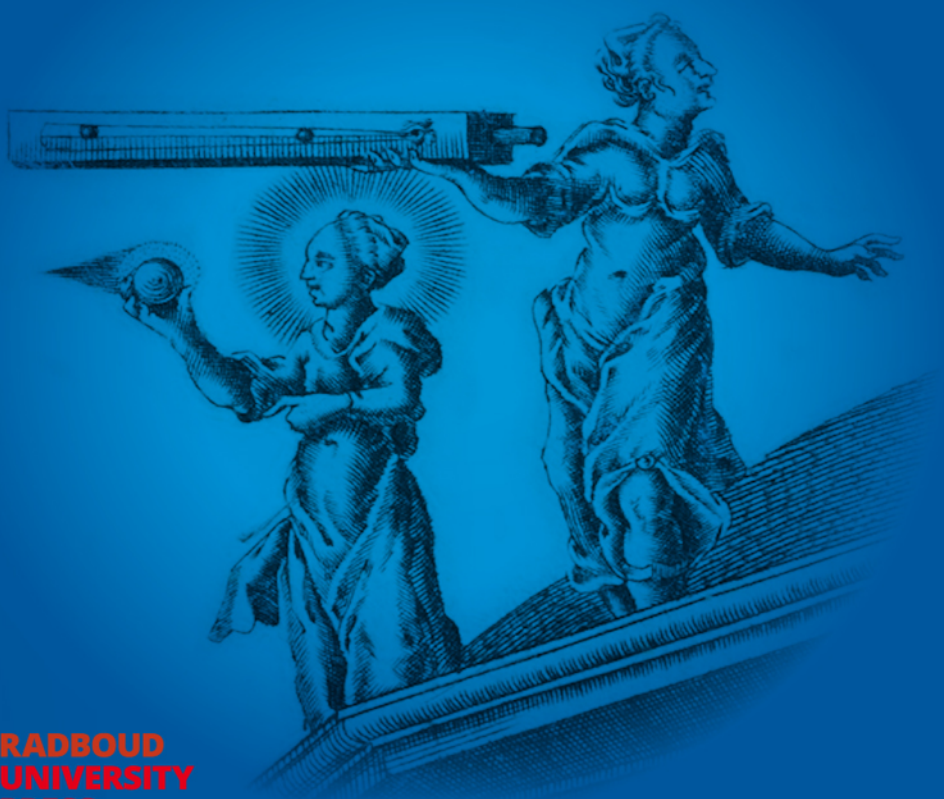
JOHANNES KEPLER

Dioptrice

TRANSLATED BY

Søren S. Larsen



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JOHANNES KEPLER

DIOPTRICE

Translation and introduction
by Søren S. Larsen

The illustration on the cover of this book is a detail from the frontispiece of Kepler's *Tabulae Rudolphinae* (Ulm, 1627), showing two nymphs atop the roof of the Temple of Urania. One of them, *Optica*, holds a telescope on which an eye and two round bodies of equal size are sketched. Rays grazing the bodies illustrate the dependency of apparent size on distance from the observer. The other nymph, *Aegle*, holds a sphere representing the Earth, surrounded by its atmosphere. A cone-shaped shadow extends into space behind the Earth, which is illuminated by light emanating from Aegle's head, symbolising the Sun. The scene is described in Johann Baptist Hebenstreit's poem *Idyllion*.

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Sæ. Cæ. Mtis. MATHEMATICI

DIOPTRICE

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Demonſtratio eorum quæ viſui & viſibilibus propter Conſpicilla non ita pridem inventa accidunt.

Præmiſſæ Epiſtolæ Galilæi de ijs, quæ poſt editionem Nuncij ſiderij ope Perſpicilli, nova & admiranda in cælo deprehenſa ſunt.

Item

Examen præfationis Ioannis Penæ Galli in Optica Euclidis, de uſu Optices in philoſophia.

