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Light, heat and sound in Robert Grosseteste's Physics

Torino, 2016

Cover: Bishop Robert Grosseteste, window on the South transept Westernmost. St Paul's Parish Church, Morton, Near Gainsborough. Courtesy Wikipedia.

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Introduction

Robert Grosseteste (c.1175 – 1253) was one of the most prominent thinkers of the Thirteenth Century. Philosopher and scientist, he was Bishop of Lincoln from 1235 to 1253. He was heavily influenced by Augustine, whose thought permeates his writings; from him, Robert drew his Neoplatonic outlook. However, he also made extensive use of the thought of Aristotle, Avicenna and Averroes.

As explained in one of his treatise, God is the Eternal Light. God first created 'forma prima' and 'materia prima'. Forma prima is the Lux. Coming from a point-like entity, the light, due to its very nature, diffused itself becoming the dimensional form of the matter. Dragged by the light, the matter expanded into the space to create the sphere of the finite universe. From its spherical boundary, the Lux created the Lumen, the luminosity, which moved inwards, towards the center of the universe where there is the Earth. In a sequence from the outer sphere to the inner one, each of the nine celestial spheres of heavens is created. The innermost is the sphere of the moon, which produces through its own Lumen, the four spheres consisting of fire, air, water and earth.

And here, in the part of the world where the four elements of the ancient physics dominate, we have the phenomena on which Grosseteste exercised his science. His medieval physics is the science of Nature, of which we will discuss in this book. This science is quite different from the Galilean physics. However, in the scientific treatises written by Grosseteste, we find some features preparing the born of the new physics that produced the Galilean revolution and the Newtonian mechanics. This is the reason why Robert Grosseteste, English statesman, philosopher and scientist, is defined by Alistair Cameron Crombie as the real founder of the tradition of the scientific thought in Oxford.

In this book we will propose a discussion of this Grosseteste's physics, in particular that which in described in his treatises on light, heat and sound.

Amelia Carolina Sparavigna, Torino, November 2016.

Contents

Grosseteste

Robert Grosseteste (c. 1175 – 9 October 1253) was an English philosopher and theologian who became Bishop of Lincoln from 1235 to 1253. For the scientific treatises that he wrote, a well-known historian of science, Alistair Cameron Crombie, defined Grosseteste "the real founder of the tradition of scientific thought in medieval Oxford, and in some ways, of the modern English intellectual tradition"[1]. For his work for the church, upon his death Grosseteste was revered as a saint in England, but attempts to have his canonization failed.

Little is known of his youth. He may have studied the liberal arts at Hereford, thanks to his connection with William de Vere, Bishop of Hereford, and a recommendation from Gerald of Wales[2]. Grosseteste became master of arts by 1192 and then acquired a position in the bishop's household. At the death of this patron, Grosseteste disappeared from the historical record for several years. He appeared again in the early thirteenth century as a judge-delegate in Hereford. By 1225, he became deacon of Abbotsley in the diocese of Lincoln. On that period in his life, scholars have different opinions. Some of them are telling that he began a teaching career in theology at Oxford, whereas some others are telling that he studied also theology at the University of Paris. However, clear evidence is telling that by 1229/30 he was teaching as lector in theology to the Franciscans, who had established a convent in Oxford about 1224. Grosseteste remained in this post until March 1235. Moreover, Hugh of Wells, Bishop of Lincoln, appointed him as Archdeacon of Leicester[3], gaining a prebend that made him a canon in Lincoln Cathedral. After a severe illness in 1232, Grosseteste resigned all his benefices (Abbotsley and Leicester), but retained the prebend.

Grosseteste was a master of theology and trained the Franciscans in the standard curriculum of the theology taught at university. Among these Franciscans, we find Roger Bacon the most famous of

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[1] A. C. Crombie, The History of Science from Augustine to Galileo, 1959, Courier Corporation.

[2] Robert Grosseteste, Available at https://en.wikipedia.org/wiki/Robert_Grosseteste

[3] Archdeacons: Leicester, Available at http://www.british-history.ac.uk/fasti-ecclesiae/1066-1300/vol3/pp32-35

his disciples. Stimulated by the lectures of Grosseteste, this scholar gained a profound interest in optics and other sciences. Besides Bacon, also John Peckham considered Grosseteste as an inspiration for his studies.

Besides lecturing on the Bible, Grosseteste preached at the university and within the diocese as well, collecting some of the sermons and short reflections, in a corpus that today is known as his Dicta. Besides the scientific manuscripts, also these theological writings are revealing his interest in the natural world.

In February 1235, Hugh of Wells died, and the canons of Lincoln cathedral elected Grosseteste as Bishop. He was consecrated in June at Reading. A detailed description of the vast and important activity of Grosseteste as bishop is given elsewhere[4]. Being not the subject of this book, we recommend the reading of the given reference. Here, in the Appendix, we will just point out his political activity by means of a unusual method, by georeferencing "Roberti Grosseteste Epistolae", the collection of his Letters.

Grosseteste died in the night between 8 and 9 October 1253. He was between seventy and eighty years of age. He is buried in a tomb within Lincoln Cathedral.

It seems that a tendency of modern writers exists to exaggerate Grosseteste's political and ecclesiastical services, and to neglect his performance as a scientist and scholar. The opinion of his own age, that we can find expressed by Roger Bacon for instance, was very different. His contemporaries considered him a statesman having good intentions, but they stressed upon his defects of temper and discretion. For them, he was the pioneer of a literary and scientific movement.

Grosseteste wrote a number of early works in Latin and French; among them a "Chateau d'amour" exists, an allegorical poem on the creation of the world and Christian redemption. He also wrote a number of theological works, including the influential Hexaëmeron, in the 1230s. However, Grosseteste is best known as for his treatises concerning what today is called "science" or "physics".

From about 1220 to 1235 he wrote several treatises, among which the best known are De Luce, on his metaphysics of light and

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[4] Robert Grosseteste, Available at https://en.wikipedia.org/wiki/Robert_Grosseteste

cosmogony, and De Iride, on optics and rainbow.

Let us follow Roger Bacon and maintain the fact that Robert Grosseteste played a key role in the development of the science in Oxford. As remarked by several scholars[5], Grosseteste had, as a consequence, a fundamental role in the Western physics. Crombie, that we have already mentioned, even claimed Grosseteste as the first in the Latin West to develop an account of an experimental method in science, with his systematic use of the method of "experimental verification and falsification"[6]. It is true, as we will see in reading his treatises, that Grosseteste is often using the "experimentum". However, it is necessary to tell that Grosseteste's experimental method was quite different from the modern methods used in controlled experiments. Actually, Grosseteste derived his conclusions on the basis of a mix of considerations, appealing to authority and to the everyday observation (this was the Latin "experimentum"). He made use of thought experiments and of some certain metaphysical assumptions, such as the principle of the "least action", that we will find, for instance, in reading his De Iride.

Grosseteste was the first thinker that fully understood the Aristotle's thought on the dual path of scientific reasoning. In one way, a scientist generalizes the particular observations into a universal law; then, in the opposite direction, passes from the universal law to the prediction of particular phenomena. Grosseteste defined this approach the "resolution and composition". Moreover, he said that both paths should be verified through "experimenta". From the Oxonian scholars, through the Oxford Calculators of Merton College, these ideas moved during the following centuries towards Padua and Galileo Galilei.

Another important Grosseteste's idea was that of the subordination

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[5] N. Lewis, Robert Grosseteste, The Stanford Encyclopedia of Philosophy, Winter 2010 Edition, http://plato.stanford.edu/entries/grosseteste/ ; G. ten Doesschate, Oxford and the Revival of Optics in the Thirteenth Century, Vision Rev., Volume 1, 1962, Pages 313-342.; Ludwig Baur, editor, Die Philosophischen Werke des Robert Grosseteste, Bischofs von Lincoln, Beiträge zur Geschichte der Philosophie des Mittelalters, Volume 9, 1912, Münster: Aschendorff Verlag. This volume is considered the standard edition of Grosseteste's philosophical works and scientific opuscula.

[6] A.C. Crombie, Grosseteste's Position in the History of Science, in Robert Grosseteste: Scholar and Bishop, ed. Daniel A. Callus, Oxford: Clarendon Press, 1955, Pages 98-120.

of the sciences. For instance, when we consider geometry and optics, we have that optics is subordinate to geometry, which is giving the laws governing the rays of light. This means that geometry is the science which is fundamental for the calculations that we need in optics. Knowing the laws and being able of modelling them by means of the geometry, we are able to create any desired instrument, to see the far distant objects or the very small ones, that is, to have telescopes and microscopes. This is precisely what we find in Grosseteste's De Iride.

Following Boethius' arguments – as Grosseteste is explicitly telling – he concluded that the mathematics was the highest of all sciences and the basis for all others. This is agreements with his Neoplatonic outlook, which considers the light as "forma prima", the first form of all things, the source of the dimensions of the matter and of its motions. Hence, since light propagates in the space through its geometry of lines and points, it can be modelled by geometry, that is, by mathematics. Let us consider that, at Grosseteste's time, mathematics consisted of arithmetic and geometry.

Reflection, Refraction and Optical Instruments

Let us start the discussion of Grosseteste's Physics from his optics and then from his most famous treatise, De Iride, concerning it. As we have told previously, Grosseteste made use of thought experiments and of some assumptions, such as the principle of the "least action", a principle that we will find in this treatise.

In the next chapter the reader finds a translation of De Iride, translation that we proposed in[7]. In spite of the title, the treatise is not only a discussion about the rainbow. In fact, in the first part of the text we can read a study of reflection and refraction of light. Besides these phenomena that Grosseteste discussed also in his treatise entitled On Lines, Angles and Figures, we have some words about optical instruments too. In the second part of De Iride, Grosseteste continues writing about the rainbow as a phenomenon of refraction of light. Let us tell that Grosseteste imagined the

[7] A. C. Sparavigna, Translation and Discussion of the De Iride, a Treatise on Optics by Robert Grosseteste, arXiv, 2012, History and Philosophy of Physics. arXiv preprint arXiv:1211.5961; A. C. Sparavigna, On the Rainbow, a Robert Grosseteste's Treatise on Optics. International Journal of Sciences, 2013, 2(9), 108-113.

rainbow as the product of a huge optical instrument, consisting of a stratified medium created by the humidity carried by a cloud. He explains how the shape of the rainbow is originated and the creation of its colors. The original Latin text used for the translation is in[8]. We add also three figures, to illustrate corresponding passages of the treatise concerning the geometrical optics.

De Iride

Optics and physics have to speculate on the rainbow. However, the same "what" the physics needs to know, is a "because of what" the optics needs. And in fact, Aristotle, in the book on the meteorology, did not show "because of what", in the sense of optics, but "what" is the rainbow, which is physics, in a quite short discussion. Hence, here, in this treatise, the "because of what" concerning optics we start to discuss and explain in our manner and time opportunity.

First then, let us say that optics is a science based on the figures of the visual perceptions, and it is subaltern to the science based upon figures and schemes (the geometry), which contains lines and radiating surfaces, being them cast by the radiating sun, or by stars, or by any other radiant body. And it has not to be thought that the going out of visual rays from eyes is only a virtual argument, without any reality, as people, who consider “the part and not the whole”, are arguing. But let us note that visible objects are of a nature similar to the nature of the shining and sparkling sun, the radiation of which, combined with the radiation of the external surface of a body, completes the total perspective of vision.

Therefore, some philosophers, when handling these natural things, are considering the natural visual perception as passive, that is, as an "intro-mission”. However, mathematicians and physicists, concerning the nature of visual perception, think that it occurs according to an "out-emission". Now, this part of the sight, which is effected by an out-emission, Aristotle plainly discussed in the last chapter of his book on the animals, that "the back of the eye sees

[8] The Latin text is that given by “The Electronic Grosseteste”, http://www.grosseteste.com, which is reporting the printed source from Pages 72-78 of the book by Ludwig Baur, editor, Die Philosophischen Werke des Robert Grosseteste, Bischofs von Lincoln, Beiträge zur Geschichte der Philosophie des Mittelalters, Volume 9, 1912, Münster: Aschendorff Verlag.

far away; from its emission it is not divided, nor consumed, but its ability of sight goes forward from him and right to the things we are seeing." And again, in the same: "Three are our conscious senses, namely, sight, hearing and smell; they come out from the organs, just as water emerges from canals, and therefore a long nose has a good smelling." In optics, then, the true position concerning the rays is that of their emission.

Of which (optics), there are three main parts, according to the three ways of transition the rays have to the objects of vision. Either the path of the rays to the visible object is straight through a transparent medium having a specific feature, interposed between who is looking at an object and the object itself. Or, it is ruled by a path directed to a body having a virtual nature, that is, a mirror, reflected by it, back to the object we are seeing. Or it is the passage of the rays through several transparent media of different kinds, where, at the interfaces, the ray is broken and makes an angle, and the ray comes to the object not by a straight path, but by means of several straight lines, having a number of angles at the related interfaces.

The first part of this science is named "de visu", the second "about mirrors". The third part is coming in our possession unknown and untouched. We know, however, that Aristotle had discussed this third part, which is the much more difficult, and the subtlety of which was by far the more remarkable, emerging from the deep heart of Nature. This part of optics, if fully understood, shows us the way in which we can made objects at very long distance appear at very close distance, and large things closely situated appear very small; and small things at a certain distance we can see as large as we want, so that, it is possible for us to read the smallest letters at incredible distance, or count the sand, or grain, or grass, or anything else so minute. In what way, however, it is necessary to understand how this wonder happens; once understood, it will become clear to everybody.

Visual rays, penetrating through several transparent different materials, are broken at interfaces; and the parts of these rays, which we find in the different existing transparent materials, are angularly connected at the interface of them. This, however, is clear by means of an experience, the principle of which is set down in the book on the mirrors: if we cast an object into a vessel, and the distance is assumed that this object may not be seen by us, and some water is poured into, it happens that we can see what is inside (see Figure 1).

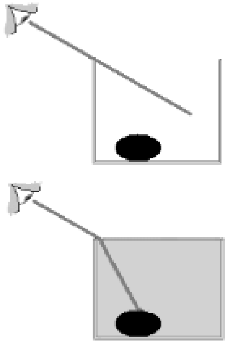

Figure 1: The experiment with the vessel.

And the same is displayed by a body having a continuous nature too; therefore, the visual ray, at the interface of two transparent media with different features, must be subjected to a contiguity law. When one total ray is generated from a source, the continuity of it cannot be broken, except when its generation is broken, and at the interface of two transparent media, the ray cannot be discontinuous; at the interface, we cannot have a full continuity and a complete discontinuity and therefore, at each point of the interface the two parts of the ray are, not directly, but angularly connected.

But, how large is the angular deviation from the straight path associated to a ray? Let us consider the ray from the eye through the air medium, incident on a second transparent medium, as a straight line to the point, where it is incident on the transparent medium. Then let us make a line deep in the transparent medium, a line that makes equal angles with the surface of transparent medium, that is, normal to the interface. Then, I say that the prolongation of the ray in the second transparent medium is following a line, separating of a certain angle from the normal, angle which is one half of the angle “i” obtained as follow. “i” is the angle given by the line which is the prolongation of the ray, without interruption and direct, drawn away from the point of incidence deep into the medium, equal to the angle “i”, drawn above the surface of the second transparent medium. So we have determined the amount of the refractive angle of the rays.

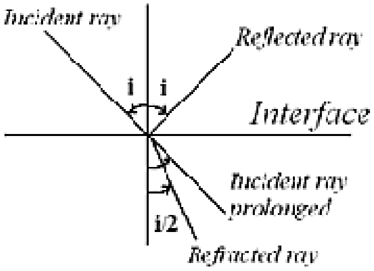

Figure 2: Grosseteste's law of reflection and refraction. Calling *i* the angle of incidence, Grosseteste considered the angle of refraction *r* equal to *i*/2.

We know that there are similar experiments giving the refraction of the rays on mirrors, fitting an angle equal to the angle of incidence (Figure 2). And the same tells us that principle of the philosophy of Nature, namely, that "every action of the Nature is well established, most ordinate, and in the best and shortest manner as it is possible."

Moreover, the object which is seen through a medium composed of several transparent materials, does not appear to be as truly is, but it is appearing composed by the concurrence of the rays from the eye, continuous and direct, and by the lines starting from the viewed object and falling on the following surface, the nearest to the eye, according to its normal. This is clear to us from experiments and from a similar reasoning that we know: that an object seen in a mirror appears in the concurrence of the propagation of the lines of sight and the lines drawn directly upon the surface of the mirror, normal to this surface (Figure 3).

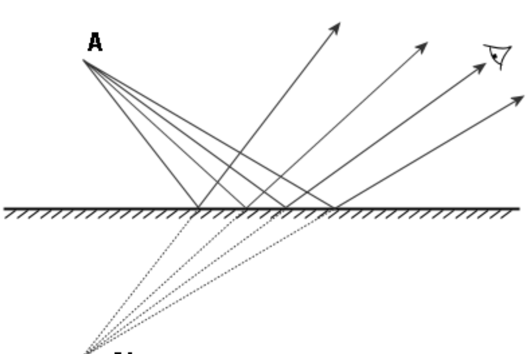

Figure 3: The plane mirror. A' is a virtual image of A.

It is evident, then, what is the quantity of the angle according to which the ray is broken at the interface between transparent media and where the image of an object appears, arising from several transparent media. Let us add also those principles of optics, which are given by the philosophers studying the natural phenomena. We have the following: given the amount of the angle under which an object is seen, it appears its position and size, according to the order and organization of the rays. It is not the great distance rendering a thing invisible, except by accident, but the smallness of the angle under which it is seen. It is clear that it is possible, using geometrical ratios, knowing the position and the distance of the transparent medium, and knowing the distance from the eye, to tell how an object appears; that is, given its distance and size, it is possible to know the position and the size of the image.

It is also clear how we can design the shape of the transparent medium, in order to have this medium able to receive the rays coming out from the eye, according to the angle we choose, collecting and focusing the rays as we like over the observed objects, whether they are large or small, or everywhere they are, at long or short distances. In such a way, all objects are visible, in the position and of the size given by the device; and large objects can appear short as we want, and those very short and at a far distance, on the other hand, appear quite large and very perceptible.

And in the third part of optics we have the study of the rainbow. Undoubtedly, it is not possible the rainbow be given by a direct crossing of the solar rays in the cavities of the clouds. Because the continuous illumination of the cloud does not produce an arc-like image, but some openings towards the sun, through which the rays enter the cavity of the cloud. And it is not possible that the rainbow is produced by a reflection of the rays of the sun upon the surface of the volume of the raindrops falling down from the cloud, as reflected by a convex mirror, so that the cavity of the cloud receives in this manner the reflected rays, because, if it would be so, the rainbow would not be an arc-like object. Moreover, it would happen that increasing the altitude of the sun, the rainbow would be greater and higher, and decreasing the sun altitude, the rainbow would be smaller; this is contrary to what is shown by the experience. It is therefore necessary that the rainbow is created by the refraction of the sun's rays by the humidity carried by the cloud.

Let me tell then, that outside the cloud is convex and inside it is concave (hollow[9]). This is clear from the nature of "light matter" and "heavy matter". And that, what we see of a cloud is smaller than a hemisphere, even though it appears to us as a hemisphere, and when the humidity comes down from inside the cloud, it is necessary that it assumes the volume of a convex pyramid at the top, descending to the ground, and therefore it is condensed in the proximity of the earth, more than in its upper part.

Then, there are four transparent media overall, through which the rays of the sun penetrate, that is, pure air containing the cloud, second the cloud itself, third the highest and most rarefied humidity coming from the cloud, and fourth, the lower and denser part of that humidity. From all the things discussed before on refraction and related angles at the interface between two media, it is necessary the rays of the sun are first refracted at the boundary of air and cloud, and then at the boundary of cloud and humidity, so that, after these refractions, the rays are conveyed in the bulk of humidity, and after, they are broken again though its pyramidal cone, however, not assuming the shape of a round pyramid, but in the form similar to the curved surface of a round pyramid, expanded opposite to the sun. Therefore its shape is that of a bow, and to us (in England), the rainbow can be austral, and, because the aforesaid cone is close to the earth, and it is expanding opposite the sun, it is necessary that more than a half of that cone falls below the surface of the earth, and the rest of it falls on the cloud, opposite the sun.

Accordingly, on sunrise or sunset, a semicircular rainbow appears and is larger; when the sun is in other positions, the rainbow appears as a portion of the semicircle. And, when the altitude of the sun is increasing, the portion of the rainbow decreases. And for this reason, in those places where the sun can reach the zenith, the rainbow never appears at noon.

Aristotle tells that the "quantity" of the different arcs we can see on sunrise and sunset is small, but, Aristotle's small "quantity" is to be understood not concerning the "size" but the luminosity, which happens because the rays are passing, during these hours, through a large quantity of vapor, much larger than in other hours of the day.

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[9] In the following discussion of De Iride we will show that also Pliny the Elder, in his Natural History, defined a cloud producing a rainbow as hollow.

Aristotle himself suggests, as a consequence, that there is a reduction of that which is shining because of the rays of the sun in the clouds.

For what concerns the colours of rainbows, let us remember that color is light mixed with a transparent medium; the medium is diversified according to the purity and impurity, and the light is fourfold divided; it is to be divided according to the brightness, and of course, to the obscurity, and according to intensity and tenuity; and according to these six different enumerations, the variety of all the colors is generated; the variety of colors that appears in the different parts of a single rainbow is mainly due to the intensity or tenuity of the rays of the sun. When there is a greater intensity of light, it appears that the colors are more luminous and bright, but when there is less intensity of light, it appears that the color turns to the dark color of Hyacinthus.

And because the intensity of light and the decrease of intensity is not subjected to a rule, except in the case of light shining on a mirror, or passing through a transparent medium, which, by means of its own shape, can gathers the light in a certain place, and, in a certain place can disrupt the light, diminishing it, and the arrangement of receiving the light is not a fixed one, it is clear that that it is not in the skill of an artist to reproduce the rainbow, but it is possible to imitate accordingly to a certain arrangement.

On the other hand, the difference of the colors of a rainbow from those of other rainbows is due to the purity and impurity of the transparent medium supporting it, as well as from the brightness and obscurity of the light impressing it. If we have a pure transparent medium and bright light, the color is whitish. If the recipient medium is a mixture of vapors and mist and the light is hazy, as occurs near the East and West, the colors are less splendid and their brightness reduced. In the same manner, according to the enumeration of brightness and obscurity of light and of purity and impurity of the medium, all the arcs of various colors can be seen.

Here is the end of the discussion on the rainbow, according to a Lincolnian.

Discussion of De Iride

First of all, Grosseteste is distinguishing optics from physics, that is, the science of Nature. The physics is the description of the natural phenomena, whereas optics (perspectiva ars, in Latin[10]) is analyzing the reasons of the phenomena. Of course, optics is linked to the visual perception: about it, there were two ancient Greek schools, providing a different explanation of vision. The first was proposing an "emission theory": vision occurs by means of rays emanated from the eyes and received by objects. We can see an object directly, or by means of refracted rays, which come out of the eyes, move in a transparent medium and, after refraction, arrive to the object. Among the others, Euclid and Ptolemy followed this theory. The second school proposed the “intro-mission” approach that sees vision as coming from something, representative of the object, which is entering the eyes. Aristotle and Galen followed this theory, which seems to have some contact with modern theories[11]. In the Grosseteste’s treatise, it seems that he had mixed Aristotle’s ideas with the out-emission theory, and therefore, in the translation I used simply “emission”, when Grosseteste is talking of Aristotle.

