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THE CAMERA OBSCURA: A CHAPTER IN THE PRE-HISTORY OF PHOTOGRAPHY

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THE CAMERA OBSCURA: A CHAPTER IN THE PRE-HISTORY OF PHOTOGRAPHY

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

By


* * * * *

The Ohio State University
1986

Dissertation Committee:
Kenneth Marantz
Arthur Efland
Francis Richardson

Approved by
Adviser
Department of Art Education
...One of the first days of the month of October 1833, I was amusing myself on the lovely shores of the Lake of Como, in Italy, taking sketches with Wollaston's Camera Lucida, or rather I should say, attempting to take them, but with the smallest possible amount of success. For when the eye was removed from the prism—in which all looked beautiful—I found that the faithless pencil had only left traces on the paper melancholy to behold.

After various fruitless attempts, I laid aside the instrument, and came to the conclusion, that its use required a previous knowledge of drawing, which unfortunately I did not possess.

I then thought of trying again a method which I had tried many years before. This method was, to take a Camera Obscua and to throw the image of the object on a piece of transparent tracing paper laid on a pane of glass in the focus of the instrument. On this paper the objects are distinctly seen, and can be traced on it with a pencil with some degree of accuracy, though not without much time and trouble.

I had tried the simple method during former visits to Italy in 1823 and 1824, but found it in practice somewhat difficult to manage, because the pressure of the hand and pencil upon the paper tends to shake and displace the instrument (insecurely fixed, in all probability, while taking a hasty sketch by a roadside, or out of an inn window); and if the instrument is once deranged, it is most difficult to get it back again, so as to point truly in its former direction.

Besides which, there is another objection, namely, that it baffles the skill and patience of the amateur to trace all the minute details visible on the paper; so that, in fact, he carries away with him little beyond a mere souvenir of the scene—which, however, certainly has its value when looked back to, in long after years.

Such, then, was the method which I proposed to try again, and to endeavour, as before, to trace with my pencil the outlines of the scenery depicted on the paper. And this led me to reflect on the inimitable beauty of the pictures of Nature's painting which the glass lens of the Camera throws upon the paper in its focus—fairy pictures, creations of a moment, and destined as rapidly to fade away.

It was during these thoughts that the idea occurred to me how charming it would be if it were possible to cause these natural images to imprint themselves durably and remain fixed upon the paper.

William Henry Fox Talbot
The Pencil of Nature, 1844
In Memory of Suzanne Seel

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ACKNOWLEDGMENTS

Very special appreciation is given to Dr. Kenneth A. Marantz for his guidance and direction throughout the writing of this dissertation. Thanks go to the members of the advisory committee, Dr. Arthur Efland and especially Dr. Frank Richardson, as well as to the members of the generals committee, Dr. Leonard Jossem and Dr. Walter Liedtke, for their valuable comments and suggestions. Special thanks go to Sylvia S. Marantz for her technical assistance in translating some very thorny Latin passages. Sincere respect and appreciation are given to my parents, Boyd and Jacquelin Sayer, who taught me the importance and joy of learning. Finally, I offer my deepest appreciation and thanks to my husband, Wiley Sanderson, whose encouragement, support and faith have sustained me over the many years of this research.
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INTRODUCTION

In the late Autumn of 1833, Henry William Fox Talbot, a well-to-do Englishman and amateur scientist, was in Italy on his honeymoon. Like most tourists, Talbot wanted a pictorial record of his visit to Lake Como. He was trying to make a drawing with an instrument he had purchased for his trip, but it was one he had not used before going to Italy. This camera lucida, a relatively recent drawing invention (1806), consisted of a prism and sight on the end of a telescoping tube that clamped to a drawing board. By looking into the sight, one saw and could trace the virtual image on the paper. Frustrated, Talbot thought of another drawing instrument he had used on earlier visits to Italy, the camera obscura. This was a small wooden box with a lens at one end that projected an image via a mirror onto a sheet of ground glass on the top of the box. Apparently, Talbot had been no more successful with this device than with the camera lucida. While pondering the problems of "imprinting" the camera obscura's image onto the paper, however, Talbot hit upon an idea that would eventually lead to his invention of a negative/positive light sensitive chemical process used in the camera obscura. This process
became known as photography.

The drawing device Talbot recalled, this camera obscura or literally "dark room," had been in existence in many forms for centuries. It had been an important tool in astronomy for solar observation as well as in optics as demonstration of the nature of light and vision. It had been recorded in scientific writings as early as Aristotle's Problemata of the 4th century B.C. The various writings in which the camera is found reflect the philosophical traditions current at the time. Some of these philosophies were reactions to previous ones, and, in time, replaced the old. Often a number of conflicting philosophies coexisted, such as the various Greek notions of vision popular into the 15th century. By the 16th and 17th centuries, three major and very diverse philosophies had developed. The natural or organic philosophy, which had its origins in Greek science, used paradigms as the syllogism to systematize the world. The magical or mystical, founded on Neoplatonic interest in the writings of the Egyptian Hermes Trismegistus, saw in nature the dominant characteristics of beauty, contrivance and surprise. The mechanistic view of the world was a 16th century revival of Archimedean ideas which found the greatest popularity in the 17th century writings by Hobbs,
Descartes and Mersenne. Writings on the camera obscura can be found in each of these contexts.

The history of this instrument, then, spans many centuries, from Aristotle to the invention of photography in the 19th century. Traditionally, historians who have approached the camera obscura as a topic have tended to chronicle the technical advancements of the tool without considering in what contexts these developments were made. Many aspects influenced the development of the camera, including political, social, technical, scientific and artistic concerns.

This study considers some of the most relevant influences on the camera obscura during this broad time span from the Greeks to the 19th century. The purpose here is to interpret rather than to catalog the events of the instrument. Primary to the study is determining the significance of the camera in both science and art, and how the technology in these two fields influenced and affected its use. Within this broad spectrum, however, the view is narrowed. Issues concerning the validity of linear perspective as a faithful representation of nature, the relationship of perspectival geometry to the geometric optics of the camera, or the relationship of vision to other systems of imaging, as the camera and linear
perspective, are not considered. While attitudes and biases towards the camera are discussed, this study does not attempt a social history of the tool. No effort has been made to analyse specific works of art in order to claim that the camera was influential in their execution. However, some brief and rather general comments are made in the last chapter concerning the technical development of the camera in relation to the 17th century Dutch painter Jan Vermeer.

Only the more significant treatises from this broad time span are analyzed to understand the role in which the camera functioned. Frequently, sections of this literature become highly repetitive, due in part to lines of influence by authors, to philosophical approaches, and to limited understanding of the tool. Those works adding no new insight into the general understanding of the tool, therefore, are not considered in this study.

Finally, this study questions some very basic assumptions that historically have been made about the camera obscura. These include its importance in painting, its widespread use by artists after the 16th century, and its importance in blending art and science in the tradition of linear perspective. Today, these claims seem to stem from an outmoded need to justify photography as art by
establishing some link to the traditions of art. As the history of the photography is still a relatively young area of study, it may be time to consider photography in a broader historical context than the traditional art-dominated one.
CHAPTER 1
THE BEGINNINGS:
GREEK AND ARABIC OPTICAL TRADITIONS

Like photography, the camera obscura is tied to the concept of time, for it was in the development of a systematic measurement of time, first into days, then into months and years, that the camera obscura was born. Nature imposed the unit of day. Man ordered these into months, beginning each with the arrival of a new moon; then he tried to determine the number of months in a seasonal cycle. The day was also subdivided into hours that were measured by the motion of the sun across the sky during the day and by the burning of candles during the night. This accounting, necessitated by the agriculture of the community, required a system of mathematics and astronomical observation, not only for keeping track of passing time but also for predicting future events (Clagett, 1963; Crombie, 1967; and Dampier, 1971).

The camera obscura was developed as a tool for astronomical observation, a forerunner of the telescope as well as the photographic camera. The earliest astronomical tools were simple methods for calculating the passage of
the sun across the sky. A bronze rod or gnomon was used to record the shadow of the sun as it moved across the floor, an engraved plate or dial. Some of these early sundials included a thin brass plate having a small hole drilled in it, or a small metal ring which was attached to the gnomon and projected the image of the sun onto the dial. The earliest recorded document of such an image-forming device is found in China in the fifth century B.C. (Hammond, 1981; Needham, 1954; and Straker, 1971). The application of such an image forming device seems to be an extension of a common, naturally observable experience, that of a solar image being cast on the ground through the spaces between the leaves in a tree, or on the floor through a chink in the roof.

The Chinese, Babylonians, Chaldeans and Egyptians each demonstrated varying degrees of sophistication in their development of astronomy and mathematics. The Egyptians evolved a highly sophisticated form of geometry, while the Babylonians developed a more advanced system of algebra. The Egyptians depended on the annual flooding of the Nile to mark their year, while the Chaldeans put more credence in their astrology than astronomy, and the Babylonians, as early as the sixth century B.C., were able to calculate the relative positions of the sun and moon in advance and to
predict a solar eclipse (Dampier, 1971).

These early astronomical observations and calculations were empirical, that is, based on immediate observable events. So, too, the practical application of these observations was more important than the why or how of events. Such explanations were in the provence of astrology, religion or magic.

Greece inherited the knowledge of the ancient world, made their own additions and distilled this into a natural philosophy and science which became the foundation of western civilization. Astrology and mythology existed, but it was the philosopher who searched for a natural rather than mystical explanation of the universe. With Aristotle, knowledge was systemized and classified, scientific research began, and reasoning was identified as inductive or deductive. In geometry, the paradigm became a model for a uniform and permanent abstract order, eliminating the confusion of empiricism. To the Greek scientist, knowledge and understanding were more important than practical usefulness. He explained the real world by creating theoretical models, and mathematics, in particular geometry, became the rational system of proof.

Greek geometry and astronomy were highly advanced by the fourth century, and it is here in Greek astronomy,
according to Clagett (1955), that "we have a brilliant example of the fruitful application of geometrical techniques to scientific inquiry" (p. 106). The objects in the heavens either give off their own light or reflect light from another source; it is by this light man observed the celestial bodies and their motions. Ancient astronomers, by the incorporation of "observatories" into their temples and the alignment of their architecture such as Stonehenge or the tombs and monuments in the Nile valley, implicitly assumed the "rectilinear propagation" of light, that is, that light travels in straight lines. But ancient astronomers did not need to understand the principle in order to use it. To understand optics and astronomy, one needs a working philosophy of the nature and behavior of light, and the Greeks took on the task not only of explaining the nature of light but also of dealing with the deviations from that natural behavior. It is here that their reasoning fell short, for "the principle of rectilinear propagation...is not the sort of belief that one can verify simply by not being able to see around corners" (Straker, 1971, p. 41).