AVGVSTAE VINDELICORVM, typis Davidis Franci.

Cum priuilegio Cæſareo ad annos XV.

M. DCXI.

JOHANNES KEPLER
MATHEMATICIAN OF HIS HOLY IMPERIAL MAJESTY

DIOPTRICS

OR

Demonstration of those things that occur to vision and visible objects by means of the recently invented Conspicilla.

Preceded by Letters from Galileo concerning those new and wonderful things which have been discovered in the heavens with the help of the Perspicillum after the publication of the Starry Messenger.

And also

Examination of the preface by Jean Pena of France to Euclid's Optics, concerning the benefits of Optics in philosophy.

AUGSBURG,
by the press of David Franck.

With Imperial privilege for fifteen years.

M. D C X I

To the Most Reverend and Most Serene Prince And Lord,

Lord Ernest, Archbishop of Cologne,

Septemvir Elector[88] of the Holy Roman Empire, Archchancellor for Italy, Bishop of Liège, Administrator of Münster, Hildesheim, and Freising, Prince of Stavelot, Count of the Rhine Palatinate, Duke of Upper and Lower Bavaria, Westphalia, Angria, etc., Margrave of Franchimont.
My most merciful Lord.

Most Reverend and Most Serene Prince-Elector, Most Merciful Lord: When in recent years the dioptric pipe, certainly not to be counted among common contrivances, was added to the great heap of inventions of this last century, some would contend for the laurels of its invention, while others would devote themselves above all to perfecting the instrument, for the former is chiefly a matter of chance, whereas the latter must be governed by reasoning. Indeed, Galileo achieved a most splendid triumph in demonstrating its benefits for the investigation of astronomical secrets, as someone to whom industriousness had provided a purpose and fortune had not denied success. I, for my part, driven by some honourable emulation, have opened a new field for mathematicians to exercise the power of ingenuity, that is, to employ the principles of geometry in the demonstration of the causes that underpin such sought-after and delightfully various and numerous effects. Because I had, in fact, published the *Optical Part of Astronomy*[89] six years earlier, in which I used this new way of reasoning to demonstrate, for the first time as far as I know, a number of things concerning the means of vision and about optical devices,[90] which remain unshaken up to this day, it seemed fitting that I should demonstrate that the same foundations, upon which I had constructed my account of the means of vision and the effects of simple optical devices, also suffice for the combination of different transparent lenses

88 The Electoral College of the Holy Roman Empire consisted of seven prince-electors (German "Kurfürsten") who elected the ruler of the Empire. One of these was the Archbishop of Cologne.

89 That is, the *Optics*.

90 In fact, Kepler also uses *perspicilli* here, clearly not referring to telescopes (which are not discussed in the *Optics*).

in one pipe: and consequently, that it is not even possible (which is an argument for truthfulness) that this demonstration be accomplished by any principles other than those I have used. And since Euclid had fashioned catoptrics[91] as the kind of optics which deals with reflected light, the name being derived from the principal apparatus of this kind, mirrors, and their wonderful and delightful variety, the name Dioptrics was born for my booklet following this example, because it mainly deals with light refracted by dense transparent media, both natural in the human eye and artificial in a variety of *perspicilla*. By its subject, dioptrics is thus distinguished from catoptrics as one kind [of optics] from another; in such a way, however, that dioptrics comes first and catoptrics follows, above all because catoptrics is concerned with images, the true nature of which cannot be fully understood without knowledge about the eye that must be obtained from dioptrics.

