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Physics and Optics in Dante's Divine Comedy

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ABSTRACT. The Divine Comedy is a poem of Dante Alighieri representing, allegorically, the journey of a soul towards God, in the framework of Dante's metaphysics of the divine light. However, besides metaphysics, we can find in the poem several passages concerning the natural phenomena. Here we discuss some them, in order to investigate Dante's knowledge of Physics and, in particular, of Optics.

Keywords: Medieval Science, History of Science, History of Optics

1. Introduction. Dante Alighieri was one of the most educated persons of his time. He knew deeply the logic, physics and metaphysics of Aristotle. The theology came to him from the thought of Albert the Great and Thomas Aquinas, that Dante, in his Divine Comedy poem, places among the "Wise Spirits" in the Heaven of the Sun [1]. He also knew very well the classic literature and the Neoplatonic thought. As Thomas Aquinas, Dante aimed that his listeners were practicing philosophy, but the poet was teaching through a poetry in Vulgar, rather than through a prose in Latin. Dante's philosophy, which is present in his poem, the Divine Comedy, was supported by a metaphysics, that we can define as a metaphysics of the Light of Divine Love [2]. In such a manner, when Dante in his allegorical journey comes to the Empyreum, a region beyond physical existence, the highest place of his medieval cosmology, the Comedy presents its "sense of a complete harmonization of divine light, divine love, and divine life" [3]. Besides metaphysics, we can find in Dante's poem several passages concerning the natural phenomena. Here we discuss some of them, in order to investigate Dante's knowledge of Physics and, in particular, of Optics. Reference [4] helps us in investigating the Divine Comedy to evidence these points.

2. The journey in the realms of afterlife. The Divine Comedy, *Divina Commedia*, is the poem written by Dante Alighieri, from approximately 1308 and his death in 1321. This poem is an allegorical journey in the realms of afterlife, based on the vision of the world of medieval Western Europe. 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.

The Comedy is composed of 14,233 lines, divided into three *Cantiche*: *Inferno* (Hell), *Purgatorio* (Purgatory), and *Paradiso* (Paradise). In the first canto, the prologue of the poem, Dante is in a dark wood, where he meets the Roman poet Virgilio. In the third canto, Dante and Virgilio enter the Hell. Virgilio guides Dante through Hell and Purgatory; Beatrice, Dante's ideal woman, is leading him through the Paradise.

The structure of the three realms is given in a numerical pattern of 9 plus 1, for a total of 10. There are nine circles of *Inferno*, and Lucifer is contained at its bottom, which is the center of the Earth. We have nine rings around the Mount Purgatory, and the Garden of Eden at its top. Then, Dante finds the 9 'cieli' (heavens), the nine celestial spheres of Paradise, crowned with the Empyreum, and God, the radiating point of Light. In each of the circles, rings and spheres, Dante and his Guides meet different characters, because each of these places is concerning a different sin or virtue. Here in the Figure 1 a sketch of Dante's world.

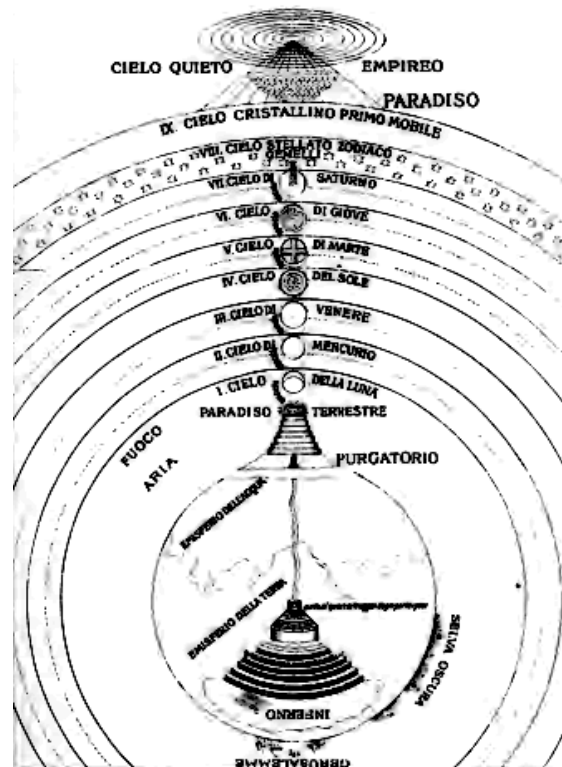


Fig. 1. The world of Divine Comedy, as shown by Michelangelo Caetani, duca di Sermoneta, in his book "La materia della Divina commedia di Dante Alighieri dichiarata in VI tavole", Passerini G.L. editor, 1921.