By the fifth century B.C., Greek scientist-philosophers had begun to investigate the mechanics of vision and were attempting to determine the link between the eye and the
object seen. The Atomists developed the emission theory where the object emitted Simulacra, an image or shadow of itself, which left the object in a type of radioactivity and traveled to the eye. The Pythagoreans believed that the eye emitted the rays which strike the object and then are reflected back to the eye. The Platonic school favored a theory that combined the two emission theories above, while Aristotle considered vision as being the result of a movement between the object and the eye. This last theory, according to Gioseffi (1966) was the anticipation of Christain Huygens' wave theory which was introduced in the seventeenth century. However, it was the Pythagorean theory of emission that dominated optical thinking, even into the Renaissance.

In 300 B.C., Euclid wrote the first treatise on optics, a study of vision and things seen. Based on the Pythagorean emission theory, his was an oculocentric approach to optics. In this highly influential *Optics*, Euclid applied geometry to the theory of rectilinear propagation, equating straight lines with the visual ray, and making this "perspective" the beginning of geometrical optics based on the concept that rays of light or vision follow a straight or rectilinear path if otherwise not obstructed. In this work, however, Euclid did not mention image formation
through a small aperture, a discussion which could serve as a proof for the theory of rectilinear propagation, but one which would have challenged his basic premise that the eye emitted the visual ray. Another work, *De Speculis*, discussed below, was attributed to Euclid and was widely circulated in the West during the thirteenth century. This work does contain a discussion of image formation through small apertures. Nevertheless, Euclid's *Optics* enjoyed a great popularity throughout the following centuries and formed part of the foundation in the Renaissance development of the linear perspective theory.

It was the astronomers who were more cognizant of image formation through small apertures. The Greeks had struggled to find an effective method of observing the sun, particularly during a solar eclipse, without causing damage to the eyes. Common practice included watching the sun's reflection on the surface of a pond or stagnant water, or by looking through smoky quartz, if there were no mist or fog or the sun was not near the horizon. Even these methods were still potentially dangerous to the observer's eyes.

In a work attributed to Aristotle, the *Problemata*, the author, in Book XV, "Problems Connected with Mathematical Theory," asked:
Why is it that when the sun passes through quadrilaterals, as for instance in wickerwork, it does not produce a figure rectangular in shape but circular? (Hett, 1936, p. 333)

Further on, he gave his reader an alternative method for observing a solar eclipse, although this is not the purpose of his text. Again, he asked a rather straightforward question:

Why is it that in an eclipse of the sun, if one looks at through a sieve or through leaves, such as a plane-tree or other broad-leaved tree, or if one joins the fingers of one hand over the fingers of the other, the rays are crescent-shaped where they reach the earth? (Hett, 1936, p. 341)

Both of these questions deal with what Lindberg (1968) calls the theory of images formed by "finite" apertures, that is, openings having a specific shape and measureable size; these would be different from "point" apertures where the opening is tiny in relation to the distance from the aperture to where the image is formed, and where the image is its sharpest or maximally resolved. Lindberg refers to these two instances, both finite and point aperture formed images, as "pinhole" images; however, the word "pinhole" more accurately describes the point aperture, and I have chosen to use the term exclusively for this situation.

The distance between the aperture and the image is called the focal distance or focal length. Even when there is no lens but only an aperture to form the image the focal
distance must be long enough, in relation to the aperture size, for the rays to be correctly focused and the image clearly formed (Fig. 1).

Figure 1

If the aperture is too large or the focal distance too short, the image is blurred because more than one ray of light from any one point on the subject enters the aperture causing the formation of multiple points, a phenomenon known as diffusion (Fig. 2).

Figure 2

If the aperture is too small or the focal distance too long, the image is blurred because the edge of the aperture blocks the light ray and permits only a part of the ray to
enter, a phenomenon known as diffraction (Fig. 3).

![Figure 3]

When the distance between a finite aperture and the formed image is greatly increased, the aperture becomes in effect a pinhole. When the distance between a finite aperture and the formed image is severely shortened, the image takes on the shape of the opening.

In understanding the theory behind an image formed with a point aperture, three facts exist: 1) the light rays travel in straight lines through the opening, 2) the light rays intersect in the opening without mingling, and 3) the image that is formed is in full color, inverted and reversed from right to left. In understanding images formed by finite apertures, however, the problem of the size and shape of the opening must come into consideration, as these can affect the way in which the image is formed. It is not an easy concept to grasp, as the author of the Problemata realized and as many later writers discovered too; these two questions were not satisfactorily answered
in western science until the riddle was solved by Johannes Kepler in 1604 and Francesco Maurolyco in 1611.

The author of the *Problemata* did attempt to answer his own questions. In the case of the image formed through the wicker, he stated that if solar rays are straight when they go through an opening that has straight sides, then the projected image must have straight sides too. The image only seems round because those rays at the extremities of the aperture (those hitting the edges or partially cut off by the material in which the hole is located) are weak and more difficult to perceive (an effect called "fall off" in photography.) The author offered supporting "evidence" for this by stating that from a distance squares seem circular and spheres seem flat.

Straker (1971) informs us that this particular argument was not only influential in later optical works, but also that it is important since the author presented it "because he had come to the conclusion that the geometry of the rays themselves leads necessarily to a rectilinear image of the sun behind any rectangular opening" (p. 50).

In addressing the second question of images formed through various type apertures during a solar eclipse, the author correctly explained what happens with a point aperture, which was not the problem at all. While not
dealing with the problem finite apertures, he did introduce here an element which became the standard description in later discussions, that of two cones or pyramids of light joined at their vertices, one from the sun to the aperture and the other from the aperture to the earth (Fig. 4).

![Figure 4](image)

This is known as the double cone model of propagation. These cones consist of rectilinear rays intersecting at a common vertex in the aperture. If a ray is removed from the sun-aperture cone, said the author, the corresponding ray is eliminated from the aperture-earth cone. If the subject becomes crescent shaped, so will the projected image, which is what happens during a solar eclipse.

What do these passages on image formation in the *Problemata* tell us about the *camera obscura* in the fourth century B.C.? For one thing, we know that the writer relied on a conceptual rather than visual proof, as the *Problemata* was not illustrated. The lack of an illustration, even a geometrical diagram, does not help our
understanding of a complex theory which is rather confusingly explained in both instances. It should not be surprising to realize, then, that the solution to this problem of image formation comes at a time when an artistic vision of space has been developed to compliment the conceptual geometry of Aristotle.

Another important point to note here is the fact that there is no clear evidence that this is a true "camera" in the sense that the event happens inside a darkened room. The ability to form the image of the sun through an aperture is recognized and acknowledged, but it appears to be an event that accidentally occurs. One could acknowledge that during a total solar eclipse, one's environment becomes a darkened place, but for other solar observation, such as for measuring the diameter of the sun, there is no indication here or elsewhere in Greek scientific literature that any solar observation, including solar eclipses, took place in a camera obscura.

In fact, Greek scientific writing seems to be silent on the methods used for solar observation, other than the dioptra of Hipparchus, which is mentioned in the Almagest, or "greatest work," of Claudeus Ptolomeus around 150 B.C. The dioptra, used to measure the diameter of the sun and moon, consisted of a long beam or rod with two metal
plates, one at each end (Fig. 5).

Figure 5

One plate was permanently attached at the end of the rod, and contained two holes which were used in sighting the top and bottom of the sun. The second plate, which was near the observer, moved back and forth in a groove on the rod. This plate also had a hole drilled in it, equidistant from the two sides and in the lower half of the plate near the rod. While looking through the hole of the back plate, the observer moved this plate back and forth until he could see the top and bottom of the sun positioned in the two holes of the front plate, thus creating an angle of view. The diameter was then calculated from the distance of the two holes in the front plate, and the distance between the two plates (Cohen & Drabkin, 1948).

Any one of the three holes could have formed an image of the sun on the opposite plate, but if the Greeks realized this and used this method for solar observation, such as during an eclipse, it is not mentioned. In fact,
Ptolomy never mentions image formation through an aperture, either as an observational method or as a theoretical problem.

The Greeks had identified the basic theoretical concept of the *camera obscura*, that of image formation through an aperture, but their application of image formation, by strictest definition, was not yet the *camera obscura*. The first record of an image formed in a true *camera obscura* occurred in the 9th century A.D. in China, while in the same century the Arabs took up the theoretical problem of image formation.

In China, Tuan Chheng Shih discussed the image of a pagoda being formed through an aperture, noting that the image was inverted. Incorrectly attributing this inversion to the fact that the pagoda was near the sea which could produce such an effect, Shih apparently confused the inverted image with reflections he had seen on lake surfaces, as the scene across a lake is reflected in the water upside down to the viewer standing on the opposite side. Another Chinese writer Shen Kua later correctly explained the inversion of the pinhole image by comparing the light rays to an oar in its oarlock, that is, when the handle is down, the blade of the oar is up. In the 10th century Yu Chao-Lung, constructing models of pagodas and
projecting their image through an aperture and onto a screen, studied the direction and divergence of the light rays (Nakayam & Sivin, 1973; Hammond, 1981).

The Chinese, however, never developed the concept of image formation beyond a simple recognition of linear propagation, nor did they utilize the camera obscura to any significant extent. The Chinese never developed their geometry to the same level as the Greeks, nor did they take the same attitude as the Greeks had toward the importance of geometry in constructing a theoretical proof. By the 13th century, Chinese interest in science declined rapidly and was not revived until reintroduced in the 16th century by Jesuit missionaries. Thus, while the Chinese were aware of images formed in the camera obscura, they made no significant contribution to the development of the theory of image formation or to the development of the camera technology (Hammond, 1981).

The Arabs, on the other hand, preserved and transmitted a large body of the Greek scientific writings during the darker period of western scholarship. By the 10th century nearly all of the text from Greek science that would eventually become available to the western world were preserved in Arabic. The Arabs also contributed much to scientific understanding, from their attitude toward of
science to specific discoveries in optics and vision. The Arabs had acquired their information directly from the Greeks of the Byzantine Empire, as well as second hand from the Syriac centers of Nestorian Christians in eastern Persia where, during the 6th and 7th centuries, a great number of Greek scientific works had been translated into Syriac. Many of these works included writings on medicine and human vision. After Arabic conquests, these Syriac centers of translation continued their work, where Christian, Jewish and Arabic scholars alike worked on translations from Syriac into Arabic.

In the 9th century the Arab scientist al-Kindi (Abu Ysuf Yaqab Ibn Is-haq), in his De aspectibus, conducted an experiment with the camera obscura in order to prove rectilinear propagation of light from a luminous body. Using a candle opposite a finite aperture, the image of the candle was projected onto a screen on the other side of the aperture. Al-Kindi stated that if a straight line is drawn from the outer edges of the aperture, the line will proceed to the outer edge of the candle. A geometric diagram is included to illustrate the proof (Fig. 6). The candle is represented by a circle, its cast rays traveling in straight lines through the edges of the aperture and projecting its image on the screen. The aperture is finite,
and we see this illustrated by the fact that the light rays intersect not in the aperture but before it at a place where a point or pinhole aperture should be. The actual opening is behind the intersection of the light rays and corresponds to the size of the width of the second pyramid or cone of light. The edges of the cast image correspond to the straight lines drawn from the light source.