For this reason, I have also revisited the means of vision and the principles of simple lenses, both in order that dioptrics, in a certain sense, might be completed, and also because the principles of the instrument[92] are connected to the human eye and the instrument itself is composed of simple lenses,[93] so that one cannot be explained without the other. Finally, some have judged[94] that I treated these things somewhat obscurely in the *Optics* so that, for many, it is not a lack of intellect but rather the fault of the teacher that hinders them from comprehending what has been written and demonstrated. Therefore, in order to address their concerns, I have presented some things here more briefly, others more extensively, and expressed some in different words; I have listed definitions of the

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91 Johann G. Brengger, in a letter dated 23rd Dec 1604 (KGW vol. XV, Letter #310) had expressed doubts to Kepler about Euclid's authorship of the *Catoptrice*. Kepler, however, dismissed these concerns (KGW vol. XV, Letter #317).

92 That is, the telescope.

93 Also here, Kepler uses *simplicibus perspicillis*.

94 Note to p. 332 in KGW vol. IV: among those who had written to Kepler about the difficulty of the *Optics* were David Fabricius, Michael Mästlin, and Johannes Papius.
From Mästlin's letter, Jan 28th 1605: "I must admit that you sometimes pursued subjects loftier than my intellect and learning could satisfy." (KGW vol. XV, Letter #322)
From Papius' letter, Feb 26th 1606: "If only your Paralipomena [Optics] were as clear as it is ingenious and subtle. In my whole life, nothing so difficult has been presented to me on any mathematical, or I dare say, nearly any philosophical subject matter […] If I were with you, I would be a most troublesome student, always doubting." (KGW vol. XV, Letter #375)

terms I use with geometric liberty and included them in a continuous sequence among the propositions at suitable locations; and I have added more diagrams (which are the true letters of geometers). Even if, by this effort, I have not eliminated all obscurity, I hope that those dedicated to philosophy will, to some degree, forgive my shortcomings and find this effort to be of some value.

Furthermore, I devoted myself to this task chiefly at a time when my mind, numbed by a mournful coldness, was warmed by the most munificent Sun of the presence of Your Most Reverend and Serene Highness, and was awakened from sleep by its gentle urging and repeated encouragements, as if by some Mercury. Finally, the various delightful and ingenious contrivances of your mathematician and noble chamberlain, the esteemed Mr. Johannes Zuckmesser, as well as his most skilful glass polishing, which I saw were bringing remarkable delight to Your R. S. H., have prompted me to emulate his same diligence. But if these reasons alone had not impelled me to dedicate this Dioptrics of mine to Your R. & S. H., then even just this would suffice: that mathematical booklets, as they are far removed from the understanding of the common people and therefore regarded with contempt by them, are offered to no-one more appropriately than to those who are able to judge them; those endowed by nature with a sharp intellect, whose contemplation and love of philosophy have led them to a perfect understanding of these matters. It is unknown to me whether, at this time, you have an equal amongst princes in this understanding. Certainly, among the professors of academies, those who are equal in this judgement are fewer than would be beneficial.

If, in the very numerous dedications of books, the praises of patrons were no more embellished than these, I believe the trust in the virtues of patrons, which dedications have cooked up almost to the point of evaporation, would soon be restored. And to this very end, I refrain from further commemorating the virtues of Your R. & S. H. (as is customary in dedications), lest I would appear to be a cobbler wanting to judge beyond the shoe.[95]

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95 Proverb from the *Natural History*, Book 35, of Pliny the Elder (vol. VI, p. 258 in the transl. by J. Bostock & H. T. Riley, 1857). Cf. "Let not the cobbler go beyond his last".

Furthermore, I hang no other ivy[96] for the reader than to indicate that the book has been approved by so eminent a prince and ordered to see the light of day. And now, I most humbly commend myself to Your R. & S. Highness. Farewell. January 1st of the eleventh year of the seventeenth century: which I pray will be most fortunate for Your R. & S. H. in governance, in the pursuit of wisdom, and in the preservation of health.

Your Most Reverend and Most Serene Highness'

Most Devoted

Mathematician to His Holy Imperial Majesty

Johannes Kepler

96 Roman metaphor - that is, "I shall offer no further assurance".

JOHANNES KEPLER'S
PREFACE TO THE DIOPTRICS,
on the benefits and excellence of the recently invented *perspicillum*, and on the new celestial discoveries made through it.