In the first part of the treatise, Grosseteste is describing some phenomena that we can obtain with lenses; he seems to describe, for instance, a magnifying glass useful to see the small things or read the small letters in a book. Moreover, he tells that we can made objects at very long distance appear at very close distance, and large objects appear very small, and small things we can see as large as we want. Had he some sort of microscope or telescope? We do not know. In any case, we can suppose that he had some reading stones. A reading stone was a lens having hemispherical shape, that was placed on a text to magnify the letters, so that people with presbyopia could read. Reading stones were among the earliest common uses of lenses[12]; they were developed in the 8th century, by Abbas Ibn Firnas. The function of reading stones was replaced by the use of spectacles from the late 13th century onwards. Early reading stones were made from rock crystal (quartz) as well as

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[10] D. Harper, Online Etymology Dictionary, 2012.

[11] Visual Perception, http://en.wikipedia.org/wiki/Visual_perception

[12] Reading Stone, http://en.wikipedia.org/wiki/Reading_stone

glass.

To tell the true, the earliest written records of lenses date to Ancient Greece. In his play, The Clouds (424 BCE), Aristophanes is mentioning a burning-glass, a lens used to focus the sun's rays to produce fire. Pliny the Elder shows that burning-glasses were known to Romans[13], and mentions what was probably a corrective lens. Nero was said to watch the gladiatorial games using an emerald, probably concave to correct for myopia[14]. Pliny is also describing the magnifying effect of a glass globe filled with water.

Very interesting in the Grosseteste's description is the fact that he finds and remarks the reason of these effects in the refractions of the rays. Grosseteste is also proposing a law of refraction. This law is telling that the angle of refraction is one half the angle of incidence. Of course, it is quite different from the Snell's law that we use today, which is containing the trigonometric functions of angles and the refractive indices.

Reflection and refraction of light had been already studied by ancient Greek scientists. The fact that the reflected angle is equal to the incident angle was well known. However, refraction is a more complex phenomenon. Ptolemy found a relationship regarding the angles of refraction[15]; this was an empirical law, fitting figures with experimental data. He measured the refraction from air to water, and water to glass. Ptolemy plotted r, the refractive angle, against i, the incident angle, at ten-degree intervals from i=0 to i=80 degrees. The resulting values of r were in agreement with the sine law.

The refraction of light was accurately described by Abu Sad al-Ala ibn Sahl, in the manuscript On Burning Mirrors and Lenses, of 984 [16]. Ibn Sahl was a Persian mathematician, physicist and optics engineer of the Islamic Golden Age promoted by the Abbasid court of Baghdad. He made use of his studies to work out the shapes of lenses that focus light with no geometric aberrations. Ibn Sahl's treatise was used by Alhazen, who wrote in 1021 in his Book of

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13 Pliny the Elder, The Natural History, translated by John Bostock, XXXVII, Chap. 10.

14 Pliny the Elder, The Natural History, translated by John Bostock, XXXVII, Chap. 16.

15 Snell's Law, http://en.wikipedia.org/wiki/Snell's_law

16 A. Mark Smith, Ptolemy and the Foundations of Ancient Mathematical Optics: A Source Based Guided Study, American Philosophical Society, 1999, Volume 89, Part 3.

Optics. Abu Ali al-Ḥasan ibn al-Ḥasan ibn al-Haytham (c. 965 – c. 1040), Latinized Alhazen, was an Arab scientist, mathematician, astronomer and philosopher, who made significant contributions to optics and visual perception, and the first to explain that vision occurs when some light bounces on an object and then arrives to the observer's eyes[17].

The law was rediscovered by Thomas Harriot in 1602, who did not publish his results although. In 1621, Willebrord Snellius (Snell) derived a mathematically equivalent form, that remained unpublished during his life. René Descartes independently derived the law in terms of sines in 1637, in his treatise “Discourse on Method”. After Descartes' solution, Pierre de Fermat proposed the same solution based on his principle of least time, postulating that "light travels between two given points along the path of shortest time."[18] Let us note that, in De Iride, after a sentence on the reflection of rays from mirrors, Grosseteste writes a principle of “least action” too, quite before Fermat: Et idem manifestavit nobis hoc principium philosophiae naturalis, scilicet quod "omnis operatio naturae est modo finitissimo, ordinatissimo, brevissimo et optimo, quo ei possibile est".

It is remarkable that Grosseteste does not use in any of his treatise on optics a term such as “diopter” or “dioptron” (instrument to look through), a term which is coming from Greek. The ancient Greek dioptra were astronomical and surveying instrument, dating from the 3rd century BC. The dioptra were sighting tubes or, alternatively, rods with a sight at both ends, attached to a stand. So, the ancient dioptra usually had no lenses. However, in Italian, we use “diottro”, to define the interface between two different optical media. And “diottrica” is the science concerning the light refracted by diaphanous media. In English, the term diopter arrived from French, having the same meaning it has in Italian. Probably Grosseteste knew that the Greek term diopter was used for surveying; the second sense, that of optical medium, had not yet arrived from French.

After the part of the treatise on geometrical optics, where

[17] Peter Adamson, Philosophy in the Islamic World: A History of Philosophy without any Gaps. 2016, Oxford University Press.

[18] Principle of Least Action, http://en.wikipedia.org/wiki/Principle_of_least_action

Grosseteste is stressing the fact that if we know the rules followed by the rays of light we can give the position and magnitude of the images of objects, he continues with the description of the rainbow. His theory on the rainbow, such as those of other medieval scholars on it[19], are partially coming from the ancient Greek and Roman science. For instance, Pliny the Elder is describing it as follow[20]: "what we name rainbows frequently occur, and are not considered either wonderful or ominous; for they do not predict, with certainty, either rain or fair weather. It is obvious, that the rays of the sun being projected upon a hollow cloud, and the light is thrown back to the sun and is refracted, and that the variety of colours is produced by a mixture of clouds, air, and fire. The rainbow is certainly never produced except in the part opposite to the sun, nor even in any other form except that of a semicircle. Nor are they ever formed at night, although Aristotle asserts that they are sometimes seen at that time; he acknowledges, however, that it can only be on the 14th day of the moon. They are seen in the winter the most frequently, when the days are shortening, after the autumnal equinox. They are not seen when the days increase again, after the vernal equinox, nor on the longest days, about the summer solstice, but frequently at the winter solstice, when the days are the shortest. When the sun is low they are high, and when the sun is high they are low; they are smaller when in the east or west, but are spread out wider; in the south they are small, but of a greater span. In the summer they are not seen at noon, but after the autumnal equinox at any hour: there are never more than two seen at once."

After reading this Pliny's discussion concerning the rainbow, it is easy to appreciate the evidence that Robert Grosseteste knew very well the works of the Latin writer. For instance, he tells about the concavity of a cloud, as Pliny considers a "hollow cloud", to explain the generation of the rainbow.

A curiosity: Pliny is telling that Aristotle mentioned the moonbow (also known as a lunar rainbow or white rainbow). It is a rainbow produced by moonlight. Its formation is exactly the same as for a rainbow we see during the day, caused by the refraction of light in

[19] R. L. Lee Jr. and A. B. Fraser, The Rainbow Bridge: Rainbows in Art, Myth, and Science, Penn State Press, 2001.

[20] Pliny the Elder, The Natural History, Translated by John Bostock, II, Chap.60.

water droplets. Grosseteste does not refer to it.

Pliny does not talk about the colours of the rainbow, which are instead discussed by Grosseteste, who continues the analysis of the nature of colours in another treatise entitled De Colore, which is very short, and probably of the mid-1220s. In both De Iride and De Colore, Grosseteste tells that the colours are created by the purity or impurity of the transparent medium when light, intense or not, is passing through it. From ancient time, it was well known that a prism can create the color of the rainbow[21]. However, during the Middle Ages, it was believed they were produced by impurities in the medium; this idea survived until the Newton's experiments with prisms and his theory of the dispersion of light.

After reading this treatise, we can stress again what we have previously told. Undoubtedly, Grosseteste saw a key role for geometry in the explanation of natural phenomena. Deeply concerned with a detailed investigation of Nature, his treatises were a strong stimulus to the thinkers in the Oxford of 14th century to start the progress towards the mathematical physics.

Grosseteste's Colours

Here we start the discussion of the abovementioned treatise, the De Colore. In this treatise Grosseteste continues the discussion on light and colours that he started in De Iride.

In De Colore, our medieval scientist describes two manners of counting colours: one gives an infinity of tones, the other count gives seven essential colours. In both cases, colours are created by the purity or impurity of the transparent medium when light is passing through it. This was the medieval explanation of colours that survived until Newton's experiments with prisms.

Before reading De Colore, let us shortly remember what Grosseteste proposed in the De Iride. He supposed that colours are coming from the interaction of light with more or less transparent media: color sit lumen admixtum cum diaphano, he wrote.

He continued enumerating the features of transparent media and light: a medium is diversified according to its purity and impurity, but the light is fourfold divided. The light is to be divided

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[21] A. C. Sparavigna, The Play of Colours of Prisms, arXiv:1207.3504, arXiv, 2012.

according to the brightness (claritas), and, of course, obscurity, and according to intensity (multitudo) and tenuity. From these features, the colours arise: secundum harum sex differentiarum connumerationes sint omnium colorum generationes et diversitates, varietas coloris in diversis partibus unius et eiusdem iridis maxime accidit propter multitudinem et paucitatem radiorum solis. According to the six different enumerations, the variety of all the colours is generated, colours that appear in the different parts of a rainbow, mainly due to the intensity or tenuity of the rays of sun.

In De Iride, Grosseteste does not tell us what the colours are, that is, he does not write down a list of colours. Only one is mentioned, the Hyacinthus: ubi enim est maior radiorum multiplicatio, apparet color magis clarus et luminosus; ubi vero minor est radiorum multiplicatio, apparet color magis attinens hyacinthine et obscuro. Where there is a greater intensity of light, it appears that the colors are more luminous and bright: but where there is less intensity of light, it appears that the colour turns to the dark colour of Hyacinthus.

The hyacinthos is the name of a blue cornflower[22]. We know by its description in the Natural History of Pliny the Elder that, for the Latin world, the hyacinthos was a precious stone too. Pliny tells that it was very different from amethysts. The great difference between amethyst and hyacinthos is that "the brilliant violet which is so refulgent in the amethystos, is diluted in the other stone"[23]. John Bostock, who translated the Pliny's History, reports that this could be the name of the oriental amethyst or violet sapphire, not the hyacinthine of the modern English, meaning a stone of a yellowish colour, as in yellow zircon. The colour then described by Grosseteste was a violet one. So, let us start the reading of De Colore, here translated from the Latin text [24].

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[22] D. Harper, Online Etymology Dictionary, http://www.etymonline.com/index.php

[23] Pliny the Elder, The Natural History, Translated by John Bostock, London. Taylor and Francis, Red Lion Court, Fleet Street, 1855.

[24] The Latin text is that given by "The Electronic Grosseteste", www.grosseteste.com/, which is reporting the printed Source: Die Philosophischen Werke des Robert Grosseteste, Bischofs von Lincoln, W. Aschendorff, 1912.

De Colore

Colour is light incorporated in a transparent medium.

In fact, there are two different media: there are pure transparent media separated from earth materials or impure media mixed with them. And the light is four-fold differentiated: there is the bright and the obscure light, and the intense or the tenuous light. I do not say that an intense light is a light diffused by a great object, but it is the light that we can observe in a point where a large amount of it is collected by means of a concave mirror, and the light falling on the entire surface of the mirror facing the sun is reflected in the center of the sphere of the mirror. And then the power of light collected in this center ignites immediately a combustible material. So, an intense bright light in a transparent pure medium is the white. Tenuous light in an impure medium is black. And by telling this, we are explaining what Aristotle and Averroes told, who consider that blackness is lack of light and whiteness is richness in the appearance of light.

It also follows from this speech, that the colours near the white, in which we can arrive regressing from the whiteness and by variation, are seven, neither more nor less. Similarly, there will be seven colours near the black, which we find when progressing from darkness towards whiteness, until we have a combination with the other seven colours, to which we arrive descending from white. Since the essence of whiteness is made of three features, the intensity of light, its brightness and the purity of the transparent medium, two of them remaining fixed as we like, the third can be relaxed, and then this is how three colours are created; or anyone of these three features remains fixed, and the other two relaxed, and so will have other three colours, besides the three colours of the first triple generation; or all the three features are at the same time relaxed, and so the overall seven colours from the whiteness will directly obtained.

A similar procedure exists, by means of which we can show that through seven colours from the blackness we can progress towards the white. In general then, sixteen combinations would be: two of course are the ends (white and black), and seven at one end, attached to it by the tension of ascending, and, at the other end, by the remission of descending, merging in the same colours in the middle. Now, in any of the intermediate colours, the grades of tension and remission are infinite. Hence, by counting and combining the features, which can be intensified and released, that is, the intensity, the brightness of light and the purity of transparent media and their opposites, the essential colours that we can obtain are nine. By counting the degrees of tension and remission we have an infinite number of tones of intensity.

Now then, it is clear to whom who knew deeply and inwardly the principles of the natural science and of optics, not only by reasoning, but also by experience, that we have, according to the manner stated above, the essence of colours and their multitude. That is, knowing how to form a transparent medium, whether it were pure or impure, in such a way to receive a bright light, or, if it is preferred a dark light, and through the devised form in this very transparent medium, the light is reduced, or multiplied at pleasure; and so through the skill of combining all the modes, the colours that we want can be rendered visible. This is the end of the treatise on colours by a Lincolnian.

Discussion of De Colore

Colour is light incorporated in a transparent medium.

But we can have different media: pure and transparent media or earth materials, or their mixtures. In the same manner the light has different features. One is its intensity: to explain it, Grosseteste talks about the concave mirrors and the focusing of rays. In the Latin text, he is defining the intensity as the "lux multa", because he is clearly referring to the focus of the mirror, where we can have a "radiorum multiplicatio", multiplication of rays, because in the focus we collect several rays of light.

Grosseteste is distinguishing pure and impure transparent media, impure because of the mixture with earth materials. "Earth" is one of the four classical elements in ancient Greek philosophy and science, commonly associated with qualities of heaviness and matter[25]. Here we can associate the earth materials to the defects and the impurities that we have in transparent media such as crystals. However, since Grosseteste is discussing about colours,

[25] A.C. Sparavigna, Robert Grosseteste and the Four Elements, International Journal of Sciences, 2013, Volume 2, Issue 12, Pages 42-45.

we could also suppose that he was trying to merge the pure colours that we can see in the dispersion by a prism to those that we can obtain using pigments. We have for instance the earth pigments for painting, some of them well known since prehistoric times. The clay earth pigments, ochre and sienna for instance, are naturally occurring minerals, principally iron oxides.

For what concerns the dispersion of light from prisms, this was a phenomenon described even in the Natural History by Pliny the Elder[26]. Since this book was one of the ancient books that the scholars of the Middle Age used for their treatises on Nature, it is quite probable that Grosseteste experimented with prisms, even if he did not discuss the phenomenon in his treatises (we have already remarked in the discussion on the rainbow the fact that Grosseteste knew Pliny's volumes).

Grosseteste defines white and black. An intense bright light in a transparent pure medium is the white. Tenuous light in an impure medium is black. "And by telling this, we are explaining what Aristotle and Averroes told, who consider that blackness is lack of light and whiteness is richness or appearance of light". And also, "et hic intendebat Philosophus per 'nigredinem' privationem albedinis", wrote Henricus Bate, a Flemish astronomer around 1300[27], in his Speculum divinorum et quorundam naturalium[28].

Of course, we could imagine a symbolic meaning too[29]. In the early Middle Ages, black was commonly associated with darkness and evil. Clothes of black colour were worn by Benedictine monks as a sign of humility and penitence.

In the 12th century a theological dispute about the colours of clothes broke out between the Cistercian monks, who wore white, and the Benedictines. Pierre the Venerable, a Benedictine, accused the Cistercians of excessive pride in wearing white, but Saint Bernard of Clairvaux, founder of the Cistercians, replied that black was the

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[26] Pliny the Elder, The Natural History, Translated by John Bostock, London. Taylor and Francis, Red Lion Court, Fleet Street, 1855.

[27] H. Grabes, The Mutable Glass: Mirror Imagery in Titles and Texts of the Middle Ages and the English Renaissance, Cambridge University Press, 1982, pag.43.

[28] Henricus Bate, Speculum Divinorum et Quorundam Naturalium, parts XIII-XVI, edited by Guy Guildentops, Leuven University Press, 2002.

[29] http://en.wikipedia.org/wiki/Black#The_Middle_Ages

color of the devil, while white represented purity and "all the virtues"[30].

Let us also note that "albedo", the whiteness, is one of the four major stages of the "magnum opus" of the alchemy; along with nigredo, citrinitas and rubedo. From the nigredo stage, the alchemist undertakes a purification in albedo, passing through a chromatic sequence[31].

In Grosseteste we have that the colours can be obtained from the white, receding from it. However, he tells us that we have the colours also ascending from black. This is a dual vision, where the light becomes less pure and dark, and the darkness is ascending and increasing its purity. This is in agreement to Grosseteste's Metaphysics of Light that we will meet in the following, when we will discuss his treatise De Luce, On Light.

In De Colore, Grosseteste is also counting the colours. He tells us that the colours near the white, in which we can arrive regressing from the whiteness and by variation, are seven. Similarly, there will be seven colours near the black, that we find when progressing from darkness towards whiteness, until we have a combination with the other seven colours, to which we arrive descending from white.

Let us see how the other colours are created. For example, the white is given by brightness, intensity and purity: we can relax one, two or all these three features to obtain seven colours, as in the calculus of combinations shown in the Figure 4 (next page). We can relax one, two or all these three features to obtain seven colours, as in the calculus of combinations. The relaxation of one of the white features is rendered by a grey circles. The same we can do from the black.

A similar procedure exists starting from the black. So we have sixteen combinations: two are the ends (white and black), and fourteen near them. But, by changing the intensity of light and the purity of transparent media, the colours from black merge with colours from white, and then we have nine colours. That is: white, black and seven colours.

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[30] M. Pastoureau, Noir: Histoire d'Une Couleur, Paris, Seuil, 2008.

[31] H. Gebelein, Alchimia, la Magia della Sostanza, 2009, Edizioni Mediterranee, Roma.

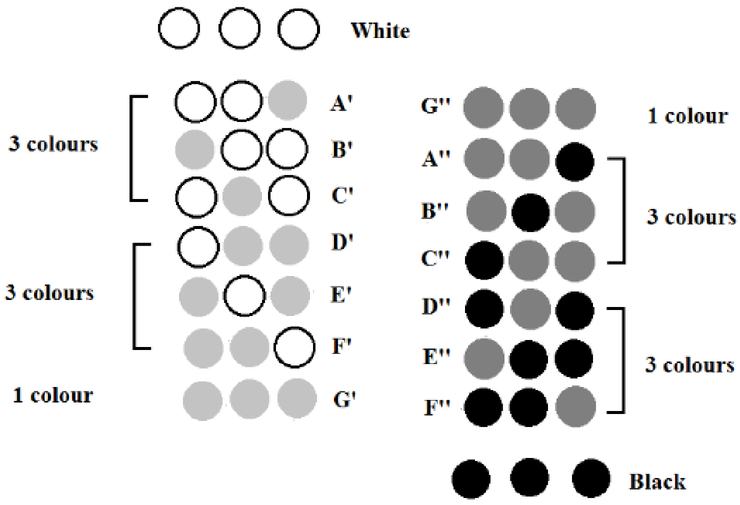

Figure 4 - The colours can be created by white, which is brightness, intensity and purity.

We can find also a quite interesting image related to the Grosseteste's theory[32], which is here adapted in the Figure 5. In it we can see that, from white we have seven colours, and seven colours from black. But these colours move on two cones, merging in the middle, where we have seven "average" colours. We can define them as the seven essential colours, that, with white and black, give the nine colours mentioned by Grosseteste. However, if we consider "the degrees of tension and remission", there will be an infinite number of tones of intensity. That is, Grosseteste counted the colours in two manners: the first is that based on combinations (Figure 4), the second is based on a continuous scale of tones, as we can have in a palette of the Paint software for instance. As shown in the Figure 6, we have an infinite number of greens: in any case, it is green.

[32] N. Silvestrini and E.P. Fischer, Colorsystem, Colour Order Systems in Art and Science, at www.colorsystem.com

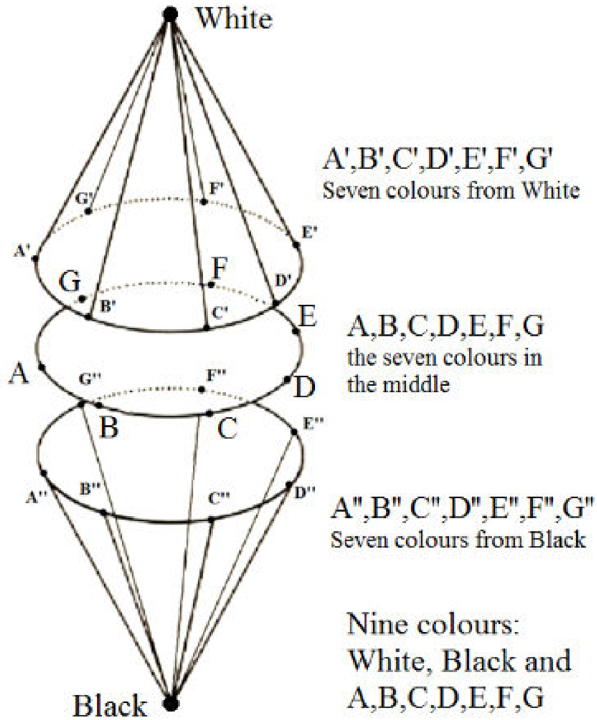

Figure 5 - The seven colours from white and the seven colours from black are merging in "average" colours, which gives a circle of seven colours. White, black and these seven colours provide nine colours (N. Silvestrini and E.P. Fischer, Colorsystem, Colour Order Systems in Art and Science).

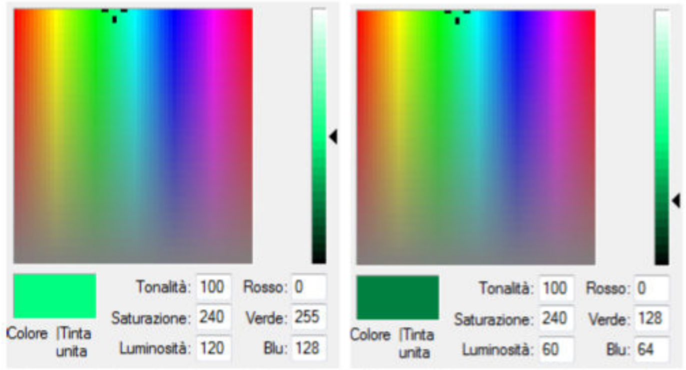

Figure 6 – An example from the palette of Paint software. We see a light green and a dark green. In any case, it is green.

A recent discussion of the Grosseteste's colours in the RGB space has been proposed[33]. In the paper, the authors are arguing that the colour space described by Grosseteste is explicitly three-dimensional. For what concerns the Latin text, let us note that Grosseteste is using, to describe the light, the terms "lux" and "lumen". Lux is light in its source, whereas lumen is reflected or radiated light[34].

In the Figure 5, we see a circle of colours obtained considering the average of the colours coming from white and black. Sir Isaac Newton proposed a circle of colours containing seven colours too. He called them Rubeus, Aureus, Flavus, Viridis, Caeruleus, Indicus and Violaceus and Rubeus, that is, red, orange, yellow, green, blue, indigo and violet. These are the names of the colours we have in the Figure 7, giving an illustration from a book by David Brewster[35], showing the experiment with the prisms made by Newton.

