

# **Galileo's Visions**

Piercing the spheres of the  
heavens by eye and mind

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## **Galileo's sensory philosophy**

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**Figure X** Galileo's *Saggiatore* by Nicholas Wade. Galileo's portrait is derived from a painting by Francesco Villamena and is framed by the frontispiece of *Il Saggiatore*.

Credit: Frontispiece of 'The Assayer' by Galileo Galilei, 1623 (engraving), Villamena, Francesco (1566–1624) / Private Collection / Photo © Christie's Images / The Bridgeman Art Library.

Galileo's interest in vision has been considered in the previous chapters and it is now time to analyse the philosophical foundations underlying his conception of senses. This is in the context of his considerations of the unreliability (and possible fallacy) of the senses. Galileo's attitude contrasts with his insistence on the need for 'sensible experiences' in order to arrive at correct conclusions in the various fields of scientific investigation, and in order to achieve a trustworthy knowledge of the world.

This can be addressed through some rather well-known pages in chapter 48 of *Saggiatore*, in which Galileo discusses two different qualities of physical bodies that were later referred to as 'primary' and 'secondary' qualities.<sup>1</sup> These pages are generally discussed on a purely philosophical basis, outside the context of Galileo's general approach to science and reality, and with no reference to his understanding of the mechanisms underlying the psychological and physiological dimensions of sensory processes.

### 10.1 Tastes, odours, colours, and so forth are no more than mere names

Galileo develops the properties and causes of sensations within the framework of a discussion on the nature of heat and of its relation to motion. Addressing (His Excellency) Virginio Cesarini, to whom *Saggiatore* is dedicated, Galileo writes:

It now remains, in accordance with the promise made above to your Excellency, for me to tell you some of my thoughts about the proposition, 'Motion is the cause of heat,' and to show in what sense this may be true in my opinion. But first I must give some consideration to what we call 'heat,' for I much suspect that in general people have a conception of this which is very remote from the truth, believing heat to be a real attribute, property, and quality which actually resides in the material by which we feel ourselves warmed.

Therefore I say that upon conceiving of a material or corporeal substance, I immediately feel the need to conceive simultaneously that it is bounded and has this or that shape; that it is in this place or that at any given time; that it moves or stays still; that it does or does not touch another body; and that it is one, few, or many. I cannot separate it from these conditions by any stretch of my imagination. But that it must be white or red, bitter or sweet, noisy or silent, of sweet or foul odor, my mind feels no compulsion to understand as necessary accompaniments. Indeed, without the senses to guide us, reason or imagination alone would perhaps never arrive at such qualities. For that reason I think that tastes, odors, colors, and so forth are no more than mere names [*puri nomi*] so far as pertains to the subject wherein they appear to reside, and that they have their habitation only in the sensitive body. Thus, if the living creature [*l'animal vivente*] were removed, all these qualities would be removed and annihilated. Yet since we have imposed upon them particular names which differ from the names of those other previous real attributes, we wish to believe that they should also be truly and really different from the latter. (SAGGIATORE, pp. 196–197; transl. pp. 309–310)

After examining the sense of hearing (by negating expressly the existence of 'sonorous or transonorous qualities'), he writes:

I do not believe that for exciting in us tastes, odors, and sounds there are required in external bodies anything but sizes, shapes, numbers, and slow or fast movements; and I think that if ears, tongues,

<sup>1</sup> Although in the context of post-Galilean science the expressions 'primary' and 'secondary qualities' were introduced by Locke, they existed in the Scholastic philosophy, although with a different meaning. In particular for most of the scholastic philosophers, primary qualities corresponded to the elementary qualities of the Aristotelian philosophy, i.e. hot, cold, wet, and dry.

and noses were taken away, shapes and numbers and motions would remain but not odors or tastes or sounds. These, I believe, are nothing but names, apart from the living animal just as tickling and titillation are nothing but names when armpits and the skin around the nose are absent. And as the four senses considered here are related to the four elements, I believe that vision, the sense which is eminent above all others, is related to light, but in that ratio of excellence which exists between the finite and the infinite, the temporal and the indivisible; between darkness and light. Of this sense and of the matters pertaining to it, I pretend to understand but a trifle, and since a long time would still not suffice to explain that trifle—or even to hint at its explanation in writing—I pass this over in silence. (pp. 199–200; transl. pp. 311–312)

These statements have generally been considered indicating a purely subjective conception of knowledge, with reference to the phrase ‘mere names’ attributed by Galileo to ‘tastes, odors, and sounds’, which would suggest that the sensations would be without any substantiality and consistence outside the subject capable of perceiving them (denoted by ‘the subject wherein they appear to reside’ or ‘the sensitive body’ or ‘living creature’). Historically, only the so-called primary qualities have been considered as a proper object of investigation according to the paradigm of the (supposedly) Galilean science. This contributes to explaining why the research in the field of sensations has lagged behind that of physics by about two centuries.

In the pages of *Saggiatore* the discourse on sensations as ‘mere names’ seems to intrude as an extraneous body into the polemics on the nature of comets that continues that initiated with the *Discorso delle comete*. Nonetheless, it represents a vital aspect of Galileo’s conception of the world that had been building up since his youth. Far from being simply a facet of his theory of sensation and knowledge, it is connected to all the dimensions of his scientific endeavour (studies on motion, mechanics, hydraulics, floating bodies, astronomy) and also to his philosophical and metaphysical conception of reality.

## 10.2 A moving hand, a statue, and a living man

In the conclusion to his first letter on sunspots, where he deals with visual themes (see Chapter 2), after mentioning the difficulty encountered in dealing with the new and intricate matters of astronomical observation, Galileo writes:

I do not want on this account to despair and to abandon the enterprise; on the contrary, I would hope that these novelties might serve me wonderfully to tune up a few pipes of this grand [but] discordant organ of our philosophy, which, in my view, many organists labor in vain to tune to perfection [*accordare al perfetto temperamento*]. And this is because they go about leaving and preserving three or four of the principal pipes out of tune, such that it is impossible for the others to respond in complete harmony. (ISTORIA, p. 28; transl. p. 7)

In Galileo’s view there is little doubt that among the ‘three or four of the principal pipes’ that make the organ of natural philosophy discordant, there is also that of a theory of sensations, and that this theory must be in complete harmony with the entire structure of the grand organ of natural philosophy (i.e. science at large).

The example that Galileo develops in *Saggiatore* in order to clarify his conception of senses is particularly efficacious. It concerns the nature of the tickling sensation:

I believe I can explain my idea better by means of some examples. I move my hand first over a marble statue and then over a living man. Now as to the action derived from my hand, this is the same with respect to both subjects so far as the hand is concerned; it consists of the primary phenomena of motion and touch which we have not designated by any other names. But the animate body which

receives these operations feels diverse sensations according to the various parts which are touched. Being touched on the soles of the feet, for example, or upon the knee or under the armpit, it feels in addition to the general sense of touch another sensation upon which we have conferred a special name, calling it tickling; this sensation belongs entirely to us and not to the hand in any way. It seems to me that anyone would seriously err who might wish to say that the hand had within itself, in addition to the properties of moving and touching, another faculty different from these; that of tickling as if the tickling were an attribute which resided in the hand. A piece of paper or a feather drawn lightly over any part of our bodies performs what are inherently quite the same operations of moving and touching; by touching the eye, the nose, or the upper lip it excites in us an almost intolerable titillation while in other regions it is scarcely felt. Now this titillation belongs entirely to us and not to the feather; if the animate and sensitive body were removed, it would remain no more than a mere name. And I believe that many qualities which we come to attribute to natural bodies, such as tastes, odors, colors, and other things, may be of similar and no more solid existence. (SAGGIATORE, p. 199; transl. pp. 309–310)

The meaning of this passage, which recalls and develops a similar example from *Discorso delle comete*, is rather evident. Outside the individual capable of perceiving, sensations have an undoubted physical reality (easy to individuate in the case of tickling although a little less so in the case of other sensations, especially the sensation of light). In his mechanistic and atomistic conception of the world Galileo tends to identify this reality with the motion of matter; the properties of matter are considered to be corpuscular, but he refuses to attribute it to a specific sensory dimension. A specific sensory quality is acquired only with regard to a specific sensory apparatus. Nothing in the world exists outside us that is specifically 'colour', 'odour', 'taste', 'sound', 'tickling', or 'warmth'. The sensorial connotation is the consequence of an action exerted by the external agencies on specific structures of the sensitive individual (animal or human), where it activates specific sensory processes. With reference to the old theory of the 'four elements', Galileo establishes a relation similar (but not identical) to that adopted by Aristotle, between—respectively—the elements of earth, water, air, fire on one side, and the tactile, gustatory, acoustical, and olfactory sensations on the other side (and also between vision and light, of which he seems to suggest the analogy with the ether or quintessence). However, he did not believe, as Aristotle did, that specific sensory qualities existed in external reality, outside the sensitive individual.