I present to you, dear reader, a booklet which is mathematical, and therefore not so easy to grasp. Not only does it require intellect on the part of the reader, but also an extraordinary attention of the mind and an incredible desire to understand the causes of things. 1

While pondering this, it seemed fitting to discuss some things pertaining to the excellence of the dioptras[97] *or perspicilla, and to their remarkable effect on the advancement of the frontiers of philosophy so that ingenious youths and other cultivators of knowledge, encouraged by this stimulus of utility, may be incited to acquire the principles of the instrument from this booklet.*

Many great examples of the benefits of all of optics were given by Jean Pena of France, the former Royal Mathematician, in the preface to his translations of Euclid's Optics and Catoptrics. However, as important as these may be, they can be considered quite childish compared to what has been revealed during the past two years through the benefit of the dioptras.

And because I have recommended that preface to the reader by mentioning it here, let us now briefly examine its main points, lest I may appear to have knowingly and deliberately promoted also the doubtful and false things that, I cannot deny, are interspersed among the true and splendid ones contained therein. Once I have resolved this, I will then finally add the things that have been revealed at the present time by the new perspicillary science.

In agreement with Pena, I hold the first teaching concerning the heavens as firmly demonstrated from optics: without a doubt, those physicists[98] *are completely mistaken, and indeed also some theologians, who believe that*

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97 The term *dioptra* can refer to astronomical instruments used in antiquity (of various degrees of sophistication), but the literal meaning of the Greek word is similar to that of the Latin word *Perspicillum* (see the introduction) and is used in that sense by Kepler here.

98 Or "natural philosophers".

there are nine or ten transparent spheres surrounding this elemental world, like the white of an egg usually surrounds the yolk, or like the layers of an onion enclose one another. For since the paths of the planets are established
2 *as eccentric by indisputable reasoning, the optician rightly concludes that rays descending obliquely from the stars through these vast revolving orbs (towards the Earth, indeed, which is situated away from the centres of some of the orbs) are going to be refracted according to the laws of optics. And with this being granted, all certainty of observations would be removed, to which experience nevertheless bears testimony. The same also follows from the quite perceptible proportion of the Earth's body to the orb of the Moon. For even if we were to ignore that the orbs are eccentric and placed the Earth at the centre of all of the orbs, the surface of the Earth would nevertheless be at a considerable distance from the centre of the lunar sphere, which it occupies with its own centre. And again, the rays from the stars would intersect the orb of the Moon obliquely as they descend to the surface of the Earth that we inhabit, and it follows that those refracted rays would disturb the certainty of observation.*

Having not yet left the vestibule of this most beautiful demonstration, Pena improvidently pushes the argument too far, removing the division not only between the orbs but also between the air and the ether. By making the substance of the ether the same as the substance of the air we breathe, he teaches with his own misstep how important it is for someone walking in the temple of philosophy to keep the eyes of optics wide open. For with the same argument by which the divisions between the spheres are removed, in turn, the distinction is firmly established between the air and what follows it just above the summits of the mountains – that is, the ether.

For although astronomical observations are not disturbed by some complex manner of mutually intertwined refractions, as the divisions and solidity of the orbs would require if they existed, they are nevertheless disturbed by a certain uniform manner of refractions when the stars approach the horizon. These refractions cannot come from anywhere else except the surface of the air we breathe, to such a degree of certainty, indeed, that in the Optical Part of Astronomy, I was even able to investigate the altitude of this surface above the surface of the Earth. Pena appeals to experience, bringing in an eyewitness, Gemma Frisius, with his

astronomical staff,[99] *who denied having detected any such refractions.*[100] *Of course, Pena did not then know about the remarkable industriousness of the greatest practitioner*[101] *of all, Tycho Brahe, who, partly through extensive efforts and partly through the magnitude and exactness of his instruments, was able to measure that minute refraction which had escaped notice by the crude instrument of Gemma and the attention of a single and solitary man. In the Optical Part of Astronomy, I also produced witnesses for refraction held in reserve by Brahe, summoned from antiquity and therefore impartial and uncorrupted.*[102] 3