![Figure 6](image)

For al-Kindi, the proposition was proven with the diagram. No discussion of image quality followed, such as whether its shape was that of the candle or of the aperture.

This passage appears at the very end of a treatise on optical problems which is based largely on the works of Euclid, Hero and Ptolemy. In this work, al-Kindi dealt with vision and the formation of shadows cast from luminous objects. Asserting that vision takes place by rays that are capable of having a physical effect on the eye, he argued against the theory of visual rays which are only mathematical abstractions and are incapable of acting
physically or physiologically. He studied the formation of shadows produced by objects that were illuminated by light entering a window, and the passage above reaffirms his uncompromising application throughout this work of the theory of rectilinear propagation. The De aspectibus was an important work, although the exact date of the work is unknown. It was translated into Latin in the 12th century by Gerard of Cremona, and proved to have an important impact on both Arabic and western scientific knowledge.

Another work appearing in the Arab scientific literature which dealt with the theory and use of the camera obscura was the De speculus attributed to Euclid. This was, according to Lindberg (1968), an Islamic compilation of theorems in geometrical optics drawn largely from Euclid's Optica, Hero's Catoptrica, and a Catoptrica attributed to Euclid, but in all probability a work of Theon of Alexandria. The work would seem to post-date the De aspectibus as al-Kindi's proof appears in Proposition 9 of the De speculus.

Three propositions appear together here, the first two dealing with the camera obscura. The third, Proposition 11, a rather confusing and erroneous demonstration of why solar rays appear to be parallel to viewers separated by short distances, would be misinterpreted in the 13th
century as also dealing with the camera obscura. The first of these, Proposition 9, restates the al-Kindi proof but carries it a step further to prove that the image on the screen is wider than the aperture. In Proposition 10, the author returns to the question from the Problemata of an eclipse observed through an opening (Fig. 7):

when the sun is eclipsed, that part of its light which enters through an opening is diminished, i.e. it is not round; nor is its incidence on the surface of the earth according to line TZ, but according to the amount of the eclipse, and the diminution of the light is proportional to the diminution of [the sun produced by] the eclipse (Quoted in Lindberg 1968, p. 160).

Figure 7

The author seemed to fully understand the theory of image formation, stating that the rays, which travel in straight lines, intersect in the aperture and form the image opposite, take on the crescent shape of the sun (are diminished) in the image as the eclipse takes place. However, his confusion is revealed as he goes further:
Let the sun be eclipsed; and let its eclipsed part be arc $DGU$ and the part of its body that then sends forth the ray be arc $DEU$. And let the ray of arc $DEU$ pass through the aperture to the surface of the earth, which is [represented by] line $TZ$. Therefore, line $TH$ is the part of the ray incident on the earth (i.e. $TZ$). And [the illumination represented by line $HZ$ is removed from the ray above the surface of the earth, for it is that part [of the earth] which is illuminated by the ray from arc $DGU$. Therefore the proportion of line $HZ$ to arc $DGU$ is the same as the proportion of line $TH$ to arc $DEU$ (Quoted in Lindberg, 1968, pp. 160-161).

An analysis of the diagram reveals that the proof is erroneous, as the light from that portion of the sun which is not eclipsed ($DEU$) must bend around the corner to illuminate $HT$ in the projected image.

It should also be noted that the proposition describes the sun's image being projected onto the earth's surface, as we gather the author of the *Problemata* also meant. Does this mean that the author of the *De Speculus* is unaware of the *camera obscura*? Lindberg includes with his discussion of this work a diagram which shows the image being projected into an enclosure. His English passages are translated from the Latin included in a 1921 article, "Alkindi, Tideaus und Pseudo-Euklid, Drei optische Werke" by A. A. Bjornbo and Sebastian Vogle, and published in *Abhandlung zur Geschichte der mathematischen Wissenschaften*. In the Latin translation of the first sentence in Proposition 9, "Cum autem sol eclipsatur, tunc illud
luminis eius, quod per fenestram ingreditur, diminutum est, scilicet non rotuncum;" (Bjornbo & Vogle, p. 118), the word "fenestram" can mean either opening or window. A Latin scribe with some knowledge of the camera obscura might "clarify" the meaning of a proposition by improving the diagram or adding his own knowledge to the explanation or proof. A case in point is a 16th century manuscript of the De speculis in the Vatican (Vat. Lat. 2975) where Proposition 9 appears with a diagram (fols. 150r-151r). Here the phrase "fenestram in domo" (a window in a house) is used and a diagram is given which shows the sunlight entering an enclosure (Fig. 8).

![Diagram of sunlight entering through a window](image)

Figure 8

It is difficult to surmise whether or not the author was acquainted with the camera obscura. If he were simply restating the Problemata passage, he might have wished to remain true to the "spirit" of the passage by describing the sun's rays as they are projected onto the ground. Diagrams illustrating such manuscripts are generally
faithful to the original, but errors do occur in copying both text and diagram. Straker (1968) muses about Proposition 10 stating,

It is tempting to suppose that there has been a corruption of the text of De speculis so that the author himself had essentially duplicated the solutions of the Problems. This would only involve the interchanging of T and Z (or TH and TZ in the text and diagram" (p. 68, note 39).

From the De speculis we have very little information concerning Arabic knowledge and use of the camera obscura. By the 11th century, however, it becomes clear through the writings of Alhazen (Abu Ali Mohammed Ibn al Hasan Ibn al Haytham) that at least one Arab scientist understood the theory of camera formed images with both point and finite apertures, and that the camera obscura was used not only for observing solar eclipses, but also as a demonstration of human vision.

Alhazen's writings covered a broad spectrum of topics, from planetary movements to theories of light, vision, color, reflection and refraction. A master of traditional Ptolemaic astronomy, Alhazen attempted to reconcile Ptolemy's theory of celestial motions with the phenomena themselves. He used the optical part of astronomy to solve the problems of planetary theory.
Yet, much of his work remained in the Arabic until this century. Only one treatise, the great work on optics entitled De aspectibus or Perspectiva, became available to the West during the Middle Ages, and not even that treatise survived assimilation into the Latin West completely intact. Straker (1971) identifies three works by Alhazen which deal with the camera obscura.

"On the Light of the Moon," discussed in Matthias Scramm's Ibn al-Haythams Weg zur Physik (Boethius: Texte und Abhandlungen zur Geschichte der exakten Wissenschaften, Bd. I) (1963), is a study of the reflective nature of the moon's light. Refuting a belief put forward in the writings on catoptrics that the moon was a polished mirror, Alhazen argued that if this were true, the moon would reflect an image of the sun while the details of the moon's surface would remain obscured. Observation proved otherwise, he pointed out, for not only does the moon reflect the light of the sun, it also emits light as a luminous body. Alhazen drew upon the one demonstration in traditional optical writings that proved the propagation of light theory, but he was not satisfied to repeat tradition by just explaining the phenomenon. Alhazen used the phenomenon of aperture formed images as an experimental device to test his theory that the moon emits light in the
same way a self-luminous body does.

In his first experiment, Alhazen inverted his dioptra, using the fixed plate as the imaging screen and the movable viewing plate as his aperture. In this way he was able to project both lunar and solar images onto his dioptra screen. He concluded that both luminous and self-luminous bodies not only emit rays of light that travel in straight lines, but also that these rays are emitted "from each and every point on the surface of...[the] body... to each and every point in the medium which lies outside that surface" (Straker, 1971, p. 76), a conclusion which took him beyond the double cone theory of preceding writers. He also concluded that colors are also inseparable from light, and just as the light rays intersect but do not intermingle in the aperture, and proceed to form the image on the screen, the same is true for colors. He also found that the colors of non-luminous bodies were weaker than colors of luminous bodies, which in turn were weaker than the actual color. This conclusion was based on his observation of colored terrestrial bodies, both luminous and self-luminous, with his inverted dioptra.

At this point, Alhazen had no need to discuss the camera obscura as a tool, that is, the size and shape of the aperture, the type of light source, or the quality of
the image. One wonders about the kinds of "terrestrial bodies" Alhazen observed, whether they were something rather mundane like al-Kindi's candles or something more exotic like a landscape or city view. Whatever his subjects, Alhazen later moved from this experiment to a study of the camera itself.

In his "On the Shape of the Eclipse," a work translated in 1914 by Eilhard Weidemann as "Abhandlung über die Gestalt der Finsternis" (Sitzungsberichte der physikalischmedizinischen Sozietat in Erlangen, 46, pp. 155-169), Alhazen set out to prove that a partially eclipsed sun will project through a round aperture a crescent-shaped image on the screen. He further noted that when the aperture is made larger, the image cast is that of the aperture (whether round, square or triangular); but the same is not true of a lunar eclipse, he observed, as the lunar crescent appears to take the image of the aperture. This last observation on the image of the lunar crescent was discussed in the last two sections of this treatise. Alhazen concluded that the apparent reason why the lunar crescent did not seem to behave as the solar crescent did had to do with the low level of illumination, and was not in violation of his propagation of light theory.
In the case of a solar eclipse, Alhazen established the fact that every point on a luminous body casts an image of the aperture onto the screen; all of the points collect to an image or pattern of illumination, which he described as the inside edges of the shadow cast by the opaque material in which the aperture is located. Going further to discuss the size and shape of the image under the same conditions of the round aperture and the partially eclipsed sun, Alhazen found many shaped crescents formed on the screen from the many points of the luminous body.

Going from general observations to a more specific analysis, he discussed the ratio of the diameter of the aperture to the diameter of the sun, which he said is exactly equal to the ratio of the distance of the aperture from the screen to the distance of the sun to the screen. In this case, the aperture is of measurable width or finite (Fig. 9). The image formed would be a slightly blunted crescent made up of many tiny crescents, and would be wider than with a point aperture formed image. If the focal length is changed by moving the aperture and screen further apart the image is focused and forms a smaller, sharper crescent.
He then proceeded to demonstrate how the image becomes the shape of the aperture when the focal distance is shortened or the aperture is enlarged. In this instance he let the ratio of the diameters of the sun and aperture be ten times greater than the ratio of distances between sun and aperture and aperture and screen. He proved that there was no shadow from the eclipse present, and therefore the shape was that of the aperture.

In his analysis of the lunar eclipse, however, Alhazen was not able to get the crescent shape on his screen. His reasoning for this failure is a rather peculiar rationalization that since the sun is 18 times larger than the moon, an aperture that is $\frac{1}{18}$th that used for a solar eclipse would be needed for the lunar eclipse. An aperture of such size would be so small that, while a crescent would be formed, the image would be so small and weak that it could not be seen. His inability to project a lunar eclipse should in no way detract from his contribution to
the understanding of image formation.