3. Gravitation, motion and time. In a previous paper [5], we have discussed some of medieval physics concerning gravitation and the form of the world. Except for a few isolated cases, dictated by a religious aversion to the ancient philosophy, to the medieval Europe, the world was a sphere. But there was a problem that arose some discussions, and this was the existence of Antipodes. Do they exist? Are they inhabited? Can we reach them?

This issue was considered by Dante Alighieri in depicting the realms of afterlife. The Earth is a sphere having at its center Lucifer, who dug the Hell with his fall. Dante and his guide Virgil, go down following the "gironi" of Hell, reaching the center of the Earth, and then rise to the Earth surface at the Antipodes where they find the Mountain of Purgatory. When Dante is passing the center of the Earth, Virgil tells him that this is "*l punto al qual si traggon d'ogni parte i pesi*", "*the point to which things heavy draw from every side*", (*Inferno, Canto XXXIV*). To Dante, the gravitation was a power applied to any mass, of which he knew, given its spherical symmetry, the direction towards the center of the Earth, that was also the center of the Universe. Therefore, the gravitation was the principle that constrained the Medieval model of universe, composed of many spheres, to rotate about the center of the world.

Using this simple theory of gravitation, Dante was able to solve another quite relevant question of his time. In 1320, in the church of St. Helena in Verona, Dante discussed the question about the two elements of water and earth; with geometric, hydraulic and cosmographic reasons, he showed that the circumference of water is not larger than that of earth, according to the nature of gravity [4]. Let us stress that the medieval scholars had not the concept of force and then could not formulate a law such as that of the universal gravitation, first proposed by Newton in the *Philosophiæ Naturalis*

Principia Mathematica, published in 1687. Dante's cosmology was 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.

"La natura del mondo, che quieta / il mezzo e tutto l'altro move, / quindi comincia come da sua meta; / e questo cielo non ha altro dove / che la mente divina, in che s'accende / l'amor che il volge e la virtù ch'ei piove." (Paradiso, XXVIII, 106-111).

"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." (Longfellow's translation)

Time has its origin from the motion of this heaven, as Beatrice tells to Dante:

"E come il tempo tegna in cotal testo / Le sue radici e ne li altri le fronde, / omai a te può esser manifesto." (Paradiso, XXVIII, 118-120).

"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." (Longfellow's translation)

4. Astronomical passages. In the Divine Comedy, Dante was often referring to astronomical phenomena, to mark the time of his journey in the afterlife's realms. And then, in the poem, there are many passages about astronomy [6]: let us remember just two of them. One is the reference to the polar stars: in the Hell, Dante encounters Ulysses. The Greek hero describes to Dante his last voyage, undertaken by him and his old comrades, beyond the Pillars of Hercules. Ulysses is heading towards the Southern Hemisphere. He sees the stars of the other hemisphere and those of the Boreal pole that no more rise above the horizon. He sailed for five lunar months and then he saw a mountain, indistinct for the distance. This is the Antipodean mountain: Ulysses, however, does not get it because a strong whirlwind does sink the ship. The sea closed over him and his companions.

"Tutte le stelle già de l'altro polo / veda la notte, e 'l nostro tanto basso, / che non surgea fuor del marin suolo. / Cinque volte raccesso e tante casso / lo lume era di sotto da la luna, / poi che 'ntrati eravam nell'alto passo, / quando n'apparve una montagna, bruna / per la distanza, e parvemi alta tanto / quanto veduta non avea alcuna." (Inferno, XXVI, 127-135).

"Already all the stars of the other pole / the night beheld, and ours so very low / it did not rise above the ocean floor. / Five times rekindled and as many quenched / had been the splendour underneath the moon, / since we had entered into the deep pass, / when there appeared to us a mountain, dim / from distance, and it seemed to me so high / as I had never any one beheld." (Longfellow's translation)

However, Dante is on a very different journey, and therefore he arrives to the conical mountain of Purgatory, made by terraces that rise to the Earthly Paradise.

In the Eleventh Canto of Purgatory, Dante alludes to the precession of the equinoxes in the following manner.

“Che voce avrai tu più, se vecchia scindi / da te la carne, che se fossi morto / anzi che tu lasciassi il ‘pappo’ e ‘l ‘dindi’, / pria che passin mill’anni? ch’è più corto / spazio a l’eterno, ch’un muover di ciglia / al cerchio che più tardi in cielo è torto.” (Purgatorio, XI, 103-108).