I hear that the esteemed Dr. Helisäus Röslin has suggested that I should solve the problem of the Sun being seen by the Dutch in the northern lands 14 days earlier than it should have been. I have not seen his book[103] *during these tumults.*[104] *However, I point out that I have dealt with this question through refraction by the air in the Optical Part of Astronomy, chapter IV, section 9, page 138.*

Pena devoted the second parts to the teaching concerning the truly eccentric paths of the planets, and he did so rightly. Optics provides very strong arguments for these. We must only be careful to avoid that the same happens to us as what befell the ancients: that, relying much too confidently on one eye of optics for fully perceiving the planetary orbits, we close the other eye of physics and thus, by attributing to optics alone, what had to be attributed equally to both optical and physical reasoning, we stray from the

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99 An instrument related to the dioptra used by Hipparchus. Also known as the "Radius Astronomicus", or Jacob's staff, it is described by Frisius in his *De Radio Astronomico & Geometrico Liber* (1545). Commentary and transl. by B. Goldstein (1987).

100 From Goldstein's translation (p. 173): "Though it is true that images of things which appear in air that is denser seem larger, in fact, they do not become larger as one can see from ordinary experience. For, though the distances between stars near the horizon appear to be greater than when they are high in the sky, nevertheless, when they are measured with the Radius, they do not differ at all."

101 *artifex.*

102 Chapter 4, sect. 10 of the *Optics*. Kepler here discusses possible evidence of atmospheric refraction in the works of Pliny, Ptolemy, Hipparchus, Proclus, and others.

103 From chapter 9, p. 79 of Röslin's *Mitternächtige Schiffarth…* (1610): "I leave it for others to think about that and to provide calculations about it; especially for Mr. Kepler, Mathematician of His Imperial Majesty, who, with his sharp intellect, will know how to adequately handle these matters and provide explanations for them." (my translation)

104 The "tumults" refer to the unrest resulting from the feud between Emperor Rudolph II and his brother Matthias.

goal again. Regarding this matter, see my Optical Part of Astronomy and the Commentaries on the Motions of Mars.

Thirdly, Pena examines the question concerning the order of the planets[105] *by means of optics. He does not reason badly, following Aristotle, that if indeed the Earth remains immobile in its place, it appears improbable that the Sun, Venus, and Mercury would traverse three distinct orbs of unequal size in an equal period of time. Rather, as held by Martianus Capella,*[106] *Campanus,*[107] *and Brahe, and as Galileo most manifestly proves below, if indeed the Sun moves, it is more fitting that they are all carried together in one orb, with the Sun encircled by the epicycles of Venus and Mercury, as if by segments of two wheels, with the Sun like an axle of the wheels. But on the contrary, it is indeed far more likely, as Copernicus held, and as the oldest Samian philosophy held so many centuries ago, that the Sun remains immobile in the middle, and that not only Mercury and Venus travel around it with their respective periods, but also the Earth itself with its companion, the Moon, in the course of one year, and the other three planets similarly with their own periods.*