The findings that have been discussed were incorporated into Alhazen's monumental Kitab fi'l-Manazir, a systematic treatise of optical principles, theorems and laws. This work was translated into Latin sometime in the late 11th or early 12th century, under the title of De aspectibus or Perspectiva. This Latin manuscript tradition, however, omitted the first three chapters of Book I. In 1572, Frederico Risner published the only printed edition, under the title Opticae Thesaurus. Following the manuscript tradition, this edition began with the fourth chapter of Book I. A commentary by Kamal al-Din al-Parisi, "Corrections of the Optics," was written in the 12th century, and was the only known Arabic source of Alhazen's treatise until 1910. While this work treated the camera obscura more generally, it continued the experimentation of light and color with the camera.

The Kitabfi'l-Manazir, an optical work in the tradition of Euclid and Ptolemy, is organized around the topic of vision. This work incorporated Alhazen's own research from the treatises already discussed, with the exception of some of the experiments from his "On the Shape of the Eclipse." The central topic of the work was Alhazen's theory of vision which was based upon physiological and optical
proofs like that of the camera obscura. The rest of the work dealt with things seen by direct, reflected and refracted light, and included the proof of the propagation of light and color given in his "On the Light of the Moon."

The first three chapters of Book I, those missing in the Latin West, were devoted to a systematic documentation of the principle of light propagation from luminous bodies, and included Alhazen's in-depth experimental foundation based on the camera obscura. In chapter three, he discussed the image of a solar eclipse as formed on a screen through an aperture, giving detailed directions on the construction of an experimental camera and the kinds of observations one could make with such an instrument. He then discussed reflected and refracted light, proving that both are also rectilinear but do not behave in the same way as light from luminous and self-luminous bodies. Finally, he turned to the central problem of all works on optics, that of vision, and this is where the Latin texts and the Risner edition begin.

The one passage included here on the camera obscura could hardly give the reader any understanding of Alhazen's grasp of the principle of camera formed images, or his innovative use of the tool. By itself, this seems merely to be an elaboration of al-Kindi's candle experiment:
The evidence that lights and colors are not mingled in air or in transparent bodies is that when a number of candles are in one place, (although) in various and distant positions, and all are opposite an aperture that passes through an aperture to a dark place and in the dark place opposite the aperture is a wall or an opaque body, the lights of those candles appear on the (opaque) body or wall distinctly according to the number of candles; and each of them appears opposite one candle along a (straight) line passing through the aperture. If one candle is covered, only the light opposite (that) one candle is extinguished; and if the cover is removed, the light returns...Therefore, lights are not mingled in air, but each is extended along straight lines (Quoted in Lindberg, 1968, p. 154).

An important comment to make about this passage is that the Latin defines the word used for the image formed on the screen through the aperture as "forma," and the phrase used for the darkened room as "locum obscurum" rather than "camera obscura." According to Omar (1977), this phrasing is consistent with the Arabic. The Latin expression camera obscura, which has become the accepted name for the phenomenon as well as the instrument, was first used by Kepler in 1604.

Hammond (1981, p. 5), citing this passage of Alhazen's candle experiment, raised the point that while Alhazen acknowledged the reversal of the candle image on the screen, he failed to mention that the image was also inverted. Al-Kindi had done a similar experiment, but his diagram made it clear that he understood the image would be
both reversed and inverted. The Latin manuscript tradition is not always consistent in reproducing the diagrams from the Kitab fi'1-Manazir, but in this instance it seems that Alhazen had no illustration of his experiment. Were this the only passage by Alhazen that addressed the problem of camera formed images, one could easily think that Alhazen did not fully grasp the concept. However, in light of his passages missing from the Latin tradition in this work, as well as his other studies, particularly that of "On the Shape of the Eclipse," we realize not only just how deeply and thoroughly Alhazen had investigated the camera obscura, but also how clear his reasoning was.

In this great work on optics, Alhazen approached his subject quite differently from his predecessors. While the Greeks had given theoretical "proofs" of their hypotheses, Alhazen constructed experiments to demonstrate his proof. He even gave instructions for conducting these experiments. Two such instruments which survived the translations in the West are used for testing his theories of reflection and refraction. Alhazen's experimental approach to what traditionally had been known as a philosophical discourse of nature is the exception. His innovation, however, did not change the course of scientific study for those who followed him. This idea of
experimental proof did not fully catch on until quite late in the history of science.

This work is important, too, in that Alhazen studied the nature of light in relation to how we see. As the work is primarily concerned with human vision, his theories were predicated upon the information and experiments included in the first three chapters, those missing sections in Latin. Here Alhazen had thoroughly demonstrated the nature of light with his use of the camera obscura. In his discussion of the eye, Alhazen implied a correlation between the eye and the camera obscura, making references to the aperture of the eye forming the images in the eye.

In Book 2, chapter 3 he stated:

...The manner in which the form arrives at the chamber of the joint nerve is the same as the manner in which light arrives from the cracks and apertures through which light enters, at the objects opposited these screens (i.e., screens) (Quoted in Omar, 1977, p. 83).

Straker (1971), however, argues that Alhazen's theory of vision prohibited any definite analogy between the image formed behind the aperture of the camera and the image formed by the eye. While the camera proof certainly supported Alhazen's theory of intromission and successfully destroyed the emission theory of vision, Alhazen realized that vision in the eye involved more than just image formation, and that the opening in the eye is too large for
the focusing distance to permit an adequately resolved image to be formed. "Indeed, the denial of the analogy is even stronger; it is precisely because the eye is not like the camera that clear and distinct vision at all distances is possible at all" (Straker, 1971, p. 432). Alhazen made this clear in Book I (Risner edition, 1572, p. 8) when he stated:

16. Vision is complete [only] when the form of the visible thing received by the crystalline humour passes through into the optic nerve (Quoted in Straker, 1971, p. 433).

We shall see this problem of the camera-eye analogy again, particularly in the work of Leonardo da Vinci.

It is not clear what impact Alhazen's writings had on Islamic science, but in all probability his study of the eye made a greater contribution to Islamic medicine than did his writings in astronomy. At the time that Alhazen was writing, Islamic science had already begun to decline. Islamic astronomy, with the exception of the invention of the astrolab, had not advanced much beyond Aristotle's day; Delambre (1817, p. 84) noted that in 928 Arab astronomers were still observing the solar eclipse by reflection in still water. It was in the West, however, that Alhazen's impact would be felt, even into the 17th century by men like Kepler, Galileo and Maurolico who would change the direction of future scientific thinking.
REFERENCES


CHAPTER II
LIGHT IN THE WEST:
THE 13TH CENTURY

In the Latin West, traditional scientific knowledge consisted almost exclusively of fragments of Greco-Roman writings that were preserved and codified in the form of encyclopedias compiled not by scientists but by litterateurs (Stock, 1978, p.8). From this tradition had come a vast and rather heterogeneous collection of beliefs dealing with the divine nature of light. Pagan and Christian philosophy was united in the concept that the Author of Nature illuminated the world and man's soul with divine light and grace. Christian scholars noted that in Genesis, God created light first before creating any of the luminous bodies of the cosmos. Augustine had reinforced this philosophy with his Neoplatonic writings, and began a tradition of Christian intellectual mysticism based on the metaphysical relationship between God and light.

One of the earliest Latin scholars to revive the study of light and optics as a natural philosophy was Robert Grosseteste, Bishop of Lincoln (ca. 1168-1253). Available to him, in addition to the traditional encyclopedic works
such as Pliny's *Natural History*, were the newly translated works coming into the West at this time. These included the *Optics* and *Catoptrics* of Euclid, al-Kindi's *De speculis* the Pseudo-Euclidean *De speculis*, Aristotle's *Metaphysics* and *Meteorology*, and the *Arithmetic* by Boethius. Missing were Ptolomy's *Optics*, which was perhaps the most sophisticated study in the Greek tradition, and Alhazen's great *Perspectiva*, which may well have been the most sophisticated study of light and optics to date. The absence of these last two works are evident in Grosseteste's own writings such as *De iride* and *De Luce* which are much more metaphysical in their orientation than works by followers of Grosseteste who had the Ptolemy and Alhazen treatises available.

Grosseteste never mentioned the phenomenon of image formation in the *camera obscura*, perhaps due to the unavailability of Alhazen's *Perspectiva* or Aristotle's *Problemata*. However, he did have two other works that mentioned the *camera obscura* phenomenon, al-Kindi's candle experiment, and the Pseudo-Euclid restatement of that experiment, with a discussion of the image of a solar eclipse formed by a non-circular opening. We can only surmise that the image formation behind a small aperture held no interest for Grosseteste, either as problem or
proof.

Grosseteste's influence, both in his writings and in his lectures to the Franciscans at Oxford, set the direction for succeeding studies on light and optics, and it is necessary to look briefly at his philosophy in order to better understand later writers who discussed the camera obscura.

For Grosseteste, optics was the most fundamental of the sciences of nature. He believed that the action and behavior of light revealed the nature of causation, and that light itself was the source of all created being. Every natural agent, he explained in his De Luce, sent out its "species" or "virtue" along geometrical lines, the straight line being the most effective, the strongest and the most perfect route of natural action. A point of light was seen as the fundamental unit for the propagation of power, and was taken to be the elementary model for the "multiplication of species." Following the Euclidean tradition of emission, Grosseteste believed that light by its very nature diffused itself in every direction,

...in such a way that a point of light will produce instantaneously a sphere of light of any size whatsoever, unless some opaque object stands in the way (Riedl, 1942, p. 104)

Grosseteste took the Greek concept of the pyramid or cone of light and made it a part of his theory of causation.
All bodies, including those that give off visible light, multiply their species, or propagate their powers according to the geometry of the pyramid. However, Grosseteste asserted that geometry could only give an account of what happened; it could not explain what happened. The cause of the observed behavior of light was to be sought in the nature of light itself (Crombie, 1953).

In making the mathematical study of optics the foundation for all creation and all causation, Grosseteste brought about a new enthusiasm for the study of optics among the natural philosophers of the 13th century, and this was his greatest contribution. This revival of interest in optics and the newly available writings of Aristotle, Ptolemy and Alhazen is seen in the work of three contemporary scholars, Roger Bacon, John Pecham and Witelo, all who wrote optical treatises in the last half of the 13th century, and all who approached the problem of image formation behind a small aperture. Lindberg (1970a, 1971a & b) has investigated the possibility of influence among the three, as they were all in Italy between 1265 and 1275, and there are some similarities in their work.

