Jerzy Burchardt (Wrocław, Poland)

THE DISPERSION OF SUNRAYS INTO COLOURS IN CRYSTAL BY WITELO*

The thirteenth century scholar, Witelo, a son of Thuringians and Poles[1], who wrote in a letter from the University od Padua that Legnica was the castle of Poland[2], was the son of Henry de Cize, the administrator (procurator ducis) for Prince Henry III in Wrocław and a Polish woman born of the knightly family of the lords of Borów near Jawor in West Silesia[3]. He was born in Poland in 1237. After studying the liberal arts in Paris, he became a teacher in Legnica which was the second parish school in Poland after Kraków[4]. In 1268, he lectured liberal arts in Padua and wrote a philosophical letter to the Master of Canon Law, Lewis in Lwówek Śląski, which I published in 1979 together with a monographical commentary[5]. When Pope Clemens IV died in the autumn of 1268, Witelo's superior, the Wrocław prince–regent and the archbishop of Salzburg, Włodzisław, sent him as a Master of Canon Law to the seat of the popes at Viterbo to settle some important affairs with the new pope[6]. From that year onwards, two factions among the Cardinals fought hard for the election of only their candidates untill 1st September 1271, when the choice finally fell to Gregory who resided in Palestine and did not arrive in Viterbo untill 10th January 1272. In the meantime, induced on by his friend, William of Moerbeke, Witelo wrote an enourmous treatise, comprising 10

* First appeared as *Odkrycie tęczy w krysztale Witelona* in: *Kwartalnik Historii Nauki i Techniki* 50, 1/ 2005, pp. 155–166.

[1] Cf. *Prologus Witelonis Perspectivae in initio: Veritatis amatori fratri Wilhelmo de Morbeka Witelo, filius Thuringorum et Polonorum, aeternae lucis irrefracto mentis radio felicem intuitum et intellectum perspicuum subscriptorum* in: C. Baeumker, *Witelo. Ein Philosoph und Naturforscher des XIII. Jahrhunderts*, Münster 1908, p. 127.

[2] Cf. *Prologus Witelonis Perspectivae in initio* ... : excerpts from Witelo's book IV, assertion 28, p. 162: *et uisus est lupus iuxta Ligniz, castrum Poloniae, aequalis altitudinis ipsi nemori, sed hoc accidit in horis crepuscularibus, ubi lux est dubia.*

[3] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, Wrocław 1984, pp. 23–25.

[4] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, pp. 37–40.

[5] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, p. 44. J. Burchardt, *List Witelona do Ludwika we Lwówku Śląskim* in: *Studia Copernicana* 19, Wrocław 1979, p. 161.

[6] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, pp. 48–50.

books, on geometrical optics entitled *Perspective*[1]. Up untill this day, historians of physics still have not investigated its contents exhaustively[2]. Later, Witelo was a diplomat for the Chech king, Przemysław Otokar II[3]. In the spring of 1275, he arrived in Poland as a Wrocław chapter priet and received the prebend of Lesser Żórawina, otherwise Wilków, known as Wilkowice since the 14th century, from the hands of Henry IV, known as the Probus, at a court session in Oleśnica Śląska[4]. In 1276, he returned to Viterbo and on 7th February 1277, he witnessed the testament of Cardinal Simone Paltanieri[5]. After the battle at Suche Kruty (Dürnkruth) on 26 August 1278 which ended in a Chech defeat, Witelo passed into the legal service of the King of the Romans (rex Romanorum) and ruler of Germany, Rudolf von Habechtspurch. It is not known whether he died in the Premonstratensian monastery in Vicogne as the later Berne manscript of *Perspective* suggests.

The writing of the Cambridge manuscript has been dated to the third quarter of the thirteenth century on 23rd August 1991 by the renowned French paleograph from the Bibliothèque Nationale, Françoise Gasparri[6].

I base my description of Witelo's discovery of the rainbow in a mountain crystal on the Cambridge manuscript text (Cambridge, Emmanuel College Library ms. 20), which includes additions and was personally corrected by the author himself, Witelo. The manuscript was written in the Papal Curia in Biterbium (now Viterbo) in 1271 by a copywriter under the close control of the author, copied from a draft copy which was later lost. Witelo's draft was written earlier, between autumn 1268 and the end of 1270.

The Cambridge text is extremely important. Witelo's supplements were later added to the following manuscripts: the Paris manuscript, Bibliothèque Nationale Fonds Latin ms. 7248 from the first quarter of the fourteenth century, the Oxford manuscript, Merton College Library, ms. 308 from the second quarter of the same century and a manuscript with changes hellenising Witelo's important optics vocabulary by William of Moerbeke (eg. dyafonus into diaphanus) in Biblioteca Apostolica Vaticana ms. Borghese 64 from the

[1] J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, pp. 50–51.

[2] Translations have been published with latin editions translated into English and mathematical and philosophical commentaries: *Liber primus*, (ed.) S. Unguru in: *Studia Copernicana* 23, Wrocław 1983, *Liber secundus et liber tertius*, (ed.) S. Unguru in: *Studia Copernicana* 28, Wrocław 1991, *Liber quintus*, (ed.) A. Mark Smith in: *Studia Copernicana* 23, Wrocław 1983. Books II–III have been published with a physics commentary and translation into Polish, (ed.) L. Bieganowski, A. Bielski, R. S. Dygdała and W. Wróblewski in: *Studia Copernicana* 29, Wrocław 1991; book IV, (ed.) L. Bieganowski, A. Bielski and W. Wróblewski in: *Studia Copernicana* 33, Warszawa 1994 and books V, VI, VII (catoptrics), (ed.) A. Bielski and W. Wróblewski in: *Studia Copernicana* 40, Toruń 2003. Cf. also J. Burchardt, *Witelo's Cosmology and psychology* published as *Studia Copernicana* 30, Wrocław 1991. These projects, which have been undertaken by physicists, opthalmologists and latin experts require great erudition, knowledge and maximal precision.

[3] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, pp. 57–58.