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105 Pena writes: "Optics teaches that of objects moving at equal speeds, the one that is more distant appears to move more slowly. And since among the three planets - namely, the Sun, Venus, and Mercury - none is slower than the others, what will optics conclude from this? (Even if I remain silent, the matter speaks for itself). Without a doubt, it will assert that the Sun, Venus, and Mercury move in the same orb. For why should it hesitate to pronounce what is not only true but also in agreement with the very wise teaching of Aristotle? Aristotle says that the farther each planet is from the highest part of the heavens, the shorter the time it takes to traverse its orb. This view could have suggested to keen interpreters the position Aristotle would assign to each planet. For if none of these three planets is farther from the highest part of the heavens than the other two, then whether or not the eternal globes of the stars revolve around the Earth, balanced and stationary at the centre of the Universe, as we seem to see, with Mercury and Venus riding on epicycles, then surely these epicycles will revolve in the same orb as the Sun, with the Sun as their centre. Or (as many great minds have conceived, and which is possible according to optics), if the Earth is a star traversing the zodiac in the space of a year, around the Sun, which is stationary at the centre of the Universe, the same epicycles of Mercury and Venus will still have the Sun as their centre. Thus, it is established from optics that the centres of the epicycles of Mercury and Venus are in the same orb as the Sun." (my translation)

106 In: *Libri Novem de Nuptiis Philologiae et Mercurii et de Septem Artibus Liberalibus* ("Nine Books on The Marriage of Philology and Mercury and the Seven Liberal Arts"), Book VIII, §856. Martianus Capella lived in the 5th Century in Carthage, then a province of the Roman Empire.

107 Campanus of Novara (1220-1296) in his *Theorica Planetarum*, actually adopted the Ptolemaic order of the planets (p. 333, Benjamin & Toomer): "From this it will be clear […] that Venus and Mercury are below the sun, as he [Ptolemy] assumed." That is, Campanus believed the epicycles of Mercury and Venus to be located between the Earth and the Sun, not centred on the Sun.

Here again, however, Pena frees himself from the thorny shrubs of intricate reasoning with some damage to the truth. And this argument 4
was indeed constrained by no particularly evident necessity but supported by probability alone. Therefore, lacking confidence in the uncertain argument, Pena timidly abandons the mobility of the Earth, as taught by Copernicus, and instead, with a light blink of the eye of optics, places his trust in some other, very slow motion of the Earth that he has investigated in detail.[108] *Having made this assumption, he thinks it follows that the fixed stars will seem to have been allotted an unequal motion, and that the lack of consistency throughout the ages testifies to the existence of this motion. But, oh Pena, this is not the way to commend the excellence of optics, applying its powers to impossible matters. Bucephalus*[109] *was truly noble, even though he could not imitate the wings of Pegasus. And if someone who has testified that Bucephalus was seen flying were accused of falsehood, this would not diminish the glory of Bucephalus. Too much, oh Pena, does this reasoning of yours depart from the principles of optics; too many things intervene between your assumed optical principle and what you conclude from it. First, concern for the accuracy of those observations that we today bring forward from that deep antiquity did not touch you. Then, you adduce the motion of the fixed stars as if it were something seen with the eyes. But it is very far removed from the perception of the eyes: the astronomer hardly dares, by a combination, which is not even such a very tight one, of three very subtle reasonings into one, to eventually declare in which position of the zodiac any fixed star may be located in any century.*

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108 Pena writes: "I proceed to explain something that cannot be denied in any way. The optical law is as true as it is brief: of objects moving with equal speed, the one that appears to move more slowly is farther away. The fixed stars, however, move with equal speed (for the astronomical hypotheses teach that celestial motions are uniform, even if they appear unequal). Yet, they seem to progress unevenly, as the observations of different times show. At the beginning of the Calippic periods, that is, during the time of Alexander the Great, the fixed stars traversed one degree of the sky in seventy-two years. In Ptolemy's era, they took one hundred years. In the time of Al-Battani, they took sixty-six years. In this century, they progress at almost the same rate as they did in the early times of Calippus. From this, it is evident that the Earth was farthest from the heavens during Ptolemy's time, came closest during the era of Al-Battani, and in our age is at a moderate distance from both extremes […] I assert solely from Optics that the Earth progresses from place to place by some motion, and that this progression over time is very slow, as scarcely any inequality of such motions can be perceived in less than four hundred years." (my translation)

109 The horse of Alexander the Great.