### 10.3 Aristotle and his real sensibles

For Aristotle (Figure 10.1) colour, taste, odour, sound, touch (or the tangible quality) were the proper objects of sensation (i.e. *aisthēta*, i.e. sensibles; or *aisthētai poiōtētes* i.e. sensible qualities), i.e. specific qualities of external reality having an autonomous existence, independent from the existence of individuals capable of perceiving them, and finalized to produce a specific sensory modality. They belonged to the category called 'proper sensibles' (*idia aisthēta*) being expressions of a specific quality of the external object potentially interacting with a particular sense (of which it was the 'proper' object). Colour<sup>2</sup> (like the other proper sensibles) was therefore considered as existing in the real world, independently of its action on the specific sensory mechanism of the perceiving individual, even though their existence *in actu* required interaction with the correspondent sense. The physical reality of proper sensibles is asserted by Aristotle in various passages. For example, in *De anima* ('On the soul') when speaking of earlier conceptions (and particularly of those

<sup>2</sup> The Greek term for colour, *chrōma*, had a somewhat wider meaning than colour nowadays and also included black and white. In Aristotle's conception, the different hues resulted from a mixing in different degrees of black and white.



**Figure 10.1** Aristotle's *De Anima* by Nicholas Wade. A portrait of Aristotle (derived from an engraving in *The historic gallery of portraits and paintings*, 1810) is combined with Greek text from *De Anima*.

expounded by atomists) he wrote: ‘This relation of the object to the subject of sensation was not rightly comprehended by the early natural philosophers [*próteron physiologoi*]. They thought that there was nothing white or black apart from vision, and no flavour independently of taste’ (transl. Wallace, 1882, p. 137).

For Aristotle, touch, requiring contact in order to experience it, was often taken as the most important sense, and the one relative to which others could be related: ‘The primary form of sense is touch, which belongs to all animals’ (Ross, 1931, p. 413b). It is perhaps for this reason that Aristotle maintained that touch is a single sense, that the number of senses is restricted to five, and that: ‘there cannot be a special sense-organ for the common sensibles either’ (p. 425a). Touch presents more problems because its sensitivity is not localized to a particular sense organ, and the experiences derived from the skin are many and varied. Aristotle confronted these aspects of anatomy and experience and reached similar conclusions:

In dealing with each of the senses we shall have first to speak of the objects which are perceptible by each.... I call by the name of special object of this or that sense that which cannot be perceived by any other sense than that one and in respect of which no error is possible; in this sense colour is the special object of sight, sound of hearing, flavour of taste. Touch, indeed, discriminates more than one set of different qualities. Each sense has one kind of object which it discerns, and never errs in reporting that what is before it is colour or sound (though it may err as to what it is that is coloured or where that is, or what is sounding or where that is). Such objects are what we propose to call special objects of this or

that sense. 'Common sensibles' are movement, rest, number, figure, magnitude; these are not peculiar to any one sense, but are common to all. (Ross, 1931, p. 418b)

Later in *De anima* Aristotle distinguished between experience and organ: 'By a "sense" is meant what has the power of receiving into itself the sensible forms of things without the matter... By "an organ of sense" is meant that in which ultimately such a power is seated' (p. 424a). This, again, provided problems for the experience of touch, because there was no specific organ associated with it. Once more, the issue was voiced by Aristotle: 'If touch is not a single sense but a group of senses, there must be several kinds of what is tangible. It is a problem whether touch is a single sense or a group of senses. It is also a problem, what is the organ of touch' (p. 422b).

Aristotle distinguished the proper from the common sensibles (*koina aisthēta*), these being those properties of objects that we can apprehend through the work of various senses (most frequently touch and vision): 'motion, rest, shape, size, number, unity', with the addition of the broad categories of time and space. Another important distinction he made concerned the so-called 'sensibles *per accidens*' (or 'incidental sensibles': *aisthēta kata sunbebēkos*), which are those qualities that can be accidentally associated to a proper sensible, but are not an essential constitutive element of it.

One of the important distinctions between the different sensibles of Aristotle's theory of sensations concerned the possible occurrence of errors. For him errors arise more commonly in the case of incidental sensibles, and they might also happen in the case of common sensibles, whereas no error can occur in the case of proper sensibles. Concerning these last ones, the impossibility of errors seems to belong to their very definition:

The so-called object of sense-perception may mean three different things, of which two are said to be perceived directly in themselves, the third incidentally and with regard to its concomitants. Of the two first-mentioned, one is proper and confined to each one of the senses separately, the other is common to them all. By the proper is to be understood that which it is impossible to perceive by any other sense than that appropriated to it and with respect to which that sense cannot be deceived. So it is that colour stands to sight, sound to hearing, flavour to taste: touch, however, it must be added, deals with a number of different qualities. Each single sense in fact discerns these different qualities, and is subject to no delusion as to whether it be a colour or whether it be a sound that it perceives: its only doubt is what it is that is coloured or where it is, or what or where is the body that is sounding. Such are the objects of perception which are said to be peculiar to each separate sense. The common sensibles are movement, rest, number, figure, magnitude such properties being peculiar to no one single sense but shared in common by them all. Movement for instance is perceived at once by touch and by sight. (Aristotle, *De Anima*, II, 5; transl. Wallace, p. 93, revised)

A deception can arise in the case of incidental sensibles, when, for example—as Aristotle puts it—by seeing from afar a person dressed in white one says that he is 'the son of Diaries', because normally the son of Diaries is dressed in white. There is no possibility of error in the perception of the white colour (a proper sensible), but the error is possible in the association of this sensation with the idea of the 'son of Diaries', an association which is purely incidental and contingent. By examining the various circumstances in which there could be errors or fallacies of the senses, one gets the impression that this never occurs at the very moment of sensation (considered to be always trustworthy), but in a somewhat later phase which implies a more or less explicit act of judgement. This may occur in associating a particular sensation with another one belonging to a different sense (this happens with common sensibles) or with a memory or concept (as it happens with incidental sensibles). In this context it is appropriate to mention that Aristotle's confidence

in senses is repeatedly asserted in the *Dialogue* by his spokesman Simplicio as when he says that for the Greek philosopher the data of senses must be preferred to any logical argument:

SIMPLICIO: Aristotle would not give assurance from his reasoning of more than was proper, despite his great genius. He held in his philosophizing that sensible experiments were to be preferred above any discourse built by human ingenuity, and he said that those who would contradict the evidence of any sense deserved to be punished by the loss of that sense. (DIALOGO, p. 24; transl. p. 32)

Aristotle's survey of the senses was more extensive than those of his predecessors (see Beare, 1906). Most of the knowledge we have of the earlier Greek commentators derives from the writing of his pupil, Theophrastus (c. 370–286 BC). Without his work *On the Senses* our understanding of early theories of the senses would be even more meagre. Theophrastus categorized writers on the senses into two groups: those who considered that the senses were stimulated by similarities or by opposites. Thus, taste and touch could be treated as similar, since both involve contact. The means of sensing by sight, hearing, smell, and taste was speculated upon by most writers, but less was said about touch. For example, with regard to Alcmaeon of Croton (fl. 500 BC), Theophrastus wrote: 'All the senses are connected in some way with the brain; consequently they are incapable of action if [the brain] is disturbed or shifts its position, for [this organ] stops up the passages through which the senses act. Of touch he tells us neither the manner nor the means of its operation' (Stratton, 1917, pp. 89–91).