“What fame shalt thou have more, if old peel off / from thee thy flesh, than if thou hadst been dead / before thou left the ‘pappo’ and the ‘dindi,’ / ere pass a thousand years? which is a shorter / space to the eterne, than twinkling of an eye / unto the circle that in heaven wheels slowest.” (Longfellow’s translation)

5. Dante’s Physics. Astronomy was one of the arts of the Quadrivium and then had a very important part in medieval culture. And then, it is not surprising to find it in Dante’s works. Physics was a part of the philosophy of Nature. We can ask ourselves if Dante is also referring to it in his Comedy; the answer is positive. For our investigation of Dante’s physics, we find a huge help in a book written in 1804 by Giovanni Bottagisio [4]. Bottagisio was a landowner with a passion for Dante’s works that led him to write a work on the scientific aspects of the Divine Comedy. Among physics, Giovanni Bottagisio considers optics and atmospheric phenomena, but also the behavior of animals and human biology.

As Bottagisio tells in his introduction [4], “To my best knowledge, no one had considered so far to make an “anatomy” of Dante’s poem, to learn about the physics that he discussed in very gentle and seemly way. Only Benedetto Varchi, in a lecture about the generation of the human body, had reviewed a corresponding passage (Purgatory, XXV)”. The mathematician and poet Giuseppe Torelli in a letter to Abbot Clemente Sibiliati, professor at the University of Padova, exhibited and explained a physical passage (Purgatory, XV) on the reflection of the light that strikes the surface of water, or a mirror. Besides these two examples, no one preceded Bottagisio. He picked up from the three poems of the Comedy, twenty or more passages, regarding physical things, omitting those concerning astronomy, already discussed by other scholars, in order to understand the physics that Dante was knowing.

According to Bottagisio, Dante was a theologian, a metaphysician and a moralist; but he was also a “poet of physics” , who described in verse some natural and scientific phenomena in a graceful manner. Following Giovanni Boccaccio, Bottagisio tells us that Dante had Brunetto Latini as his teacher of physics. Dante studied and disputed in public about physical phenomena even in Paris, where he went after his exile from Florence. Let us see some passages that Bottagisio had discussed in his book.

6. Optics. Let us start with geometrical optics. In the Purgatory, Dante uses a similitude from the reflection of light.

“Come quando dall’acqua o dallo specchio / salta lo raggio all’opposita parte, / salendo su, per lo modo parecchio / a quel che scende, e tanto si diparte, / dal cader della pietra, in igual tratta, / si come mostra esperienza e arte: / cosi mi parve da luce rifratta / ivi dinanzi a me esser percosso. (Purgatorio, XV, 16-23).

“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.” (Longfellow’s translation)

Dante is telling that the light of an angel, who appeared to him, 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, “dal cader della pietra”, from the “falling of a stone”, that is, from the line perpendicular to the reflecting surface, “as experience and art are demonstrating”. The perpendicular line is called the “falling of a stone” by the ancient scholars; Bottagisio tells that this metaphor was used by Albertus Magnus.

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 [7,8]. According to the Poet, 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” [9].

It remains to establish the scientific sources that Dante knew and used in the Comedy and also in his Convivio. According to [10], the scientific observations were often derived from encyclopedic compilations. For his astrological knowledge, Dante used the Liber de aggregatione scientiae stellarum of Alfraganus and the Sphera written by John Sacrobosco. Moreover, the interest of Dante for optics and physics and for the metaphysics of light may indicate a possible relationship with Bartholomew of Bologna [10], who was influenced by Robert Grosseteste. Bartholomew of Bologna, who died about 1294, was an Italian Franciscan scholastic philosopher, follower of John Peckham [11]. Among his works we find the Tractatus de Luce, on optics and the metaphysics of light. Already about 1290, several chapters of the Tractatus de Luce were reported by the Franciscan Servasanto da Faenza, in his work De Exemplis naturalium [12]. In Bartholomew’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 gives evidence of the Oxonian 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 [12-14].

7. In the light of the Moon. 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), Beatrice leads Dante through the nine celestial spheres of Heavens, to the Empyreum. The nine spheres are concentric, as in the standard medieval geocentric model of cosmology, derived from Ptolemy. The Empyreum is immaterial. In the Canto II of Paradiso, Dante is in the sphere, or heaven, of the Moon.

In the heaven of the Moon, Dante finds a wonderful place that attracts all his attention. Beatrice, that can read his mind, summons the poet to direct his mind to God in gratitude for having reached the heaven of the Moon. Then Dante describes his feelings: he seems to be wrapped in a cloud which is shining like a diamond hit by the sun. The moon welcomes Beatrice and 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.