Roger Bacon (ca. 1219-1292) was greatly influenced by the writings of Grosseteste. He understood and completely agreed with Grosseteste's metaphysical approach to optics,
yet he was able to go beyond this attitude in a further exploration of the modes of action of natural bodies. He followed Grosseteste's theory of the multiplication of species, but expanded it to contain five kinds of propagated species, which are included in his *Opus Majus*. This work also contained a large section on optics, which for the most part is a commentary on Aristotle, Ptolomy and Alhazen. He even complained occasionally in his *Opus Majus* about the poor quality of translations that he had available of the Alhazen treatise (Burke, 1962, p. 497 is one example).

Unlike Grosseteste, Bacon tried to find phenomena that would best demonstrate the way in which the "species" were multiplied from "agent" to "patient." Bacon turned to the propagation of light through a small aperture in order to explore the action of light in producing heat and brightness, and chose the one case which most directly and most obviously challenged the mathematical principle of rectilinear propagation, that of explaining a round image projected through a rectangular aperture. Bacon's "explanations" are found in several of his treatises, including the *De speculis comburentibus*, the *Opus Majus*, and the *De multiplicatione specierum*; these last two works each have two different discussions concerning camera
formed images. In his *Speculum astronomiae*, Bacon suggests the use of the *camera obscura* as an observational instrument.

In his first attempt to deal with this question, found in the *Opus Majus*, Bacon stated:

*If it should be said that the light [of the sun] entering through a large triangular opening or through one of another polygonal figures does not fall in spherical form, but does so when it enters through a small opening, we must state that the small sides of the small opening are not far apart and therefore the light in a short distance is able to regain its figure; but when it passes through a large figure, it cannot do so easily but it will do so at some sufficient distance, if obstacles are removed (R. B. Burke, 1962, pp. 136-137).*

Here Bacon set aside his belief in the theory of the multiplication of species along rectilinear paths, and instead concluded that the rays from the sun were able to round themselves off after going through a multi-angular aperture. He came to this conclusion by observing that when the screen was near the aperture, the illuminated portion had the shape of the aperture, but when the screen was moved farther back, the illuminated image gradually became round. A similar but more developed analysis is made in the *De multiplicationes specierum* (Fig. 10):

*Through an oblong or multi-cornered aperture is incident in a shape conforming to the shape of the aperture, especially if the aperture is rather large, since if it is too small the light is incident in a round figure...Although in a*
small distance the light does not assume the required (circular) shape, it does acquire this shape in a sufficient distance. For the larger the aperture, the greater the distance (required) for it to assume this shape, since the large dimensions of a many-sided aperture are more elongated from a circle and sphere...the species of the sun would become equal to the portion of the sun multiplying the species...For the angles of the two triangles, which have as bases the chord of the portion of the sun multiplying the species and the chord of the species falling on the wall, are equal, since they are vertically opposite; and by hypothesis the sides of those triangles are equal. Consequently the bases, which are the chords of portions of the sun and of the species of those portions, are equal (Quoted in Lindberg, 1968, pp. 163-164).

FIGURE 10

Bacon went further to confirm the ability of solar rays to round themselves off by citing an observation that the sun appears rounder at noon than at other times of the day when it is nearer the horizon. The solar rays are weaker in the morning, for instance, because they pass obliquely through terrestrial vapors. The author of the Problemata had asked,

Is it because the sun's rays fall in the form of a cone and the base of the cone is a circle, so
that no matter what object they fall upon the rays of the sun must appear circular? (Hett, 1936, p. 333)

Bacon's affirmative response to this revealed his belief in the natural activity of light and its natural tendency to strive toward circularity; this belief would pervade optical studies through the 17th century.

A second solution, again derived from the Problemata, was also provided in both the Opus Majus and the De multiplicatione specierum. First he asked how it came to be that a round image of the sun is cast through a cornered aperture. Then he proceeded to set up the problem in such a way as to avoid solving it by requiring that the screen be set as far away from the aperture as the aperture was from the sun. By doing this, Bacon had made the opening effectively a point aperture, and had done the same thing the author of the Problemata had done: he failed to solve the problem of images formed by large apertures and avoided the problem of shape.

One final attempt to explain this problem is found in Bacon's De speculus comburentibus, a short commentary on burning mirrors found in the Pseudo-Euclidean De speculis. Here he was merely interested in the rectilinear modes in which light is propagated, and he used the phenomenon of image formation in the camera obscura to test his
propagation theories. In this case, Bacon discarded the idea that light rays strive for natural rotundity, and instead based his solution on two observations: 1) the image cast by the sun and passing through a triangular aperture are round like the sun rather than triangular like the aperture, and 2) the beam of light passing through the aperture appears to contract just past the opening, and then dilates to assume the shape of the sun as the screen is moved away from the aperture. The first observation, of course is true, but the second is questionable, causing some real problems for Bacon in his analysis of the problem.

Using his five modes of propagation to determine which fit his observable facts, Bacon found the only two would work (Fig. 11):

light can be multiplied along either parallel or intersecting lines; if along intersecting lines, the place of intersection can be on or in the sun, between the sun and the aperture, or beyond the aperture (Quoted in Lindberg, 1970a, p. 216).

FIGURE 11

Bacon's faulty observation caused him to question three of his five modes, which formed the core of his theory of
multiplication of species. He rationalized that the rays in these three modes, which were not directly included in the pyramid or cone of light, were so weak as to be invisible.

Bacon was not successful in trying to explain this problem. His belief in the metaphysical aspects of light led him to rationalize the natural rotundity of light or its invisibility when it did not fit into his observation of the phenomenon.

Bacon's final reference to the camera obscura is found in his Speculum astronomiae, a technical manual designed to teach the use of the Toledan Tables which were a compilation of data on celestial measurements and the parameters of solar and lunar eclipses. While most of this data was not a result of direct observation, the procedure for measuring that area of the solar or lunar disk which is obscured during the eclipse required qualitative measure, not casual estimation in terms of large or small.

In the closing passages of the text, Bacon suggested the use of the camera obscura for observing a solar eclipse, giving instructions for its use. This passage is significant, for it is the first time in the European astronomical tradition that the camera obscura was explicitly recommended for observing a solar eclipse.
There was no mention of the **camera** in the tables themselves nor in their commentaries. Nor could Bacon have found a reference to the **camera obscura** in any of the astronomy handbooks or observational techniques of the time. In all probability, the idea had come from the **Problemata**. Regardless of the source, Bacon's instructions were fairly clear:

If however, on a day when the sun will be eclipsed, (you want) to observe the entire eclipse without damage to your eyes, when it begins, how long the sun remains eclipsed, and the amount of the eclipse, then observe the fall of the rays of the sun through any round aperture and watch diligently the bright circle which the rays have formed in the place onto which they fall. When you see the rotundity of this circle become eclipsed in some part, you know that at the same time the brightness of the body of the sun is eclipsed in the part opposite that part (eclipsed in the bright circle); for when the rotundity of the bright circle begins to be eclipsed, then the sun begins to be eclipsed from the opposite part. And similarly, while the rotundity of the bright circle grows, the eclipse diminishes, and proportionately in degree. Indeed, there will be as many digits of the diameter of the sun eclipsed as there are digits of the bright circle (eclipsed) which the rays of the sun project in the place where they fall after passing through the middle of the round aperture. And thus ends this (tract) (Quoted in Straker, 1971, pp. 116-117).

Bacon's reference to the "digits" of the diameter of the sun and image was, of course, part of what the instructional manual was about: making precise quantitative measurements to be used with the Toledan Tables. However,
Bacon was rather vague about the size of the hole one should use, a fact which is fine if one only wants to observe the eclipse, but one that is unsatisfactory in terms of critical measurement. For his suggestion to be of any value, Bacon needed to specify a point aperture.

Nor did Bacon specify where this event is to take place (i.e., whether outside, in a dark place, or a room) or where the rays might fall (i.e., whether on the ground, a screen or a wall). In fact in none of these passages did Bacon indicate the actual camera obscura, and we seem to find ourselves back at much the same point as with the Greek Problemata. Unlike the 4th century B.C., however, other evidence exists that confirms the fact that the camera obscura was known and used in the 13th century, as we shall see with William of St. Cloud below.

Bacon had available the Alhazen passage which referred to the image of candles being projected in a dark place, and one could assume that his observations of images formed in non-circular apertures were also made in a dark place. His faulty observation that the image was constricted behind the aperture could have been due to either too little or too much ambient light. It could be argued that Bacon probably used a very dark place and because it was so hard to see what he was doing, he invariably resorted to too
large an aperture to increase the light level. It could also be argued that Bacon's failure to mention a dark place was a result not of ignorance but of assumption on his part; either he assumed the reader understood that one did this type of observation in a dark place, or he assumed the reader understood that everything gets dark during an eclipse.

It is much more difficult to think that Bacon assumed the reader understood the need for a point aperture to make precise measurements during the eclipse. As he never made a distinction between images formed by finite and point apertures, we are uncertain whether or not Bacon even realized the need for a point aperture in this instance. His diagrams give us no clue to his comprehension of image formation, as they appear in his less than successful analysis of image formation with non-circular apertures. The one included in the Opus Majus has little in common with the passage it illustrates, while the second which is predicated on unsound reasoning is difficult to understand.

With the exception of the last passage recommending the use of a camera obscura during an eclipse, Bacon's discussions of the camera formed image had nothing to do with the actual camera obscura. They serve instead as a demonstration or proof of rectilinear propagation, as
well as of his own theory of spherical propagation, and as such are only a small aspect of the larger work. The *Opus Majus* was encyclopedic by nature, containing chapters on philosophy versus theology, the study of languages, mathematics including music, astronomy, geology, experimental science and morals. The discussion on image formation is found in his fifth chapter "Perspectiva," the Medieval Latin term for optics. His *De multiplicatione specierum* was an expansion of the "Perspectiva" and included much additional information. In 1268 these two works were sent secretly to the Pope at his request while Bacon was apparently under confinement by his Franciscan order in Paris.

Bacon's failure to explain the theory of image formation should in no way detract from his contributions in the history of 13th century science. Bacon's mythical reputation as "Dr. Admirabilis" persisted into the 18th century where he was seen as an ingenious alchemist, skilled mechanician and dabbler in the black arts. His several imprisonments by his own order, as well as his rather visionary predictions in his scientific writings, has not only supported such a myth, but also resulted in his being credited for the invention of a mechanically propelled boat, a flying machine, gun powder, improved
vision through the use of glasses, the microscope, the telescope, and the camera obscura.

Outspoken and uncautious, his imprisonments apparently a matter of internal discipline, Bacon, as a scientist, was a free and to some extent an imaginative thinker. This can be seen not only in the passages that seem to predict future inventions as the telescope, but also in such thinking as his belief that light rays do penetrate dense bodies even though we cannot see this happen. He spent much money researching lenses and even sent the Pope a lens as an inducement to experiment. Yet, he may never have recognized the image forming capabilities of the lens, as he never connected the lens with the camera obscura. Nor did he ever make any comparison between the camera and the eye in his study of human vision.