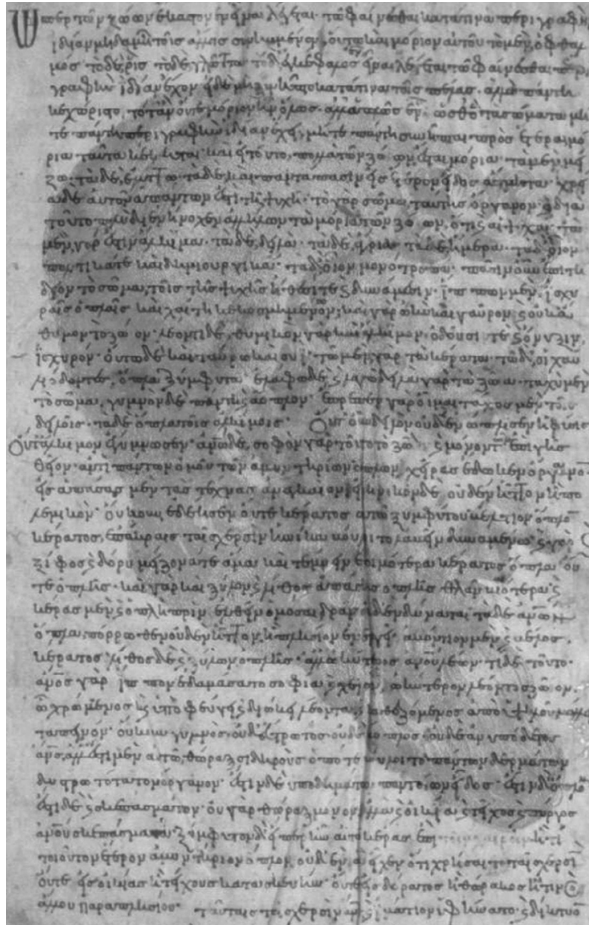
Alcmaeon located the centre of sensation in the brain, although Aristotle did not adopt this view, referring the processes of perception to the heart. In the context of touch, Anaxagoras (c.500–438 BC) discussed sensing warmth and cold, and Democritus contrasted heavy with light, and hard with soft. Plato wrote that touch distinguished between hot and cold, hard and soft, heavy and light, as well as rough and smooth. Theophrastus himself said relatively little about touch. His theory of the senses in general involved some intermediary between the object and the sense organ; for vision, hearing, and smell this could be more readily maintained than for touch.

The approach by Galen (Figure 10.2) to the senses displayed the advantages of anatomical dissection. He berated Aristotle for denying that all the senses do not have connections with the brain: 'Hence all the instruments of the senses—if we are to believe our eyes that see and our hands that touch them—communicate with the encephalon' (May, 1968, p. 391). Galen's theory of the senses was physiological, and it was based on the concept of *pneuma* advocated by Empedocles: 'Unless the alteration in each sense instrument comes from the encephalon and returns to it, the animal will still remain without sense perception' (May, 1968, p. 403). Galen restricted his discussion to the 'four sense instruments in the head, namely, the eyes, ears, nose, and tongue, all of which take the source of their sensation from the encephalon' (p. 400).

The situation remained relatively unchanged through the medieval period: 'Aristotle's account of sensation and perception was held in great esteem in the Middle Ages, and his systematic approach and many of his specific doctrines were widely copied' (Kemp, 1990, p. 35). Attention was directed principally at interpretations of vision, with much less heed paid to the other senses. Developments did occur in fusing Aristotle's account of the senses with Galen's pneumatic physiology, and the medical tradition of describing diseases of the senses became more refined.

#### 10.4 The sensibility of a modern peripatetic

In Galileo's day, the theme of the different sensibles of the Aristotelian tradition, and of the causes or deceptions in sensory appearances, was reconsidered in 1612 by Giulio Cesare Lagalla (or La Galla), professor at the University of Rome, in a small book entitled *De Phaenomenis in orbe lunae*



**Figure 10.2** Galen’s usefulness by Nicholas Wade. A profile portrait of Galen is combined with a page of Greek text from his *On the usefulness of the parts of the body*.

(‘On the phenomena in the orb of the moon’). It critically discussed the observations of the moon made by Galileo with his telescope (and various related scientific novelties). In this book Lagalla asserted the infallibility of sensations in the case of the proper sensibles, considered as specific properties (*passiones*) of the object, and, in accordance with the Aristotelian doctrine, he admitted the possibility of error only in the case of common sensibles and sensibles *per accidens*. For the common sensibles he invoked a classical example, that of the rod (or a stick) partially immersed in water, which appears to be bent. For the sensibles *per accidens* he uses the example of somebody who thinks they have met Socrates when they happen to encounter a man resembling him because of a flat nose and frizzy hairs.

In the marginal annotations that he writes in his personal copy of Lagalla’s work, Galileo counteracts the arguments of the peripatetic philosopher with incisiveness and wit by evidencing the intrinsic inconsistency of his adversary’s reasoning. As for instance when, with a pungent irony, he writes:

If sense is deceitful with common sensibles, then when one sees a bird flying or a horse running, this is false. (OG III, p. 399)

Or when, speaking about the rod of Lagalla's example, he says:

If sight is deceitful in judging the rod, half-immersed in water, as broken, because the figure is a common sensible, then it should also be deceitful when it is out of the water, where the figure is still a common sensible: to what purpose then to introduce the water? (p. 394)

Or when, in the same context, he says:

Is he [Lagalla] not aware of the fact that, when he says that sight is deceitful when it judges, on the basis of colour, the wood to be straight or broken, he is placing the deception in the proper sensible, and not in the common one. (p. 397)

Within the framework of peripatetic philosophy to which he adhered, in his *De Phenomenis in orbe lunae*, Lagalla, despite recognizing the importance of Galileo's achievements with the telescope,<sup>3</sup> attacked almost all his interpretations of the astronomical novelties and also many other aspects of the new science that was undermining the foundations of Aristotelian philosophy. In particular he rejected the Copernican idea of the mobility of earth and of the centrality of sun, he was against the mountainous nature of the moon's surface, he also opposed Galileo's interpretation of the causes of the lunar candour, and he retained the idea of the immutability of skies against the evidence of new stars. He also criticized Galileo's idea of the applicability of mathematical reasoning to the study of natural phenomena. As a matter of fact all Lagalla's discussion on the possible fallacies of common sensibles aimed at undermining the importance of experimental evidence as a means to arrive at reliable scientific conclusions.

One of the points addressed by Lagalla concerned the infinity of the cosmos and the plurality of worlds. These he imputed mainly to the philosophy of Democritus, which was revived in his era particularly by 'an author of a condemned name' (that, although not mentioned, was easily identifiable as Giordano Bruno). Despite his lack of scientific penetration, Lagalla was able to understand that many of Galileo's astronomical discoveries were indeed fitting with the idea of a cosmos less limited and geocentric than that of the traditional Aristotelian and Ptolemaic conceptions and more akin to the idea of an infinity of worlds advocated by Bruno. Among Galileo's relevant observations were the discoveries of the four satellites of Jupiter (which made clear that the world could accommodate more than a planetary system) and the great number of stars revealed by the telescope and the starry nature of the galaxies. These pointed to a potentially infinite number of celestial bodies among which the earth might lose its cosmological and anthropological centrality.

## 10.5 Atomistic condensations and expansions

Atomism was central to Galileo's conception of the world and it invested many facets of his scientific and intellectual vision of natural phenomena. It was also central to his conception of senses, which was closely related to his global conception of reality and to his effort to supplant the traditional philosophy of Aristotle with an entirely new philosophy. This was implied in the metaphor of the 'discordant grand organ' in need of re-tuning, which bore an obvious reference to Aristotle's *Organon* of philosophy. Galileo invoked the metaphor of the organ in various writings in addition

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<sup>3</sup> Lagalla was one of the members of the Roman intelligentsia who benefitted from the telescopic demonstration given by Galileo during his visit in Rome in the springtime of 1611. Besides confirming the reality of telescopic appearances, in his book Lagalla narrates the episode in which the Tuscan scholar, with use of his instrument, made distinctly visible the inscriptions on a monument at a distance of 'not less than 2 miles' from the observation place (OG III, p. 330; on the episode see another testimony in OG XI, p. 117).

to the first letter on sunspots. A reference to the atomism of Democritus is developed in the writings of Galileo and of his student Benedetto Castelli. This particularly concerned his analysis of floating bodies (in 1611) in opposition to some members of the Florentine conservative intelligentsia (and particular his old adversary Lodovico Delle Colombe), and in the *Discorso intorno alle cose che stanno in su l'acqua o in quella si muovono* ('Discourse on the matters that float on or move inside the water') published in 1612. Atomism, in both its physical and mathematical dimensions is also central to the first day of the dialogue in the *Discorsi e dimostrazioni matematiche intorno a due nuove scienze*, the last great work of Galileo published in 1638, four years before his death.