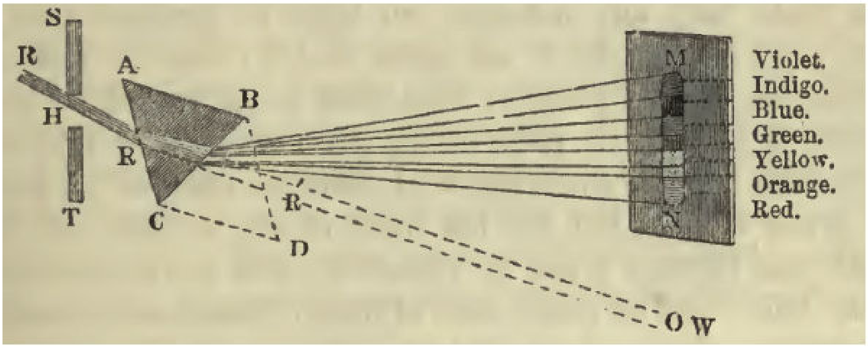

Figure 7: Illustration from the Brester's book.

Newton used seven colours by analogy to the number of notes in a musical scale[36]. It would be interesting a comparison of Newton's colours with those of Grosseteste. However, Grosseteste did not

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[33] H.E. Smithson, G. Dinkova-Bruun, G.E.M. Gasper, M. Huxtable, T.C.B. McLeish, and C. Panti, A Three-Dimensional Color Space from the 13th Century, J. Opt. Soc. Am. Opt. Image Sci. Vis., 2012, Volume 29, Issue 2, Pages A346-A352.

[34] C. C. Riedl, Robert Grosseteste, On light, Marquette University Press, Milwaukee, Wisconsin, 1942.

[35] David Brewster, Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton. Volume 1, 1855, Edinburgh, T. Constable and Co.

[36] D. Allchin, Newton's Colors, SHiPS Resource Center.

provide the name of them, besides one, the Hyacinthus which is a Violaceus (violet) colour.

We can ask ourselves whether the Grosseteste's work had some influences until the Newton's times or not. It seems that this is so, as we can find in the book on the life of Sir Isaac Newton, written by David Brewster[37]. Let us consider what Brewster is telling on colours: he reports that Newton's friend and tutor, Isaac Barrow (1630-1677), delivered some optical lectures, which were published in 1669. "In the preface of this work – Brewster writes – he acknowledges his obligations to his colleague, Mr. Isaac Newton, for having revised the manuscripts, and corrected several oversights, and made some important suggestions. In the twelfth lecture there are some observations on the nature and origin of colours. … According to Dr. Barrow, White is that which discharges a copious light equally clear in every direction; Black is that which does not emit light at all, or which does it very sparingly. Red is that which emits a light more clear than usual, but interrupted by shady interstices. Blue is that which discharges a rarified light, as in bodies which consist of white and black particles arranged alternately. Green is nearly allied to blue. Yellow is a mixture of much white and a little red; and Purple consists of a great deal of blue mixed with a small portion of red. The blue colour of the sea arises from the whiteness of the salt which it contains, mixed with the blackness of the pure water in which the salt is dissolved; and the blueness of the shadows of bodies, seen at the same time by candle and daylight, arises from the whiteness of the paper mixed with the faint light or blackness of the twilight". In the Brewster's words, we find that the Grosseteste's framework of the combinations of the features of light (copious and clear) and of transparent media (pure or not) is maintained in the Barrow's approach to colours.

The first Newton's studies on prisms were made on 1666, aiming to improve the optical instruments, in particular the telescopes. He found the white light a mixture of colours refracted differently by a transparent medium. Experimenting with two prisms, he showed that a second prism can be used to put back together the light into white light (see Figure 7). If the origin of colours were the impurity

[37] David Brewster, The Life of Sir Isaac Newton, Harper & Brothers, New York, 1840.

of the transparent medium, this recombination would be impossible. Newton therefore, with his experiments, disrupted the medieval framework of optics, showing that it is not the purity or impurity of a medium that, interacting with light, gives the colours, but the different refractions of the components of the white light.

The Propagation of Light

Robert Grosseteste, concerning light and its propagation, based the description of the observed phenomena on the use of geometry. Here we analyze his treatise entitled De Lineis, Angulis et Figuris, seu Fractionibus et Reflexionibus Radiorum (On Lines, Angles and Figures). Since Grosseteste considered that the propagation of light had the main role in the creation of the world, the use of its geometry becomes a method to solve the complexity of the physical world. However, besides the use of geometry, we find in this interesting text the description of some phenomena concerning the intensity of reflected and refracted light, which seems well-posed, even if we compare the words written by Grosseteste to the modern Fresnel theory.

As we have previously told, Crombie[38] described Grosseteste as the first in the Latin West to talk of experimental methods in science, giving a special importance to mathematics in explaining the physical phenomena. The empirical observation is the main factor for Grosseteste's discussion of Nature, sometimes gaining well-posed conclusions on phenomena. But this empirical observation, which is the Latin "experimentum", is far from an experimental method involving a controlled experiment. Therefore, Grosseteste's method is not a Galilean method. He derives his conclusions from observations, thought experiments and principles, like the principle of "least action" that we find here again, in De Lineis, Angulis et Figuris. Let us remember that we found it in De Iride.

As previously told, Grosseteste gave a relevant role to mathematics, and in De Lineis he remarks that "the consideration of lines, angles and figures is of the greatest utility since it is impossible for natural philosophy to be known without them ….

[38] A.C. Crombie, Augustine to Galileo. The History of Science 400-1650, Philosophy, 1955, 30 (114), pages 272-273.

All causes of natural effects have to be given through lines, angles and figures, for otherwise it is impossible to have knowledge of the reason, the 'propter quid', concerning them."[39] In the treatise, On the Nature of Places, a continuation of On Lines, Grosseteste remarks that "the diligent investigator of natural phenomena can give the causes of all natural effects, therefore, in this way by the rules and roots and foundations given from the power of geometry". Undoubtedly, Grosseteste saw a key role for geometry in the explanation of natural phenomena. And this emphasis on the importance of geometry and mathematics was a stimulus to thinkers in the Oxford of the 14th century, who established the basis for the beginnings of a mathematical physics, studying in particular light and optics[40].

Grosseteste imagined the light having even a fundamental role in the creation of the world[41]: it was the light propagating in the space and dragging the matter, that originated the world from a point at the beginning of times. The light is then the central actor in the Grosseteste's thought, and, consequently, the optical phenomena described by geometry are the most important subjects of physics. We can tell therefore that his approach to the complexity of the physical world was based on the assumption of some models, models that could be solved with geometry; however, the solutions of them are always subjected to the experience of occurring phenomena.

The Power of Light

As we have seen in De Iride, Grosseteste used the geometry in optics, in the reflection and refraction of light. Besides the geometry, Crombie[42] is remarking that Grosseteste developed an

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[39] N. Lewis, Robert Grosseteste. The Stanford Encyclopedia of Philosophy (Winter Edition, 2010) ; L. Baur, Editor, Die Philosophischen Werke des Robert Grosseteste, Bischofs von Lincoln, Beiträge zur Geschichte der Philosophie des Mittelalters, Münster: Aschendorff Verlag, 1912.

[40] A. C. Crombie, Augustine to Galileo. The History of Science 400-1650, Philosophy, 1955, 30 (114), pages 272-273.

[41] A. C. Sparavigna, From Rome to the Antipodes: The Medieval Form of the World, arXiv, 2012, http://arxiv.org/abs/1211.3004

[42] A.C. Crombie, Science, Art and Nature in Medieval and Modern Thought, Continuum International Publishing Group, Aug 2, 2003.

analysis of the powers propagated from the natural agents. This analysis is found in four related essays written most probably in the period from 1231 to 1235 AD. The treatises on Optics are De Colore, De Iride, De Lineis, Angulis et Figuris, and the treatise entitled De Natura Locorum. Crombie shortly commented the De Lineis, Angulis et Figuris telling that according to Grosseteste "the same power produced a physical effect in an inanimate body and a sensation in an animate one. He established rules for operation of powers: for example the power was greater for shorter and straighter the line, the smaller the incident angle, the shorter the three-dimensional pyramid or cone; every agent multiplied its power spherically. Grosseteste discussed the laws of reflection and refraction (evidently taken from Ptolemy) and their causes, and went on in De Natura Locorum to use Ptolemy's rules and construction with plane surfaces to explain refraction by a spherical burning glass". Let us add, to Crombie's words, that Grosseteste used the optics of Alhazen and Alkindi too[43], besides that of Ptolemy.

This Crombie's discussion about the power of rays is quite stimulating to analyze the Grosseteste's treatise. Let us read it in the following section, where we are translating it from the Latin source[44]. We will see that the discussion on the power of reflected and refracted rays is interesting and seems well-posed when compared with the rigorous approach given by the Fresnel reflectance formulas. To the Grosseteste's words, we add some illustrations too.

De Lineis, Angulis et Figuris, seu Fractionibus et Reflexionibus Radiorum

The utility of considering lines, angles and figures is huge, because it is impossible to know the philosophy of Nature without them. They are valid for the entire universe and, unconditionally, for all its parts. They apply in connecting properties, such as in straight and circular motions. And they apply in action and passion

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[43] Late Medieval and Early Modern Corpuscular Matter Theories, edited by C.H. Lüthy, J.E. Murdoch and W. Royall Newman, Brill, 2001, Page 190.

[44] The Latin text is available at "The Electronic Grosseteste", http://www.grosseteste.com/

(reaction), and this is so, whether in the matter or in the capacities of perception; and this is so again, whether in the sense of sight, as it is occurring, or in any other sense in the action of which it is necessary to consider also other things, besides that which is producing the vision. Then, since we have discussed elsewhere of those things pertaining to the whole universe and to its parts in an absolute sense, and of those which are consequent to straight and circular motions, now we have to tell something concerning the universal action, when it is receiving a lower nature; this universal action is a player able of various features, so far as it happens when it is descending to act in the matter of the world; moreover, other things can be questioned, that can educate us to proceed "ad majora".

Therefore, all the causes of the natural effects must be given by lines, angles and figures, because it is impossible to know in another manner the "propter quid" in them. It is clear the following: a natural agent propagates (multiplies) its power from itself to the patient, the person or thing that undergoes some action, that is, whether it is acting on sense or on matter. This virtue is sometimes called "species", sometimes "likeness", and it is the same, in any way we call it; and the same thing is instilled in the sense and in the matter, or vice versa, when heat makes warm to the touch and gives itself to the cold body. For, it does not act through deliberation and choice; and therefore in one way it acts, whatever it is occurring, whether it is a perception or something else, animated or inanimate. But, because of the diversity of the objects of action we have different effects. Moreover, in the perception, this received power produces, in some way, a spiritual and noble effect; on the other hand, when acting on the matter, it produces a material effect, such as the sun produces, through the same power, different effects in different objects of its action, because it hardens the clay and melts the ice.

Moreover, the power produced by a natural agent can move along a shorter line, and then, it is more active, because the patient receiving it is less distant from the agent, or it can move along a longer line, and then it is less active, because the patient is more distant. And the power can come directly from the surface of an agent, or with mediation. Moreover, if it comes without mediation, it can come by a straight line, or by an oblique line. If, however, it comes by a straight line, then there is a stronger and better action, as Aristotle assumes in V Physics, because the nature acts in the shorter available way. But the straight line is the shortest of all, as he says in the same book. Similarly, a straight line has equality and no angles; and equal is better than unequal, as Boethius tells in his Arithmetic. Moreover, Nature acts in the possible shorter and better way, and therefore it works better on a straight line. Again, every compact power is stronger in its operations. But, the greater union and unity is in a straight line rather than in distorted line, as stated in V Metaphysics. And then an action works stronger on a straight line.

The straight line can fall either at equal angles, that is perpendicular to the surface, or at unequal angles. If it falls at equal angles, the operation is stronger for the three abovementioned reasons, because the line is shorter and equal and its power comes more uniform through it to the parts of the patient, person or thing that undergoes the action. A line, however, is falling down with equal angles on a body perpendicularly, that is with right angles, when it falls on a plane; when it falls on a concave body, it is at acute angles; but when it is falling over a sphere, it happens at angles larger than the right angle. This is shown as in the following, because, if a line is drawn passing through the center of a sphere, it makes a right angle with the line of contingency (tangency), and the line of tangency makes with the sphere on both sides the angles of contingency; then, the line falling on the sphere makes two angles with its surface, each angle larger than the right angle, being the sum of the right angle and the angle of contingency. Thus, when the power falls with angles which are not only equal, but right, then it would seem the action to be very strong, because there is complete equality and uniformity. If, however, it (the line of propagation of power) is not a straight line but it is a curve, nevertheless, not circular, because a natural agent does not produce its own strength according to a circle, but according to the diameter of the circle for the sake of brevity, it is manifest that such a line will have some angles (Figure 8). And this will not occur, as long as there is a single medium, or while there is only one body; but it is necessary that two media exist, whence in the first the power is propagated along some straight lines, and in the second along other lines.

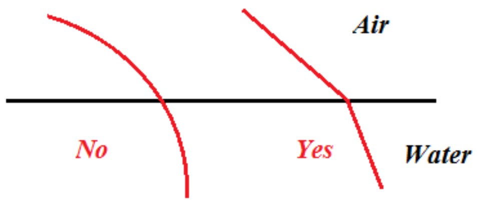


Figure 8

This can happen only in two manners. First manner: that the body of the patient is dense, so as to impede the transit of power, especially in regard to our perception, and then it is said we have a reflected line, which is turning back the power. Second manner: the body the light is passing through is thin in density, which allows the propagation of power. If we have the first case, then we have the ray falling on a dense body, it falls with equal angles, that is, perpendicularly to the body, or with unequal angles, that is inclined. If we have the first manner, then it returns into itself through the same path, along which it arrived to the body. The reason of this is due to the following: the line falling on the body makes such an angle, as it is the angle made by the reflected line. And therefore it is proper that it is reflected at the same angle, upon which the ray travelled and return by the same pattern, because if it were redirected with another angle or following another pattern, turning to the left or to the right, it would be impossible that the return forms an angle equal to the angle of incidence; it would be larger or smaller. In the case that the ray is not falling perpendicularly, then it comes back along such a pattern, able to make an angle with the surface of the resisting body equal to the angle of incidence, namely, the angle which is made by the incident line with that body, for the argument already mentioned. Generally speaking, the angle of incidence and the angle of reflection are equal, and that is to be assumed now.

Since these are the two modes in which reflection may happens, it is to be understood that the reflected power into itself, because of a doubling of the power in the same place, is stronger than the reflected power in another path. Nevertheless, and this is in the essence of reflection, the action of the reflected ray is weaker, when there is the reflection in the same path, since each reflection is weakening the power, and this precise reflection, which is making the power to have a complete deviation of 180° from the straight prolongation of the incident ray (that is, the direction the ray would have if it were to pass through the body), is highly weakened; and this is for the ray, which is moving on the same path on which it came from. Moreover, the path is totally contrary and opposed to the incident one, as it must be.

When we have a reflection from some bodies polished to have the same nature of the mirrors, then we have the best reflection and stronger action; but when reflection happens on rough bodies, the "species", that is, the appearance of objects to the sight, are dissipated, and the action is weak. The reason is given by Averroes, the Aristotle's Commentator, in his discussion on the sound, saying that the parts of a body surface smooth and polished, for its equality and uniformity, all together are concurring into a single action in the reflection of the species; and therefore the whole power, as it came, is reflected back from the polished body. But when the parts of a rough body are unequal, those parts protruding are reflecting the species first, and therefore there is not an agreement of the parts in a unique action, and for this reason we have a dispersion of this species randomly, and this is not a good operation.

When the reflection is obtained by means of some concave bodies, the action is stronger, than when the bodies are plane or convex, and this happens because the rays reflected by a concave surface converge together; this does not happens for the other cases. Indeed, if the medium encountered by the light is not impeding the transit of power, a ray incident at equal angles, that is perpendicularly, maintains the straight line and is the strongest ray. But the ray, which is incident at unequal angles, that is, inclined, deviates from the straight line that the ray had in the first medium and that it would still have if the medium were homogenous. This deviation is called refraction of rays.

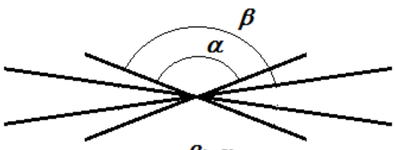
The refraction is twofold: when the second medium is denser than the first, the ray is refracted to the right and passes between the prolongation of the direction of incidence and the perpendicular drawn from the point of incidence in the second medium. When the second medium is rarer, the ray is refracted to the left, receding from the perpendicular beyond the prolongation of the incident ray. And then, since these are the facts, we need to understand the reason why the power incident along a refracted line is higher than the power along a reflected ray; this happens because a refracted line little deviates from the prolongation of the incident ray, which is the strongest, and the reflected line largely deviates in the opposite direction, and then the reflection is weakening the power more than refraction.

About the power of the two modes of refraction we can tell that the power refracted to right is greater than that refracted to left, since this power, that to the right, is closer the perpendicular to the interface, whether this is the perpendicular line drawn from the incidence point or a line drawn from the agent, from which the perpendicular line and the refracted line have their origin. Besides these three fundamental lines, there is a fourth accidental line, along which an accidental and weak power moves. Which, indeed, does not come directly from an agent, but is coming from a power propagated by any of the three abovementioned lines; in such a manner, from a ray entering a window, by chance, it comes the light to all the corners of a house. However, this power is the weakest one, because it does not come directly from the agent, but it is separated from the power of the agent, in a straight line, or reflected or refracted. These facts we told about lines and angles.

About the figures, there are two kinds of them that we have to consider here. One of these is suitable for propagation of power, namely the sphere. And this happens for the following reason: every agent emanates its power spherically, since it does all around and in every direction (diameter): upwards and downwards, ahead and aback, right and left. And this is shown by the manner in which it is possible to draw a line in a certain direction from an agent located at the center, and in all directions from all the different positions, and therefore it is proper to use that spherical figure. And this is in agreement with what the Commentator (Averroes) says on the (Aristotle's) De anima. Also, wherever we put the sensor to receive, we can feel such an agent at a proper distance; however, this happens only by species or by the power coming from the agent. So the power is propagating everywhere.

Another figure, however, is required for the natural action, that is, the pyramidal one: since, if the power is coming out from a single part of the agent and ending onto another single part of the patient, and so on for all the parts of agent and patient, we always had the power from a part of the agent falling onto a sole part of the patient, and then the action will never be strong or good. However, the action is complete, when the power of the agent comes from all the points of the agent or from its whole surface to every point of the patient. But this is impossible, except under the pyramidal figure, because the power that comes from each of the parts of the agent are concurring in the cone of the pyramids and are gathered together and then they all are able to act more strongly upon the part of the patient where they are condensed.

Therefore, an infinite number of pyramids can come out from a surface of an agent, pyramids having the same basis, namely, the surface of the agent, and there are so many cones as the pyramids are, falling into different points of the medium or on all sides of the patient, and there can be an infinite number coming out from surface, some shorter some longer. However, those cones which are equal in length and size, do not have different features, because they act in the same manner, though there can be a variety of features coming from the recipient matter, inasmuch it is concerning it. But when one pyramid is shorter than another, and both are coming out by the same agent, we have a quite difficult problem to solve, that of telling whether is the cone of the shorter pyramid acting more on the patient or not.



$\beta > \alpha$

Figure 9

And then, we ought to suppose that the shorter pyramid acts more, because its cone is less distant from its source, and for that reason, there is more power in it than in the longer pyramid and then the patient is more closely connected to the agent and therefore strongly altered by its power. Moreover, if the rays which are in the bulk of a shorter pyramid, that come from the right side, are prolonged besides the vertex, uninterrupted and straight, they will form smaller angles with the left beams, which are in the bulk of the pyramid, than the similar rays which are coming from a longer pyramid, as it is clear from the 21th section of first book of Euclid Geometry, and also by the common sense (Figure 9).

And in the same way, the rays coming from the left of the pyramid, which continues beyond the vertex, uninterrupted and straight, are closer to the rays of the right side in the bulk of the pyramid, than the consimilar rays of a longer pyramids. Then, because any congregation or union is more active, the cone of a short pyramid acts more and alters the patient more than a longer cone. However, we could object rationally that, when from all the surface of an agent the power is coming in a longer pyramid, we have there more power, because the cone is more acute than that of a shorter pyramid, and all the power is condensed for a greater operation, and there is also to add the following, that the rays of a longer pyramid are close to the rays of the agent, those lines which are drawn perpendicularly from the ends of the diameters of the agent, and then they are stronger, because the perpendicular progression is the strongest: it can be said that these reasons seems rather well posed, and they could be, if there were not the strongest reasons to the contrary, which we have mentioned previously. This is the end of the treatise by a Lincolnian on the reflections and refractions of rays.

Discussion of De Lineis

The treatise has a strong Incipit: let us therefore report, after the Grosseteste's words what A. G. Padgett is telling about Grosseteste[45]: "Even as he translated and interpreted Aristotle, Grosseteste placed Aristotelian natural philosophy in a broader Christian and Neo-platonic world view. … he was committed to a natural philosophy based upon mathematics. This emphasis derived from Platonic and Pythagorean traditions, as mediated to him through Patristic authors like Augustine. A mathematical natural philosophy is demonstrated in a number of his works, particularly works on astronomy, light, and in his treatise on geometry, De Lineis, Angulis et Figuris."

As we have seen in reading De Lineis, it is not only a treatise on

[45] A.G. Padgett, The Roots of the Western Concept of the "Laws of Nature": From the Greeks to Newton, Perspectives on Science and Christian Faith, Volume 55, Number 4, December 2003.

geometry, as told by Padgett, but on the geometry applied to light propagation. Padgett continues telling that in the incipit of the treatise, Grosseteste defends his mathematical approach to natural philosophy. “Notice that Grosseteste wants to use geometry, which was long a key tool of astronomers, within natural philosophy. This is a decisive step in the history of Western science, although Grosseteste was not alone in making it.”

Continuing our reading of the Grosseteste’s treatise, we find that the philosopher is proposing a universal action descending in the lower world, according to an Aristotelian view of the universe[46]. And this action can have material and spiritual effects, for instance, helping a person to achieve some intellectual results (ad majora). In the Latin text, we find also that Grosseteste refers to the “species”. “Species” in Latin means “seeing”, “view”, “look”, or “sight”, but also “external appearance”, “general outline” or shape. Then the “species” is that feature of the power of light which allows perceiving the shape of an object.

In De Lineis, we find the “propter quid” that we have already encountered in De Iride. The “quid” is the effect, or the phenomenon, that the physics needs to describe, and the “propter quid” is the answer given by the research, on the causes of the phenomenon. And here Grosseteste is telling that without the geometry we are not able to find the “proper quid”. As previously told, in the first part of his treatise, Grosseteste is claiming the necessity to use mathematics and geometry to explain physics.

How is the light moving? According to Grosseteste, it is a principle of least action to rule it. We can repeat also what Grosseteste is telling in De Iride: “And the same tells us that principle of the philosophy of nature, namely, that every action of the nature is well established, most ordinate, in the best and shortest manner, as it is possible.” This principle is aiming to find a figure in the complexity of the world.