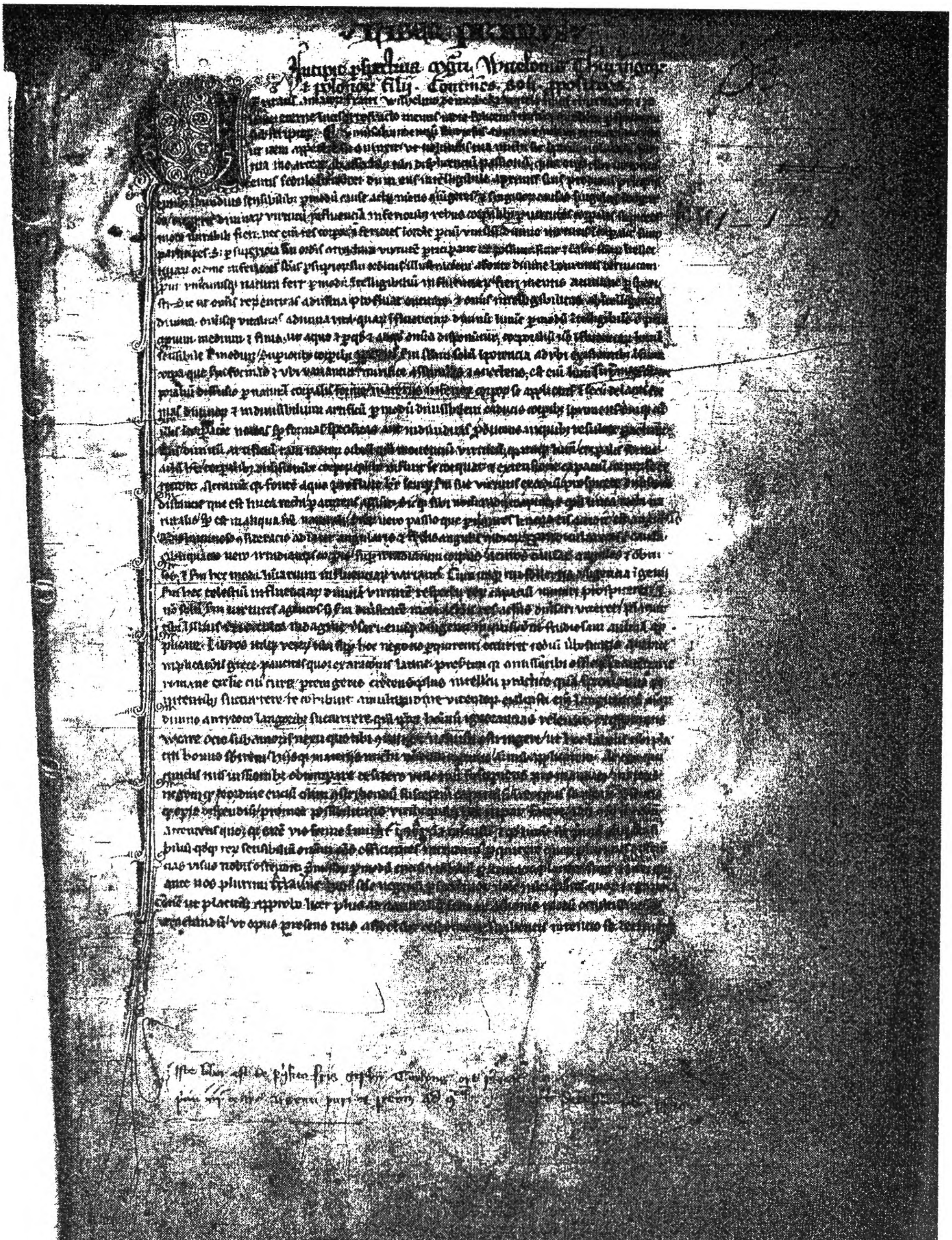
[4] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, pp. 60–62, pp. 77–79. J. Domański, *Nazwy miejscowe dzisiejszego Wrocławia i dawnego okręgu wrocławskiego*, Wrocław 1967, p. 114.

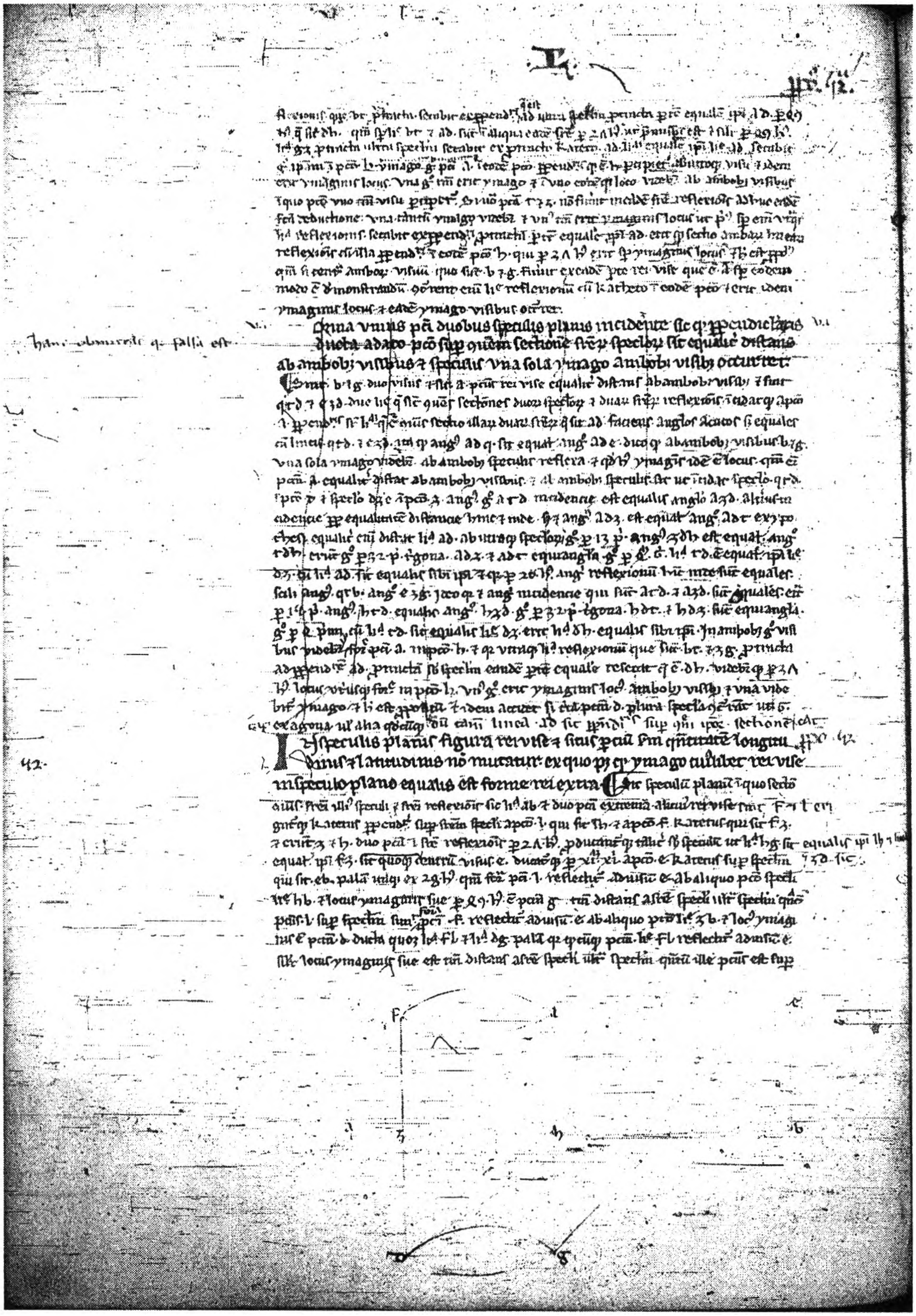
[5] Cf. J. Burchardt, *Witelo filosofo della natura del XIII sec. Una Biografia*, p. 66.