In addition to these works, atomism was also a fundamental reference in many of Galileo's other texts from the early research on gravity which had been largely inspired by the physics of Archimedes. Galileo rejected the explanation based on the Aristotelian idea of absolute gravity and levity (as specific attributes of the various elements, with the element of earth being the heaviest and the element of fire being the lightest). Galileo developed instead the conception of 'gravity in species' (i.e. specific gravity) which would result from the different states of condensation and rarefaction of matter composed of minute corpuscles interspersed by vacuum. In one of his first texts which referred to atomism (the manuscripts dealing with motion known as *De motu antiquiora*)<sup>4</sup> the concept of condensation and rarefaction is considered within the framework of a Platonic myth of creation. Having created the world, the Divine Maker (*divinus Opifex*) concentrated the by-products of the creation of the very vast celestial sphere (*vastissimae caelestis excrementa sphaerae*) at its centre, in order to avoid offending the sight of the most blessed immortal spirits of the heavens. Afterwards, however, in order not to leave empty an immense cosmic space (and also with the aim of attenuating the extreme physical gravity of the concentrated matter), the Maker expanded the primordial matter such as to locate it progressively in zones corresponding to the traditional four spheres of elements (i.e. the concentric spheres of earth, water, air, and fire). Within the framework of this allegorical representation (that anticipates the myths of creation present in the *Dialogue* and in the *Discorsi*), Galileo could undermine Aristotle's explanation of natural motion in the terrestrial world (based on the concept of absolute gravity and levity). He could also connect one of the basic aspects of traditional cosmology (the four spheres of the terrestrial world) to the physical concepts of condensation and rarefaction, capable of accounting for the specific gravity hypothesis invoked to explain his own experiments on motion and floating bodies. The four elements belonging properly to the four spheres were nothing other than four differently condensed aggregations of the same small particles. As to the matter of the heavens this would represent the ultimate level of rarefaction of the primordial matter and it would be akin to light. A resonance of this conception linking the constitution of the world to a terrestrial physics of strong Archimedean and atomistic inspiration is indeed present in the earlier considered pages of *Saggiatore* dealing with senses, where Galileo establishes a relationship between the various sensations on one side, and the four elements on the other side, and adumbrates a correlation between vision and light.

Within the framework of atomism, the different qualities of objects cannot be accounted for by the Aristotelian categories of matter and form, and need to be explained on the basis of the different states of configuration and movement of the minute bodies from which the matter of universe is made. This is what Galileo tries to do in *Saggiatore* by elaborating the sensorial conceptions of

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<sup>4</sup> See OG I, pp. 243–417. An excellent discussion of the importance of atomism in Galileo's work is found in Galluzzi, 2011.

the classic atomists and inserting them within the framework of his global epistemological and ontological vision of the world, based on a concept of order and necessity, and strongly averse to any trivial anthropomorphic finalism.

## 10.6 The silence of Nature

By saying that tastes, smells, colours, etc. would have no existence in the absence of the individuals endowed with sensory capabilities, Galileo is not simply asserting the intrinsic subjectivity of sensations nor is he putting sensations outside the realm of scientific investigation. In marked contrast to the dominant Aristotelian tradition, he is saying that nature does not contain specific signals for the purpose of sensory communication with living beings. Put in other terms, there is no specific language through which nature talks to living beings (and especially to humans) by signs especially adapted to their sensory processes. For Galileo, sensations are the results of actions exerted on the sentient individual (*corpo sensitivo*) by purely objective elements, lacking any definite sensory attribute. These elements (or agencies) are identified with matter in movement of diverse rarefaction or subtlety: on the one hand the dense and tough matter involved in tactile sensation and, on the other, the extremely rare 'ultimate and deepest level of resolution' of the matter which might possibly account for light and, through it, vision.

If we take aside the more mechanistic aspects, this is the epistemological conception which underlies modern sensory physiology. In the external world there are no flavours, no odours, no colours, no sounds, but only molecules, mechanical or electro-magnetic waves (or other types of energies) which are a part of the universe. All this exists independently, and has no definite and constitutive relation with sentient individuals. Throughout evolution, sensory systems have arisen and become adapted to exploit these moving molecules or energies in order to gather information about the external (or internal) world. By themselves, however, molecules have neither taste nor smell, mechanical vibrations are not intrinsically sonorous, and electromagnetic waves are not coloured. Sensory qualifications arise from the interaction between the objective environmental elements with specific biological systems of varying complexity, but all evolved in such a way as to interact effectively with them. Not only the characteristics but also the very existence of these qualifications depends on the characteristics and existence of those biological systems. If they were removed, sensory qualities would lack any definite reality.

In Galileo's own words:

I think that tastes, odors, colors, and so forth are no more than mere names so far as pertains to the subject wherein they appear to reside, and that they have their habitation only in the sensitive body. Thus, if the living creature were removed, all these qualities would be removed and annihilated. (SAGGIATORE, p. 196; transl. p. 309)

To evaluate the modernity of Galileo's conception of sensation we could compare these words with two short passages from modern books dealing with sense physiology. In the chapter entitled 'Coding of sensory information' written by Esther P. Gardner and John H. Martin in a contemporary textbook of neuroscience, the authors write:

Colors, tones, smells, and tastes are mental constructions created by the brain out of sensory experience. They do not exist, as such, outside of the brain. Thus, we can answer the traditional question raised by philosophers: Does a sound exist when a tree falls in the forest, if no one is near enough to hear it? We now believe that the fall causes vibration in the air but not sound. Sound only occurs when pressure waves from the falling tree reach and are perceived by a living being. (Gardner & Martin, 2000, p. 412)

In *Eye and Brain*, a very popular volume on visual physiology and psychology, Richard Gregory pointed out some of the basic principles of visual perception in contemporary science with these words:

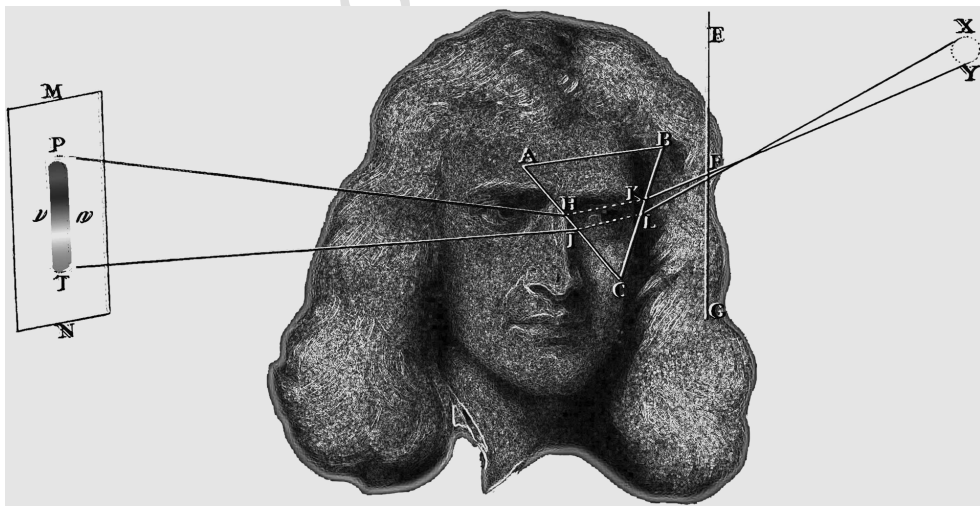
We should realize quite clearly that without life there would be no brightness and no colour. Before life came, especially higher forms of life, all was invisible and silent though the sun shone and the mountains toppled. (Gregory, 2005, p. 85)

## 10.7 Chromatic ambiguities

Colour vision provides an apposite example to illustrate these modern views of sensory science. Similar to some of the most evolved monkeys, humans perceive colours through the interaction of electromagnetic oscillations of wavelengths between 400 and 700 nanometres with a photoreceptive system based on three types of retinal cones. These cones are sensitive to a rather wide band of wavelengths, with peaks of sensitivity around, respectively, 430, 550, and 570 nanometres loosely named as blue, green, and red cones. In ordinary conditions, stimulation with long wavelength waves tend to induce a sensation of red, while the stimulation with intermediate or short wavelengths produces, respectively, the sensation of green or blue. Because of this we tend to speak of red, green, and blue lights, in the tacit assumption that colours are objective and unequivocal attributes of specific forms of light.

