and often obscure and confused, debate in the 17^{th} century was the *vis viva* controversy. Although many issues bearing on force, matter, movement and conservation of quantities were involved, the main question was whether the 'living force' of an object was proportional to mv or to mv^2. Adopting the idea, mainly defended by Leibniz, that the latter was the case, Huygens proved a version of the law of conservation of energy in collisions of inelastic bodies. All of these achievements were major contribution to the science of dynamics.

Interested in astronomy, Huygens built his own telescope, with which he discovered a moon of Saturn: Titan. Wishing to improve on the available telescopes, in 1656 he created one which was 7 metres long, and which was better that its rivals, if somewhat clumsy to use. Huygens also developed a new eyepiece for his telescope, the general design of which is still used in some telescopes today. Using improved instruments like these, he discovered that what Galilei had described as 'Saturn's ears' was in fact a ring around the planet.

Christiaan Huygens also did important work on the pendulum clock. Galilei had already observed that the period of a pendulum is independent of the amplitude of its swing, for small amplitude. But it was Huygens who first deduced the formula for this period,

$$T = 2\sqrt{\frac{l}{g}},$$

where l is the length of the pendulum, and g is the gravitational acceleration. In fact, Huygens computed g from this formula. He went on to actually make accurate pendulum clocks, although they could not be used – as he had hoped – at sea. (Accurate clocks that could be used on sea-faring vessels were highly sought after in the 17^{th} century, as they would solve the main problem of navigation: determining one's longitude. This was finally achieved only as late as 1759, by John Harrison, an English clock maker.) Noticing that the pendulum's period changes for large amplitudes, Huygens developed an ingenious device known as the cycloidal pendulum. Here, the pendulum swings between two curved surfaces, which are constructed in such a way that as the clock's amplitude becomes larger, it's length becomes so much shorter that the period remains constant. Huygens' analysis of this kind of curve, the cycloid, was also a major contribution to mathematics. As another, and highly original, contribution to mathematics, Huygens published the first document on probability calculus ever, in 1657.

An open question in 17^{th} century physics was the nature of light: should this be conceived of as particles, or as waves? Huygens chose the latter option, and developed the well known *Huygens' Principle*, which states that every point on a wave front acts as a source for new spherical waves. (It should be noted that Huygens' waves were not continuous, but rather displacements of small, yet finite, ether particles forming a discrete grid.) From this principle Huygens deduced the laws of reflection and refraction.

Leaving unmentioned numerous other contributions to physics and mathematics, I will now turn to Huygens' methodology.

3 Huygens and methodology

3.1 Changing the rules

Even more than by the concrete discoveries made, the 'scientific revolution' is characterised by a radical change in the methods employed by scientists. In order to find out how Christiaan Huygens fits into this period, we need to take a look at the developments that were taking place. Very generally speaking, the major changes in science were *mathematisation*, *mechanisation* and the advent of *empiricism*.

Before the scientific revolution took place, science was still largely Aristotelian. In Aristotle's science, there was no place for mathematics. Indeed, it was absurd to assume that mathematics and physics could have anything to do with each other. The subject of mathematics was unchanging objects that did not have independent existence; the subject of physics was changing objects that did have independent existence. Quite clearly, physics and mathematics were each other's opposites. However, the late 16^{th} and especially the 17^{th} century saw mathematics enter science, introduced by people like Copernicus, Kepler, Galilei and – perhaps in a less straightforward way – Descartes.

Aristotle created a very influential scheme of causality, recognising no less than four different kinds of cause. The most important of these was the 'final cause', which specified the 'aim' or 'goal' of something. However, this kind of cause was not restricted to the actions of thinking beings, but in fact applied to everything in nature. Thus, the final cause of rain was that it allowed the plants to grow; the final cause of the falling of a stone was that it wanted to be close to its natural place. Renaissance thinking only strengthened this way of thought, allowing all kinds of sympathies, antipathies and souls into scientific explanations. In the scientific revolution, this was replaced by a mechanical philosophy. Nature did not have any occult properties, was not ruled by spirits and sympathies; it consisted of particles moving through space according to strict, impersonal laws.