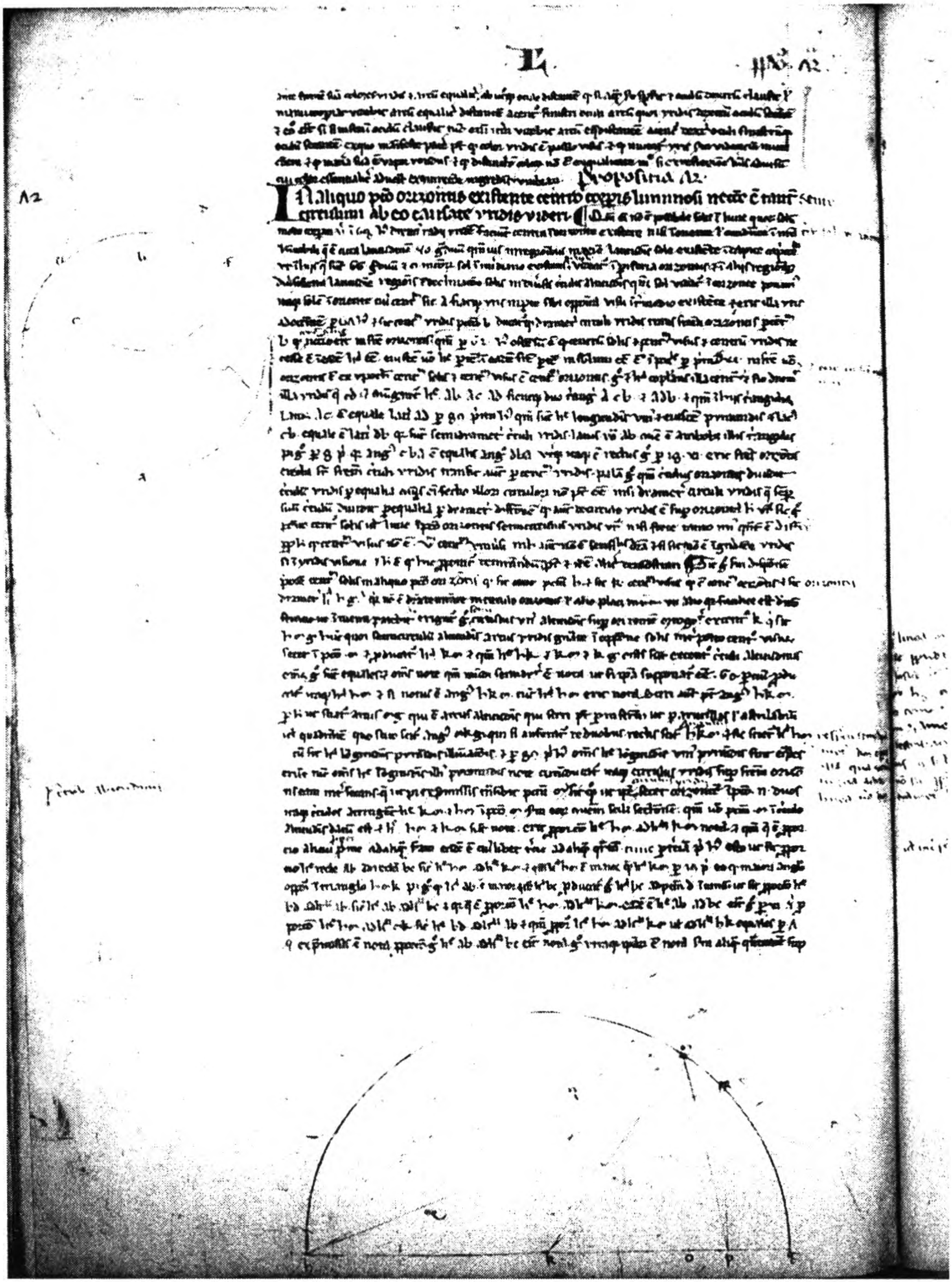
[6] F. Gasparri, letter dated 23 August 1991. Pour le manuscrit: Cambridge, Emmanuel College Library, ms. 20: *il me semble pouvoir dater cette écriture de la deuxième moitié du XIIIe siècle, mais pas nécessairement de la Fin du siècle: on pouvait peut–être dire troisième tiers du XIIIe.*