Isaac Newton's prism experiment (Figure 10.3) represented an advance in colour science, by changing the origin of chromatic sensations from intrinsic qualities of the objects (as Aristotle maintained) to specific properties of light radiations. In the famous article on the *Philosophical Transactions* in which he communicated his discovery, after linking the various colours of light to their different degree of refraction through the prism, he wrote:

Colours are not *Qualifications of Light*, derived from Refractions, or Reflections of natural bodies (as 'tis generally believed,) but *Original and connate properties*, which in divers Rays are divers. Some Rays



**Figure 10.3** *Newton's spectrum* by Nicholas Wade. The portrait of Isaac Newton (derived from an illustration in Wood, 1885) is combined with his diagram of a beam of sunlight passing through a prism and forming an elongated spectrum (from his *Opticks*, published in 1704).

are disposed to exhibit a red colour and no other; some a yellow and no other, some a green and no other, and so of the rest. Nor are there only Rays proper and particular to the more eminent colours, but even to all their intermediate gradations. (Newton, 1671/1672, p. 3081: original emphasis)

Despite great progress in the physics of light promoted by Newton's prism experiment, the close relationship he established between luminous rays 'which differ in degrees of Refrangibility' and colours, has been somewhat misleading from the point of view of the physiology of colour sensations. This is because of the inherent ambiguity resulting from the mechanisms of colour vision, based on the differential stimulation of three types of broad-band retinal receptors. A person can have exactly the same chromatic sensation, for instance of yellow, either in the presence of electromagnetic oscillations of about 600 nanometres wavelength, or in the presence of an appropriate combination of two waves, one in the longer and the other in the shorter region of the spectrum (for instance, 630 and 550 nanometres). This would happen when the two wavelengths of the combination are capable of stimulating the red and green sensitive cones exactly in the same way as the single 600 wavelength oscillation does. This means that, starting from the perception of a given chromatic hue (yellow in this case), we cannot infer in an univocal and straightforward way the characteristics of the stimulating light.

But there is more. The experiment in which exactly the same yellow sensation is perceived with different types of light is valid only for an individual possessing a particular type of system of three type of cones with those determined bands of sensibility. A person (or an animal) looking at those same lights might have a different sensation originating from the single-wavelength light and from the composition of two different wavelengths. For humans this could happen in the case of anomalies of colour vision. Most animals have a different system of colour vision from ours: for instance, one based on only two type of cones (as is the case for most mammals), or four types of photoreceptors (as in honeybees), or three cones, but different from primates (as in some fishes, reptiles, and birds). To further complicate the matter, exactly the same light (or combination of lights) irradiating from an object can appear of different colours to the same individual, depending on the characteristic of the light in the background surrounding the object and on the condition of light adaptation.

## 10.8 Limited senses

This could be summarized by saying that electromagnetic waves exist in nature but there would be no colour if there were no individuals capable detecting those particular electromagnetic waves. Or perhaps by saying that 'tastes, odors, colors, and so forth are no more than mere names so far as pertains to the subject wherein they appear to reside, and that they have their habitation only in the sensitive body', as Galileo wrote a little less than four centuries ago (and modern neurophysiology straightforwardly confirms).

Concerning the sensation of sound present in the quotation from Gardner and Martin (and also alluded to by Gregory), we have here another opportunity to point to the elusive relationship that exists between external agencies and sensations. In the presence of mechanical oscillations, a living individual endowed with an appropriate system of acoustic detection would perceive a sound if pressure waves of a certain intensity and frequency reach the auditory receptors (in humans some particular types of ciliated cells situated in the inner ear). However, if the instrument producing the oscillations (a diapason, for example) is placed on the skin (for instance, on the palmar surface of the finger or near some joints) an entirely different sensation would result: a kind of swarming or numbing sensation that we normally call vibration because usually we associate it with a vibrating body. This means that a given mechanical stimulus can produce

two entirely different sensations with reference to the specific sensory apparatus it is capable of stimulating. In other words, there are mechanical oscillations in the real world but it would be impossible to say what is a sound and what is a vibrating sensation without the presence of a living and perceiving individual.

With reference to mechanical stimulation the discourse could be broadened by taking into consideration the action exerted on the body surface by strong pressure. In response to this type of stimulation, a normal individual would perceive pain in addition to the tactile sensation.

There are, however, particular neurological conditions in which a person might be deprived of the pain sensation. This may happen, for instance, in syphilitic myelopathy (*tabes dorsalis*) and also in a very rare syndrome of congenital insensitivity to pain (congenital analgesia). In these circumstances, in the presence of a violent mechanical stimulus, the person would still perceive only pressure sensation, but would not feel pain.

The discussion could be broadened further by considering less conventional senses, some of which were unknown in Galileo's age. Among them are the electric sense of many fishes, the echolocation system of bats, the magnetic sense which contributes to the migratory orientation of birds, and the capability of detecting the angle of light polarization present in some fishes, reptiles, and birds. Within an Aristotelian perspective, one would be obliged to assume the existence of other proper sensibles, in addition to the physical entities constitutive of the universe (corpuscles, forces, energies) for any new sensory modality.

## 10.9 A closed world

The investigation of sensory organs was particularly vibrant in Galileo's era, particularly their gross anatomy, and it involved some of his former colleagues in Padua (like Fabricius ab Aquapendente—his personal physician—and Giulio Casseri; see Chapter 1). On the basis of his knowledge, Galileo could not anticipate the development of modern sensory science. However, being an accurate observer (and a 'true philosopher' as he declared to be) he was aware that Aristotle's proper sensibles would have implied an unjustified, and potentially unlimited, multiplication of the 'entia' of the external world (in the form of 'qualities', 'affections', or 'virtues'). This would have occurred as a consequence of the multiplication of the possible relational targets on which the external object might possibly interact in the sensory process (the sensitive man or the insensitive statue in the case of the tickling sensation in his expressive example). According to an Aristotelian view, any new dimension of sensitivity would require a new proper sensible. The number and characteristics of these proper sensibles thus would depend on the number and characteristics of the sentient individuals, a position that Galileo considered to be unjustified. This difficulty was one of the reasons why the Aristotelian tradition tended to keep a fixed number of senses (five) and refuted, by ad hoc hypotheses, the possibility of new sensations. A particularly serious consequence of this has been the obstacle to accepting the existence of other senses like vestibular sense and other forms of proprioception in humans (Wade, 2003) and, moreover, electroreception and electrolocation, the complex sensory organization by which many fishes can detect the presence of other organisms and swim avoiding obstacle even in the most complete darkness (Moller, 1995; Finger & Piccolino, 2011).

## 10.10 Of an inexorable nature, of books, plants, and brains

The idea of a world characterized by definite sensory qualities specifically adapted to senses (particularly to human senses) was diametrically opposed to Galileo's basic principles regarding the

nature of the universe. Although the universe can be known to humans according to Galileo's famous aphorism of the 'book of universe', it was not specifically constructed to be comprehensible for them. The metaphor of nature or universe as a book, which is present in many of Galileo's writings, is (as already mentioned in our Chapter 1), particularly well developed in *Saggiatore*:

Philosophy is written in this grand book, I mean the universe, which stands continually open to our gaze. But it cannot be understood unless one first learns to comprehend the language and comprehend the characters in which it is written. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures, without which it is humanly impossible to understand a single word of it; without these one is wandering about in a dark labyrinth. (SAGGIATORE, p. 25; transl. pp. 184–185)

The allusion to the language of mathematics and to its abstract characters (triangles, circles, and other geometric figures) serves to highlight the difficulty rather than the ease of deciphering it. Galileo says that nature is regulated by well-defined laws, and its therefore knowable, but these laws are difficult to investigate and require considerable effort to be understood, being written in a language that is not directly suited to human comprehension. In Galileo's view, the book of nature or of the universe is not meant for communicating a specific message to humans. In this sense, despite the similarity of terminology, the book of the universe implied by Galileo's words is opposite to 'the book of the world' of medieval and Renaissance scholars. According to these different views, endorsed, for instance, by Giordano Bruno and Tommaso Campanella, the world was the book by which God communicated to human beings his deep messages, often in a somewhat mysterious way, according to a language rich in symbolism of religious, and often astrological and alchemical dimensions.