Observation was, of course, ever important to scientists. But Aristotle had pointed out that while studying nature, we should not interfere with her, lest we disturb the natural processes. Thus, doing controlled experiments was useless, since we certainly couldn't expect to find any truly natural processes that way. Again, this philosophy was replaced by an empiricist outlook, initially championed by people like Galilei. At the end of the scientific revolution, doing controlled and oft repeated experiments in order to obtain precise information about nature was a well-established practice.

3.2 Huygens and Cartesianism

The most influential philosopher of the first half of the 17^{th} century was certainly René Descartes. Although he did not do many concrete experiments, he mathematised and mechanised nature very radically. The only concepts allowable in physics, according to Descartes, are *matter* and *motion*. The universe consists of particles of different shapes and sizes, which fill the whole of space. In fact, matter is nothing else than extension – every other attribute of matter is occult and ought to be rejected. The only basic physical process is collision. Because everything is extension, the form of reasoning applicable to nature is geometry. Physics, then, is simply the application of geometry to observed phenomena.

The young Christiaan Huygens met Descartes, who lived in the Netherlands at the time and made occasional visits to Huygens' parental home, and was very impressed by his philosophy. Huygens was immensely influenced by the Cartesian conception of science. Still, he did not follow it unquestioningly. He soon discovered differences between Descartes' physical theorems and his own observations, which led him to careful experimentation and the development of better theorems. Being less philosophically minded than Descartes, Huygens adopted a more pragmatic approach to science. He rejected the idea that the only attribute of matter was extension, thus escaping the almost suffocating philosophical restrictions Descartes had placed on physical explanations. Although still operating within a largely Cartesian framework, Huygens did not adopt its restrictive methodology.

3.3 Mechanics and mathematics

Rejecting parts of the Cartesian methodology was important, and quite typical of the later 17^{th} century. But Huygens also played an important role in the *adoption* of a method: namely that of mathematical physics. Galilei had already stressed the importance of mathematics, yet it was not the central part of his physics. He often developed ideas and theories, and only later put them in a mathematical form for clear and effective presentation. Mathematics did not directly teach us anything about nature, is was more a mode of presentation. Descartes theoretically raised the status of mathematics, but in his own physical works he did not employ it to even a moderate extent. For Huygens, however, physics and mathematics were inseparable.

Huygens was a great mathematician, well versed in both the analytic geometry of Descartes and the classical geometry of Euclid and Archimedes. He consistently used this talent in his physical writings, mathematising physical problems time and time again. For Huygens, the standard way of solving a problem was this: first, describe the physical system in a mathematical way. In other words, we must represent our physical problem by a number of mathematical hypotheses. Secondly, we use mathematical – in fact, geometrical – analysis, and deduce results. At the end, we translate these mathematical results back to physics. This method seems strangely modern, and shows the central role mathematics played for Huygens.

The kinship of mechanics and mathematics also becomes clear when we take a closer look at his mathematical methods. Huygens did not use the calculus that was to be developed by Leibniz and Newton, and with which we are so familiar nowadays. Instead, he adopted a geometric way of thinking, dating back to the ancient Greeks. Here, mathematics is supposed to be about curves, and curves are defined by a way of constructing them. In fact, mathematicians only recognised a curve as a real mathematical object once it was shown how to construct it – in a mechanical way. Huygens actually sketched the design of a machine which could create a curve known as the 'tractrix', in order to justify studying it. Thus, it was not just physics that was mathematised, but also mathematics which was physicalised.

For Huygens, influenced by Cartesianism as he was, the fundament of all physics was mechanics – the study of matter in motion. And mechanics was, in a less simplistic way than for Descartes, simply applied mathematics. Huygens used his mathematical method with huge success, also because he always limited himself to those physical problems that allowed themselves to be described mathematically. We can see Huygens as the first true mathematical physicist, and his successes may well have been of paramount importance for securing the recognition of mathematics as the central tool of physics.

Still, Huygens' method was not identical to that of later physicists. His geometric analysis was to be replaced by the calculus used with great skill by Newton. In this way, Huygens both marks a beginning and an end: the beginning of a fully mathematical physics, and the end of the geometric method. This places him right in the middle of the methodological changes that define the scientific revolution.

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