“Pareva a me che nube ne coprisse / lucida, spessa, solida e pulita, / quasi adamante che lo sol ferisse. / Per entro se’ l’eterna margherita / ne ricevette, com’acqua recepe / raggio di luce, permeando unita. / S’io era corpo, e qui non si concepe / com’una dimensione altra patio, / ch’essere convien se corpo in corpo repe, / accender ne dovia più il disio / di veder quella essenza in che si vede / come nostra natura e Dio s’unio.” (Paradiso, Canto II, 30-42).

“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.” (Longfellow’s translation)

What is the nature of the light, material or immaterial? I think this was the question that Dante was considering, when he was writing these words on a ray of light passing through a medium.

This light further increases the desire for reaching the highest Heaven. After thanking God, Dante asks Beatrice 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. But 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.

“Da questa istanza può deliberarti / esperienza, se giammai la provi, / ch’essere suol fonte ai rivi di vostra arti. / Tre specchi prenderai; e due rimovi / da te d’un modo, e l’altro più rimosso / tr’ambo li primi gli occhi tuoi ritrovi. / Rivolto ad essi fa, che dopo il dosso / ti stea un lume, che i tre specchi accenda, / e torni a te da tutti ripercosso. / Benché nel quanto tanto non si stenda / la vista più lontana, li vedrai / come convien, ch’egualmente risplenda.” (Paradiso II, v. 89-105).

“From this reply experiment will free thee / if e’er thou try it, which is wont to be / the fountain to the rivers of your arts. / Three mirrors shalt thou take, and two remove / alike from thee, the other more remote / between the former two shall meet thine eyes. / Turned towards these, cause that behind thy back / be placed a light, illuming the three mirrors / and coming back to thee by all reflected. / Though in its quantity be not so ample / the image most remote, there shalt thou see / how it perforce is equally resplendent.” (Longfellow’s translation).

Bottagisio explains that the distance is not changing the quality of the light reflected by the three mirrors. Ottavio Fabrizio Mossotti (Italian physicist, 1791-1863, known for the Clausius–Mossotti relation), in a letter to the Editor of Bottagisio’s book, has a relevant observation about this experiment [15]. “It seems to me that Dante, by the experiment of the three mirrors, wanted to point out the principle that flat surfaces, which emit or are illuminated in equal degree, appear to have the same brightness at any distance they are placed. This happens because the size of their image and the amount of light that receives the eye from each point are both decreasing as the inverse of the square of the distance. Therefore, there is a compensation, and each element of equal apparent extension of the image is always represented by the same amount of light reaching the eye at any distance you observe the surface. ... (The light source must be supposed to be at a large distance, comparatively to that at which the mirrors are between them). ... The theoretical principle of Dante is right, and for that time had to be a sublime truth and not common knowledge”.

Mossotti’s brightness is the ratio of the light reaching the eye to the apparent size of the object. These both diminish with the square of the distance, so the brightness remains constant.

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 [16].

The motion and the influence of the spheres depend on angelic intelligences, as the ability of using the hammer depends on the mind of the blacksmith; like in the human body where we have a soul, which is one, but manifests itself in the different organs to perform different functions, we have the angelic intelligence from the eighth heaven that unfolds from heaven to heaven and is manifested in different forms, merging with the different matter of the various stars. From this reason, it comes the change in brightness from star to star and then also the spots of the Moon.

Bottagisio is also remarking that the Pythagoreans, and also the mathematician Christian Wolff in his *Elements of Astronomy*, have considered the spots of the Moon being seas, lakes and ponds, which reverberate the rays they receive from the sun, most of them being absorbed. Let us 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 (1175-1253), considered the founder of the scientific thought in the medieval Oxford. 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.

8. The rainbow. Robert Grosseteste wrote on reflection and refraction in his treatise entitled *De Iride* (on Rainbow) [7, 8], where, after a discussion on the propagation of light he proposed his explanation of such natural phenomenon. Then, the rainbow was a subject of physics. In the *Divine Comedy*, we find the rainbow too:

"E come l'aere, quand'è ben piorno, / Per l'altrui raggio, che 'n sé si riflette, / Di diversi color si mostra adorno." (*Purgatorio XXV*, v. 91-93).

"And even as the air, when full of rain, / By alien rays that are therein reflected, / With divers colours shows itself adorned." (*Longfellow's translation*).

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 [7]. "Necesse est ergo, quod iris fiat per fractionem radiorum solis in roratione nubis convexae" [8]. 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.

"Come si volgon, per tenera nube, / Du' archi paralleli e concolori, / Quando Giunone a sua ancella jube, / Nascendo di quel d'entro quel di fuori." (*Paradiso, XII*, 10-13).

"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." (*Longfellow's translation*).

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 the *Divine Comedy* we can see some of the Oxonian theory of light rendered in poetry.

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