After stating this principle, Grosseteste discusses what is happening when light falls onto a surface, that is, he is discussing about illumination. We know that illumination is following a cosine law, a geometric relationship between the illuminance of a surface and

[46] E. Grant, A Source Book in Medieval Science, Harvard University Press, 1974.

the angle of incidence of the illuminating rays[47]. The observed maximum of illuminance is therefore obtained for normal incidence, as Grosseteste is telling in his text. For what is concerning the angles, let us stress that in the Grosseteste's discussion, we can find that the Medieval scientists regarded "contingent angles", that is the angles of tangency, as having a finite magnitude[48]. Therefore the contingent angle is different if it is of a convex or concave surface.

The Grosseteste's treatise is also discussing the reflection and refraction of light as told by its title. We find here that Grosseteste is explaining that to bend the light we need several different media, so that at the interfaces the ray is broken with certain angles. This is discussed in De Iride too, where we have found even a law of refraction, which tells that the angles of refraction are one half the angles of incidence.

In the Latin text, Grosseteste is telling that the power "multiplies" along a straight line. Therefore, he imagined the light propagating by multiplying itself[49], and here, in translating his words, we rendered this propagation like that proposed by Huygens for the waves. In 1678, Christiaan Huygens considered that each point of a luminous wavefront could be the source of a spherical wavelet. The sum of these wavelets determines the new propagated wavefront. He assumed that the secondary waves travelled only in the forward direction. And then the light is "generating" itself, in the sense of propagation. Probably, Grosseteste imagined a similar mechanics, without waves however.

Grosseteste is also discussing the "doubling" of the power (in the Latin text, Grosseteste is proposing a "gemination"). A possible interpretation can be the following: let us consider a ray of light normally incident on a surface and the reflected ray, radiated back into the half-space of the incident ray. It means that in the volume occupied by these rays, which is the same, we have a "doubling", a superposition of power. In any other case, that is, when the

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47 P. Tregenza and D. Loe, The Design of Lighting, Taylor & Francis, 1998; J.L. Lindsey, Applied Illumination Engineering, The Fairmont Press, Inc., 1997.

48 E. Grant, A Source Book in Medieval Science, Harvard University Press, 1974.

49 C.C. Riedl, Robert Grosseteste, On light, Marquette University Press, Milwaukee, Wisconsin, 1942.

incidence is oblique, a certain volume of the space can be occupied just by the incident or by the reflected ray. And therefore, to Grosseteste, the power of the reflected rays is depending on the angle of incidence: his description is in agreement with the fact that the light falling at an angle on a surface tends to be increasingly reflected as the angle of incidence increases, and the transmission reduced. For a normal incidence in fact, we have the largest amount of transmitted power and, of course, the smallest amount of reflected power.

Usually, the behavior of the reflected light with the angle of incidence is studied with the Maxwell's equations, allowing to derive the Fresnel equations (see for instance, the Fresnel laws of reflection as discussed by a chapter in the first volume of the Feynman Lectures on Physics), which can be used to predict how much of the light is reflected and refracted. On a specular reflection then, we have that the fraction of the reflected light increases with the increase of the angle of incidence.

Let us remember that the Fresnel reflectance for metals and dielectric materials is very different. For a metal such as aluminum, the reflectance is always above the 85%. For a glass having a refractive index of n=1.5, the reflectance is of only 4% at normal incidence, but 100% at grazing. "This effect, in fact, is what makes polished metals look like metal, and polished glasses not look that way. It's also why it's hard to comb your hair in a shop window; you are looking at the angle of minimum reflectance."[50]

In the Grosseteste's text, we can find also that he is distinguishing between specular and Lambertian surfaces. Very interesting is the fact that Grosseteste is using an analogy with the sound waves, telling that Averroes, the Aristotle's Commentator, studied the sound propagation and the role of irregular surfaces in break down the reflection of it. The treatise continues with an analysis of emitted and received power, based on pyramids and solid angles; it ends with proposing and solving a question concerning the power of small and large solid angles.

Let us emphasize that the discussion of Grosseteste about the power of the reflected and refracted light is in qualitative agreement with the Fresnel formulae of reflection and refraction. The discussion

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[50] S.H. Westin, http://www.graphics.cornell.edu/~westin/misc/fresnel.html

of the illumination of surfaces is quite good too.

In the De Lineis we have the basis of the Grosseteste's reasoning on light, which is viewing that the natural agents act by the multiplication of their power or species, a view developed further on by Roger Bacon[51].

However, let us note that if we consider the "multiplication" as propagation, this could be a sort of propagation of light as Huygens imagined several years after. According to N. Lewis, "Grosseteste holds that the intensity of operation of the natural agent will be a matter of its distance from what it acts upon, the angle at which it strikes it, and the figure in which it multiplies its operation, this being either a sphere or cone. He establishes certain rudimentary rules to this effect, such as that the shorter the distance, the stronger the operation". However, as we have seen from reading Grosseteste's treatise, some observations on the power of transmitted and reflected light are more than rudimental, because probably he experimented about them.

The Light and Grosseteste's Metaphysics

Here we start the discussion of the most famous treatise written by Grosseteste, that entitled "De luce, seu de incohatione formarum", "On Light and the Beginning of Forms". It is the treatise where he is proposing his metaphysics of light and his cosmogony.

Grosseteste was heavily influenced by Augustine, whose thought permeates his writings and from whom he drew a Neoplatonic outlook[52]. However, he also made extensive use of the thought of Aristotle, Avicenna and Averroes[53]. Grosseteste lived in a period during which two main factors dominated the culture. One was the birth in the Western Europe of universities, which can be regarded as the evolution of previous modes of instruction; the second

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[51] N. Lewis, Robert Grosseteste. The Stanford Encyclopedia of Philosophy, Winter Edition, 2010.

[52] R.M. McInerny, A History of Western Philosophy, 1963, University of Notre Dame Press.

[53] N. Lewis, Robert Grosseteste, in The Stanford Encyclopedia of Philosophy, Summer 2013 Edition, Edward N. Zalta Editor.

factor was the impact of Islamic philosophy, which was the vehicle to the West of the integral knowledge of Aristotle[54]. In this framework, Grosseteste developed an original account of the generation and nature of the physical world in terms of the action of light. The world is the Latin “mundus”, which is the Earth and heavens together. In the Grosseteste’s thought the mundus had the form of a sphere as in the ancient Aristotelian cosmos.

Before reading De Luce, let us see the discussions of some scholars on this Grosseteste's treatise. First, let us consider the item on Grosseteste in the Stanford Encyclopedia of Philosophy is written by Neil Lewis of Georgetown University. Lewis defines light as the leitmotif running through Grosseteste's works. Besides in his writings on optics, light occupies a prominent place in all Grosseteste's works, in accounting of sense perception which is relating body and soul, in his theory of knowledge based on illumination, and in the origin and nature of the physical world.

Grosseteste's metaphysics rests on a hylomorphic account of the nature of bodies (the hylomorphism is a philosophical theory developed by Aristotle, which conceives being as a compound of matter and form); according to this approach, our philosopher proposed his cosmology, described in De Luce. We find that the firmament, which is the outermost heavenly sphere, is the simplest body of the world, composed of first matter and first form. And, to Grosseteste, the first form was Lux, the Light.

De Luce opens with an argument for the identification of first form with Lux: first form and first matter are in themselves simple substances. The first form, which is also called "corporeity", is coming from the extension of matter into three dimensions, thereby yielding a dimensioned body[55]. An entity without dimension could only have this effect if it instantaneously multiplied and diffused isotropically in all directions. In fact, these are features of light, for light is essentially self- multiplicative and self-diffusive, and a sphere of light being instantaneously generated from a point

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54 R.M. McInerny, A History of Western Philosophy, 1963, University of Notre Dame Press.

55 N. Lewis, Robert Grosseteste, in The Stanford Encyclopedia of Philosophy, Summer 2013 Edition, Edward N. Zalta Editor; S. Oliver, Robert Grosseteste on Light, Truth and Experimentum, Vivarium, 2004, Volume 42, pp. 151-180 ; S. Oliver, Philosophy, God and motion, 2006, Routledge.

source. Moreover, light is dragging matter along with its diffusion. Thus, Grosseteste concluded that light is in fact the first form.

He saw in the "metaphysics of light" some of God's creation of the physical universe and an explanation of why it took its form. At the beginning of time, God created first form, Lux, in first matter. As explained by Lewis, first form and first matter are in themselves indivisible and simple. And, according to Grosseteste, the finite multiplication of a simple cannot generate an item with size. But, the infinite multiplication of a simple will generate a finite quantity (quantum). Therefore, through the infinite multiplication of first form in first matter, extended bodies can be produced and thus the physical universe created. It is remarkable that, to account for bodies of different sizes, Grosseteste argued that there are infinities of different sizes that stand in different ratios.

Let us add to Lewis' observations, which are like those we can find in the discussion and translation of De Luce given by Clare C. Riedl[56], some other comments. Grosseteste's first form indivisible and simple, in Latin "simplex", is similar to the indivisible of Bonaventura Cavalieri's calculus[57]. These indivisibles were dimensionless until the development of differential calculus by Newton and Leibniz. The sum of these indivisibles is able to give lines, surfaces and volumes. In the translation of De Luce proposed in this book, I consider the Grosseteste's indivisible as an entity, that is, something that exists in itself, referring to it as a dimensionless being (Riedl used the term "being").

Grosseteste used the light to explain the genesis of the Aristotelian cosmos as a system of nested celestial spheres surrounding the four sublunary or elemental spheres. Matter and light existed at the beginning of time at a single point. The infinite self- multiplication of the initial point of light extended the first matter into a spherical form, because light diffuses itself spherically. Let us observe, that what Grosseteste is telling is a manifest anticipation of Huygens' theory of the propagation of light[58].

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[56] C.C. Riedl, Robert Grosseteste, On Light (De Luce), 1942, Marquette University Press.

[57] A.C. Sparavigna, Gabrio Piola e il suo Elogio di Bonaventura Cavalieri, 2013, Lulu Press, Raleigh, North Carolina.

[58] A.C. Sparavigna, Robert Grosseteste and his Treatise on Lines, Angles and Figures of the Propagation of Light, International Journal of Sciences, 2013, Volume 2, n. 9, pp. 101-

The outermost parts of the matter of the sphere thereby generated, unlike the parts of the matter below them, were maximally extended and rarefied and formed the outermost sphere, or first sphere, the firmament. Since the light is essentially self-multiplicative, this light in this outermost sphere continued to multiply itself, but back inwards, toward the center from all parts of the outermost sphere, because it had already diffused itself outward as far as it possibly could. However, the light – as explained by Neil Lewis – being a substantial form, "cannot exist apart from matter, this inwardly directed light drew with itself what Grosseteste calls the spirituality of the matter of the outermost sphere, and thus luminosity (Lumen), a body comprised of light and the spirituality of this matter, proceeded inwards". The Lumen moves inwards, concentrating the matter existing below the outermost sphere, "leaving in its wake below the outermost sphere a second sphere comprised of matter whose parts were rarefied as much as they could be. This sphere in turn generated luminosity, which moving inwards further concentrated the matter below it and rarefied the outermost parts of this matter so as to produce the third sphere." In this manner, the repetition of such process creates the nine celestial spheres, "each sphere being comprised of matter whose parts were incapable of further rarefaction".

This description proposed by Lewis, and in particular his referring to a wake, that is, a visible track of turbulence left by something moving through water or air, allows us to imagine the Grosseteste's universe as formed by spherical waves in the volume of the universe, as the concentric waves on the surface of water. Grosseteste knew this phenomenon for sure and then he used it for modelling the Aristotelian world.

Let us continue the Grosseteste's description of world creation. The lowest celestial sphere, the lunar sphere, also generated luminosity, which moved inwards and concentrated the matter below it. But this luminosity had a low power and therefore produced a sphere comprised of incompletely dispersed matter, the

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107; J.W. Goering and E.A. Mackie, Editing Robert Grosseteste: Papers Given at the Thirty-Sixth Annual Conference on Editorial Problems, University of Toronto, 3-4 November 2000, 2003, University of Toronto Press.

sphere of Fire. Likewise, fire generated luminosity producing below it the sphere of Air. This process continued, giving the spheres of Water and Earth, the latter being comprised of the most concentrated and dense matter. These classical four elements, unlike the celestial spheres, are capable of alteration, growth, generation and corruption[59].

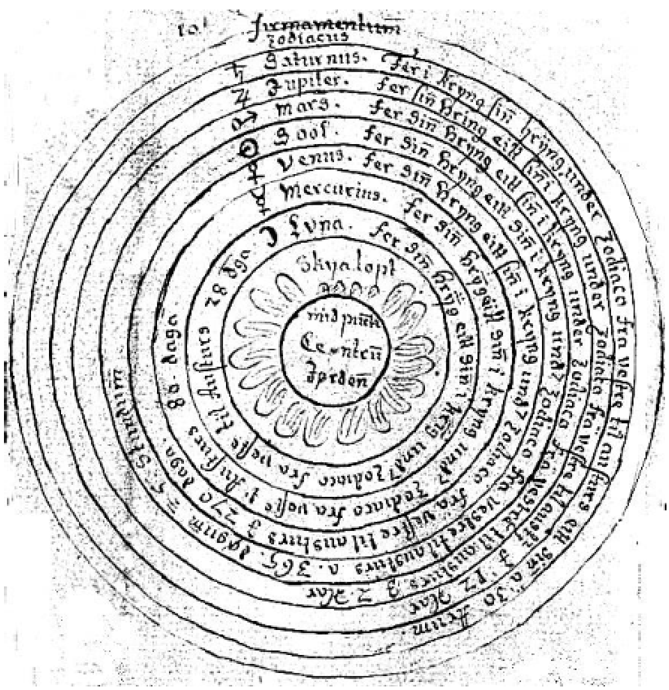

Figure 10 - A geocentric world view, like in the Grosseteste's cosmology. Note the firmament above the sphere of the Zodiac. This image is adapted from an Icelandic manuscript, now in the care of the Magnusson Institute in Iceland. Courtesy: Wikipedia.

For what concerns the motion of the heavenly bodies, Grosseteste tells they can only move with a circular movement because the luminosity in them is incapable of rarefaction or condensation, and as a result cannot incline the parts of their matter upward, to rarefy them, or downward, to condense them. Then, the heavenly

[59] N. Lewis, Robert Grosseteste, in The Stanford Encyclopedia of Philosophy, Summer 2013 Edition, Edward N. Zalta Editor.

spheres receive movement from an intellective motive power. But the elements can be rarefied and condensed; they can incline the luminosity in themselves away from the center of the universe, so as to rarefy it, or toward the center so as to condense it, and this accounts for their natural motion up and down.

The metaphysics of light is an original idea that Grosseteste used to explain the world as imagined by Aristotle, a machine consisting of nested spheres, and the distinction between the motion of celestial and sublunary bodies. In the Figure 10, we have seen these spheres, depicted in an Icelandic manuscript. It is a geocentric world, with the firmament above the sphere of the Zodiac.

Grosseteste and the Augustinian thought

Ralph Matthew McInerny (1929 – 2010) was a Professor of Philosophy at the University of Notre Dame. He wrote about Grosseteste in the second volume of "A History of Western Philosophy", in the chapter on the philosophy of the Thirteenth Century. This chapter starts with the discussions on thoughts of William of Auvergne and Alexander of Hales, at the University of Paris. The works of these philosophers are good examples of the new philosophical writings that had started in the Western universities, during that century. Meanwhile, McInerny continues, "at Oxford the example of Robert Grosseteste is an indication of a quite different response to the new literature. Robert, who was later to become bishop of Lincoln, was well acquainted with the works of Aristotle. … The thing that strikes the reader of the philosophical writings of Grosseteste, edited in 1912 by Ludwig Baur, is the preponderance of mathematical and scientific topics. It is easy to feel that here is independence and originality of a sort unknown in William of Auvergne and Alexander of Hales. Further consideration leads, however, to the judgment that, despite the mathematics, Grosseteste is actually representative of a conservative mentality, that in him Augustinianism lives on in a less adulterated form than in his continental contemporaries. It is customary, convenient, and fitting that the flavor of Grosseteste's work be exhibited by his contribution to Augustine's theory of illumination"[60].

Then, McInerny continues with the discussion of the De Luce. "The following amounts to a rough translation of the beginning of that essay. I think, Grosseteste writes, that the first bodily form, what some call corporeity, is light, for light of its very nature (per se) diffuses itself in all directions such that, given a point of light, a sphere of light of whatever size is immediately generated unless something opaque (umbrosum) impedes. Matter's extension in three dimensions follows necessarily on corporeity, but matter itself is a simple substance lacking dimensions. So too, form is a simple substance also lacking dimensions, and it cannot account for the dimensions matter comes to have. To account for the extension of matter, Grosseteste says, I nominate light. Extension in all directions is a per se property of light; it diffuses and multiplies itself everywhere. Whatever performs the task of introducing dimensions into the compound of form and matter must therefore be either light or something that does this just insofar as it participates in light. Corporeity, bodily extension, is either light or a participation in light: something which acts through the power of light." Then McInerny tells, "Grosseteste's own opinion is simply put. Light is the most noble form of bodies and is that in bodies which makes them most akin to separate substances.".

Grosseteste used light to explain the extension of bodies, therefore he used it to explain the constitution of the universe too. Using an experimentum, we can check the diffusion of light by the interposition of an obstacle. For this reason, Grosseteste holds that any point-like source of light has an intrinsic limitation on the extent of its diffusion. "As for the constitution of the cosmos, then, - observes McInerny - he can begin with a single body which may be thought of as light and matter, a compound of form and matter: its diffusion to the extent of its intrinsic power will produce a sphere which is finite and whose limit is the heaven. Then, by thinking of that outer limit of light reflecting on the center from which it radiated, Grosseteste speaks of the generation of the celestial bodies." This is a typical geocentric vision of the universe. "The degree or intensity of light provides Grosseteste with a scale

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[60] R.M. McInerny, A History of Western Philosophy, 1963, University of Notre Dame Press.

on which he can compute the ontological status of entities, so that the universe for him is a hierarchy of lights or a hierarchy based on degrees of participation in light. Thus far Grosseteste's use of light to explain the cosmos may seem only the inspiration of one who had been impressed by the application of mathematics to natural phenomena, like the distribution of light from a source and like the rainbow. … At any rate, beyond his attempt to interpret the physical world by means of light as his basic concept, Grosseteste's theory must be seen as a continuation of the Augustinian doctrine of illumination. St. James spoke of God as the Father of lights and St. John of Christ as the light of the world, and it may not be too much to say that what Augustine had developed from such scriptural remarks as these is as important for the development of Grosseteste's universe of light as anything of an observational nature." To his discussion, Ralph McInerny suggested references[61].

A remarkable man of science

Clare C. Riedl proposed in 1942 a translation and discussion of De Luce[62]. This translation is the one commonly used for studying this Grosseteste's treatise. Riedl is telling that Grosseteste was "without question one of the most remarkable men of science of his time". In fact, he studied optics, in particular the reflection and refraction laws, pointing the way to microscopes and telescopes. In philosophy, "Grosseteste represents, and indeed might be called the founder of, a new tradition, characterized by the blending of philosophy with experimental science. This tradition continued to be characteristic of philosophy at Oxford in opposition to the more metaphysical type of speculation which prevailed at Paris."

According to Riedl, De Luce is significant because is an example of the philosophic-scientific synthesis of the Oxford School, and it was an important source of the Metaphysics of Light and was

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[61] S. H. Thomson, The Writings of Robert Grosseteste, Bishop of Lincoln, 1940, Cambridge; L. Baur, Die philosophischen Werke des Robert Grosseteste, Münster, 1912; Die Philosophie des Robert Grosseteste, Münster, 1917; A. C. Crombie, Robert Grosseteste and the Origins of Experimental Science, 1953, Oxford; D. A. Callus, Ed., Robert Grosseteste, Scholar and Bishop, 1955, Oxford.

[62] C.C. Riedl, Robert Grosseteste, On Light (De Luce), 1942, Marquette University Press.

fundamental for the medieval conceptions relative to cosmology. To understand the treatise, as Riedl is pointing out, it is necessary to consider some aspects of Grosseteste's doctrine of matter and form: the terminology is Aristotelian but ideas are original. According to Grosseteste, matter is not pure potency, as it was for Aristotle, but possesses in its own right a certain minimal reality. Matter is a substance then, and the form completes, perfects and actualizes it, giving it a dimension.

The first corporeal form is the light: it is more than the form of corporeity, it is also a principle of activity. And Riedl remarks: "Every body, he (Grosseteste) believes, has a motion or activity which is natural to it, because it proceeds from an intrinsic principle. The intrinsic principle from which this motion or activity proceeds must be the form, since matter is passive.".

De Luce can be considered as composed of two parts, the first is concerned with the Metaphysics of Light proper, the second contains a cosmogony obtained from this metaphysics.

Grosseteste bases his theory on the fact that a feature of corporeity is the requirement of an extension in the three dimensions. He knows the property of light to diffuse in all directions, multiplying itself, and that a point source is producing a sphere. The light then gives instantaneously a three-dimensional object. Therefore, he concludes that the light is suited to fulfil the requirement of extension. The light can be joined to the matter as its form; being the form inseparable from matter, the light will necessary carry matter along with it in its diffusion and self- multiplication. The light of which Grosseteste speaks in this treatise is not the ordinary physical light but a simple substance, almost spiritual in its properties. Moreover, Grosseteste uses two words: Lux and Lumen. First form is Lux, whereas the reflected or radiated light is Lumen, the luminosity. We will consider again Lux and Lumen in a further discussion.

In the second part of the treatise, Grosseteste is proposing a philosophy of the Genesis. Riedl remarks that in this philosophy, it is the light which is giving the principle of continuity in nature, for, as being the first corporeal form, it is common to all things in the universe from the lowest of the elements, earth, up to and including even the firmament. The universe (mundus) with its thirteen spheres is the typical medieval world. It is geocentric with the ninth heavenly sphere that Ptolemy added to Aristotle's eight. According to Riedl, it seems that the cosmology we find in De Luce shows considerable traces of the influence of Alpetragius (Al-Bitrogi).

On the movements of the spheres, Grosseteste tells that there is the diurnal motion. It is imparted by the outermost sphere, the firmament. This is a somewhat new theory in Grosseteste's day, the suggestion coming from an Arabian writer, Thebit ben Coran (Ibn-Thabit), referred frequently by Grosseteste[63].

It's time to read the treatise, of which I am proposing a translation using some physics and mathematics terms, to enhance the role of science in Grosseteste's thought. The original Latin text, like that of the previously considered treatises and the others that we will see, is freely available at www.grosseteste.com.

De Luce

The first corporeal form, which is also referred to as "corporeity", is in my opinion the light, because the light, Lux in Latin, due to its very nature, diffuses itself in every direction in such a way that a point source will give instantaneously a sphere of light of any size, unless some object producing shadows is obstructing its rays. Corporeity is coming from the extension of matter in the three dimensional space, and this happens in spite of the fact that both corporeity and matter are in themselves substances lacking of dimension. But a form, which is in itself simple and dimensionless could not induce dimensions in every direction into the matter, which is likewise simple and dimensionless, except by multiplying itself and diffusing itself instantaneously in every direction and thus extending matter in its own diffusion. It is so, because the form cannot abandon matter, since it is inseparable from it, and matter itself cannot be deprived of form. Now, let us consider light, which has its nature characterized by the property of being able of multiplying itself and diffusing itself instantaneously in all directions. Whatever is acting, either light or a participation in light, that is something which acts through the power of light, we have an agent which accomplishes this operation by itself. Corporeity, therefore, is either the light itself or an agent which

[63] C.C. Riedl, Robert Grosseteste, On Light (De Luce), 1942, Marquette University Press.

performs the operation previously mentioned and is able to induce dimensions into matter, as a result of participating in light, and acting through the power of it. But the first form cannot induce dimensions into matter through the power of a consequent form. Therefore, light is not a form consequent to corporeity, but is corporeity itself.