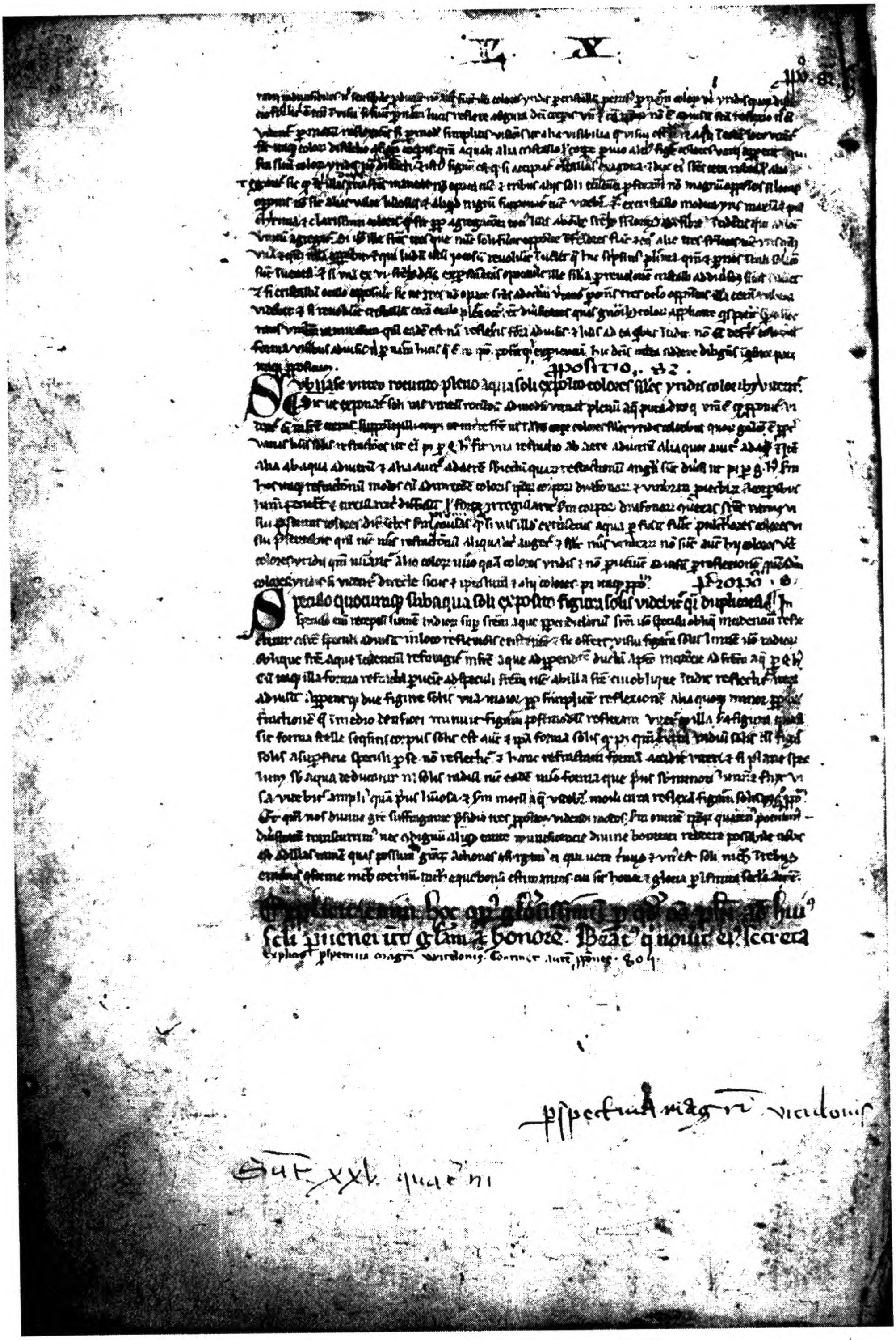
second quarter of the fourteenth century. Other manuscripts included only some of the author's supplements.

Because of the great importance of the Cambridge manuscript, I include below a copy of its four pages.









On the first page the author states that he is the son of Thuringians and Poles (Witelo, filius Thuringorum et Polonorum). The next page is especially important. It comes from the fifth book, on catoptrics. Between assertions 51 and 52, the writer copied the following unnumbered assertion from the draft: *Forma unius puncti duobus speculis planis incidente, sic quod perpendicularis ducta a dato puncto super communem sectionem superficierum speculorum sit equaliter distans ab ambobus visibus et speculis, una sola ymago ambobus visibus occurret.* After the statement had been copied, Witelo supplemented it in his left–leaning hand with the phrase: *dum tamen linea .ad. sic perpendicularis super communem ipsorum sectionem eat.* Then, once again, he read the whole, thinking hard over it and crossed through the whole statement, adding a prohibition against ever copying it again in the left margin using the statement: *Hanc obmittas, quia falsa est.* This phrase is omitted from later manuscripts of Witelo's *Perspective.*

I also attach a copy of the third page of the Cambrigde manuscript because of the author's addition it includes. In the tenth book, in assertion no. 72, *In aliquo puncto orizontis existente centro corporis luminosi necesse est tantum semycirculum ab eo causate yridis videri*, Witelo writes of having come from Poland in the right margin: *terre scilicet polonie.* Other manuscripts have incorporated this marginal addition by the author into the main run of the text. Finally, on the last, fourth copy of the last page of the Cambridge manuscript, I quote a fragment of assertion no. 81 from the tenth book which speaks of discovering the rainbow in a crystal. It comes from lines 5–9: *Et istius signum est, quod si accipiatur cristallus exagona* (...) *tunc videbitur etiam ex cristallo modica yris maxima et pulcherrima et clarissimi coloris, quod fit propter agregationem totius luminis ab omnibus superficiebus ad interiorem incidentis, qui ad locum unicum aggregatur.* In contrast to the famous Basilea edition of F. Risner from 1572, the Cambridge manuscript writes that *aliquid nigrum superponatur*, meaning that Witelo covered the upper part of the crystal he experimented upon with something black whereas the text as given by Risner states that *aliquid nigrum supponatur*, meaning that – contrary to the author's intentions – a black covering was below the crystal.

In the tenth book of *Perspective*, Witelo concentrated on the passage of light from one medium to another, astronomical problems, metereological problems and the formation of rainbows. The book had never before been worked on, translated or commented. In the prologue to the book, he mentioned transparent stones – rock crystal and beryl – not to be confused with the element beryllium (the text probably speaks of beryllium aluminium silicon oxidase, i. e. $Be_3Al_2Si_6O_{16}$). Because of similarity, he added glass. He also added that the shapes of the glass and transparent stone could be round, flat or irregular. The differences in these properties of their sides and facets determined the differences in reception by both eyes[1]. In assertion no. 48 of the

[1] Cambridge, Emmanuel College Library, ms. 20: *Prologus. Alia uero corpora dyafona nobil assueta sunt quidam lapides, ut cristallus, berillus et similes et sunt vitra ... Vitrorum uero et lapidum dyafonorum figure sunt rotunde aut plane uel irregulares. Unde si secentur a planis superficiebus fient in illis communes sectiones, aut circuli, aut linee recte, aut irregulares, secundum quarum diuersitatem variatur diuersitas passionum, que visibus occurrunt.*

tenth book, Witelo argues that if a spherical crystal is left in the sunlight, it may be used to enkindle a fire in a flammatory object behind it. In this way, Witelo set oakum on fire (stupa). At the end of the assertion he also added that if part of a sphere of crystal which is smaller than half (less than a hemisphere) is used in such an experiment, the flammatory matter centrally located behind it shall burst into greater flame since all the parallel rays meet in the centre of the sphere. However, the diversity of results of such investigations is very great (latitudo). This is a problem for those who are interested to solve[1].