Galileo frequently develops the theme of nature characterized by inexorable laws, not necessarily accessible to the human understanding. This theme is evident in the discussion on the relationship between the language of the Bible and that of nature. This is what he wrote in his letter to Castelli on 21 December 1613:

The Holy Scripture and nature both equally proceed from the divine Word, the former as the dictation of the Holy Spirit and the latter as the most observant executrix of God's orders; moreover, in order to adapt itself to the understanding of all people, it was appropriate for Scripture to say many things which are different from absolute truth in appearance and in regard to the meaning of the words; on the other hand nature is inexorable and immutable, and she does not care at all whether or not her recondite reasons and modes of operations are revealed to human understanding, and so she never transgresses the terms of the laws imposed on her. (OG V, p. 282; transl. Finocchiaro, 1989, p. 50).

Galileo expressed himself in similar terms in his 1615 letter to the Grand Duchess of Tuscany, Christina of Lorena. In this important text, when speaking of 'the open book of the heavens', he stresses the difficulty of investigating the secrets of nature:

Nor should anyone think that the reading of the very lofty words written on those pages is completed by merely seeing the sun and the stars give off light, rise, and set, which is as far as the eyes of animals and of common people reach; on the contrary, those pages contain such profound mysteries and such sublime concepts that the vigils, labors, and studies of hundreds of the sharpest minds in uninterrupted investigations for thousands of years have not yet completely fathomed them. (OG V, p. 329; transl. Finocchiaro, 1989, p. 103).

In another letter addressed on 21 May 1611 to Msgr. Piero Dini, a Vatican prelate and one of his colleagues at the Accademia Fiorentina, Galileo discussed the theme of the language of nature and of its independence with respect to the possible understanding that humans can have of it.

This discussion is inserted within the context of his discovery of the satellites of Jupiter and the incredulity by which this observation had been received by the conservative intelligentsia of the time. There are many atomistic allusions in the text, signifying Galileo's general intellectual approach:

It would appear boldness, or even temerity, on my side if I attempted to circumscribe within the narrow limits of my understanding the understanding and operating of nature. In the past few days, when I was in the house of my lord, the Most Illustrious and Excellent Marquis Cesi, I saw the pictures of 500 Indian plants, and I had to declare that, either they were a fiction, denying that such plants are to be found in the world, or, if they did exist, they were vain and superfluous, since neither I nor any of those present knew their qualities, properties and effects. Certainly I do not believe that in the most ancient and coarse centuries, nature abstained from producing the immense variety of animals, gems, metals and other minerals, from providing those animals with any of their members, muscle, articulation; and that, moreover, it failed to move the celestial spheres, and, in sum, to produce and operate its effects; and that happened because those people, unaware of the properties of plants, stones and fossils, did not know the function of all parts of animals, and did not penetrate the courses of the stars. And indeed it would appear to me ridiculous to assume that the things of nature start to exist, when we start to discover and understand them. (OG XI, p. 107)

On the one hand, nature does communicate with humans through a language specifically adapted to their senses. On the other hand, nature does not receive any ontological justification from the knowledge that humans can have of its production and of its ways of operating.

In the *Dialogue* the theme of the inexorability of nature, and of the possibility that its ways of operating could exceed human imagination, recurs many times. An aspect of the relationship between nature and the possible understanding of it by humans emerges in a passage in which Sagredo points to the absurdity of the conceptions of the Aristotelian philosopher Scipione Chiaramonti. In the context of his criticism of the astronomical novelties, Chiaramonti stated that one of the absurdities implied in the Copernican conception had to do with fact that it attributed the same motions to 'things of very different nature'. In his opinion this could not happen because:

Observation teaches us that the operations and motions of matters of different nature are diverse. And reason confirms this, for otherwise we should have no way of comprehending and distinguishing their nature, if they did not have their special motions and operations capable of guiding us to the cognition of their substances. (DIALOGO, p. 264, revised)<sup>5</sup>

To the Aristotelian principle invoked by the peripatetic philosopher, Sagredo wittily replied:

Two or three times in this author's argument I have noticed that in order to prove that matters stand in such-and-such way, he makes use of the remark that in just this way they accommodate themselves to our comprehension, and that otherwise we should have no knowledge of this or that detail; or that the criterion of philosophy would be ruined; as if nature had been made the brain of man, and then arranged everything to conform, to the capacity of his intellect. But I should think rather that nature first made things in her own way, and then made human reason skilful enough to be able to understand, but only by hard work, some part of her secrets. (DIALOGO, p. 258; transl. pp. 264–265)

For Aristotle, and for his followers of the Middle Ages and Renaissance, things existed only in the function of mankind for whom their existence is justified. This ontological finalism had also

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<sup>5</sup> The readers acquainted with Dante's *Divina commedia* (Divine comedy) may perhaps remember that a similar principle (different causes should produce different appearances and vice versa) is invoked by Beatrice in the II *Canto* of the *Paradiso* in order to rebut one of the possible explanations for the spotted aspect of the moon face.

a gnoseological implication. The existence of a thing is justified by its being knowledgeable. The geocentric conception in cosmology was just an aspect of this fundamental anthropocentric view based on the idea that the sun, planets, and stars were there just to make life on earth possible and to exert a variety of influences on mankind. Genuinely new discoveries posed problems because it was difficult to conceive that something, created or existing specifically for humans, might have existed for millennia without humans having knowledge of it. Besides being centred on mankind, the old universe was thus closed not only physically but also because all had been created for ever, and nothing really new could arise and develop in it.

In the cognitive sphere, an earth at the centre of the universe (and a human microcosm at the centre of the macrocosm) corresponded with humans capable of knowledge because they could interpret the signals that nature was continuously sending to their senses. The removal of mankind from this privileged, central situation had far-reaching implications for Galileo's conception of senses. If there is nothing essentially sensorial in the external world, nor specifically adapted to interact with the senses, then the senses should adapt themselves to objects so that information about them could be gathered. Sensory qualities are the consequence of such interactions which are oriented to objects rather than to mankind. This means that objects, but not sensory qualities, can exist without humans having knowledge of them. Since this interaction is not inscribed within a providential organization of the world, it does guard against the possibility of errors which can arise in various ways and are expressions of the limitation of our sensory capability. However, in spite of sensory limits, and notwithstanding the complexity of 'nature's way of operating', humans can obtain proper knowledge of reality if they are aware of the limits of their senses and submit the sensory appearances to the scrutiny of reason ('the eyes of mind').

The Copernican heliocentric conception removed man from his privileged position in the universe and the new science promoted by Galileo deprived humans of their privileged access to the special language of nature. As would later happen for other revolutionary phases of scientific progress, this was a price that human arrogance had to pay in order to extend man's inquisitive power to the world and on its laws. It also provided the conditions for novel avenues for investigating sensory physiology. So new that only after about four centuries are we starting to appreciate the importance and novelty of the reflection on the theme of senses in the work of Galileo.