The attribution to Bacon of the invention of the camera obscura is not based upon any of the passages discussed above, but rather on a discussion of mirrors in the Opus Majus:

Specula (mirrors), moreover, may be so arranged that we may see whatever we desire and anything in the house or in the street, and everyone looking at those things will see them as if they were real, but when they go to the spot will find nothing. For the specula are so placed in the dark with respect to the thing, that the images are in the open, and appear in the air at the junction of the visual rays with the perpendiculurs, therefore those looking will run
to the image and think the things are there when there is nothing but merely an apparition (Quoted in Waterhouse, 1901, pp. 271-272).

The first part of the second sentence here is confusing and problematic. In the Latin phrasing "Nam sic situabunt specula in occulto respectu rerum, ut loca imaginum sint in aperto, et appareunt in aere in conjunctione radiorum visualium cum cathetis," (Bacon, 1614), there is a problem in translating "in occulto," to mean "in the dark," as the phrase refers to hiding or concealing. Gernsheim (1968) translates the sentence thus:

For the mirrors are concealed [from the viewer] and so placed with respect to the objects, that the images are in the open and appear in the air at the junction of the visual rays with the perpendicular plane [cathesis]; therefore those looking will run to the image, and think that things appear when there is nothing but merely an apparition (pp. 17-18).

Scholars in the 17th century who read the Perspectiva and knew that mirrors were used in the camera obscura to correct the inverted image might easily conclude that this, too, was the camera obscura, given Bacon's rather mythical reputation, his previous mention of camera formed images in the Perspectiva, and his general vagueness in writing style. It is probably safe to assume that this description is not that of the camera obscura, as no mention is made of the image being formed through an aperture. Rather, Bacon described image formation with the mirror, probably a
parabolic one, which can focus and project rays just as a lens does. This reasoning seems more probable as the passage occurs in the section devoted to reflection where Bacon, going beyond Alhazen, discussed seven kinds of mirrors. In his investigation with spherical concave mirrors, Bacon attempted to "find the point from which an object of given position will be reflected to an eye of given position" (Bridges, 1897-1900, p. lxxi). The description here would be an entertaining application of the problem.

Sarton (1927-48) argues that Bacon's influence was little felt before the 16th century, as very little of his work was published before then. The Opus Majus, for example, was first published in 1733, and the Perspectiva in 1614. While it may be true that his overall influence was slow to be felt, his impact on the study of optics can be found in the works of his contemporaries, Witelo, John Pecham, and William of St. Cloud, and of later writers like Leonardo da Vinci. Significant, too, is the fact that the "Perspectiva" and the De multiplicatione specierum were frequently transcribed, and a fairly substantial manuscript collection is still extent. Witelo may not have had any direct contact with Bacon, but Bacon's influence may be seen in Witelo's Optica written sometime after 1268. His
prefatory dedication to the work informs us that Witelo was Polish, and elsewhere he stated that he decided to write a work on optics after seeing a rainbow in a waterfall near Viterbo, where Witelo had gone in 1268 as part of the Papal court. Roger Bacon's Opus Majus and De Multiplicatione specierum were sent to Pope Clement IV in Viterbo about 1267, and after the Pope's death in 1268, nothing more is heard of these works. That Witelo saw Bacon's works is fairly certain, as Witelo, in his discussion of the rainbow, referred to specific data that is found only in Bacon's Opus Majus (Lindberg 1972).

With no compunction to identify his references, Witelo borrowed heavily from a number of sources, the most notably being Alhazen, as one can see from the cross references found in Risner's 1572 edition of Alhazen's and Witelo's optical treatises. Witelo for the most part followed Alhazen's format, occasionally leaving out a point or adding information from other sources. The purpose of the work, according to his rather verbose dedicatory letter, was to "present an alternative to the 'verbosity of the Arabs and the involved arguments of the Greeks'" (Lindberg, 1972, p. xiii). Alhazen's Perspectiva was complicated, the translations were poor, and at times the writing was tedious. Witelo's effort to elucidate the Greeks and
Arabs resulted in the equivalent of 2,000 typewritten pages of the most mathematical approach to optics yet written. (Lindberg, 1971b).

In Book II, Theorems 39 through 41, Witelo discussed the problem of image formation through an aperture, for he, like those who went before him, saw the theory of rectilinear propagation demonstrated by images of the sun formed through round apertures, but saw the theory challenged with images formed through non-circular apertures. While Alhazen's discussion of image formation had dealt with the candle demonstration, Witelo's treatment, which made no reference to the candle experiment, went much further in its consideration but was much less successful in explaining the problem. Unfortunately, his investigation of the topic added little but confusion, due primarily to his faulty geometry.

In Theorems 37-38, Witelo dealt with the image formed through a round aperture, while in Theorems 39-41, he dealt with image formation with angular apertures. He began his discussion in Theorem 35, with the spurious Proposition 11 from the Pseudo-Euclid De speculis, an erroneous demonstration of why solar rays appear to be parallel to viewers separated by short distances. This proposition had nothing to do with image formation in the camera, but for
Witelo it became crucial to his subsequent consideration. In fact, its proof was a denial of the theory of rectilinear propagation, yet Witelo seemed not to recognize any conflict. Repeating the entire demonstration from his source, Witelo arrived at an even more obscure interpretation than the original: that light rays move away from being divergent and more toward being parallel, while at the same time other light rays converge on the screen within the boundary of a round image. Thus, somewhere behind the aperture, regardless of its shape, a round image would be formed.

In Theorem 36, Witelo repeated al-Kindi's proof from the *De aspectibus*, expanding it to a three dimensional aspect. He stated that all rays will touch the edge of the aperture as they are projected in a straight line through the aperture and onto the edge of the light source. Witelo made no mention of shape of either the aperture or image, as al-Kindi, also, had failed to do (Fig. 12).
In Theorem 37, Witelo correctly proved geometrically that light entering a round hole will produce a round image. His diagram and description, however, demonstrated a 13th century way of visualizing the proof (13):

If the axial ray from a pyramid of illumination arising from a luminous point is perpendicularly incident through a circular aperture onto a screen parallel to the plane of the aperture, the image formed is truly circular (Quoted in Straker, 1971, p. 156).

In other words, if a beam of light (a pyramid) is emitted from a point on the light source and within the exact center of this beam is a straight line (the axial ray) that goes through the exact center of the aperture (i.e. is perpendicularly incident), then the image is circular with the lines of perpendicular incidence acting as radii (Straker, 1971) (Fig 14).
Theorem 38 is a restatement of the preceding one, this time with the light rays entering the round aperture from an oblique angle. With Theorem 39, Witelo began his consideration of the non-circular aperture, relying on the faulty proof of Theorem 35 for the solution. Here, he concluded that the light rays would "withdraw themselves from angularity, and thus the light incident on the surface behind the aperture begins to be rounded" (Lindberg, 1968, p. 165). Theorem 40 was a more detailed look at the preceding theorem, where Witelo analyzed the shape of the image cast by a single point of light projected through a square aperture. His conclusion was that the image was a square shape with rounded off corners. Theorem 41 was the same argument for the light entering at an oblique angle.

Witelo's less than straightforward writing and his obscure reasoning would have the reader believe that the light rays must change direction, bending and twisting
until they form the desired round image. His metaphysical philosophy, like that of Roger Bacon, made the natural rounding off of light a logical probability. Witelo concluded that no matter what the shape of the aperture, the image would be round, but by arguing this, he also inferred that no matter what shape the light source, the image would always be round. Witelo's geometry was at fault. An analysis of his diagrams indicates that he consistently used an aperture so outrageously large, that in actual application, he would never get anything but the image of the aperture. Yet, his geometry consistently seemed to prove his spurious Theorem 35, and as a mathematician, Witelo believed in the credibility of his geometry just as Roger Bacon had believed what he observed with the light constriction behind the aperture.

John Pecham, Archbishop of Canterbury, fared no better in his attempt to explain away this aggravating and confounding problem. Pecham gave more attention to the problem than his contemporaries, as he was more prolific a writer on optics. He was the author of one of the most popular books on elementary optics, the *Perspectiva communis* which was frequently used as a university text through the 16th century. His other optical works included the *Tractatus de perspectiva*, a poorly organized and rambling
rudimentary treatise on optical phenomena which may have been an early draft for the *Perspectiva communis*, and the *Tractatus de sphera*, which with a revised version of the *Perspectiva communis* were much more advanced works.

There is strong evidence that Pecham knew Roger Bacon, not in their native county of England, but in Paris while Pecham was a student. This was in all probability during the time that Bacon was under confinement, and it is uncertain how freely he was allowed to associate with others. Straker (1971) has suggested that Bacon's *Speculum astronomiae* which was composed "for the use of a certain disciple named 'John' who was praised very highly by Bacon" (p. 122), was indeed Pecham.

In addition to Bacon's influence on Pecham's optical writings, it is evident that he drew heavily from Alhazen, Grosseteste (although this may have been indirectly through Bacon), and possibly Witelo. Like Witelo, Pecham declined to identify his sources, and at times it becomes quite difficult to identify them. However, his dependence on others is clearly evident in his theories of vision, propagation of light and the multiplication of species. Pecham held firmly to a belief in the rectilinear propagation of light, which is clearly stated in Book I Proposition 14 of his *Perspectiva communis*. Like his
contemporaries, Pecham saw this puzzling problem of image formation through non-circular apertures as severely challenging that theory. He first attempted an analysis of the problem in his Tractatus de perspectiva, where he argued, like all good metaphysical writers before him, that since physical bodies have a natural inclination toward circularity, light also requires a circular shape for itself. Although he had fallen into a persistent trap, Pecham correctly observed that the larger the aperture size, the longer the distance between the aperture and the image to make the circular shape evident. This analysis, however, was only a cursory one in a work not fully developed and lacking the maturation of his later writings.

A much fuller discussion appears in Book I Proposition 5 of the earlier edition of the Perspectiva communis (Lindberg, 1970b). Where Bacon and Witelo had been content to briefly explain several different instances of light entering various kinds of apertures, Pecham's treatment was considerably longer and more thorough; in fact it is twice as long as any of the other 161 propositions in the treatise. He first stated the problem to be considered: why light rays, which pass through an angular aperture of moderate size, appear rounded when they fall on "facing bodies" and why this image gets larger the further away it
becomes from the aperture. He then reviewed the literature on the problem, discussing two possible explanations given by "others."

In the first of these, Pecham observed that some people attribute the roundness of the image to the roundness of the sun, using as evidence the crescent shape of the image and sun during a solar eclipse. Here, the source for Pecham is probably Book XV, Proposition 11 of the Problemata where the author proved the double cone theory, but Pecham did not accept this as a valid argument. If this were the case, he argued, then the image would be rounded immediately behind the aperture as well as further away, but this is not what is observed.