In today's Italy transparent Quartz rock crystals in the shape of long hexagonal prisms are to be found in Elb and in the crevaces of the Carrarian white marble. Beryl aquamarine can be found among the granite also on the Elb. When he was writing the tenth book of *Perspective*, Witelo was in Viterbo in Latium, some 80 km north of Rome[2].

The last full edition of all the ten books comprising *Perspective* by Witelo does not follow authorial exactness everywhere. Its publisher from 1572, F. Risner, did not know the Cambridge manuscript. Hence I have based my translation of the discovery of the rainbow in crystal on this fair copy[3].

This important text is a fragment of an assertion in the tenth book which the fair copy numbers as 81 (Risner's edition accords it number 83) and bears the title: *A crystallo exagona soli opposita colores yridis generantur* – i. e. *In a hexagonal crystal placed in sunlight – the colours of the rainbow appear.* The fragment is to be found on the last page of the Cambridge manuscript and on the last page of Risner's edition which has a poorer text[4].
Below is a translation of the theoretical part of the assertion:

These kinds of colours arise from weakening light by refracting it towards the perpendicular [*from the line*] *extending from the centre of the solar body to the surface of one of the parallelogram faces of the crystal. And since – as we have explained in assertion 27 of the second book of this work – it is obvious that the sun illuminates more than a half of the opposite cylinder – speaking, that is, of the circular face in a circular cylinder. In a prism with angular sides this can not be the case since as individual rays arrive at the axis of the body which divides its base into equal halves, only half is then illuminated by the fall of rays, as we there said. But if this cylindrical body is transparent, then the second half of this body is illuminated through refraction*

---

[1] Cambridge, Emmanuel College Library, ms. 20, lib. X, prop. 46: *crystallo sphaerica soli opposita ignem possibile est accendi in re combustibili, que post illam. Sit centrum solis punctus a sitque crystallus soli opposita, cuius centrum b, sitque ut superficies plana centra amborum, quae sunt a et b, pertransiens secet ipsam crystallum sphaericam secundum circulum per 69 primi huius, qui sit* cdefg. *Dico quod si aliquid combustibile ponatur post hanc cristallum, ita quod cristallus sit media inter solem et rem combustibilem, ut stupam uel aliquid consimile, possibile est, ut ignis in illo corpore accendatur.* (...) *Forte tamen portio spere cristalline minor hemisperio fortius inflammaret in loco centri sui posita re inflammabili, quoniam omnes radii totali illi superficiei sperice perpendiculariter incidentes concurrerent in centro per 72 primi huius. Sed in horum experimentacione est maxima latitudo, quam relinquimus ad talia curiosis.*

[2] Cf. F. Rechinger–Moser, O. Wettstein, M. Beier, *Italien*, Stuttgart 1961, pp. 201–203.

[3] Cambridge, Emmanuel College Library, codex 20, last page. *Opticae Thesaurus, Vitellonis Thuringopoloni libri decem*, Basileae 1572, lib. X prop. 83, p. 474.

[4] Cambridge, Emmanuel College Library, ms 20, last and penultimate pages.

of rays. Thus, if a transparent surface of such a body is the sole one to be facing the sun, as is the case with four–sided bodies, then there is one strong refraction of the rays and the light, as light, passes through to the opposite face of the solid body and comes out anew also in the form of light. The same also happens in a stronger way in a spherical transparent body, not a concave one, since from the greater part of the surface of this spherical body, light is bent toward the radius which is perpendicular to the tangent surfaces of the body and parallel to the surface cutting the solar body through its centre thanks to the aspect of vision of the illuminated body, as we have shown in assertion no. 46. The convergence of so many light rays, though not all in one point, since this is not possible due to the differences between surfaces of incidence, means that light is concentrated on a naturally small area and still remains in the form of light and colourless. This concentrated light may heat a body lying in its stead and even ignite flammatory material such as oakum or other matter with the inlying property of being able to pass into combustion. If however, a transparent body placed in sunlight has more faces than just one flat or spherical surface, that is in that part which is facing the sun, as is posssible if, for instance, a tetrahedral body has one of its edges facing the sun, then rays incident on one of the sides shall be refracted to both the opposite sides and likewise with the rays incident on the other side. And if there should be air outside the face opposite the refracted light, air being a matter of lighter transparency (refractory index), rays from both sides shall again be bent – and this away from the perpendicular which is drawn from angle to angle dividing the base in half or from any other line parallel to this perpendicular in another dense body, under this transparent body, be it earth or any other body, then, sometimes, two clear lights appear and at other times they are coloured, as if the transparent body had equal angles and sides. This is clear to the investigator. Mixtures of colours can be glimpsed which then disappear: red colour with some other mixed in, as if green, which in accordance with the properties of the crystal or other translucent body are clearly or less clearly visible. It there are three facets of the body lying opposite the sun, as in a hexagonal crystal, then from each of these three, the incident light passes to the ground or other body as three lights of which the centre one remains in the perpendicular crystal column itself which divides the body's base into equal parts or is parallel to this dividing line. This light is visible unless light from the sun hinders visibility. The other two faces bend the light away from the above perpendicular by dint of the nature of the next transparent medium which is lighter – i. e. air. The fourth assertion in this book stated that when passing into a second lighter medium, light bends away from the perpendicular and this involves a certain dispersion of rays (dispersio radiorum). Among these rays which have been refracted and dispersed, colours appear due to the addition of the darkness of the crystal colour to the light passing through it and due to the addition of shadows from the crystal itself falling from above, thanks to the angularity of its edges which, according to the eleventh assertion of the second book of this work are projected onto the facet opposite to the one of ray incidence, on the opposite side to the light source. The multiplicity of these shadows gives rise to a diver-