### 10.11 The long path from Galileo's sensory science to modern sensory physiology

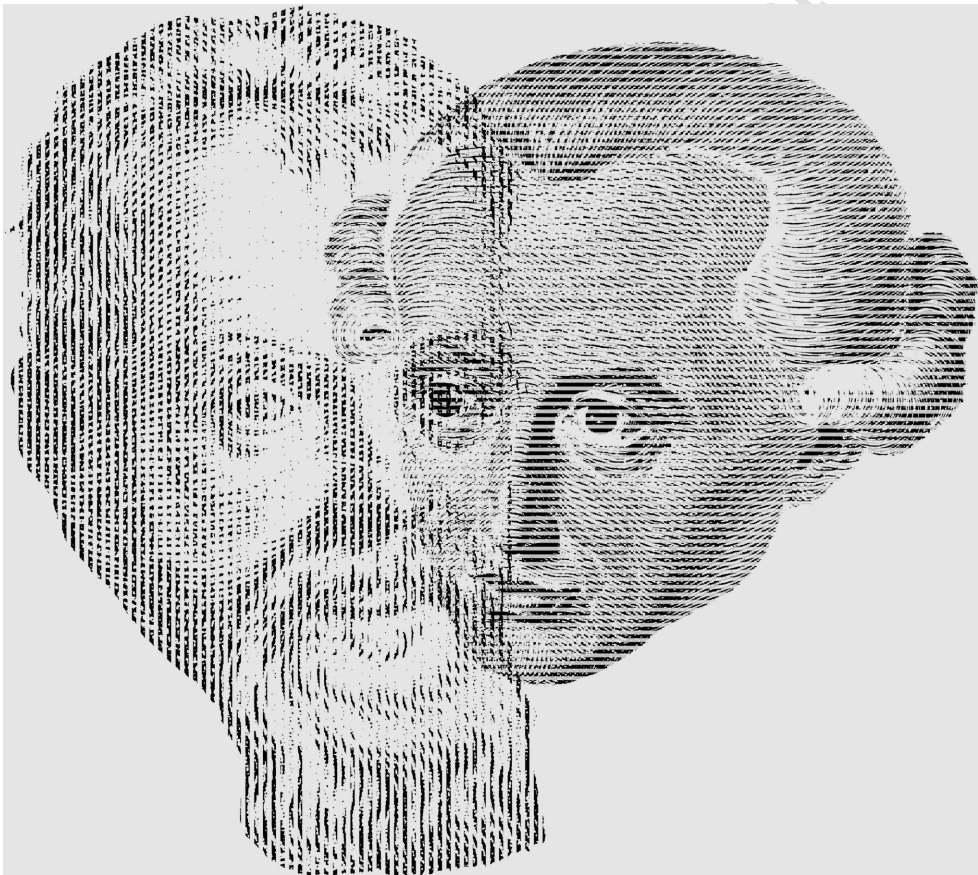
The particular nature of Galileo's interest in the senses, and especially in vision, may explain why his reflections had initially more impact on philosophical thinking than on the progress of sensory science. His elaboration of the two classes of sensory attributes of objects became the basis of Locke's (1690) distinction between 'primary' and 'secondary' sensory qualities expounded in the *Essay Concerning Human Understanding*. Galileo's general reflections on the senses had an important echo on the debate concerning the cognitive relation with reality. It involved various philosophers like Descartes, Gassendi, and Malebranche in France; Hobbes, Locke, Berkeley, and Hume in Britain; and Leibniz in Germany. They developed different views of the ontological and epistemological status of the primary and secondary qualities.

It was via a philosophical route that Galileo's sensory science resurfaced in the nineteenth century, to lay the foundations of modern sensory physiology. In a footnote at the end of section 1 of the first volume of the 1787 edition of his *Kritik der reinen Vernunft* ('Critique of pure reason'),

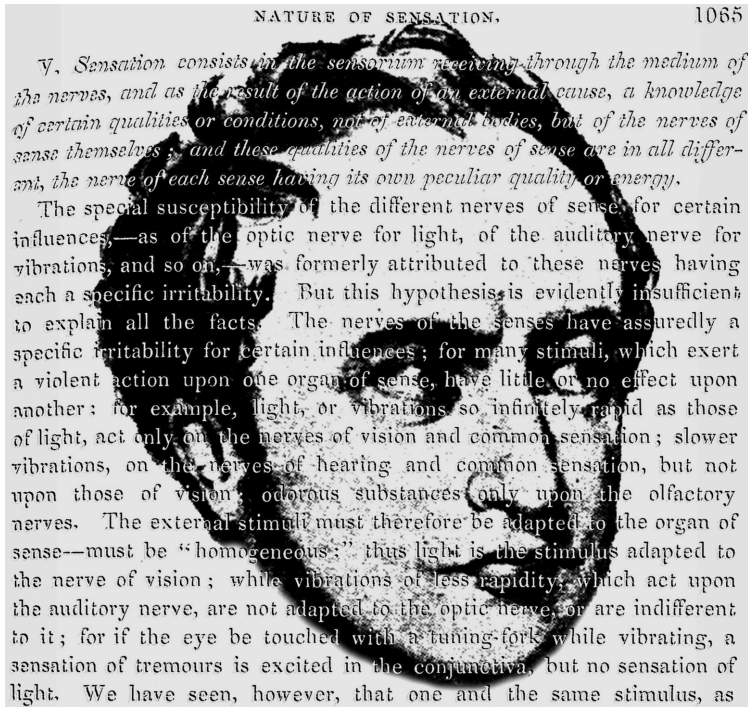
Kant, who was familiar with Galileo's work, expressed a conception of sensations somewhat similar that of *Saggiatore*:

The taste of a wine does not belong to the objective determinations of the wine, not even if by the wine as an object we mean the wine as appearance, but to the special constitution of sense in the subject that tastes it. Colours are not properties of the bodies to the intuition of which they are attached, but only modifications of the sense of sight, which is affected in a certain manner by light. (Kant, 1787, p. 77)

In contrast to Galileo (and Locke and Descartes), Kant (Figure 10.4) placed the notion of space in the mind of the perceiver, as a form of necessary 'a priori intuition'. He distinguished it, however, on epistemic and ontological bases, from colours, tastes, etc. to which he assigned the more subjective status of sensations (i.e. pure alterations of the perceiving subject) rather than



**Figure 10.4** *Galileo Galileo and Kant seeing eye to eye* by Nicholas Wade. Galileo's portrait is based upon Leoni's engraving and that of Immanuel Kant is derived from an engraving in Hartenstein (1853). Kant developed a transcendental theory of mind which drew upon both rationalism and empiricism without being allied to either. Rather than accounting for ideas in terms of experience, Kant adopted the opposite strategy of accounting for experience in terms of conceptual categories. That is, our conscious, phenomenal world is a cognitive construction. He accepted that all knowledge arises from the senses, but it is not treated in a passive way.



**Figure 10.5** Müller's doctrine by Nicholas Wade. The portrait of Johannes Müller is based on an illustration in Hirsch (1929). It is combined with text from Müller describing an aspect of his doctrine of specific nerve energies.

intuitions (these being more universally valid). The view of space (and time) as intuitions derived from the impossibility, within the framework of Kant's transcendental idealism, of knowing the 'Ding an sich' (thing in itself).<sup>6</sup>

Kant's conceptions became a philosophical reference for the German physiologist Johannes Müller (Figure 10.5) when formulating his doctrine of 'specific nerve energies'. This doctrine states that the modality of the sensations produced by different stimuli on a given nerve is relatively independent of the nature of the stimulus, but is a specific expression of the sensory nerve stimulated. As Müller put it 'the same external cause excites different impressions in different senses, according to the nature of each sense, namely the sensation of the specific nerve' (Müller, 1840, p. 251). Even if determined normally by external causes, sensations are always expressions of internal 'conditions or qualities' of the nerves. The action of external stimuli is only to excite these internal conditions of the nerves, also referred to as 'energies' from the Greek term *ενεργεια* (action, vigour) used by Aristotle.

<sup>6</sup> As shown in a recent essay by Gary Hatfield, Kant's conception of primary and secondary qualities changed considerably since his first writings (as, for instance, *Physical Monadology* of 1756) up to his more developed formulations of his mature works. Another important aspect of Kant's (and Helmholtz's) treatment of primary and secondary qualities remarked by Hatfield is the reference to the Newtonian conception of force as primordial to the categories of space and time (Hatfield, 2011).

Müller, who criticized contemporary philosophers for ignoring the biological constraints imposed by the specificities of sensory mechanisms in their theories of knowledge, provided many examples of the subjective and internal nature of sensations, and of its specific dependence on the characteristics of the sensory apparatus. For instance: 'the same number of vibrations in a tuning-fork, which imparts its sensations to the auditory nerve, will be perceived as tickle in the nerves of touch. Something completely different to vibrations must be produced if it should be experienced as sound, and this requirement lies in the auditory nerve' (Müller 1840, p. 256). As Müller warned afterwards, with words which resound with the passage from *Saggiatore*:

there is no sound in the world without a living ear, but only vibrations; without a living eye there would be no light, no colour, no darkness in the world, but only the imponderable oscillations that correspond to light and its matter, or their absence. (Müller, 1840, p. 261)