Moreover, it is opinion of scholars that the first corporeal form is the worthier and nobler and more excellent essence than all the forms coming after it. It has a high resemblance to the forms that are existing separated (from matter). That is, light is the worthier, nobler and more excellent essence than all corporeal things. It is more than all other bodies similar to the forms that exist separated (from matter), namely, the intelligences. Light therefore is the first corporeal form.

Due to its nature, light, which was the first form created in first created matter, multiplied itself an infinite number of times and expanded itself isotropically in all directions. In this way, to the very beginning of time, light caused the spreading of matter, that could not leave behind, by pulling it along with itself, into a quantity equal to the mass of the entire machine of the world[64]. Let us stress that this extension of matter could not be obtained through a finite multiplication of light, because the multiplication of a simple entity a finite number of times does not produce a "quantum", that is a quantity, as Aristotle shows in his De Caelo et Mundo. However, the multiplication of a simple entity an infinite number of times must give a finite quantity, because a product which is the result of an infinite multiplication exceeds infinitely the entity multiplied. Now, one simple entity cannot exceed another simple entity infinitely: only a finite quantity infinitely exceeds a simple entity. Therefore, an infinite quantity exceeds a simple entity by infinity times infinity. When light, which is in itself an entity, is multiplied an infinite number of times, it must extend matter, which is likewise an entity, into finite dimension.

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[64] In the Grosseteste's Latin text, we find the Mundi Machina. Sacrobosco also spoke of the universe as the machina mundi, the machine of the world, suggesting that the reported eclipse of the Sun at the crucifixion of Jesus was a disturbance of the order of that machine. This concept is similar to the clockwork universe analogy, very popular during the Enlightenment, as told in Wikipedia. http://en.wikipedia.org/wiki/De_sphaera_mundi

It is possible, however, that an infinite series of terms is related to an infinite sum in every proportion, numerical and non-numerical[65]. Some infinites are larger than other infinites, and some are smaller. Thus, the series of all numbers, even and odd together, is infinite. At the same time, this series is greater than the series obtaining from all the even numbers, which is infinite too, because it is exceeding it by the series of all the odd numbers. The series, too, of all numbers starting with one and continuing by doubling each successive number is infinite, and similarly the series of all the halves of these doubles is infinite. The series of halves must be half of the series of doubles. In the same way the series obtained from all numbers starting with one and multiplying by three successively is three times the series of thirds corresponding to them.

It is likewise clear, for all given numerical proportions, that we can have a proportion of finite to infinite according to each of them.

Now, let us consider an infinite series of all doubles starting from one, and an infinite series of all the halves corresponding to these doubles: if one, or some other finite number, is subtracted from the series of the halves, after this subtraction we will have no longer a two to one proportion between the first series and what is left of the second series. Therefore, there will not be any numerical proportion. The reason is the following: "if a second numerical proportion is to be left from the first as the result of subtraction from the lesser member of the proportion, then what is subtracted must be an aliquot part or aliquot parts of an aliquot part of that from which it is subtracted. But, a finite number cannot be an aliquot part or aliquot parts of an aliquot part of an infinite number."[66] Therefore, when we subtract a number from an infinite series of halves, we have a non-numerical proportion between the series of doubles and what is left from the series of halves. (So we have numerical and non-numerical proportions).

After this discussion, it is clear that light through the infinite multiplication of itself extends matter into finite dimensions, that

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[65] In mathematics, a series is the sum of the terms of a sequence, and in infinite sequences the series continue indefinitely.

[66] This paragraph on the aliquotes is from the Riedl's translation.

can be smaller and larger according to certain respective proportions, numerical and non-numerical. In fact, if light through its infinite multiplication extends matter into a dimension of two cubits, by the doubling of this infinite multiplication, it extends it into a dimension of four cubits, and by the dividing in half, it extends it into a dimension of one cubit. Thus it proceeds according to numerical and non-numerical proportions.

In my opinion, this was the meaning of the theory of those philosophers who told that everything is composed of atoms, and that bodies are composed of surfaces, surfaces of lines, and lines of points. This opinion does not contradict the theory that a magnitude is composed only of magnitudes. In fact, "whole" is said in so many ways as "part" is said. Thus, we say that a half is part of a whole, because two halves make a whole. We say that a side is part of a diameter, but this is said in a different meaning: no matter how many times a side is taken, it does not make a diameter, but it is always less than the diameter[67]. Again, we say that an angle of contingence is part of a right angle because there is an infinite number of angles of contingence in a right angle. When an angle of contingence is subtracted from a right angle a finite number of times the latter becomes smaller[68]. Differently, a point is a part of a line in which it is contained an infinite number of times; when a point is removed from the line a finite number of times, this does not shorten the line.

To return to the main subject of this treatise, I say that light through its isotropic infinite multiplication extends matter into the form of a sphere and, as a necessary consequence of this extension, the outermost parts of matter are more extended and more rarefied than those inside the volume, close to the center of the sphere. Since the outermost parts of the sphere become highly rarefied, the inner parts have the possibility of further rarefaction.

In such a manner the light acted, by extending first matter forming a sphere and by rarefying its outermost parts to the highest

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[67] Riedl explains that Grosseteste is talking about the shorter sides of a right triangle inscribed in a semi-circle, the diameter of which is the hypotenuse of the triangle. "No matter how much either of these sides is extended it will never equal the diameter until it becomes identical with it, in this case there is no longer a triangle".

[68] We have already seen the angle of contingence in De Lineis, Angulis et Figuris.

possible degree. In this outermost part of the sphere, light fully completed the potentiality of matter, and left this matter without any susceptibility of further impression. Therefore, the first body in the outermost part of the sphere of the world, which is called "firmament", is perfect because it has nothing in its composition but first matter and first form. It is therefore the simplest of all the structures of the world, having the greatest possible extent, with respect to the parts that constitute its essence and with respect to its quantity.

Firmament is an object of the category "body", with the specific property that, in it, the matter has a complete actuation through the first form alone. But the "body", which is in this and in other bodies, has in its essence first matter and first form, and so it drives the matter to complete it through the first form and to reduce it through the first form.

When the first structure, the firmament, was complete, it diffused its luminosity, the Latin Lumen, from every part of itself towards its center. Lux, the light, after the fulfilment of the first body, naturally multiplied itself from it, and necessarily diffused to its center. And since lux is form inseparable from matter, during its diffusion from the first body to the center, extended along with itself the spirituality of the first body matter. And thus, we have a diffused light, a luminosity, the Lumen, coming from the first body, and this luminosity is a spiritual body, or if you prefer, a bodily spirit. This luminosity, in its transit, does not split the medium through which it is passing, and thus it passes instantaneously from the bulk of the first heaven to the center of the sphere. Furthermore, its passing is not to be understood in the sense of an entity passing instantaneously from that heaven to the center, for this is perhaps impossible, but its passing takes place through the multiplication of itself and an infinite generation.

This luminosity, expanded from the first body toward the center and gathered together the mass existing below the first body; and since the first body could no longer be lessened because it was completed perfectly and invariably, and since, too, there could not be an empty space, it was necessary, in this gathering of mass, the outermost parts be disgregated and expanded. Therefore, the inner parts of the aforesaid mass became denser and the outer parts rarefied. So great was the power of this luminosity, which was gathering together mass, aggregating and disgregating matter, that the outermost parts of the mass contained below the first body were elongate and rarefied to the highest degree. Thus, in the outermost parts of the mass in question, the second sphere was created, completed and susceptible of no further impression. And this is the creation and perfection of the second sphere, where we have luminosity generated by the first sphere and the light, which is simple in the first sphere, is doubled in the second.

Just as the luminosity generated from the first body completed the second sphere, leaving a denser mass below the second sphere, so the luminosity generated from the second sphere completed the third sphere, leaving below this third sphere a mass of even greater density, after aggregation and disgregation. This process of simultaneously aggregation and disgregation continued in this way until the nine heavenly spheres were completed, gathering together, below the ninth and lowest sphere, the dense mass which constitutes the matter of the four elements.

The lowest sphere, the sphere of the Moon, which is generating luminosity from itself too, by its luminosity aggregated the mass contained below itself and, after this aggregation, rarefied and expanded its outermost parts. However, the power of this luminosity was not so great to produce a further expansion of the outermost parts of this mass to the highest degree. For this reason, mass was left imperfect and capable of being aggregated and disgregated.

The highest part of this mass was disgregated, although not to the greatest possible extent. By its disgregation, fire is coming and the matter of elements remains. This fire, generating luminosity from itself, aggregated the mass contained below it, with the disgregation of its outermost parts, but not completely, and in this way it produced air. Air, also, generated from its spiritual body or from its bodily spirit, produced water and earth by means of aggregation of inner parts and disgregation of its outer parts. But because water retained more of the power of aggregation than of disgregation, water remained together with the heavy earth.

In this way, therefore, the thirteen spheres of our world were created. Nine of them, the heavenly spheres, are not subject to change, increase, generation or corruption because they are complete, that is, perfect. The other four spheres have the opposite mode of being, that is, they are subject to change, increase, generation and corruption, because they are incomplete. It is clear that every higher body, in virtue of luminosity which proceeds from it, is that body featuring the body that comes after it. And like the power of unity is in every number that comes after it, so the first body, through the multiplication of its luminosity, is in every body that comes after it.

Earth is from the aggregation in itself of higher luminosities from all the higher bodies. For this reason earth is called Pan by poets, that is 'the whole,' and it is also given the name Cybele, which is like "cubile", from cube, that is, a solid. For this reason earth, that is, Cybele, which is the most compact of all bodies, is the mother of all the gods; because in her the higher lights are gathered together, however not driven for her own operation, but the luminosity of any sphere can be raised from it into act and operation. Thus every one of the gods can be considered generated from her as from of a mother. The intermediate bodies have a twofold behaviour. Towards lower bodies they have the same behaviour as the first heaven to all remaining things, and, they are related to the higher bodies as earth is related to all further things. And in this manner, some features of them remain in everything.

The image and perfection of all bodies is light, but in the higher bodies it is more spiritual and simple, whereas in the lower bodies it is more corporeal and multiplied. Furthermore, all bodies have not the same features, even though they all proceed from light, whether simple or multiplied, like the numbers, which are not all of the same kind, in spite of the fact that they are all derived from unity by a greater or lesser multiplication. And in this discussion, perhaps, we find the meaning of the sentences telling that "all is one, in the perfection of one light" and also, "those, which are plural, are plural through different multiplication of light itself".

Since lower bodies participate in the form of the higher bodies, a lower body because of its participation in the form of the higher body, receives its motion from the same incorporeal moving power by which the higher body is moved. Therefore, the incorporeal power from an intelligence or spirit, who moves the first and highest sphere in the diurnal motion, moves all the lower heavenly spheres in the same diurnal motion. However, these spheres receive their motion weakened in proportion as these spheres are lower, because purity and strength of the first corporeal light in it is proportionally lower.

So we have the elements participating in the form of the first heaven. However, they are not moved by the mover of the first heaven in a diurnal motion. Although they participate in that first light, they are not obedient to the first moving power, since that light in them is impure, weak, and the purity, which it has in the first body, diluted; moreover, they possess the density of matter which is the principle of resistance and disobedience. However, there are some who believe that the sphere of fire rotates with a diurnal motion, and they consider the rotation of comets to be a sign of this. They say also that this motion is available in the waters of the sea, so that the tide of the seas is coming from it. But the right philosophers say that the earth is free from this motion.

In this same way, too, the spheres that come after the second sphere, the Zodiac, usually called the eighth when we call them from the earth upwards, all are transmitting the motion of this sphere, because they participate in its form. Therefore, this motion is proper to each of them in addition to the diurnal motion.

As previously told, the heavenly spheres are perfect and are not receptive of rarefaction or condensation, the light in them does not strain the parts of matter either away from the center, to rarefy them, or toward the center to condense them. And then, the heavenly spheres are not receptive of up or down motion but only of circular motion due to an intellectual moving power, which, by looking at itself in a corporeal manner, revolves the spheres to have a circular corporeal motion. On the contrary, elements are incomplete, and then subjected to rarefaction and condensation; the luminosity which is in them inclines them away from the center so as to rarefy them, or toward the center so as to condense them. And on this account they are naturally capable of being moved in an upward or downward motion.

In the highest body, which is the simplest of all bodies, there are four features, namely form, matter, composition and composite. The form, being the simplest, holds the position of unity. Matter, because of twofold potency, namely its susceptibility to impressions and its receptiveness of them, and also for its density which is proper to matter, which is primarily and principally a characteristic of duality, rightly selects a dual nature. But composition has a trinity in itself because there appears in it matter with form and form with matter, and the typical property of the composition, which is found in every composite as a third feature, distinct from matter and form. And we have also the composite proper, after these three constituents, which is considered as a quaternity. Therefore, in the first body, in which all other bodies exist virtually, there is a quaternity and therefore the number of the remaining bodies is basically no more than ten. Because we have one coming from the form, two from matter, three with the composition and four from the composite: when they are added make a total of ten. Therefore ten is the number of the spherical bodies of the world, because the sphere of the elements, although it is divided into four, is nevertheless one by its participation in earthly corruptible nature.

From these considerations it is clear that ten is the universal perfect number, because every perfect whole has inside something like form and then it is a unity, and something like matter and then it is duality, something like composition and then it is a trinity, and something like composite and then becomes quaternity. We cannot add a fifth to these four. For this reason, every perfect whole is ten. It is clear also that only five proportions, found in these four numbers, one, two, three, four, are suitable for composition and to have the harmony able to stabilize every composite. And only these five proportions are the harmonies we find in musical melodies, in pantomimes and rhythmic measures[69].

This is the end of the treatise on light of the Lincolnian.

A Note on De Luce

In preparing this translation, I used the term "disgregation", which we will find in a following translation[70] of another Grosseteste's treatise, concerning the four classical elements, fire, air, water and

[69] Grosseteste is describing the Greek tetractys of the decad. It is a geometrical representation of the fourth triangular number and a mystical symbol of Pythagoreanism. The number was also associated with planetary motions and music.

[70] A.C. Sparavigna, Robert Grosseteste and the Four Elements, International Journal of Sciences, 2013, Volume 2, n. 12, pp. 42-45.

earth. Here, we have seen that the Lux is the pivot about which the nature is turning.

Due to its importance, De Luce had been discussed by several scholars; of some of them we have already reported their conclusions. De Luce contains several ideas suitable to a comparison to modern physics and mathematics. As told by J. Cunningham[71], in this treatise we find that Grosseteste imagined that matter existed at the beginning of time at a single point, "except that it did not exist in any sense that we would understand since it had no dimensions. It was neither three, two or even one-dimensional. It was therefore innate, but without existence in either time or space. Then God issued His first fiat saying 'Let there be light' and at that instant a shared of light issued from the divine and entered matter. As it did so it gave to matter dimension; or as Grosseteste would put it, 'corporeity.' This was 'the beginning' … No-one can read the Tractatus de luce today without thinking of the Big Bang theory."

Lux and Lumen from Grosseteste to Dante Alighieri

In this part of our book, we will evidence some features linking Robert Grosseteste to Dante Alighieri. That is, we will investigate the influence that the metaphysics of light and the discussions on the nature of light, that was fundamental for Grosseteste, had on the Dante's thought and works. Both persons, Dante Alighieri and Robert Grosseteste, let the light pervade their vision of the world. In particular both distinguished Lux from Lumen.

Durante degli Alighieri, (c.1265-1321), simply Dante, was a major Italian poet of the Middle Ages. His Divine Comedy is widely considered a masterpiece of world literature[72]. During his time, in a Western Europe where the overwhelming majority of texts was written in Latin, Dante preferred the use of the Tuscan dialect, his Mother Language[73]. This choice was essential for the Divine

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[71] J. Cunningham, Robert Grosseteste: Light, the Universe and Learning, Talk at Bishop Grosseteste University.

[72] H. Bloom, The Western Canon, 1995, Riverhead Books.

[73] E. Price Sayer, translated by (1887). The Banquet of Dante Alighieri. Project Gutenberg EBook, http://www.gutenberg.org/cache/epub/12867/pg12867.html

Comedy, that became a precedent of fundamental importance for the Italian writers after him, and for establishing the Italian language[74].

In his works, Dante, that was one of the most educated persons of the time, displayed his philosophical knowledge and the metaphysics he developed consequently. He knew deeply the works of Aristotle and the thought of Albert the Great and Thomas Aquinas, "Wise Spirits" in the Heaven of the Sun[75], the Neoplatonic thought and the classic Latin literature. However, for proposing his poetry and philosophy, Dante preferred the use of the Vulgar than of the Latin.

Dante's philosophy was supported by a metaphysics, which is a metaphysics of the Light of Divine Love[76], as we can see from the Divine Comedy, his allegorical journey in the realm of the afterlife. In such a manner, when Dante comes to the Empyreum, the region beyond physical existence and the highest place of his medieval cosmology, the Comedy presents its "sense of a complete harmonization of divine light, divine love, and divine life"[77].

Dante based his journey in the realms of afterlife on the medieval model of the world, where the Earth was at the center of the spheres of heavens. In the poem written in the first person, Dante describes his journey through Hell and Purgatory, and then his rise through Heavens, up to the Empyreum and the vision of God. This travel is representing allegorically a soul's journey towards the Divine Love of God.

By means of a digital text we can easily count the frequency of words in it and see the occurrence of Love (Amor) and Light (Luce, Lume) in the poem. The result of counting can be shown in a time-series, where "time" is represented by the line of the poem. We find

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[74] E. K. Haller, Dante Alighieri. In Matheson, Lister M., Icons of the Middle Ages: Rulers, Writers, Rebels, and Saints, 2012, Greenwood.

[75] R. Lansing, The Dante Encyclopedia,2011, Routledge.

[76] A. C. Sparavigna, Using Time Series and Graphs in the Analysis of Dante's Divine Comedy. International Journal of Sciences, 2014, 3(12), 33-40.

[77] J. Bainbridge Webster and I. Torrance, The Oxford Handbook of Systematic Theology, 2007, OUP Oxford.

a relevant increasing presence of Light and Love, so that the Paradise is the triumph of Light and Divine Love[78].

Let us stress that Dante uses two terms for light: Luce and Lume. Luce is the Latin Lux and Lume is the equivalent of the Latin Lumen. Also in the Vita Nuova and in the Rime, Dante employs two words to describe the light[79]. To the modem readers, Luce and Lume may appear to be synonyms, but a contextual examination tells us that Dante distinguished them, according to classical and medieval philosophy on nature of light and its components[80]. However, being Dante a poet, he used both terms with a certain degree of creativity, when emphasis was required[81].

The Latin distinguished between Lux and Lumen, even if the words were originated from the same root. We find the two terms widely used in the Bible. Perhaps, one of the most relevant passage is John (8:12): "Iterum ergo locutus est eis Jesus, dicens: Ego sum Lux mundi: qui sequitur me, not ambulat in tenebris, sed habebit Lumen vitae". The Latin antecedent words of Luce and Lume appear together: Lux is the light of the world, that is Jesus. It is different from the Lumen of life, understood as the earthly illumination in the human environment.

From biblical foundations until Dante’s time, the philosophers have constructed theories about the nature of light, its natural and metaphysical features, including distinction between Lux and Lumen. In the century before Dante’s death, philosophers such as our Robert Grosseteste and, after him, Thomas Aquinas, Albert the Great, Bartolomeo from Bologna wrote about light, on its nature as substance and phenomenon, its primacy over other materials during the creation of the world, and the relationship between God and light[82]. In fact, the theories of philosophers of thirteenth and fourteenth century did not agree on these issues, but they shared at least two characteristics, relevant to a discussion of Dante’s poetry.

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[78] A. C. Sparavigna, Using Time Series and Graphs in the Analysis of Dante's Divine Comedy. International Journal of Sciences, 2014, 3(12), 33-40.

[79] G. W. Doebler, Non Mi Può Far Ombra: Le Distinzioni fra Luce e Lume nelle Rime di Dante. Tenzone, 2006, 7, 29-50.

[80] Ibid.

[81] Ibid.

[82] Ibid.

First, Lux belongs to heavens and then to God and divine things. Second, Lux is a phenomenon distinct from Lumen, rays, shine, heat and other things that are considered to be derived from Lux[83].

Dante's works indicate that the poet knew at least the principles of the contemporary theories, and then Dante used Luce and Lume, not only for convenience to the rhythm of the text, but also as technical terms with their specificity[84].

The notion of light, Lux, linked to divine things was not of medieval origin. It was coming from centuries of philosophical speculations that led to metaphysical and cosmological theories. In particular, the Neoplatonic systems were rich in speculations concerning light[85]. Plotinus (c.205 – c.270) was the major Greco-Egyptian Neoplatonic philosopher who first developed a metaphysics of light, in a cosmos where, from the One, an immaterial light is radiating outward; this light is becoming dimmer and dimmer until it shades off into darkness and matter[86]. Augustine (354 – 430) combined the teaching of Neoplatonism and Plato's Idea of the Good with revealed truths, and accepted the Platonic distinction between sensible and spiritual light[87]. Christ is the spiritual Light, Lux, that enlightens every man, although man is free to turn toward or away from the Light. The Augustine's theory of illumination, the Lux that becomes Lumen, like told in John (8:12), had considerable impact on medieval thought. In later centuries of Middle Ages, an amalgamation of Christian, Jewish and Arabian thought led to a fuller development of the metaphysics of light[88].

As previously told, also Thomas Aquinas (1225 - 1274) proposed a philosophy of Light. Although the details of the philosophy of Grosseteste and of Aquinas are different, the relationship between lux and lumen is similar. Thomas writes: "lux est qualitas activa

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[83] G. W. Doebler, Non Mi Può Far Ombra: Le Distinzioni fra Luce e Lume nelle Rime di Dante. Tenzone, 2006, 7, 29-50.

[84] Ibid.

[85] C. E. Schültzinger, The Metaphysics of Light, New Catholic Encyclopedia,2002, vol. 8, Detroit: Gale.

[86] Ibid.

[87] Ibid.

[88] Ibid.

corporis caelestis, per quam agit […]. Ipsa igitur participatio vel effectus lucis in diaphano, vocatur lumen. Et si fit secundum rectam lineam ad corpus lucidum, vocatur radius. Si autem casetur ex reverberatione radii ad corpus lucidum, vocatur splendor. Lumen autem commune est ad omnem effectum lucis in diaphano. […] Nam cum lux sit qualitas primi alternantis, quod est maxime perfectum et formale in corporibus, illa corpora quae sund maxime formalia et mobilia sunt lucida actu; quae autem propinqua his, sund receptiva luminis sicut diaphana; quae autem sunt maxime materialia, neque habent lumen in sui natura, neque sunt luminis receptiva, sunt opaca. […] (Tommaso d'Aquino, De Anima Commentarium. Liber II, Lectio XIII [420-422])"[89].

Lux is the highest form, "qualitas active", while Lumen indicates the propagation of light towards Earth, and also when light encounters a transparent medium. According to Thomas, Lumen is the effect of Lux and a means for its dissemination. Unlike Lux, Lumen is not active by itself. Note that this corresponds to what John told: Jesus is Lux, but Lumen Vitae is something possessed by each man[90].

Therefore, Grosseteste's theory of light and his vision of science had a decisive influence upon the natural philosophers at Oxford and Paris. To a certain extent, he influenced Dante too. In fact, we can find in Dante's poetry several passages concerning the natural phenomenon of light and optics: as told by G. Bottagisio[91], in a book investigating the Divine Comedy to evidence the passages concerning physics, Dante was a poet of physics.