sity of colours when they mix with light, since where a ray is incident nearer than the surface investigated near which very many rays are converged, the mixed crystal and shadow colour is reflected, since the ray is strongly illuminated, and a red colour arises. In other weaker rays, through the mixing of many colours of bodies and shadows, other, intermediate colours arise. By this, three colours are formed, since the rays fall from the three upper surfaces to any lower surfaces and red can be seen constantly from this side as perpendicular to the surface of the crystal in the rainbow which forms on passing through the surface opposite the sun, aggregating all its rays, and projecting onto its surface through refraction due to the transparency of air. Then, sometimes, three rainbows arise due to the threefold refraction in the lighter second medium, as has already been written, since three times three gives a square, ie. nine. Hence there shall then be nine distinct colours. If the number of the above three upper faces is multiplied, thus through the three lower faces there shall each time arise three seperate colours. In this way, there shall be a clear distinction in the colours at the edges of the body since from the edge lines, which are set and indivisible, reflected or refracted rays shall form an indivisible and natural whole. These colours of the rainbow in crystal do not arise through the nature of the colours of real rainbows which are distinguished only in vision, though arising from the nature of the light reflected from the above mentioned body. Thus their cause does not lie in their reflection into our eyes. By nature, they are not seen as reflected but by simple vision, just like other visible objects which reach our eyesight and are seen by everyone in that same place. The distinction of colours is thanks to the shape of the body. Since also from any other crystal or other small body of a different shape, different colours appear which can not be identified according to the localisation of colours of the rainbow[1].

---

[1] Cambridge, Emmanuel College Library, ms 20, last and penultimate pages: *A cristallo exagona soli opposita colores yridis generantur. Huiusmodi enim colores generantur ex debilitate luminis propter refractionem ad perpendicularem, ductam a centro corporis solis ad superficiem unius paralellogrammi ex lateribus cristalli. ... Si uero corpus dyafonum, soli oppositum, fit plurium superficierum quam unius plane uel circularis, secundum eam scilicet partem, qua soli opponitur, utpote si corpus quadrangulum secundum unum suorum angulorum soli opponatur, tunc fiet refractio radiorum incidencium uni superficiei ad ambas superficies oppositas et similiter radiorum incidencium alteri superficiei. Et cum ex parte opposita lumini refracto aer, qui est corpus rarioris dyafoni, occurrerit, refringentur radii ab utraque superficie, ab illa perpendiculari, que ab angulo ad angulum ducta, in corpore basem ipsius per equalia diuideret, uel alia ei equedistante et in alio corpore denso, illi corpori dyafono subiecto, ut terra uel alio corpore quocunque, tunc quandoque apparebunt duo lumina clara, aliquando uero colorata, ut* (W: *si*) *corpus dyafonum fuerit equalium angulorum et superficierum. Et hoc patet experimentanti. Eruntque tunc ibi duo colores confusi, non plures: color scilicet rubeus et alius mixtus, quasi viridis, qui secundum cristalli uel alterius peruii* (W: *corporis*) *dispositionem magis* (W: *sunt*) *intensi, uel remissi. Quod si superficies corporis, quo ad partem soli oppositam, fuerint tres, ut sunt in cristallo exagona, tunc a qualibet superficierum oppositarum soli, que sunt tres, receptum lumen, cuilibet superiorum trium superficierum reddit corpori opposito, ut terre uel alteri corpori cuicumque fiuntque tria lumina, quorum medium manet in ipsa perpendiculari columpne cristalline, basem suam per equalia diuidente uel ipsi diuidenti equidistante. Et fit visibile* (W: mg dex. *e lumini illud*), *nisi ut lumen solis inpediat. Alia uero duo refranguntur a dicta perpendiculari propter naturam secundi dyafoni rarioris scilicet aeris. Dictum est enim in 4 huius, quod medio secundi dyafoni rariore existente, refractio fit a perpendiculari. Et est quasi quedam dispersio radiorum* [my emphasis]. *Apparent autem colores in istis luminibus sic reflexis et refractis propter mixtionem nigredinis coloris cristallini cum lumine penetrante et propter admixtionem umbrarum parcium ipsius cristalli prominentium secundum acumen suorum angulorum, que per XI secundi huius proiciunt ad partem oppositam incidencie radiorum in partem aversam corpori luminoso, quarum umbrarum numerus facit diuersitatem colorum, quando lumini permiscentur,*

Below is a translation of another fragment:
If you take a hexagonal rock crystal (cristallus exagona) and cover two of its surfaces with red or other wax so that its third surface is not in shadow, then through its remaining three surfaces which are exposed to the sun through a small opening – provided that the place is not in too great a light and that something black is placed above (aliquid nigrum superponatur) – there will appear a rainbow of constant proportions which shall be beautiful and brightly coloured. It arises thanks to concentrating all the light from all the upper surfaces which falls down and converges on one spot. (end of translated quote)[1].

Witelo added to his calligrapher's text, above the line, the word: duas, ie. two, and the scriptwriter, undoubtedly an Italian, wrote the Italian word, inferiore instead of inferiora[2].

After describing this discovery, Witelo continued, as in the translation below, information concerning investigating light in crystal.

If the three surfaces earlier facing the sun are placed below and the other three above, then sometimes one rainbow will appear and at other times no rainbow. Whoever amuses himself with such experiments shall find what I write true. He shall also chance across many things which I have here very much enjoyed discovering (end of quote)[3].

I add here also the whole ending of the assertion. *If anyone covers one of the six abovementioned surfaces in their investigation, then by turning the crystal to various positions similar phenomena shall be discovered. Thus, if he*