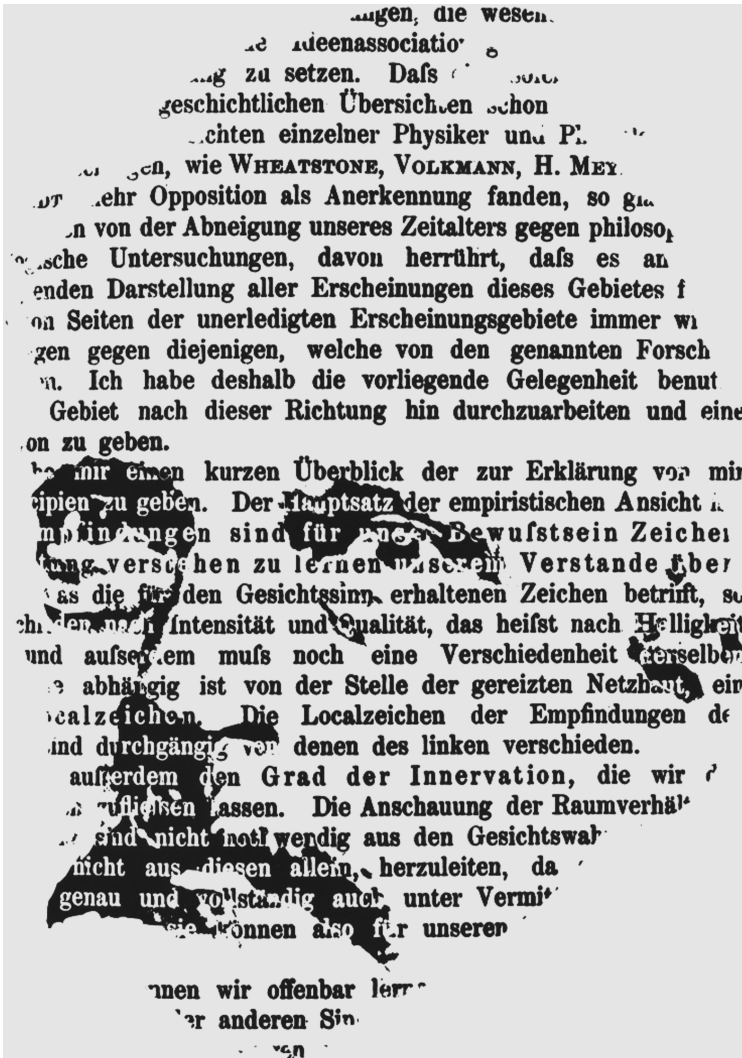
In elaborating his general views of sensory physiology, Müller was summarizing and extending observations and conceptions developed before him by several scientists, but the philosophical grounds of his doctrine were undoubtedly inspired by Kant, as is also clear in the work of Müller's student, Hermann Helmholtz (Figure 10.6). In his monumental volumes on physiological optics and hearing, and in other texts as well, Helmholtz elaborated Müller's views of the senses on both a physiological and a philosophical basis, and thus laid the theoretical framework for the subsequent development of modern sensory neuroscience (see Cahan, 1994; Finger & Wade, 2002a, 2002b).

Like Müller, Helmholtz rejected any close correspondence between the sensations on one side and the reality they represent on the other. The process whereby sensations are produced involved both the external objects and the sentient individual: the way they interacted was somewhat similar to a chemical reaction. The outcome depended on the nature of both reacting elements and the laws of the process can only be specified with relation to the properties of the two elements. For Helmholtz, sensations were 'signs', 'tokens', or 'representations', which, in order to provide us with knowledge of reality, need to be 'interpreted' or 'deciphered' by our mind; they need not be similar to the external things they represent:

The sensations of the senses are tokens for our consciousness, it being left to our intelligence to learn how to comprehend their meaning. Evidently, any other sensations, not only of sight but of other senses also, produced by a visible object when we move our eyes or our body so as to look at the object from different sides or to touch it, etc., may be learned by experience. The content of all these possible sensations united in a total idea forms our idea of the body; and we call it perception when it is reinforced by actual sensations. The only psychic activity required for this purpose is the regularly recurrent association between two ideas which have often been connected before. (Helmholtz, 1925, pp. 533–534)

In spite of this, and of the consequent impossibility of knowing the ultimate nature of the world (Kant's 'thing in itself'), the representations derived from senses are of fundamental significance, the consistency of the law of causality assuring the validity of the inferences based on sensory data:

It is in this way that the representations of the outer world are images of the regular flow of natural events, and if they are formed correctly following the laws of thought, and if by our actions we can interpret them correctly in reality, then these interpretations are the only true ones; all others are false. (Helmholtz, 1867, pp. 446– 447)



**Figure 10.6** *Tokens of sensation* by Nicholas Wade. A portrait of Hermann Helmholtz (derived from a frontispiece in Helmholtz, 1924) can be seen in German text from Helmholtz (1896) describing the intelligence of perception. He adopted the concept of unconscious inference to account for the way in which we learn to see and how common perceptions can arise from varied patterns of stimulation.

In 1868, in a famous lecture on ‘The New progresses of the theory of vision’ (*Die neueren Fortschritte in der Theorie des Sehen*) Helmholtz wrote:

Similar light produces under like conditions a like sensation of colour. Light which under like conditions excites unlike sensation of colour is dissimilar. (Helmholtz, 1895, p. 226)

For Helmholtz, the regularity of the production of a given sensation in a given sentient individual, ‘under like conditions’, ensures that the subjective and apparent character of sensations is

not by itself deceitful as it could happen for pure illusions devoid of any usefulness in the path of human knowledge.

To exemplify the deception to which we are prone by assuming a close correspondence between the external world and sensations, he referred to the long-held supposition of the existence, in the rays of the sun, of a heating agent distinct from light, by which the sun might produce a heating effect and a sensation of warmth, in addition to that of light (an agent long referred to as 'caloric fluid'):

As long as humans did not reflect on the nature of sensations, they were inclined to report immediately on the quality of sensations of external things, and to assume two agents corresponding to two sensations. (Helmholtz, 1867, p. 195)

Helmholtz was a contemporary of Charles Darwin. An important aspect of the new conception of the senses that emerged from his own work (and from that of Müller) is that it removed the obstacles that, in the Aristotelian tradition, prevented sensory science from becoming a part of the Darwinian paradigm. In the course of evolution, living organisms could develop new senses, better adapted to their evolving lifestyle and to their habitat; in order for this to be possible, the existence in the external world of proper sensibles, specific for any new sense, need not be invoked. The new vista on sensory science which emerged with Müller and his students was indeed open to new senses (and thus potentially Darwinian). This emerges in a passage in which, after having remarked that light does not suffice to make objects manifest, Müller wrote:

Many other agents would similarly play the same role; if there were for electricity, as for light, a delicate organic reagent, electricity would also have, as light does, the property of revealing the existence of a material world. (Müller, 1840, p. 258)<sup>7</sup>

By 1840, when the second edition of Müller's *Handbuch der Physiologie des Menschen* was published, the idea of a possible electric sense was nothing more than a theoretical possibility. It was indeed four years later that James Stark, a Scottish surgeon, discovered in the tail of the skate the existence of a small organ similar to the big organs by which electric fishes (torpedoes, electric eels, and Nile catfishes) produce their powerful shocks (Stark, 1844). It was many years later that the French microscopist, Charles-Philippe Robin, and the Russian physiologist, Aleksandr Ivanovich Babukhin (or Babuchin), showed that these small organs produced a weak electricity (Robin, 1865; Babuchin, 1877). It was more than a century before electroreception and electrolocation (the mechanisms that allow several fish species to detect the presence of other animals and navigate in the complete darkness) were discovered in Cambridge by the (German) zoologist Hans Werner Lissmann (Lissmann, 1951, 1958; Lissmann & Machin, 1958). In this context Müller's remark might appear somewhat prophetic, but it should be considered that the new sensory physiology that he was promoting was dynamically open to new senses. This was because senses were conceived as adaptations developed by animal

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<sup>7</sup> In another respect, electricity played an important role in both defining the senses and providing evidence for the doctrine of specific nerve energies. Indeed this relationship was appreciated many years before Müller in the physiological enquiries of Charles Bell: 'If light, pressure, galvanism, or electricity produce vision, we must conclude that the idea in the mind is the result of an action excited in the eye or in the brain, not any thing received, though caused by an impression from without. The operations of the mind are confined not by the limited nature of things created, but by the limited number of our organs of sense' (Bell, 1811/2000, p. 12). Before Bell, Alessandro Volta had come near the doctrine of specific nervous energies in his studies on animal electricity (see Piccolino, 2003; Piccolino & Bresadola, 2003/2013).

and humans to a universe where there exists nothing specifically 'sensible', but only matter in movement, oscillations, and energies.

This was what Müller and Helmholtz argued in the nineteenth century and Galileo with extraordinary astuteness foresaw more than two centuries earlier, in the pages of *Saggiatore* which have been the heart of the argument in this chapter.

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