Dante's cosmology was, like that of Grosseteste, a medieval cosmology with nine heavens having the Earth as their common center. Above the starry heaven, there is the crystalline heaven of Primum Mobile, the "first moved", linking God and the universe. The existence of the Primo Mobile depends on nothing else than light and love of God.

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[89] G. W. Doebler, Non Mi Può Far Ombra: Le Distinzioni fra Luce e Lume nelle Rime di Dante. Tenzone, 2006, 7, 29-50.

[90] C. E. Schültzinger, The Metaphysics of Light, New Catholic Encyclopedia, 2002, vol. 8, Detroit: Gale.

[91] G. Bottagisio, Osservazioni sopra la Fisica del Poema di Dante, Nuova Edizione del Testo del 1807, a cura di G.L. Passerini, 1894, Città di Castello, S. Lapi.

“The nature of that motion, which keeps quiet / The centre and all the rest about it moves, / From hence begins as from its starting point. /And in this heaven there is no other Where / Than in the Mind Divine, wherein is kindled / The love that turns it, and the power it rains.” (Paradiso, XXVIII, 106-111, Longfellow’s translation). Time has its origin from the motion of this heaven, “And in what manner time in such a pot / May have its roots, and in the rest its leaves, / Now unto thee can manifest be made.” (Paradiso, XXVIII, 118-120).

In the metaphysics of Grosseteste, we have found the creation through light radiated from a point. Dante does not speak of such a primeval point of created light; he does describe creation as a radiation of divine light or will (Paradiso. XIX, 89-90). Dante explains the motion and functioning of universe, as believed to operate by means of divine and created light. And then, Dante tells us that a ray of divine light strikes the Primum Mobile, that is the Primal Motion (Paradiso. XXX, 100-108), which is completely and uniformly diaphanous. “There is a light above, which visible / Makes the Creator unto every creature, / Who only in beholding Him has peace, / And it expands itself in circular form / To such extent, that its circumference / Would be too large a girdle for the sun. / The semblance of it is all made of rays / Reflected from the top of Primal Motion.” (Longfellow’s translation)

The Primum Mobile takes vitality and power from Lumen: in this sphere, the light is changed into material energy which is transmitted below to the sphere of fixed stars. “Since each star has a unique composition, it receives (from above) and in turn transmits (below)” (Paradiso, II, 112-123)[92]. “God’s light is imparted to the nine orders of angels, each of which conveys this light to the sphere of the material universe in its charge. Subsequent to God’s initial act of creation, and apart from the highest part of each human soul, everything on earth is created and governed by means of light and power given off by the planets and stars (Paradiso, VII 130, XIII, 52, Convivio 2.6.9)”[93]. Therefore, Dante was undeniably influenced by the metaphysics of light, but scholars disagree as to how strictly Dante adhered to these theories.

[92] R. Lansing, The Dante Encyclopedia, 2011, Routledge.

[93] Ibid.

We have seen that Robert Grosseteste was profoundly interested in optics and by the reflection and refraction of light. After metaphysics then, we can ask ourselves what was Dante's knowledge of optics. Giovanni Bottagisio helps us[94], giving us some passages in the Divine Comedy on optics.

In Purgatory, Dante uses a similitude from the reflection of light. "As when from off the water, or a mirror, / the sunbeam leaps unto the opposite side, / ascending upward in the selfsame measure / that it descends, and deviates as far / from falling of a stone in line direct, / as demonstrate experiment and art, / so it appeared to me that by a light / refracted there before me I was smitten." (Purgatorio, XV, 16-23). The light of an angel, who appeared to Dante, hits him in the face as the ray of light, descending from the sun, hits the surface of water, or a mirror, and is reflected to the other side. It is coming out on the same way that it went down, that is, forming equal angles on both sides. Therefore, the reflected ray departs with an angle equal to the incidence angle, from the "falling of a stone", that is, from the line perpendicular to the reflecting surface, "as experience and art are demonstrating". Here we find that the perpendicular line is called the "falling of a stone" by the ancient scholars; Bottagisio tells that this metaphor was used by Albertus Magnus. That is, the perpendicular to a reflecting surface is like the "falling of the stone" to the surface of the ground.

Dante tells that the law of reflection was proved by "experience" and "art", and then we can imagine, as Bottagisio is telling, that Dante had saw some instruments designed to make experiments of geometrical optics. Let us note that the "refracted light" in this Dante's passage is actually a "reflected light"; Dante was using the language of ancient physics, which was not using two different terms for reflection and refraction. We can find the same use of term "refraction" in Robert Grosseteste's works on optics. According to both Dante and Grosseteste, to prove the laws of optics, besides the experience, the Latin "experimentum", we need also the "art", which at Dante's time was known as "catottrica"[95].

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[94] G. Bottagisio, Osservazioni sopra la Fisica del Poema di Dante, Nuova Edizione del Testo del 1807, a cura di G.L. Passerini, 1894, Città di Castello, S. Lapi.

[95] Dante Alighieri. La Divina Commedia, col commento di G. Biagioli, Napoli, Puzziello Libraio Editore, 1838. Vol.2, Page 202.

Some of Dante's most scientific discussions of light are in his Convivio (The Banquet)[96]. In Book 3, Dante distinguishes the sensible light into three features: Luce, Raggio and Splendore. He tells that the philosophers call Luce the light as it exists in its original source (in quanto esso e nel suo fontale principio), as it is in the sun or in a flame of a candle[97]. Raggio is the ray of light, as the light which exists in the medium between its source and the first body which it strikes (in quanto esso e per lo mezzo, dal principio al primo corpo dove si termina). Rays are in fact describing the propagation of light in geometrical optics. Splendore is the light when it is reflected in the space by an object, which it had illuminated (in quanto esso e in altra parte alluminata ripercosso). Dante then was aware of the medieval distinction of the features of light.

The scientific sources that Dante used in the Comedy and in the Convivio were the encyclopedic compilations[98]. For his astronomical knowledge, Dante used the Liber de aggregatione scientiae stellarum of Alfraganus and the Sphera written by John Sacrobosco. The interest of Dante for optics and physics and for the metaphysics of light indicate a knowledge, probably a direct knowledge, of the work of Bartholomew of Bologna[99], who was influenced by Robert Grosseteste. Bartholomew of Bologna, who died about 1294, was an Italian Franciscan scholastic philosopher, follower of John Pecham. Among his works we find the Tractatus de Luce, on optics and the metaphysics of light. Already in 1290, several chapters of the Tractatus de Luce were reported by the Franciscan Servasanto da Faenza, in his work De Exemplis naturalium[100]. In Bartholemew's work, we can find an Oxonian origin of his luministic theory. In the Tractatus de Luce, this theory appears as a natural aesthetic legacy, an aesthetic legacy that in Dante is quite clear. The Tractatus de Luce evidences the Oxonian

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[96] E. Price Sayer, translated by (1887). The Banquet of Dante Alighieri. Project Gutenberg EBook; R. Lansing, The Dante Encyclopedia, 2011, Routledge.

[97] R. Lansing, The Dante Encyclopedia, 2011, Routledge.

[98] C. Vasoli, Dante Alighieri, in "Il Contributo italiano alla storia del Pensiero: Filosofia", 2012, Istituto dell' Enciclopedia Italiana, www.treccani.it

[99] Ibid.

[100] E. Guidubaldi, Bartolomeo da Bologna, 1970, in VV.AA. Enciclopedia Dantesca, vol.1, Istituto della Enciclopedia Italiana, Roma, pp.526-527.

influence either through explicit references to Robert Grosseteste's work, readable in it, either through the clear symptoms of a lesson entirely absorbed by Dante and rendered in his Convivio[101].

Dante's Paradiso begins at the top of Mount Purgatory. After ascending through the sphere of fire, believed to exist in the earth's upper atmosphere (Canto I), Dante enters the heaven of the moon. The moon welcomes Dante within herself, without opening, like the surface of the water when it is receiving a ray of light. On the Earth, tells Dante, we cannot understand how a solid body can penetrate into another solid body, without suffering any change. "It seemed to me a cloud encompassed us, / luminous, dense, consolidate and bright / as adamant on which the sun is striking. / Into itself did the eternal pearl / receive us, even as water doth receive / a ray of light, remaining still unbroken. / If I was body, and we here conceive not / how one dimension tolerates another, / which needs must be if body enter body, / more the desire should be enkindled in us / that essence to behold, wherein is seen / how God and our own nature were united." (Paradiso, Canto II, 30-42). What is the nature of light, material or immaterial? This was the question that Dante was considering, when writing these lines of the poem.

This light further increases the desire for reaching the highest Heaven. After thanking God, Dante asks Beatrice, the soul of his beloved woman that is accompanying the Poet in Paradise, to explain the phenomenon of the dark spots of the Moon. He believes that these spots depend on the different density of this celestial body. Beatrice confutes his argument, by an experiment. The experiment is on the role of distance, between an observed and surfaces reflecting the light. We can take three mirrors, placed at unequal distances from a light source; we will see them equally resplendent, that is, with the same splendor. This experimentum is explained in Paradiso II, v. 89-105. Bottagisio explains that the distance is not changing the quality of the light reflected by the three mirrors.

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[101] E. Guidubaldi, Bartolomeo da Bologna, 1970, in VV.AA. Enciclopedia Dantesca, vol.1, Istituto della Enciclopedia Italiana, Roma, pp.526-527; L. Olschki, Il Canto XXX del Paradiso, Il Giornale Dantesco, 1933, XXXVI; M. Mocan, La Trasparenza e il Riflesso: Sull'Alta Fantasia in Dante e nel Pensiero Medievale, 2007, Pearson Italia S.p.a.

After proposing the experiment with the three mirrors, Beatrice continues with her explanation, which becomes more metaphysical: the brightness of the celestial bodies varies as the force of virtue varies from star to star. This virtue is the heavenly power, that we can find in Grosseteste's metaphysics of light too [12]. Let us also note that Dante, through Beatrice's words, is summoning the use of an "experimentum". The same we can find, for example, in the works of Robert Grosseteste. The Grosseteste's "experimentum" of his medieval physics, like that of Dante, was obviously different from an experiment of modern physics; it was referring to a thought experiment (Gedankenexperiment) or the experience of a related natural phenomenon.

Robert Grosseteste wrote on reflection and refraction in De Iride. As we have seen, in the treatise, after a discussion on the propagation of light he proposed his explanation of such natural phenomenon. The rainbow was a subject very attractive for Dante too. In the Divine Comedy, we find "And even as the air, when full of rain, / By alien rays that are therein reflected, / With divers colours shows itself adorned." (Purgatorio XXV, v. 91-93).

In fact, if we imagine that the meaning of Dante's reflection was that of a refraction, it seems that the poet was in agreement to Grosseteste, who told that it is "necessary that the rainbow is created by the refraction of the sun's rays by the humidity carried by the cloud" in its convexity. "Necesse est ergo, quod iris fiat per fractionem radiorum solis in roratione nubis convexae".

Also the double rainbow is present in the Dante's Comedy, with the second rainbow being the image of the first reflected by the cloud. "And as are spanned athwart a tender cloud / Two rainbows parallel and like in colour, / When Juno to her handmaid gives command, / The one without born of the one within." (Paradiso, XII, 10-13).

These Dante's passages on rainbow are reinforcing what we have previously told on the scientific treatises that he knew. May be, he had not a direct knowledge of Grosseteste's works, but in Dante's works we can see some of the Oxonian theory of light rendered in poetry. It seems evident that Dante adhered to a general philosophy of light that was shared by several thinkers of the Middle Ages, but his interest for optics, which is displayed by the Comedy and the

Convivio, is illuminating a strong link between the Poet and Robert Grosseteste.

The Heat of The Sun

Here we start the discussion of another Grosseteste's treatise, that entitled De Calore Solis, on the Heat of Sun.

The study of the heat and related phenomena has a long history. The first to have proposed a theory on heat was Heraclitus, the Greek philosopher who lived around the 6^{th} century BC in Ephesus. He is well-known for his proverbial "Panta rhei", all things are flowing. According to Heraclitus, the four classical elements of nature (air, water, earth and fire) are subjected to transformations, which are the replacement of one element by another: "The death of fire is the birth of air, and the death of air is the birth of water."[102] He saw the fire as the central element, controlling and modifying the others elements. The universe was in a continuous state of flowing as a result of transformations caused by the fire.

The ancient Greek philosophy imagined the universe created by four elements then. Quite probably, Plato was the first to use the term "element", "stoicheion", in reference to air, fire, earth and water. The Greek word "stoicheion" is meaning "smallest division" or "syllable", the smallest unit used to create all the words; therefore, by analogy, all the things are composed of elements such as the words of syllables. Moreover, according to Aristotle, the elements have some features: he tells that air is wet and hot, fire is hot and dry, earth is dry and cold, and the water is cold and wet[103]. And, because these four elements are corruptible, Aristotle added the incorruptible Aether as the fifth element, or essence, the quintessence, and since we do not see any changes in the heavenly regions, the stars and skies above the Moon must be made of it.

The Hellenistic period, a period between the death of Alexander the Great in 323 BC and the emergence of ancient Rome, saw the

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[102] The Art and Thought of Heraclitus: A New Arrangement and Translation of the Fragments with Literary and Philosophical Commentary Cambridge University Press, Sept. 3, 1981.

[103] A.C. Sparavigna, Robert Grosseteste and the Four Elements, International Journal of Sciences, 2013, Volume 2, Issue 12, Pages 42-45.

flourishing of science. In the Egypt of this Hellenistic tradition, under the Roman Empire of the first Century CE, Hero of Alexandria invented a steam-powered device[104]. However, it was only in the late 18th century that heat engines, having the steam as working fluid, were developed and used on a large scale.

The Hellenistic cultural and scientific tradition continued in the Arabic world. In the Western Europe, after the fall of its part of the Roman Empire, it started a decline of the knowledge of Greek, and so the Christian Western Europe was cut off from an important source of ancient learning.

Although some scholars maintained some spirit of scientific inquiry, the Europe saw a certain stagnation. However, during the High Middle Ages, a period starting from the 11th century, the West Europe had begun to reorganize its scientific thought. This was stimulated by the fact that some of the ancient works of the Greek philosophers re-entered the West through translations from Arabic to Latin[105]. Their commentaries of the ancient philosophers had a great influence on medieval scholars, who mixed them with the Christian theology. Eventually, Aristotle was claimed as the greatest thinker of the ancient world, and the Aristotelian physics became the physics mostly accepted by the European Churches.

Based on Aristotelian physics, things are moving according to their essential nature, that is, according to the elements in them. The motions in the sublunary world, that is, on Earth, were based on the tendencies of elements. Stones contained the element earth, and earthy objects tended to move naturally in a straight line toward the center of the earth, which is the center of the universe, unless otherwise prevented from doing so by some violent action. Fire has the tendency to move upwards. Celestial objects, which are made of the fifth essence, are moving in circles, because circular motion is a never ending motion and therefore perfect.

For what concerns the heat in this Aristotelian framework, it was in the 11th century that al-Biruni (Abū Rayhān Bīrūnī),

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[104] A.C. Sparavigna, Water, Air and Fire at Work in Hero's Machines, Archaeogate, 2011, January 24.

[105] A.C. Sparavigna, From Rome to the Antipodes: The Medieval Form of the World, International Journal of Literature and Arts, 2013, Volume 1, Issue 2, Pages 16-25.

proposed movement and friction as causes of heat, which in turn produces the element of fire[106]. For this reason, the apparent lack of movement of the Polar Regions causes them to be cold. The earth and the water form one globe, surrounded by the atmosphere. But, the atmosphere is in contact with the sphere of the Moon, and becomes heated as a consequence of the friction between the spheres. In this manner, the fire is produced, surrounding the air. Also Avicenna says that heat is generated from motion in external things, whereas is generated inside in the living beings.

In the 13th century, the Islamic philosopher Abd Allah Baydawi discussed the heat in the same manner. Hot and cold are among the most obvious and plain sense perceptions. Heat has the specific ability to separate different elements and to join elements that are similar, for instance, when boiling water to vapor. The heat is then producing flux and circulation, and melting, according to the coarseness of the thing (in the Grosseteste's treatise on the Elements, that we will discuss in a further chapter, we find a reference to the coarseness too). Baydawi considered a natural and an artificial heat, and that the artificial heat may occur through motion-change, the proof of this being through experiment[107]. In reading the treatise De Calore Solis, On the Heat of the Sun, we will find that Grosseteste is invoking the motion as a source of heat too.

De Calore Solis

Since our main aim here is the discussion of the heat of the Sun, let us first of all inquire, in general, what is the principle of generation of heat. That is, how many and what are the principles of heat generation. Since they are three, that is, hot bodies, motions and concentrations of rays, it is better to know that in these three cases

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[106] A.C. Sparavigna, The Science of al-Biruni, International Journal of Sciences, 2013, Volume 2, Issue 12, Pages 52-60.

[107] Vv. Aa., Nature, Man and God in Medieval Islam, Islamic Philosophy Theology and Science, Texts and Studies, Edited by H. Daiber and D. Pingree, Volume XLV, Brill, 2002.

there is a heat of a single nature involved (univocal heat[108]). This univocal heat produces a univocal effect. When, therefore, there is a univocal undergoing effect, we shall find a univocal cause: in fact, every univocal effect has a univocal cause.

It is clear that the heat in all these things is univocal: because heat generated in any of these manners has the same power, makes the same accomplishment. Let us stress that this is not stated in an equivocal sense, open to more than one interpretation, but in a univocal sense. Therefore, let us search this univocal cause! In all of them, the immediate cause of heat is disgregation. Hence then, a hot thing generates heat, doing it by the disgregation of its matter. In what way, however, this disgregation is occurring in movement and in condensation of rays, it is difficult to see.

Now, the local motion, from which heat is generated, is divided into natural motion and violent motion. The natural motion is divided into straight motion and circular motion. First, we speak about the violent motion, that is, about a heavy body violently moved. It is referred that a heavy body is violently moved in three ways: up, down, or down, however not directly to the center (of the Earth). In all these cases, in a violent motion, it appears that a disgregation exists as a result of the motion. Indeed, in a violent motion there is a two-fold power, that is, natural and violent, which moves every part of the mobile in different directions. Then, from this tendency to different directions follows disgregation. And thus, as a result of the violent motion, it is necessary that what is moving is disgregated according to its parts, and thus we have heat. And because in the first of the violent motions (upwards), there is the greatest opposition in the inclinations of the two motive powers, because they tend to move in opposite directions at all, we have as a consequence the largest disgregation and heat; in the second and in the third motion, however, the generation of heat is moderate. And this is very clear from the use of reason and experiment.

The same thing is clear in the natural motion. For, heat is generated in the motion during which an object is naturally moving downwards. There is a twofold power, and accordingly a twofold force, namely natural and violent, that actually moves

[108] In the Latin text, Grosseteste defines the heat as "univocus", and therefore I translated it as "univocal", in the sense of "being of a single kind".

every part of the object. The fact that there is a natural force is evident. But we can prove that there is a violent force too: any object that is heavy and moving downwards, but not towards the center of the Earth, is moved violently. All the parts of the body do not move downwards, directly towards the center of the Earth. Therefore, all the parts of the body move violently.

I prove the minor: the parts of a heavy body always keep the same distance (from each other) in general. Since, then, when they are moved downwards as a whole, they are moved on parallel lines, that is, on lines that are equidistant. Moreover, the equidistant lines, extended to infinity, from one part or the other, will never meet. Therefore the parts of the body that moves naturally downwards, move on lines which never meet, therefore, they do not move towards the center of the Earth, because if they moved directly to the center, they would move on lines running together, converging towards the same center. Thus, it is obvious the following principle, that, accordingly, on each part of the body moving naturally downwards, there is a two-fold force (a natural force and a violent force), tilting to different directions. However, the opposition between these two forces is small compared with the great opposition of stresses among the parts of a body in violent motion. And therefore, among all the motions which are generating heat, in the natural motion we have that the minimum amount of heat is generated.

From these arguments, it is clear that there is only one cause which is generating heat from the natural straight motion and from the violent motion and heat from a hot body.

In the third (generation of heat) too, it is clear this similarly: that, indeed, from a collection of rays some heat is generated by the univocal cause of heat. This is clear according to "Of the Mirrors", where it is told that some tinder is ignited by a concave mirror placed at Sun: and this happens because of a disgregation. In fact, a ray in a dense transparent medium is more incorporated than in a subtler medium; we are not telling of a complete incorporation as it happens in heat, but a slight incorporation of it. However, due to this incorporation, the ray is dragging some air along; that is, when the rays are collected in the same point, at this very point, where each ray is coming along its straight pattern, we have a large dispersion of air in different directions; and so it will be disgregation and, as a consequence, heat. Then, it is clear that in these three kinds of hot there is a univocal cause.

Let us consider now the heat generated by the Sun. If, then, the Sun is generating heat, it will be as a hot body generates heat, or as motion generates heat, or as a concentration of rays generates heat. That the Sun does not generate heat as heat is generated by a hot body is clear from the following: it was proved in VII book of Physics by Aristotle, that it is necessary that the agent which is producing an alteration and the object which is to be altered need to be in immediate contact. Therefore, if there were a medium between the first, which is producing an alteration (alterans), and the last, which is altered (alteratum), it would be necessary that this medium were previously altered by the heat of the hot Sun, before altering the last object (alteratum) otherwise the abovementioned "alterans" and "alteratum" would not be in immediate contact.

Therefore, being between the Sun and air several media, and, nearest the Sun, which is altering by means of its heat, there is the quintessence or a portion of quintessence, it is necessary that this fifth element be previously altered by the heat of the hot Sun, before the air being altered. But this is impossible, because if it were alterable, it would be corruptible. Therefore the first manner is impossible, that is, it is impossible the Sun heats in the manner that a hot body generates heat.

Somebody could tell by chance that the heat in the Sun is virtually hot as the pepper is. But there is not agreement. Because the hot of the pepper is virtual not actual, it does not move, it cannot be moved, it cannot alter or being altered. And the same it would be for the Sun. But this is impossible: therefore this assumption is false.

That the heat is not generated from the motion of the Sun is clear too. In the same manner, the motion does not generate heat, unless in each part of the moving body there are some different tendencies to move the parts in different directions. But in everything that is moved circularly and not violently, any chosen part of it has the same inclination of the whole and there are not differences: each part has the inclination to move on a circular motion. Therefore from the circular motion it is impossible to generate heat. But, perhaps, you would say that the cause of the heat is not inside of what is moved in a circular trajectory, but it is from the outside, just as it is in the lower world from the resistance of the medium. This, however, has a twofold falsehood: one is because in the lower bodies, the resistance of the medium is not the source of the heat produced during motion[109]. Because, if it were so, it would be that, because the medium can offer equally resistance to that which is moved naturally, and to that which is forced to move, heat would be equally generated in the violent motion and in the natural motion. But this is false, as it is clear by experience: and therefore the former is false too. The other reason why it is false is in the fact that the Sun and the other stars, when moving, do not have resistance, because they are not moving by their own movements, but, since they are fixed in their own spheres, they are moving through the motion of their spheres like a ship in a river, which is moved by the motion of the river, as the Philosopher proves in his book about heavens and world.

The only possibility which remains is that the Sun generates heat through concentration of rays. This is clear: the rays of the Sun are, to some extent, incorporated in the transparent volume of the air, which is naturally dense; but the rays of the Sun falling on the surface of earth, which can be plane or concave or convex, are reflected at equal angles, as it is shown by the last of the principles in the book "On the Mirrors". Then, if the rays fall perpendicularly, they are reflected perpendicularly; and for this reason the ray are falling and reflected along the same path, in the completely opposite direction, and there is the largest disgregation; this happens at latitudes of the equator[110], when the Sun is passing through the Zenith of these regions, and in the places declining from the equator, towards south or north, which have a latitude less that the latitude of the tropic of Cancer or less than that of the tropic of Capricorn, in the other hemisphere.