In the second example, Pecham stated that "others," this time Bacon in his De speculis comburentibus, had argued that it was due to the intersection of rectilinear rays, this explanation being one of Bacon's five modes that had fit his observation of constriction behind the aperture. Pecham analyzed the various intersecting pyramids passing through an aperture using a geometric proof much like that of Bacon's (Fig. 15). Here, he tried to prove that the outermost pyramid KHM, which gives shape to the beam of light as a whole, is already round before the rays have progressed very far beyond the aperture.
He had rejected Bacon's idea that some rays were invisible, but in doing so, he was forced to acknowledge their presence. Ultimately, he failed in his proof and concluded that this outermost pyramid formed by the rectilinear propagation of light does in fact conform to the shape of the aperture and cannot be circular. As he was now faced with compromising his belief in the theory of rectilinear propagation, Pecham retreated to his original reasoning that the true cause of rotundity is because light naturally is moved toward this shape when propagated at some distance.

Given the way that Pecham had presented his problem, his geometrical proof was correct. Since those rays are not invisible as Bacon suggested but can be seen, a round image behind the aperture is impossible. In trying to avoid the same shortcoming that Bacon had faced, that of using too small an aperture, Pecham inadvertently faced the
same dilemma that Witelo had, that of using too large an aperture for a geometrically sound solution.

In Book I Proposition 7 of the revised *Perspectiva communis* (Lindberg, 1970b, pp. 73-83), Pecham set forth what was his longest and most impressive analysis of image formation. He established the problem identically as he had in the first version. However, he cited as the first explanation by "others" his very own conclusion from the earlier version, while not admitting that he was the "some" who said the image was round due to the natural tendency of light to move toward rotundity. He argued the invalidity of this idea by pointing out that if it were always true, then there would be no crescent-shaped image formed during a solar eclipse. He went further to reaffirm that both light and sight proceed only in straight lines.

The second explanation in the revised version was that "others" attributed the cause to mathematical or geometrical reasons based on the fact that the radiation of light can be presented in straight lines. In other words, the analysis depends not upon the tendency for light to assume a spherical shape, but upon the geometry of the radiation of light which is expressed by straight lines (Lindberg, 1968). In this argument, rather than discarding Bacon's reasoning as he had done in the previous version,
Pecham gave a more skillfully argued, but nevertheless spurious version of Bacon's explanation.

First, he reinforced the double cone theory and demonstrated that rectilinear solar rays, after passing through the aperture and intersecting, really do form a circular image. Then, with his geometry, Pecham proceeded to disprove this by very carefully and rigorously demonstrating that by direct radiation, the incident rays are non-circular when the aperture is not round. This same conclusion, even more clearly stated and argued, also appeared in Pecham's *Tractatus de sphera*.

Finally, Pecham introduced what Lindberg (1970b) refers to as "an ingenious reductio ad absurdum," (p. 43). First, he assumed that the principle of direct propagation was true, so that light falling from the sun through an equilateral triangular aperture produced a round image some distance from the aperture. Pecham then suggested blocking the inside of the aperture with the largest circle that could be inscribed therein, thus producing three little triangular shapes around the outside of the circle. His reasoning was that if it were true that the light passing through the entire aperture, before insertion of the circular disk, became round by direct radiation, then the light passing through the three little triangles would
produce round images that would fall within the boundary of the image produced by the central circular beam. However, this is impossible.

Having destroyed what were then the only viable explanations, Pecham was forced to give his own theory, a confusing and rambling statement of three principles of light and vision, but with no indication from Pecham as to how these can be used to explain circular image formation through a non-circular aperture.

Pecham did give a more clearly stated, although erroneous conclusion to this problem in the *Tractatus de sphera*. Here he asked a more difficult question: if light naturally rounds itself off, then how can the partially eclipsed sun cast a crescent-shaped image of itself? Pecham said that light had two characteristics, direct or primary light, and ambient or secondary light. The primary light always casts an image shaped like the aperture, he argued, while the secondary light diffuses itself outside and beyond the path of the primary light and will always take a circular form. Under sufficient light intensity, the secondary light will superimpose itself over the primary light and form a circular image, but in insufficient light, as during a solar eclipse, the secondary light is too weak since the primary light, which in fact has caused the
secondary light, has been partially eliminated. This should mean then, based on his statement above, that the image projected is that of the aperture, since the light is from the primary source. Pecham argued, however, that since this primary light is also reduced, it now takes the image of the eclipse. This was Roger Bacon's argument that Pecham had rejected in the second case of the earlier *Perspectiva communis*. Bacon had said this secondary light was invisible; Pecham, in rejecting this notion was then faced with acknowledging the existence of these rays. Here he has not only acknowledged them, he has figured out a way to explain them. Since the secondary light is so weak during the eclipse, the primary light, now in the shape of the crescent, dominates the secondary light in the form of a double cone or pyramid and projects a crescent image. It is a clever explanation, however untrue.

Pecham realized his inconsistency in dealing with this problem, particularly in the *Perspectiva communis*, for at the very end of his Proposition 7 of the revised edition, Pecham ended his discussion of camera formed images with this: "And I shall not envy anyone treating [the matter] better [than I], but would venerate [him] as a teacher" (Lindberg, 1970b, p. 83).
For all his effort, Pecham never did solve the puzzle. The solution which circulated most freely, unfortunately, was the earlier *Perspectiva communis*; this is extent in a very large number of manuscripts, and went through a number of published editions beginning as early as the Cardano version of 1482-3. In 1542, Georg Hartmann published a highly edited version which took many liberties with Pecham's original text. Hartmann frequently added or deleted phrases changing the meaning or significance of a passage. In Pecham's discussion of an image formed during a solar eclipse, Hartmann added the phrase "in loco tenebros," or "in a dark place." This phrase is absent from the manuscripts and earlier printed editions. The Hartmann version, however, was most influential and almost all of the subsequent editions copied the Hartmann changes. As a result, the invention of the *camera obscura* has also been attributed to Pecham. Pecham's later and more mature writings, the revised *Perspectiva communis* and the *Tractatus de sphera*, are quite rare as manuscripts, and neither was ever published.

It seem remarkable that within a ten year period in the 13th century, from approximately 1268 to 1278, three different scholars would produce major works on optics, and all would deal, although ineffectively, with *camera* formed
images. In terms of the camera obscura, it is significant to note that, with the exception of Bacon's Speculum astronomiae, these were optical works, not works on astronomy, and as such their authors were concerned with understanding the physics of light. The problem of image formation through an aperture was a theoretical challenge and nothing more. As 13th century scholars, they were writing about what they called natural philosophy, not science. They relied on mathematical proofs, rather than observation or experimentation, to support their theories, even when the mathematics, as we have seen, was faulty.

Through their education in church dominated universities, they became masters or doctors of the liberal arts and the whole of philosophy, trained to teach the entire curriculum from morals and ethics, to mathematics and astronomy. We see the church approved, quasi-religious metaphysical philosophy present as they reasoned through some of the thornier issues of camera formed images, and we also recognize that this philosophical perspective often as not interfered with their reasoning. As clerics, their careers were dominated by the church, and we saw an instance where the church had to discipline one of these men.
Yet, it seem surprising when one considers the broad-based education these men had, that as "generalists" in the sciences they were not as integrated in their thinking through a problem as the Arabs had been. Alhazen, for example, drew upon practical experience, experimental data, and his knowledge of medicine, vision, optics and astronomy when dealing with the problem of camera formed images. Bacon, Witelo, and Pecham confined their thinking to one field or another, either optics, or in Bacon's case, astronomy. When an eclipse was mentioned by these men, it served only as an instance of a theoretical optical problem.

If these theoretical optical works by Bacon, Witelo and Pecham were the only evidence of the camera obscura that we had from the 13th century, we could not say for certain whether or not the camera was known beyond a paper geometrical proof. However, if we look to the astronomers, we find the documentation needed to dispel any doubts. While this documentation is not vast, as 13th century astronomy was an applied rather than theoretical science, nevertheless physical evidence does exist.

The astronomer William of St. Cloud (Guilelmus de Sancto Clodoaldo), who may in fact have been English, wrote in an almanac of 1292 about a camera obscura used for observing a solar eclipse in 1285:
In the year of our Lord 1285, on the 5th day of June, it happened that those who too intensely observed the sun (during the eclipse) their vision was impaired when they turned their eyes back into the darkened room. This condition of being dazzled lasted with some two days, with others three and with some others several days, according to the length of time they had stared at the sun and according to the degree in which their eyes were sensitive...In order to eliminate this and to be able to observe without danger the time of the beginning, of the end, and the extent of the eclipse, they made in the roof of a closed house, or in the window, an opening turned towards that part of the sky where the eclipse of the sun would appear, and the size of the hole was about the same as that made in a barrel for the purpose of decanting wine. The light of the sun entered through this opening, before which, at a distance of twenty or thirty feet, something flat, for instance a sheet was placed. A ray of light will be seen delineating itself on the sheet in a round shape, even if the aperture is angular. The spot illuminated will be larger than the opening and so much greater as the sheet is moved away from it, but then it will be more feeble than if the sheet is placed closer (Quoted in Potonniee 1972, p. 21).

Alhazen, in his 11th century Kitab fi-l'Manazir, had given specific instructions on the construction and use of the camera obscura, but this information had not reached the West in written form. When this knowledge, during the ensuing two centuries, did reach the West through an obviously oral tradition is not known. Bacon had been the first Western scholar to record the use of a camera obscura in observing a solar eclipse, but with William's description we find the first solid confirmation that an enclosure or chamber was being used in solar observation.
The almanac in which this appears was a compilation of the positions of the planets for the period from 1292 to 1311. William was a highly skillful astronomer and mathematician, having in 1290 determined experimentally the obliquity of the eliptic, with his results being less than a degree in error. Sarton (1927-48) noted that "this was the only direct determination of that quantity by a Christian astronomer of medieval times" (vol. 2, p. 990). William had also invented an instrument called the "directorium," the description of which is now lost, and in 1296 he prepared a perpetual calendar for Queen Maria of France. Interestingly, the preface to this calendar was a statement on the great practical value of scientific research.

Bacon's influence on William, perhaps, may been seen in this account, as the Speculum astronomiae had been written thirty years earlier. Sarton (1927-48) suggested that Bacon's influence could also be found in a similarity of views on scientific research found in William's prologue to the Kalendarum regina. Whatever the source, William gave the richest and most thorough description yet recorded. Unlike Bacon's astronomical instruction manual for students of astronomy, William's almanac was intended to be used by other astronomers as a reference. Yet, William took a
somewhat benign didactic position as he carefully described a method for solar observation which might not have been thoroughly familiar to his colleagues. He addressed every specific detail that one needed to know: how large the hole should be and where it should be located; the necessary focal length required, and the suggestion of a movable screen which allowed a more critical focusing; the information that the image projected would be round no matter what the shape of the aperture, and that the image would be larger than the opening; and the suggestion of compromising image sharpness (i.e. when the screen is further away from the aperture) for image brightness (i.e. when the screen is closer to the aperture). We recognize in his description points that had been debated by Bacon, Witelo and Pecham, (i.e., the angular aperture or the size of the aperture and image). William, however, was uninterested here in theory, although his thoroughness may be an indication that he was not unfamiliar with the theoretical debate.