---

quoniam ubi radio luminis perpendiculari magis quo ad superficiem incidencie, circa quam in viciniori multorum radiolorum fit aggregatio, color cristalli et umbre commixtus reflectitur, quia ille radius magis est luminosus, tunc fit color rubeus. In aliis uero radiis secundum sui debilitatem et colori corporis et umbrarum plurium commixtionem alii colores medii generantur. Fiunt autem tres colores, quoniam ex tribus superficiebus superioribus radii colliguntur ad quamlibet inferiorum superficierum et color rubeus semper ab illa parte videbitur, ubi (W: in mg. dex. *radius per) pendicularis super superficiem cristalli in generate yridis, oppositam soli, aggregatis omnibus radiis, sue superficiei incidit, post refractionem factam ex aeris interpositi dyafonitate. Et tunc quandoque tres yrides generantur, propter triplicem naturam refractionis in medio secundi dyafoni rarioris, ut premissum est. Et quia ter tria faciunt quadratum, qui est nouem, erunt tunc nouem colorum indiuidua, multiplicatis trium superficierum superiorum numero in numerum trium inferiorum. Tres uero erunt specifice differencie colorum. Et fit istorum colorum per angulos corporis sensibilis distinctio, quoniam a linea angulorum, que actu etiam et indiuisibilis est, reflexi uel refracti radii indiuisibiles nihil sensibile producunt. Non autem fiunt isti colores yridis per cristallum penitus per naturam colorum vere yridis, quorum distinctio formaliter est tantum in visu, sed fiunt per naturam lucis reflexe a natura dicti corporis. Unde et causa ipsorum non est ad uisum facta reflectio. Nec enim videntur per modum reflexionis, sed per modum simplicis visionis, ut alia visibilia, que visui offeruntur et a quolibet in eodem loco videntur. Fit itaque colorum distinctio a figura corporis quoniam a qualibet alia cristallo uel corpore peruio alterius figure colores varii apparent* (W: in mg. dex. *qui) secundum situm colorum yridis non* (W: *sunt) distincti.*

[1] Cambridge, Emmanuel College Library, codex 20, Witelo, *Perspectiva*, lib. X prop. 81, p. 202: *Et istius signum est, quod si accipiatur cristallus exagona et due eius superficies cera rubea uel alia tegantur, sic quo inter illas duas tertia superficies maneat non opaca, tunc et tribus aliis soli transeunti per foramen non magnum oppositis, si locus operationis non sit alias valde luminosus, aliquid nigrum superponatur, tunc videbitur etiam ex cristallo modica yris maxima, pulcherrima et clarissimi coloris. Quod fit propter agregationem totius luminis ab omnibus superficiebus superioribus ad inferiora incidentis, qui ad locum unicum agregantur.*

[2] Cambridge, Emmanuel College Library, codex 20, Witelo, *Perspectiva*, lib. X prop. 81, p. 202.

[3] Cambridge, Emmanuel College Library, codex 20, Witelo, *Perspectiva*, lib. X prop. 81, p. 202, continuation of excerpt: *si uero ille superficies tres, que nunc soli fuerint opposite, inferiores fiant et e conuerso alie tres superiores, tunc yris quandoque una et quandoque nulla apparebit. Et qui ludum istum iocosum reuoluerit, inueniet que hic scripsimus plurima quam et per nos in tali solatio sunt inuenta.*

positions the crystal opposite his eyes so that the three unshadowed faces are in sight, then he shall see red wax through them. When he turns the crystal in front of his eyes, then he will find many different positions with moving colours always partly shaded. Such is the nature of the reflection of forms in sight and the light which falls into the eyes. Since colour and the form that is seen come to the eyes thanks to the properties of light which is found therein. A diligent investigator may add much to what I have written. I have therefore proven my assertion[1]. Here the quote ends.

Considerably earlier, in the tenth book of *Perspective*, Witelo, investigating the phenomenon of the rainbow in assertion number 65 of the fair copy (in Risner's edition number 67), identifies its colours: the upper colour of Phoenician purple, i. e. red (*puniceus*), then green, the colour of leek (*prasinus*), between them yellow (*xanthus*), below green, the sky–blue of the Tyrene Sea, i. e. azure (*alurgus sive lazurius*). Witelo would visit this sea and observe the changes in its colour. He looked carefully at the colours of the rainbow when observing one at a waterfall near Viterbo which fell from the Balneum Scopuli hill[2].

Witelo explained that the light of the sun is refracted by droplets in the mist and reflected into the eyes of the observer by the convex surface of other droplets deeper within the fog, thus forming a rainbow[3].

Later, around 1310, Theodore of Freiberg presented a theory which holds to this day that the incident light ray is refracted on entry into rain drops and then, within the drop itself, is subject to three reflections on the back surface of the drop, with one of these forming the primary rainbow and the second and third forming arcs in *De iride et de radialibus impressionibus*. Thus, the refracted rays leave the drop and reach the eye of the observer[4].

---

[1] Cambridge, Emmanuel College Library, codex 20, Witelo, *Perspectiva*, lib. X prop. 81, p. 202, ending to continuation of excerpt: *et si unam ex VI superficiebus dictis experimentans opacauerit, ille similia per reuolutionem cristalli ad diuersos situs inuenient. Et si cristallum oculo opposuerit sic, ut tres non opace superficies ad oculum uertantur, per omnes tres oculo oppositas illam ceram rubeam videbit. Et si reuoluerit cristallum coram oculo, plures occurrent diuersitates, quas generationibus colorum applicare quis poterit, semper siderans umbrarum immixtionem quoniam eadem est natura reflexionis formarum ad uisum et luminis ad ea, quibus incidit. Non enim defertur color uel forma visibilis ad uisum nisi per naturam lucis, que est in ipso. Poterit per experientiam hic dictis multa addere diligens inquisitor. Patet itaque propositum.*

[2] Witelo, *Perspectiva*, lib. X prop. 65 Cambridge fair copy: *uisus iudicat magis ab albo receder quam puniceum videturque ibi lumen reflexum sibi viride seu prassinum et secundum hunc colorem prassinum pyramidum facta reflexione, cum dicte conditiones sensibiliter a prius entibus conditionibus variantur, videtur lumen plus nigra accedere et fit uisui color alurgus siue lazurius, ... Color uero xanthos qui inter colorem viridem et colorem puniceum videtur in yride non est color distinctus ab aliis. ... Inuenimus et nos diebus estivis circa horam uespertinam uel ante modicum circa Biterbium in quodam precipitio apud balneum, quo dicitur Scopuli, aquam uehementer precipitari. Descendentesque ad uidendum, quid in ipso posset accidere, soli sibi opposito uidimus yridem perpetuam, sole sibi circa aspectum sibi debitum existente et multas ex proprietatibus yridis notauimus.*

[3] Cf. D. C. Lindberg, *The science of optics* in: *Science in the middle Ages*, (ed.) D. C. Lindberg. Chicago 1978, p. 362. Witelo, *Perspectiva*, lib. X prop. 67 (ed. of Witelo's *Optics* by E. Risner, Basileae 1572, p. 461) *«Tricolor est omnis yris»: colores autem iridis secundum uerum, quod se nobis post multos cogitatus et experientias obtulit, sic possunt declarari. Quia enim totus uapor roridus (qui est materia iridis) in superficie et profundo est irradiatus, et ipsius est multa profunditas: patet quia ipse in aspectu sui ad solem serenius et immixtius habet lumen, mixtum tamen cum colore uaporis, qui niger est, ut in aquosis uaporibus euidens est (sunt enim omnes nigri) natura aute lucis est immiscere se coloribus rerum, ad quas reflectitur.*

[4] Witelo, *Perspectiva*, lib. X prop. 67 (ed. Risner, p. 461), p. 362.