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[109] In the Latin text, there is the term "ageneratix", which seems quite odd. I translated it as "source". See also, A.C. Crombie, Science, Optics and Music in Medieval and Early Modern Thought, Continuum International Publishing Group, 1990.

[110] Grosseteste calls it the equinoctial circle. This is the great circle on the celestial sphere midway between the celestial poles. Then, we have the two tropical circles. One of them is called the Tropic of Cancer. When this circle was named, the Sun passed through the Zenith at its latitude, when was also in the direction of the constellation Cancer (Latin for crab). However, this is no longer true due to the precession of the equinoxes. The word "tropic" comes from the Greek "tropei", meaning "turn", referring to the fact that the Sun appears to "turn back" on the solstices.

And then it is necessary, in those places, that the rays of the Sun twice a year fall perpendicularly upon them. In a place, however, the latitude of which is equal to the latitude of the tropic of Cancer or of Capricorn, it is necessary, that the Sun reaches the Zenith once a year and once a year it sends its rays perpendicularly to these places, and then, when this happens, in those places we have the largest disgregation and the highest temperatures. This is a violent disgregation, which is usually made out from a collection of rays refracted through a spherical body, or reflected from a concave mirror, but in these cases, the rays are not deviated in the completely opposite direction.

But in the climatic zones, where the latitude from the equator is greater than the tropic of Cancer, in northern regions then, because the Sun does not reach the Zenith, the rays fall at angles smaller than the right angle and are reflected according to them, therefore not reflected in the totally opposite direction. And the more distant the place is from the equator, the more obtuse the angles at which the rays fall and are reflected and the less the disgregation and heat generated. This is also shown by the experience.

If, however, it is asked, why heat is not generated in the fifth essence from the rays of the Sun, it is possible to reply in two manners: first, because they do not intersect themselves after reflection; moreover, even if they intersect after reflection in the totally opposite direction, they do not generate heat or warmth. For, since this transparent medium does not possess a dense nature, the solar rays are not in any way incorporated in it, and then they cannot disgregate in any way the parts of matter. And so, also in the highest layer of air, where the air is rarefied, the heat is minimally generated, as shown by observations. There is plenty of snow on the top of mountains, where the solar rays are brighter than in the valleys, and there is the reflection of rays as in the valleys too; however, because of a lower density of air there, the atmosphere has a smaller density and therefore a little incorporation of light with air, and a small disgregation of parts of air when rays are collected. Here, (at sea level), we have a larger incorporation of rays and as a consequence a greater disgregation and heat.

The end.

Discussion of De Calore Solis

Other published translations of De Calore Solis had been previously proposed[111]. In the first part of this treatise, Grosseteste is talking of the phenomenon of disgregation, “disgregatio” in the Latin text, as the source of heat. The Latin “disgregatio” is the dispersal of an object in several parts and then a process of separation. In the translation, I used “disgregation” because it was used by Clausius too, instead of the term “scattering” used by A. C. Crombie.

Between 1850 and 1865, the German physicist Rudolf Clausius, had the necessity to find some terms useful for the new science of thermodynamics. He used the “caloric”, introduced in 1780, by Antoine Lavoisier, for the substance of heat. In 1862, Clausius linked the integral of dQ/T, the ratio of heat exchange and temperature, to something he called “disgregation” of the body, having relation to the arrangement of molecules of the working body. This happened after reading the Carnot’s 1824 paper “On the Motive Power of Fire” that characterized the transformations of working substances in an engine cycle. In 1865, dS=dQ/T was defined as the transformational content of the working body and then it became the entropy, so to have similarity to the word energy. The term “entropy” is coming from the German “entropie”, from Greek “entropia”, a turning toward, from “en”, in, and “trope”, a turning[112].

Going back to his treatise, let us stress that Grosseteste is proposing that the heat we observe in several phenomena is the same physical quantity. Heat from hot bodies, motions and rays of light is produced according to the same principle of disgregation. In the case of the heat produced by the rays of light, it is due to the light incorporated in a medium.

Crombie explains the Grosseteste’s theory in the following way[113]: Grosseteste “concluded that all hot bodies generated heat

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[111] A.C. Crombie, Science, Optics and Music in Medieval and Early Modern Thought, Continuum International Publishing Group, 1990; G. Kish, A Source Book in Geography, Harvard University Press, 1978; R.C. Dales, The Scientific Achievement of the Middle Ages, University of Pennsylvania Press, 1973.

[112] P.M. Harman, Energy, Force and Matter: The Conceptual Development of Nineteenth-Century Physics, Cambridge University Press, Apr 30, 1982.

[113] A.C. Crombie, Grosseteste, in the Dictionary of Scientific Biography, Scribner, 1981, Pages 548-554.

by the scattering of their matter and that the sun generated heat on the earth in direct proportion to the amount of matter incorporated from the transparent medium (air) into its rays". In this framework, Grosseteste ends the treatise with a discussion on the climatic regions of the earth, according to the inclination of the rays of Sun. Geography and astronomical science are the subject of another treatise, the De Sfera[114], written according to the Scholastic astronomy.

Let us remember that the incorporation of light in matter is used by Grosseteste also in discussing the colours. In fact, to the philosopher, colours appear when the light is mixed with a transparent medium, according to the purity of it and the brightness and intensity of rays. When causing the heat, the rays of light are incorporated by air. This conclusion was probably argued by Grosseteste, after observing the scattering of light by the particles of dust and the consequent visibility of their motion.

The Impetus of Elements

De Impressionibus Elementorum is a treatise written by Grosseteste shortly after 1220 AD. In this treatise we can find a discussion of some phenomena involving the four classical elements (air, water, fire and earth), in the framework of an Aristotelian physics of the atmosphere.

For its referring to experiments, this treatise can be considered as one of his scientific treatises. Moreover, it contains some remarkable descriptions of phase transitions which are rather interesting.

Grosseteste is in fact discussing how an element can be changed, for instance the ice in water and the water in vapor, by using heat and fire. Quite interesting is also Grosseteste's discussion of bubbles.

The physics of atmosphere was the subject of one of Aristotle's works, On Meteorology, that Grosseteste mentioned in the "De Iride". On Meteorology contains the theories of the Greek

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[114] M.F. Dowd, Astronomy and Compotus at Oxford University in the Early Thirteenth Century: the Works of Robert Grosseteste. Dissertation, Notre Dame, Indiana, June 2003, available at www3.nd.edu.

Philosopher about the earth sciences, including the water evaporation, some weather phenomena, and earthquakes. As previously told, the Aristotelian physics was based on the four classic elements (Air, Water, Fire and Earth), to which the Philosopher added the Aether. This is the quintessence, the fifth and highest element in ancient philosophy that permeates all nature and is the substance composing the celestial bodies. Aristotle is then describing in On Meteorology a spherical lithosphere (Earth), a hydrosphere (Water) and the atmosphere (Air and Fire), surrounding them.

Aristotle considered that the vapor which is formed during the day rises in the atmosphere to form the clouds, however not too high, because the heat that is raising it "cannot lift it to a great height but soon lets it fall again"[115]. Not surprisingly, Aristotle is considered the father of climatology and geophysics[116].

After this short remark on the Aristotelian ideas on earth and atmosphere, we can read the Grosseteste's "De Impressionibus Elementorum". This title is usually translated as "On the Impressions of the Elements". Let us note that "impressio" in Latin means "assault, impetus, vehemence," and, figuratively, "perception"; then another translation of this title could be "On the Impetus of the Elements", a title good to enhance the presence of physics in the Grosseteste's approach.

According to R.C. Dales, in this treatise, written shortly after 1220, the main features of Grosseteste's scientific method are clearly in evidence, so that it strongly differentiates from similar works of the 12th century[117].

At the beginning of the 13th century, some of the medieval scholars were strongly influenced by the Aristotle's philosophy, which had begun to circulate in France in Arabic translation,

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115 Aristotle, Meteorology, Book 1, Part 10, translated by E.W. Webster, available as classics.mit.edu/Aristotle/meteorology.mb.txt.

116 M. Allaby, Atmosphere: A Scientific History of Air, Weather and Climate, Facts On File Inc., Infobase Publishing, New York, 2009; C. Donald Ahrens, Essentials of Meteorology: An Invitation to the Atmosphere, Cengage Learning, Dec 30, 2010.

117 R.C. Dales, The Scientific Achievement of the Middle Ages, University of Pennsylvania Press, 1973.

introduced from Spain[118]. With this Aristotelian revival, we have a reassessment of using the four classical elements in discussing physics, to feature the simplest principles which are ruling the world. Most frequently, these classical elements refer to the phases of matter and then the Earth is a solid, Water a liquid, Air a gas, and Fire is the heat. Even in the poetry and religious songs of the 13th century we find the four elements to describe the Creation, such as in the Cantico delle Creature, composed by Francis of Assisi[119].

Here in the following I am giving a translation of the Latin text[120]; A translation of this work was also given by R.C. Dales[121]. The aim of my translation is that of enhancing physics.

De Impressionibus Elementorum

As told by James in his letter (James.1.17) "every best thing and every perfect gift is coming down from the Father of Lights, with whom there is no mutation or shadow of change". However, let us consider that, under some circumstances, this is immediately resulting, but in other cases it needs mediation. Therefore, the philosophers, even if they are not perfectly able of understanding the facts, ought not to be ignorant of the nature of things: and so,

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118 J.L.E. Dreyer, A History of Astronomy from Thales to Kepler, formerly titled, History of the Planetary Systems from Thales to Kepler, revised with a foreword by W. H. Stahl, Dover Publications, 1953; Medieval History, by Lynn Harry Nelson, Emeritus Professor of Medieval History, The University of Kansas. The text is available at the web page http://www.vlib.us/medieval/lectures/gerbert.html

119 Francis of Assisi was born in 1182. Son of a wealthy merchant in Assisi, he lived as a wealthy young man. After a pilgrimage in Rome, he started to live in poverty as a friar, and founded the Franciscan order, authorized in 1210 by Pope Innocent III. He is considered the author of the "Cantico delle Creature", in English known as the Canticle of the Sun. This is a religious song, considered to be among the first works written in the Italian language. In it, besides Brother Sun and Sister Moon, the Canticle thanks God for Brother Wind, Sister Water, Brother Fire and Mother Earth, that is he thanks God for the Creation. Francis of Assisi composed most of the canticle in late 1224 while recovering from an illness, the end of it on his deathbed on 1226.

120 The Latin text is that given by "The Electronic Grosseteste", ttp://www.grosseteste.com, which is reporting the printed source: Ludwig Baur, Die Philosophischen Werke des Robert Grosseteste Bischofs von Lincoln, 1912, Aschendorffsche Verlagsbuchhandlung, pages 72-78.

121 R.C. Dales, The Scientific Achievement of the Middle Ages, University of Pennsylvania Press, 1973.

they do not ignore that the rays of the heavenly bodies falling upon the physical things provide the greatest cause of their changes, such as the rays that, when reflected and condensed, are the cause of heat generated among us. A proof of this is the fact that the heat is greater in the valleys than on the mountains; and then snow remains longer on the mountains than in the valleys; and on some high mountains snow remains perpetually.

And let us note that it makes no difference, that the sun is hot in itself. For if the body of the sun were considered as hot in itself and its heat exciting heat in the things below it, then the closer a thing were to it the warmer it would be, and on the tops of the mountains there would be greater heat than in the valleys and in the upper and medium layers of air more heat than in the lower layer; but we see all the opposite facts, because the snow remains on the tops of the mountains, not in the valleys; and in the upper layer of air the hail is generated and in the lower the rain. A sign of the same: the birds of prey in the summer fly high to cool themselves, like the eagles flying very high, to mitigate the heat generated from their movement; they fly so much. The cranes and many other birds come down in the valley to escape ice and frost; on the other hand, to escape hot climate they go up to the mountains. And all these are signs of the same, that is, that heat is not transferred directly from the solar body, but from the reflection and condensation of rays.

Under these conditions it is clear that the rays go down deep in the water, being the water a transparent medium such as air, icicle and glass. Therefore, some deviation of rays exists in deep waters, then, the heat is greater at the bottom than at the surface. Hence, at the bottom of waters, the fishes live during the winter, but, in summer, they can live near the surface; during the winter, the water is frozen at the surface, however, not in its depths.

If anyone asks the following, that is, why the water congeals when it is very cold, being coldness its natural power, as it seems to be humidity and fluidity, we answer to this person that all the water is naturally cold, but not fluid; by its nature, it is frozen indeed. The fluidity results from the heat absorbed, for softening the bulk.

Again, the rays reflected from a concave mirror generate fire and tinder is ignited. Therefore, having established that the heat is clearly coming from a condensation of rays, we have that, being them condensed in the bulk of water, the water is heated, and even heated so much that it does not keep its nature of water: it passes, therefore, to the nature of the air. But, to the nature of the air, it is not proper being under the water: it comes out, over the water, and rises in a bubble as in an ampoule made of the same water. However, when several bubbles ascend on the water, due to the nature of their wet films, barely can they remain themselves, and from them, vapor or steam is formed, by which the clouds are made. But, when the generation of bubbles is in the depths of the waters, some of these bubbles pass through the earth, some remain in the waters, and some rise above the water.

Let us first talk about what is rising. If anyone wants to see this directly, put some clear water in a clear vessel, and you will perceive clearly the bubbles generated and rising, created by the heat of the fire being placed under the vessel. Let us remark that we have the same mode of generation of bubbles as discussed here and as previously told.

We have to note yet that with air and bubble there are earth and fire. In the bubble, therefore, there are the four elements, that is, the earth because of the place of generation, the air which is generated, the nature of fire during the generation of heat, and of course some water. Then, here we find a sort of first generation of the elements and the first mixture of them. When there is an abundance of water in the generated bubbles, that is, when they rise from water, we call it "humid vapor"; when earth is abundant, we call it "dry smoke"; when air is predominant, we call it "dense vapor". Then, the rising vapor rises according to the quantity, coarseness and subtlety of the generation of heat. If the heat is great and coarse, the generated bubble is great and coarse and heavy. Sometimes, it is rising just to the surface of water and there breaks imperceptible and the heat evaporates. And when the heat is more subtle, the bubble is more subtle and then weaker the heat that evaporates.

Then, bubbles do not separate from the earth surface and float here and there in the valleys. However, this occurs in the evening and in the morning, when the heat is weak, and so mist is formed. And when these small bubbles dissipate their heat, fall on the earth surface and create dew. However, if the heat is greater, it makes these aforementioned bubbles to rise at the first layer of the atmosphere. There are a first, a second and a third layer in the atmosphere. The third, however, is not at a height greater than fifty miles, as the Philosopher (Aristotle) says. The clouds are in the first atmospheric layer: sometimes each bubble loses its heat, and, being in the cloud, moves itself in the depth of the cloud. And then, the bubbles separate from each other and fall as small droplets. Drops occur indeed, although the cloud is continuous, and because it had not entirely deprived of heat, the rain falls, fluid and not frozen. By the way, let us note that the generations of rain and dew differ according to size and according to the different places of generation.

However, when the cloud rises to the second layer, there is a further loss of heat, and then the bubbles are left utterly deprived of their heat at a subsequent stage, and for this reason we have that they remain soft as wool, and become snow. However, if the cloud is suddenly rising to the second layer, suddenly is the heat lost and round stones, as the bubbles round, appear and hail is generated. This occurs especially when it is hot. However, hoar-frost is different from the ice coming from clouds, such as rain differs from dew.

The Four Elements

When Grosseteste was bishop of Lincoln, he used to end the treatises writing “Explicit tractatus secundum Lincolniensem”. Here, there is not this sentence: it means that the treatise was written before 1235, in fact shortly after 1220[122].

At the beginning of the treatise, Grosseteste is addressing the problem of heat transfer. We know that there are three methods by which heat is transferred: conduction, convection, and radiation. Conduction and convection are supported by solid and fluid media. But they cannot account for some of other phenomena, for instance, the heat we feel when sitting in front of a fire or under the sun. And then is seems that Grosseteste knew this aspect of the heat transfer, in particular by radiation, as distinguished by conduction. Let us also observe that Grosseteste noted a temperature gradient in the water of lakes and linked the temperature of water to the life in

122 R.C. Dales, The Scientific Achievement of the Middle Ages, University of Pennsylvania Press, 1973.

the lakes. However, the behavior of the thermal gradient in a lake is rather different[123].

The element Water, Grosseteste explains, is cold and wet. This is in agreement with Aristotle: in “On Generation and Corruption” of the Greek philosopher, Water is primarily cold and secondarily wet, that is, the water is defined more by cold than by wet[124]. Therefore, Grosseteste continues, the Water, which is naturally cold, becomes fluid because of heat. For the other elements: Air is primarily wet and secondarily hot, Fire is primarily hot and secondarily dry and Earth is primarily dry and secondarily cold. That is, we have four elements and four features (wet, dry, hot, cold) that can be used to describe the natural phenomena, and, among them, the phase transitions.

In reading the treatise then, we find that Grosseteste is talking about the phase transition from solid to liquid, the melting of ice, and that is happens because heat is absorbed. The phase transition occurs due to a change in energy of the participating particles. If the water is in the solid phase and the kinetic energy of molecules is sufficiently increased, we change the solid to liquid. In the solid phase, the molecules prefer to assume the lowest energy assembly: after the transition in the liquid phase, the total energy is larger. Let us say that Grosseteste was arguing that “cold” means a lower energy state of a substance.

For what concerns the bubbles, let us consider the following interesting fact: in his Latin text, Grosseteste is not using the word “bulla” for bubble, but he prefers “ampulla”, ampoule, which is a small glass vial. It means that he observed that these bubbles were objects, which were spherically contained volumes of vapors, made from a liquid. Rising at the surface of water, the wet films forming the bubbles break and the vapor inside them creates a cloud of steam, as we can easily see, as Grosseteste is suggesting, by observing the boiling water in a vessel.

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123 B. Boehrer and M. Schultze, Stratification of Lakes, Reviews of Geophysics, 2008, Volume 46, Issue 2, Pages 1-27.

124 M. Krizan, Elemental Structure and the Transformation of the Elements, in On Generation and Corruption, in Oxford Studies in Ancient Philosophy, Volume 45, Brad Inwood Editor, Oxford University Press, 2013.

It is suitable to remember that evaporation and boiling are different, and surely Grosseteste noted the difference, because he tried to distinguish the great and coarse bubbles from the very subtle ones. The boiling of a liquid happens at the boiling point of it, that is, at the temperature at which its vapor pressure equals the environmental pressure. At the boiling point, the vapor pressure overcomes the atmospheric pressure and it is allowed the bubbles to grow in the bulk of the liquid and rise. However, liquids may change to a vapor at temperatures below their boiling points through the process of evaporation. Evaporation is a surface phenomenon in which molecules escape outside the liquid as vapor, without bubbles; boiling is a bulk process in which molecules escape, resulting in the formation of vapor bubbles within the liquid.

Besides boiling, bubbles are present in the so-called effervescence process, which is the process creating the sparkling wines. It is the result of the interplay between CO_2-dissolved gas molecules, tiny air pockets trapped within microscopic particles during the pouring process, and liquid properties (in[125] it is summarized the physicochemical processes behind the nucleation, rise, and burst of bubbles found in glasses poured with sparkling wines). However, even tap water produces some bubbles too. The water has air dissolved in it. The amount of air that can be dissolved increases with pressure but decreases with temperature. Water in the tubes is usually colder than room temperature, and then the solubility of air in it is higher: as the water is poured, it warms up and the solubility of air is reduced. The air comes out even creating some bubbles. In fact, the air solute molecules can cluster together to form nuclei. When these nuclei are trapped by some defects on the glass surfaces, they start growing forming bubbles in the solution.

Experimenting with tap water, we see a slow formation and growth of bubbles, but if carbonated water is used, due to the excess of CO_2-dissolved gas, the bubbles form and grow rapidly. Supposing that Grosseteste observed the evaporation of water and the contemporary formation of the bubbles from the air dissolved in it,

[125] G. Liger-Belair, G. Polidori and P. Jeandet, Recent Advances in the Science of Champagne Bubbles, Chem. Soc. Rev., 2008, Volume 37, Pages 2490-2511.

or even the bubbles in wine, he could have argued that evaporation was accompanied by the formation of very subtle "bubbles".

After his observations on bubbles, Grosseteste describes the mist or fog forming from the surface of water bodies, and connects it with evaporation. The fog is due to the vapor that condenses into tiny liquid droplets in the air. Observing these small droplets in the fog, Grosseteste imagined their origin from vapor through its "bubbles". When vapor rises in the atmosphere, we have a cloud, a visible mass of liquid droplets or frozen crystals.

As previously told, Grosseteste is following the Aristotle's model of the atmosphere, a model that persisted for centuries essentially unchanged[126]. Besides the effort of explaining the meteorological phenomena, it is interesting the Grosseteste's description of the phases of matter, solid, liquid and vapor, and the transition between phases because of the heat involved in the process. Moreover, it is remarkable that he considered the solid state of water as its fundamental state, being necessary some heat to gain its fluidity.

Grosseteste and the Sound

De Generation Sonorum is a short scientific treatise written by Grosseteste. The subjects are sounds and phonetics. In this treatise we find the medieval philosopher discussing oscillations and elasticity of materials as the source of sound. For what concerns phonetics, he uses some motions and their combinations to describe movements of breath and articulators in producing the voice.

In De Generatione Sonorum, sound is shortly discussed at the beginning of the treatise, which quite soon departs from physics to arrive into the main topic of the treatise, the phonetics, that is, the creation of sounds by the mouth to have syllables and words. However, this treatise contains some physics of motion in the discussion of vowels and consonants. In fact, Grosseteste uses an analogy with motions and their combinations to describe how the breath and the organs of speech are creating the voice.

In this treatise then, we can find that Grosseteste considers several motions, which can be rectilinear, circular, vertical or transversal,

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126 F.J. Malina, Jet Propulsion Laboratory, Is the Sky the Limits?, at www.olats.org, on 13 Dec 2013.

and combines them to have seven “species” of motion. These are not the simple classical seven types, up/down, right/left, forward/back, and rotary, proposed by Philo of Alexandria in his treatise On Creation[127]: the Grosseteste’s motions are quite complex, suitable to be applied to mechanics in order to describe how the parts of some machines can move.

De Generatione Sonorum

When a medium able to sound is struck violently, some elements of this medium are moving out from their natural positions, to which they come back constrained by the nature of the medium; and, in such a manner, because of the strength of the attraction, by which the moving parts are affected, they completely return at their natural positions, and even have a further progression towards not natural positions; and the natural inclination of the medium, again, drives back the material at the natural position and then a subtle tremor is created at the ends of the medium. And this tremor is evident by touch and sight.

Such vibrations of each small part of the medium are necessarily a result of their displacement from the natural position, consisting in an elongation of the longitudinal dimension and a contraction of the transversal dimension; and, conversely, when returning towards the natural position, we have a contraction of the longitudinal dimension and an elongation of the transversal one. And this motion of expansion and compression in each part of the medium, where the local motion of vibration is consequent, is the sound or the natural sounding promptness. And when the parts of the sonorous medium are moving, they move the air near them, which, having a similar motion, creates a motion which arrives into the ears and this effect on the body is not hidden to the soul and creates the sense of hearing.

Moreover, we have the first moving reasons of the parts of a sounding medium in the following ways: either the motive force is internal the very sounding medium or external. The very reason of

[127] Philo of Alexandria was a Hellenistic Jewish philosopher. Philo used the allegory to attempt a fusion of Greek and Jewish philosophy. Philo's Treatment of the Number Seven in: On Creation, by Robert Kraft, University of Pennsylvania, available at the web page http://ccat.sas.upenn.edu/rak/courses/999/PHILONUM.HTM

the internal motion can be only in the breathing. However, its nature cannot be the first principle of it; and since it is not such a motion continuous in the animals, it is not produced by vegetative spirits, but it is coming from some perceptible motivations by a voluntary movement, anticipated necessarily by some previous imagination or perception, then, a sound formed by such a first cause, in which imagination exists, is the voice.

Then, a proper setting of the vocal articulators and of the breath in them gives to a certain voice its appearance and perfection. However, to this voice, the setting of the speech does not give perfection automatically. In fact, it is the literate voice, to which the abovementioned configuration provides appearance and perfection. And the voice, after completing a specific setting, pronounces a letter, as well as several settings of the voice are composing several letters.

However, the might of the voice, on the purpose of which we are writing, is nothing else but the very configuration of some instruments, vocals and breaths, by which, inside us, the letter is generated. Therefore, it is possible to represent it by means of a visible shape similar to the shape of the setting of its generation. When the technique imitates the Nature - and the Nature always works in the best possible way - and, on the other hand, this technique is not wandering, it is clear that a better representation is obtained by exterior shapes similar to the interior ones, like in a representation according to the art of grammar, where the writing was created by using some exterior shapes similar to interior shapes to represent interior settings. If an objection had to be found, it is that we can find many shapes of the same elements in several literal representations; then, let us tell that there is not a difference in their essential nature, but just in some non-essential details, for example, the shape of element A in Latin, Hebrew, and Greek and in Arabic too is a triangle. However, the same triangle is indicated differently by the scripts of the three languages mentioned above. Similarly, the shape of the element R in every language is perceptible in the figure of a ripple, as it is formed by the tongue, and so on. The sound of a vowel is similar to itself totally or partially. It is therefore necessary of being it generated by a motion similar to itself totally or partially.

But motions, after being assimilated, totally or partially, are seven: and they are straight motion, circular and of expansion and contraction. Of these, two do not differ except in the direction forwards and backwards of the straight motion; then we have the circular motion about a center which is moving straight, and the circular motion about a center in circular motion; and likely, the motion of expansion and contraction over a center on straight motion and over a center in circular motion.

Because of these seven movements, the ancient Greek set seven vowels. However, the two motions about a center in straight motion and about a center moving on circular motion, are possible to imagine, but are difficult or actually impossible to create. Because of this fact, just five motions remain, which are possible or operationally feasible.

Therefore, it is evident, that by the breath moved in a straight motion and through the trachea the vocal J is molded. Sometimes, however, there is less continuity of this same straight movement, not because the continuity is becoming trembling, but, very frequently, because it is going and coming. The true circular motion creates the form (O). Every true circular motion, about a center in straight motion, subtends a chord and any point on the circumference describes an arc on the chord, and so a pyramidal shape is created. And the motion of contraction creates the letter V, i.e. two lines concurrent towards a center. In fact the motion of expansion and contraction over a center of motion moving on a straight line subtends the basis of a triangle. And each point, which is moving in such a double motion, when there is the expansion, describes one of the sides of the triangle from the base up to the apex, and when there is the constriction, describes the other remaining side from the apex to the base; and then it is given the letter A. And in both occasions, we can create the sound of a vowel and the sound of a consonant. And even we can have two discontinuous occurrences too, because, between opposite motions as we like, there is a pause, a stationary point, in the middle: then, we have consonants which are so called because they seems to sound with another, and it is not possible to ear by themselves, but by generation of a vowel in the following occurrence.

To this I reply: the motive force, which is giving the vocalization, from the beginning of the syllable to its end, inclines the breathing and the articulators to create the vocal sound like its sound, and therefore moves breathing and articulators consequently. When, however, the said inclination is concomitant to reproduce the sound of a consonant, a combined motion resulting from two inclinations exits from the breathing and movement of the articulators, as it happens when a heavy body tends to move downwards, and it is pushed transversally, and the heavy body moves on a motion following some inclines different from the natural movement. Since, however, the inclination of a natural motion is continuous, the movement is always returning to the natural one. It is clear, therefore, that in the movement, by which the sound of consonant is formed, there is the inclination to form the vowel sound considerably, and so in the sound of a consonant, there is the sound of a vowel substantially; at last, a natural sound is like the motion of the sound of a consonant, like the natural inclination of a heavy body pushed transversally, it is the motive inclination, several times excited, however not vehemently, that gives features and forms to the actual motion, rather than the natural inclination.

Yet, it can be what Priscian said, that vowels are like the breath of life and consonants like bodies, when he referring to the fact that the sound of a consonant cannot be heard outside the mouth, except by the actual sound of a vowel. However, since the times of the formation of a consonant and of a vowel in the same syllable are different, it is necessary that the sound of the consonant can be formed in the mouth without the sound of a vowel. But, as Isidorus (of Seville) says, unless followed by the sound of a vowel within the syllable, a grumbling of a letter shall sound and, outside the mouth, it does not arrive to the ear. From what has been said, it is clear that when the movement for the formation of a consonant results in a shorter inclination to form the active vowel, a semivowel will be produced; however, when this movement is prolonged, in fact, it turns out to be speechless. From all these points, then, it is clear how a syllable is, by means of a breathing and an accent, pronounced immediately, although it may have many letters, because this unit is a continuous trend created by the sound of vowels, on which the inflection falls, such as in a natural tendency to pronounce consonants, as well as in the accidental characterization of an inflection.

Sound, Motion and Phonetics

In the first part of the treatise we find the description of the origin of the sound from the oscillations of a medium or from a body having oscillating parts. After its generation from a vibrating source, the sound propagates in the air, and when it arrives to the air inside the ears, it produces the sense of hearing. From what Grosseteste is telling in his treatise, we can argue that he could have observed some vibrating elastic media and how they are generating sounds. For instance, it is possible to observe laterally the oscillations of a thin blade: when the oscillations have a low frequency, we can easily perceive it by eyes, because our eye is able to observe clearly the oscillations up to about 20 Hertz. This situation corresponds to a low sound. It would be nice to imagine Grosseteste had observed a tuning fork (diapason) but this instrument was invented in the 1711 by the British musician John Shore[128]. However, it is possible that instead of using a tuning fork, Grosseteste had a metallic wire, bent to form a round or elliptic ring, which he could use as a medium prompt to sound when stricken. Then, he could observe that during the vibrations of such an ellipse, when the major axis elongates the minor is reduced and vice versa. This could be in agreement with the Latin text, where Grosseteste uses the term “diametrus”.

In the translation from Latin, I preferred to consider “diametrus” as “dimension”, in order to remember the Poisson modulus of elastic materials. Let us suppose an elastic material and a bar made of it. When the bar is stretched, we see usually that, to an extension in the direction of the applied tension, it is corresponding a contraction in the perpendicular directions. When a material is compressed in one direction, it usually tends to expand in the other two directions perpendicular to the direction of compression. This phenomenon is called the Poisson effect, and the Poisson's ratio measures this effect. This ratio is positive in the usual abovementioned behavior of materials. However, elastic materials having a negative Poisson’s ratio exist: these are the auxetic materials[129].

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[128] http://en.wikipedia.org/wiki/Tuning_fork

[129] A. Sparavigna, Phonons in Conventional and Auxetic Honeycomb Lattices, Phys. Rev. B, Vol. 76, No. 13, 2007, 134302, six pages.

Grosseteste's treatise is telling that the reasons for a medium to sound are two, "either the motive force is internal the very sounding medium or external." In the case that it is internal, it means that it is coming from a voluntary action on breath and articulators of speech. This is the voice. And a proper setting of breath and articulators gives to the voice its appearance and perfection.

For what concerns the Latin words used by Grosseteste, we find the "spiritus", which is the "breath", or the "breathing", and therefore, "the spirit of life" too. In Greek, on the vowels, we can have a "spirit"[130], to indicate presence or absence of a "h" sound before a letter. Let us remember that our alphabet was invented by the Semites of the Mediterranean coast, who used simple symbols to represent consonants instead of words. The Greeks used the Phoenicians alphabet, adding seven vowels, which considered as containing "pneuma", spirits, or "breath of life". The reason is because the sound of each vowel could be pronounced as long as the breath in the lungs. There are three types of vowels: long (eta and omega), dual (alpha, iota, and upsilon), and short (epsilon and omicron).

Some Latin words in the Grosseteste's treatise, such as "accentus", "formanda" and "inclinatione vocis", are words used by Marcus Fabius Quintilianus, who was a Roman rhetorician widely referred to in medieval schools of rhetoric. It is then quite possible that Grosseteste knew Quintilianus' treatises and used them. The "accentus" is the accent; "formanda" is coming from "formare" which means pronounce, create by means of the mouth. "Inclinatione vocis" is the inflection[131]. Let us also remark that "consonant" is a "sound other than a vowel"; and the term is coming from Latin "consonans", and "consonare" meaning to sound together, sound aloud[132]. Consonants were thought of sounds that are only produced together with vowels, as we find in this treatise written by Grosseteste. In the last part of it, I rendered "tempus" with "occasion", from "occurrence".

[130] http://en.wikipedia.org/wiki/Greek_diacritics

[131] L. Castiglioni and S. Mariotti, Vocabolario della Lingua Latina, Loescher Ed.,1972.

[132] D. Harper, Online Etymology Dictionary, 2012.

Van Deusen[133] tells that Grosseteste is using several terms, among then "tempus, proportion, sonus vocalis, motus contrarios, sonus consonantis" that could be also understood as a musical conceptual language. We can argue that Grosseteste, in the discussion of the voice, had in mind also the voice singing the chants of the liturgies of Catholic Church.

In the part of the treatise concerning phonetics, Grosseteste tells that the shape of the letters in the grammar is coming from a representation of some internal settings assumed when pronouncing them. In such a way, the grammar is imitating the Nature. Moreover, letters of different languages can have symbols which are only accidentally different, not substantially[134]. However, if the written letters are in their shapes representing the motions of breath and articulators when pronouncing the sound of them, we need to assimilate the possible motions in some types, each type representing a vocal sound. Then Grosseteste gives a list of motions, subdividing them in seven types according to their partial or total similarity. The assimilated motions are seven, because Grosseteste wants to represent the seven vowels of Greek. Let us remark that the seven Grosseteste's types of motion are not the classical seven motions (up/down, right/left, forward/back, rotary), proposed by Philo of Alexandria in his treatise On Creation. On the contrary, the Grosseteste's motions are quite complex.

I rendered the Latin text supposing Grosseteste was proposing a combination of motions. The seven motions are as in the following. Three motions are the straight motion, in the two directions, forwards and backwards, and the circular motion about a centre at rest. The fourth is the circular motion about a centre which is moving on a straight line. This is the description of a cycloid, even prolate or curtate. Let us remember that a cycloid is the curve traced by a point on the rim of a circular wheel as the wheel rolls along a straight line. It is then a curve generated by a curve rolling on another curve.

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133 N.E. Van Deusen, Theology and Music at the Early University: The Case of Robert Grosseteste and Anonymous IV, BRILL, 1995.

134 Ibid.; V. Law, The History of Linguistics in Europe: from Plato to 1600, Cambridge University Press, Jan 30, 2003.

After, the fifth motion given by Grosseteste is a circular motion about a centre in circular motion. This seems the description of an epicycloid, which is a plane curve produced by tracing the path of a chosen point of a circle, called an epicycle, which rolls around a fixed circle. This is the motions of the planets in the heavens as described by Ptolemy, well known by scholars such as Grosseteste. The last two are periodic motions, of expansion and contraction, wavelike motions, on a straight line and on a circumference. These Grosseteste's types of motion seem suitable to be applied to approximately describe, besides the motion of celestial bodies, how parts of some machines can move. It is possible that during the renaissance of sciences stimulated by the translation of texts from other cultures[135], such as the ancient Greek and Arabic works, some scholars started the development of a scientific language, able to describe what happens in mechanics and technology.

After this description of these motions, Grosseteste tells that the ancient Greek set seven vowels according them. However, some motions are difficult or actually impossible to render by the voice. And then he concludes that "just five motions remain, which are possible or operationally feasible". He tells about the motions associated with letters J, O, V, A, and R, because, as remarked by Law[136], the art of grammar imitates the nature, and nature does everything in the best way possible, and then the letters of the alphabets have a shape representing the motions of articulators when we are speaking. Grosseteste continues with a discussion of the consonants, "quasi cum alio sonans; et quasi per se non possit audiri, cum eius generatio praecedat, vel subsequatur tempore generationem vocalis;" consonants, which are so called because they seems to sound with another, and it is not possible to ear by themselves, but by generation of a vowel in the following occurrence.

Then, we have the formation of syllables, where Grosseteste is using again the analogy with the motion. In particular he uses the motions of a heavy body, which is falling or which is falling after

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135 A.C. Sparavigna, From Rome to the Antipodes: The Medieval Form of the World, International Journal of Literature and Arts, Vol. 1, No. 2, 2013, pp. 16-25.

136 V. Law, The History of Linguistics in Europe: from Plato to 1600, Cambridge University Press, Jan 30, 2003.

receiving a transversal push. In the first case, we are pronouncing a vowel, the natural motion. When we have a combination of two motions, horizontal and vertical, we have a syllable, where the natural motion is altered by the consonant. Let us note that Grosseteste is also observing that the body returns to the natural falling. Of course, this is rough description of the superposition of vertical and horizontal motions in the gravity field, and of the fact that vertical acceleration prevails. In any case, the initial conditions of motion are giving the "shape" to the motion.

Grosseteste ends his treatise with some further considerations on consonants and semivowels, referring to Priscian and Isidorus. Priscianus Caesariensis, who lived in the VI century, commonly known as Priscian, was a Latin grammarian. He wrote the Institutiones grammaticae on the subject. This work was the standard textbook for the study of Latin during the Middle Ages. Isidorus, or Isidore of Seville, (c.560 – 636), was Archbishop of Seville for more than three decades, and wrote on etymology.

In phonetics and phonology, a semivowel is a sound, for instance the English "w" or "j", which is phonetically similar to a vowel sound but acting as the syllable boundary, rather than the nucleus of a syllable. In fact, the description given by Grosseteste is similar to what we can read in the Wikipedia item on "Semivowel" and the same of for the discussion on "Syllable" and "Sonorant".

Conclusion

In this book we have discussed seven of the treatises written by Grosseteste, those which had a relevant role in the born of the scientific tradition in Oxford. These treatises are: De Iride, De Colore, De Lineis, Angulis et Figuris, seu Fractionibus et Reflexionibus Radiorum, De Luce, De Calore Solis, De Impressionibus Elementorum, and De Generatione Sonorum.

In De Iride, De Lineis, Angulis et Figuris, and in De Luce, we have seen the studies of Grosseteste on the light and its propagation. The geometry is used to propose a theory of the light which can explain the phenomena of reflection and refraction. Also the power of light involved in these phenomena has been investigated by Grosseteste. In De Luce, which is giving also his metaphysics of light, we find that the philosopher imagined the propagation of light as a multiplication of light itself, in a picture with resembles that of Huygens-Fresnel[137].

In De Colore we have seen the Grosseteste's theory of colours, produced when the light is mixed with matter. In De Calore Solis, the light is mixed with air to give us the heat coming from Sun. In this treatise, Grosseteste discussed of heat, a subject proposed also in De Impressionibus Elementorum.

The last treatise we have discussed is De Generatione Sonorum. This treatise is studied by scholars for its importance in the history of phonetics and music. In fact, in his Latin text, Grosseteste is using several words that could have been used in some early musical languages for liturgical celebrations. The fact that the treatise contains some interesting discussions on motions needs to be properly considered and remarked. Reading his treatise, it is clear that the philosopher widely used the combination of motions, rectilinear and circular, and vertical and transversal. For this reason, this Grosseteste's work is important in the history of physics too, because it can help understanding the roots of the modern language of physics, created by some medieval scholars in their treatises on the physical world.

Appendix - Grosseteste's Political Network

Let us just point out the role that Grosseteste had as a bishop in the politics of the time, by means of a unusual method, that is, by georeferencing the collection of his letters, the "Roberti Grosseteste Epistolae". The georeferencing is evidencing the network of the thinker, in particular, his links with other episcopal seats in England. We can see that the network was covering almost the whole England.

Georeferencing is the association of something with a location in a map[138]. Then, it is naturally used for any structure that can be related to a geographical area, such as points of interest,

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[137] In 1678, Christiaan Huygens proposed that every point, reached by a luminous disturbance, becomes a source of a spherical wave; the sum of these secondary waves determines the form of the wave at any subsequent time.

[138] Hill, L.L. (2006). Georeferencing. The MIT Press. ISBN 978-0262083546 ; Foote, K.E., & Lynch, M. (1996). Geographic Information Systems as an Integrating Technology: Context, Concepts, and Definitions. Austin, University of Texas.

monuments, buildings, roads, hospitals and so on. Usually, the action of georeferencing is made by means of a geographic information system (GIS), designed to capture, store and analyze spatial or geographical data. Therefore, any object can have a reference on a map, that is, a "georeference", like in the scholar articles we find the references for formulas, theories, data and experiments to previous published works.

Georeferencing is not limited to the abovementioned points of interest. A GIS tool, for instance Google Earth on smartphones, can be used to offer a virtual tours on historic contents or for any other cultural case, such as the life of illustrious people (for instance, a tour about Isaac Newton's life had been proposed[139]). Therefore, we can georeference the "Roberti Grosseteste Epistolae", that is, the Letters written by Robert Grosseteste, which had been collected in a volume[140]. Let us use this volume, in particular the Contents, from page xcviiii to page cxxxi. The list is giving the person to which the letter is addressed, and also the address; for instance, Letter CXVI is written to Walter Gray, Archbishop of York.

Using the places we find in the abovementioned Contents, and marking them on Google Earth, we have Figure A1. We can compare this map to that shown in the Figure A2, which is giving England under William the Conqueror[141] (this map is "older" than the one necessary for a proper comparison, but very interesting because it is showing main roads too).

Georeferencing and comparison to an historical map is evidencing the large network of the thinker, in particular, his links with other episcopal seats in England. Many letters, eleven, are addressed to the Cardinal Legate Otho; several to the Pope Gregory IX, to Bishops Edmund and Boniface, and to the King Henry III.

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[139] Sparavigna, A.C., & Marazzato, R. (2012). Georeferenced Lives. arXiv preprint arXiv:1203.0500 ; Sparavigna, A.C., & Marazzato, R. (2012). A Tour about Isaac Newton's Life. arXiv preprint arXiv:1203.4966.

[140] Roberti Grosseteste Episcopi Quondam Lincolniensis Epistolae, edited by Luard, H.R., published in 1861, London. Available at https://archive.org/details/robertigrossetes00gros

[141] Emerson Kent.com, World History for the Relaxed Historian, retrieved on 25 January 2016, from http://www.emersonkent.com/maps_by_year_from_0501.htm

It is clear that the influence of Grosseteste on his geographic area and political environment was large, covering England almost completely. The scholarly contributions of Grosseteste were profound and far-reaching several philosophic and scientific schools, but, as told in[142], remarkably Grosseteste "did not allow them to prevent him from taking his pastoral duties seriously". This is clearly evidenced by the georeferencing of his letters.

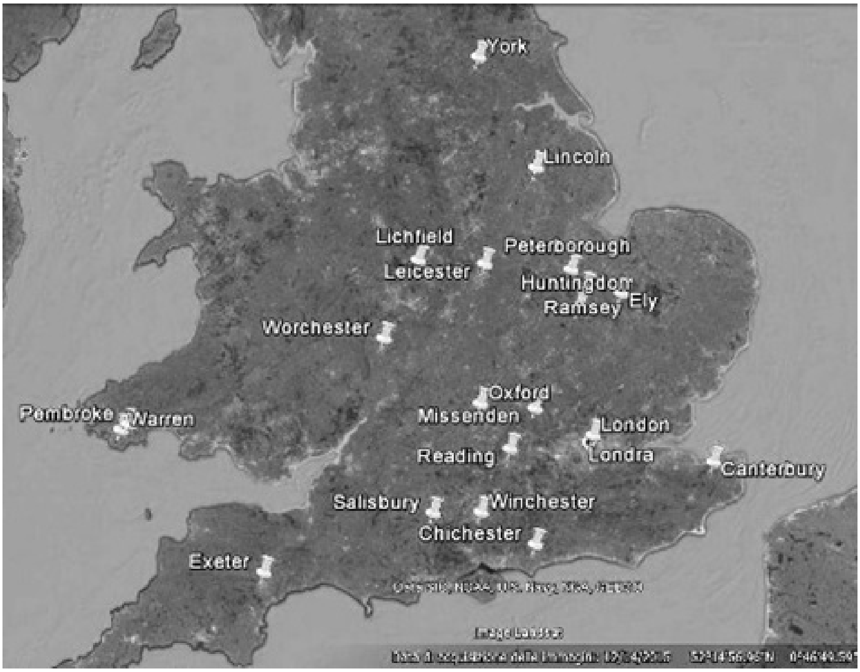

Figure A1: The map is obtained using the addresses of Grosseteste's Letters, marking them on Google Earth. Note that Grosseteste's political network was covering England almost completely.

[142] Cunningham, J.J. Editor (2012). Robert Grosseteste: His Thought and Its Impact, PIMS.

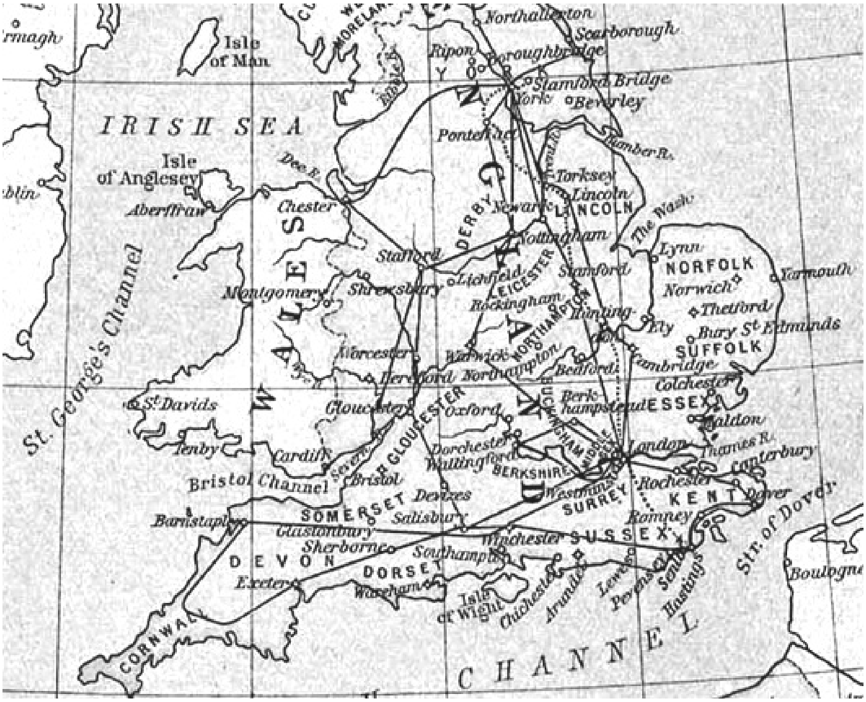

Figure A2: A part of a historical map of the Dominions of William the Conqueror about 1087. The map is “older” than the one necessary for a proper comparison, but very interesting because it is showing main roads too. Credits: University of Texas at Austin. Historical Atlas by William Shepherd (1923-26).

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