Theodore of Freiberg, Marcus Marci of Cortland, René Descartes and Francesco Grimaldi believed that the oval dispersion of a circular ray of light passing through a prism is caused by the fact that the source of light does not comprise points but is only a physical object. Newton, however, deduced from his investigations that the effect observed is that the spectrum is five times as long as it is wide and so the prism must refract more of these rays in a much greater degree than the remainder[1].

In 1604, Johannes Kepler published his supplements and additions to Witelo's *Perspective* under the title: *Ad Vitellionem Paralipomena, quibus Astronomiae pars optica traditur* in Frankfurt. He did not undertake, however, further studies on the rainbow in crystals, but concentrated on the localisation of the retina image in the eyes. Witelo maintained that the image on the retina is the same way up, whereas Kepler, after lengthy deliberations, stated, in accordance with the truth, that it was inverted[2].

According to I. B. Cohen, the author of an excellent entry on Newton in Gillispie's Dictionary of Scientific Biography, Newton did not know Kepler's treatise which suppplemented Witelo but only knew his *Dioptics* which was published in 1653 in London[3]. Newton only read the published works and was not interested in medieval manuscripts despite his studies at Cambridge Trinity College, and so he could not have known Witelo's fair copy which was kept in the same town in Emmanuel College Library. But he had neither read *Opticae thesaurus* from Witelo's *De aspectibus Alhacen's* nor *Perspective* which was published by F. Risner in Basilea in 1572.

On 11th January 1672, Newton presented his *experimentum crucis* to the Royal Society which had been carried out in 1666 on two triangular glass prisms in an optical darkness where he dispersed sunlight into a heterogenous mixture of variously refracted rays[4]. The least dispersed and refracted rays gave him a red colour and the most refracted rays – a deep violet[5]. I add here that untill 1359, Latin Europe still did not know the violet colour. It was not untill then that it was identified as a distinct colour in France (violet)[6].

Another version of investigation into light which confirmed the results of the experiment from 1666 was presented by Newton in his Optics of 1704. He then used three glass paralellopipeds and demonstrated that light was a heterogenous mixture of rays of various colours. After dispersing light into a spectrum, it included the following colours: green, yellow, orange and red. He did not mention violet on the occasion[7].

---

[1] Cf. I. B. Cohen, *Newton Isaac* in: *Dictionary of Scientific Biography*, vol. 10, (ed.) Ch. C. Gillispie, New York 1972, p. 88, footnotes 75–76.

[2] Cf. D. C. Lindberg, *Theories of vision from Al–Kindi to Kepler*, Chicago 1976, pp. 200–202.

[3] Cf. D. C. Lindberg, *Theories of vision from Al–Kindi to Kepler*, p. 43.

[4] Cf. D. C. Lindberg, *Theories of vision from Al–Kindi to Kepler*, p. 53.

[5] Cf. D. C. Lindberg, *Theories of vision from Al–Kindi to Kepler*, Chicago 1976, p. 53.

[6] Cf. O. Bloch, W. von Wartburg, *Dictionnaire étymologique de la langue française*, Paris 1996, p. 674: *un drap violet*. In the experiment from Newton's Optics he did not mention the colour violet.

[7] Cf. I. B. Cohen, *Newton Isaac*, pp. 56–58.

The first person in the history of science to have investigated optical darkness (camera obscura) was an Arabian scientist and astronomer, Thabit ibn Qurra al–Harrani, who worked in Bagdad in the second half of the ninth century. He studied the light phenomenon when light entered a dark compartment through a small aperture. We know of this from al–Biruni, since Thabit's text has not survived[1].

In 994, in Rey near Teheran, the mathematician and astronomer, Abu Mahmūd al.–Hug̃andí thought up and constructed a great sextant using optical darkness. Sunlight entered the sextant through a small aperture and fell on a cylindrical stone arc located on the celestial meridian which was to mark the consecutive degrees of the horizon, the gradient of ecclipse and give the geographical latitude of a place after determining the solar cumulations at the summer and winter solstices[2]. Around 1022, Al–Biruni wrote of his observations in detail in his exhaustive treatise on shadows[3], and around 1038, Ibn al–Haitham from Egipt made use of another type of optical darkness to observe the shape of solar ecclipse in his treatise: *Maqāla fi–Ṣūrat al–Kusūf, i. e.* On the sickle–shaped solar ecclipse[4]. Witelo, however, in the tenth book of *Perspective*, used optical darkness to obtain the rainbow in rock crystal[5].

[1] Cf. J.–F. Oudet, *Le principe de la chambre noire et les sextants monumentaux de Rayy (Xe s.) et Samarkand (XVe s.)* in: *Comprendre et maîtriser la nature au moyen âge. Mélanges d'histoire des sciences offertes a Guy Beaujouan*, École Pratique des Hautes Études – IVe section sciences historiques et philologiques, V: Hautes Études Médiévales et Modernes 73, Genève 1994, p. 51.

[2] Cf. J.–F. Oudet, *Le principe de la chambre noire ...* , pp. 30–31.

[3] Cf. J.–F. Oudet, *Le principe de la chambre noire ...* , p. 51.

[4] Cf. J.–F. Oudet, *Le principe de la chambre noire ...* , p. 52, E. Wiedemann, *Über die Camera obscura bei Ibn al–Haiṭam* in: *Beiträge zur Geschichte der Naturwissenschaften*, 39, Sitzungsberichteder Physikalisch–medizinischen Sozietät in Erlangen, 46 Band, 1914, p. 156. A. I. Sabra, Ibn al–Haytham, *Dictionary of Scientific Biography*, (ed.) Ch. C. Gillispie, p. 208: Maqāla fi–Ṣūrat al–Kusūf.

[5] Witelo, *Perspectiva*, the author's fair copy, Cambridge, Emmanuel College Library, 20, lib. X, prop. 81.