William was one of the founders of the astronomical school in Paris, where he was during 1292 to 1296. An interesting passage in a treatise entitled De visione stellarum attributed to Nicole Oresme suggests that William or one of his followers had turned the cathedral in Paris
into a *camera obscura*:

The experience that whenever the sun shines through an aperture high above the ground, as in the cathedral of Paris, then that light appears to jiggle as if the sun were moved discontinuously by shaking or trembling, and the explanation of this is the variation in its refraction on account of the changes in the medium (through which it passes)...From which it is evident that something which is moved regularly may appear to twinkle on account of a change or alteration in local motion, namely, refraction, or a condensation (of vapor in the place of refraction) (Quoted in Straker, 1971, p. 183).

Notre Dame was not the only cathedral to be used for astronomical observations. In Italy, the duomo in Orvieto and San Petronio in Bologna, just to name two examples, both were built with an aperture in the roof for projecting the sun's image onto the church floor. In San Petronio at noon on St. Valentine's Day, the sun's image falls on one of the fluted columns in the nave and creates the shape of a heart. In the marble floor of the duomo in Orvieto, there is a scale which indicates the position of the sun during various times of the year, thus serving as a kind of calendar (Plate I). This practice apparently continued into the Renaissance, as Paolo Toscanelli convinced the architect Filippo Brunelleschi to incorporate not only a gnomon on the top of the dome of Santa Maria del Fiori in Florence, but an aperture in the roof of the church as well:
...a perforated bronze plate, placed so that the sun's beams struck the pavement below along a graded strip cemented to the floor. It turned the Dome...into the greatest astronomical instrument ever built. The beam was 240 feet long, and it allowed [Paolo] Toscanelli...to effect his solstitial measurement of the inclination of the ecliptic reported by Regiomontanus, which gave 28° 30' (de Santillana, 1957, p. 60).

Finally, in Rome, Egnatio Dante, Papal astronomer to Gregory XIII, built a camera obscura in the Vatican's Tower of Winds in 1582. The aperture, incorporated into a fresco painted on the ceiling, was located in the mouth of the Father Wind of the South, and the image of the sun was projected onto a scale opposite. From the astronomical observations and mathematical calculations made with this camera obscura, the Gregorian calendar was introduced, replacing the Roman Julian calendar, which, by 1582, was 10 days in error.
REFERENCES


CHAPTER III

QUESTIONES: THE 14TH CENTURY

If the problem of camera-formed images was merely a theoretical challenge for Bacon, Witelo and Pecham, by the end of the 13th century, it had become what Lindberg (1970) called "un probleme celebre" (p. 299). However, little interest was generated in the problem during the 14th century. One reason for the lack of interest was that while new works on optics appeared during this next century, most of the energy was spent on making copies of Pecham's *Perspectiva communis*. Another factor was a change in attitude toward the veracity of the problem. Bacon, Witelo and Pecham had seen image formation as a real threat to the theory of linear propagation; 14th century writers, while implicitly accepting the validity of this theory, in general did not see it being questioned by the phenomenon of image formation. In short, the principles for investigating the theory of the *camera obscura* were no longer operational in the 14th century.

In spite of the above factors, it is significant that several of the more important optical treatises written during the 14th century dealt with this problem, although
not quite in the same way as Bacon, Witelo and Pecham had done. Why would these treatises deal with an issue that seemed rather irrelevant to the 14th century? The writers of the 14th century had not discovered a workable answer to the question of a round image projected through angular aperture, and this question stood out more prominently than most others as an issue needing a solution. Part of the attention to the problem lay in its prominence in Pecham's treatise. With all of the copies being made of the *Perspectiva communis* during the century, one could not help but notice Pecham's almost compulsive preoccupation with camera-formed images. For those who saw Bacon's treatise on burning mirrors, *De speculis comburentibus*, the problem of pinhole images constituted one quarter of the work. A few 14th century optical writers, then, realized that there were a few challenges left in the world for them to tackle. The problem of camera-formed images "was precisely the sort of problem to appeal to the dialectical temperament of the medieval schoolman" (Lindberg, 1970, p. 301).

The way in which the 14th century writers approached the problem, however, was considerably different from what we have seen. In the 14th century, optical works were no longer the general, systematic, all-inclusive works of the 13th century. Rather, they dealt with a core of
significant optical problems, often bearing a title such as "Questions on Optics." These works were much more philosophical or metaphysical in nature, placing proportionately more emphasis on principles as invisible and disappearing light rays. Not only were 14th century writers less inclined to prove a theory geometrically, they were much less adept mathematically. Lindberg (1970) refers to their geometrical analyses as being "primitive" (p. 324).

Those who addressed the issue of camera-formed images demonstrated this change in attitude by the way in which they established the problem: rather than asking why the image behind a non-circular aperture was first the shape of the aperture and then the shape of the sun, they asked if the cause of this phenomenon was due to the natural proclivity of light towards rotundity. The move away from a geometrical analysis of this problem may have had to do with the inherent problems of the geometry found in the works of Pecham and Witelo. Their geometry had been correct for the size of aperture used in the diagram, but was counter to all sensible reason or experience.

The most important work during this period to deal with the problem of camera-formed images was that of the Jewish scholar Levi Ben Gerson (1288-1344). In 1328, Levi
completed his monumental work *Milhamoth 'Adonai*, or *Liber Bellorum Dei* ("The Wars of the Lord"). The third chapter was his "Sefer Tekunah," a treatise on astronomy instruments. This work was translated from the Hebrew into Latin at the request of Pope Clement VI in 1342, and given the title *De sinibus chordus et arcubus*. In this work, Levi described an astronomical tool that he had invented, the *instrumento relevatore*, a modification of the Hipparchan dioptra or "Jacob's staff." In Levi's model, the upper, permanent plate had been replaced by a movable cross-staff, which he used for measuring apparent angular distances.

Sarton (1927-1948) suggests that Levi used this instrument in the *camera obscura* to determine more precisely the variations in the apparent diameters of the sun and moon. However, Levi's text does not mention applying this device to the *camera obscura*.

In his very thorough discussion of the *camera obscura*, Levi set forth the general problem of its use as an astronomical tool to measure at various times the diameters of the sun and the moon. The use of his method permitted an understanding with quantitative accuracy the relationship between the size of the object (i.e. sun or moon) and its apparent size in the projected image. Levi, of course, was not the first to suggest the use of the
camera obscura for astronomical observation; Bacon had mentioned it in the *Speculum astronomiae*, but Bacon failed to specify the need for a finite aperture. Levi, however, concerned with accuracy, recognized that the size of the aperture was important and would affect the size of the image projected. Avoiding any metaphysical overtones to the "pyramids of action" cited by his predecessors, Levi explained that the image projected would be larger than the aperture, and that the larger aperture would project an image larger than that of a small aperture.

In all probability Levi had discovered the importance of aperture size with his own application of the camera obscura. Making critical measurements at "various times" would mean working with the same aperture size and same focusing distance for each measurement. The sun, however, is not always opposite the aperture. Had Levi made another aperture elsewhere for his calculations, the probability is that the aperture size and focusing distance were not exactly the same. He could well have discovered by accident that these variables had to remain constant. By whatever method Levi had arrived at this information, he was the first scholar in the West to make a note of the importance of aperture size in making accurate astronomical measurements.
In his treatise, Levi went further to give specific examples of how the size and shape of the aperture can affect the viability of the astronomical calculation. He explained exactly how much wider the image is that is formed through a point aperture and that formed through a finite aperture: by an amount exactly equal to the diameter of the aperture. He also recognized the immensity in the distance between the heavenly bodies and earth in relation to image formation. Then, assuming that his reader was familiar with the method of making these measurements, Levi commented that this system with the camera obscura gave results that were as good as if they were taken with the aperture in the center of the earth (Fig. 16).

Next, Levi proceeded to address the image of the sun or moon that was projected through a square aperture:
From this demonstration it is known that if a ray should pass through an opening formed by straight lines, the ray is not received on the opposite wall in the form of straight lines in the corners, since the rays are dilated in every direction at each corner exactly according to the size of the angle intercepted by the radius of the luminous body. And the ray would arrive at the corner of the opening in the form of a quadrant of the circle, the center of which is the point of the corner. And this we sensibly observe in rays that come from the sun and moon through openings having straight lines. (Quoted in Straker, 1971, p. 208).

Levi stated that the image would have straight lines. Does this mean, then, that the image will be round. Did Levi find the solution to image formation with non-circular apertures? Lindberg (1970) argues that he did not, Straker (1971) argues that he did. The problem lies in how much the historian should read into the passage. Just how much did Levi assume his reader should provide in reading this section? Straker argues somewhat convincingly that throughout his discussion of the camera, Levi had assumed his reader already had a certain amount of information and was capable of making the inferences that Levi seemed to think were too obvious to state or restate. Straker concludes, "if it is preposterous to read the principle of a theory of the camera into Levi's discussion, one can fairly conclude that Levi preposterously expected his readers to be able to do just that" (1971, p. 213).
Levi closed his discussion by recommending the application of this same technique to observation of a partial eclipse. In a demonstration which gave the opticians a correct analysis of the crescent-shaped image, Levi stated that the smaller the aperture in the window, the more accurate the measurement. He suggested the use of a round aperture with an imaging screen, or what he called the "object-tablet," positioned perpendicular to the light rays. He clearly stated that the image would be reversed. The error of the Pseudo-Euclidean *De speculis*, that of the light having to bend around the edge of the aperture to form the eclipsed image, had been preserved in works by both Bacon and Fecham. Levi, a practicing astronomer, recognized the error of the opticians and set them straight.

Levi had dealt with image formation in three types of apertures, "any type" projecting the image onto a screen at "some distance," a small, round aperture for making precise measurements, and a square aperture projecting the image onto a screen "moderately" far behind the opening. In addition, he had provided astronomers with very powerful astronomical instrument. As Straker (1971) observes,

One almost forgets that an obscure Jewish philosopher and an ancient Muslim astronomer, whose entire writings were never available to readers of Latin, had already grappled with and solved the problem of the formation of images behind small openings. In both cases it had been
the result of their having come to the problem with a particular bias: their interest in the luminous bodies of the heavens was as astronomers, not as students of perspective, which led them directly to ask quantitative questions about the relationship between the sizes and shapes of the source and the image. To condense my argument with one word, the astronomers' visualization of the problem to be solved was different than that of the opticians (p. 222).

Levi Ben Gerson was known under a variety of names including Leo de Balneolis, Leo hebreus, Gersoni, "rabbi" Levi, but just how much influence his writing had is difficult to determine. Sarton (1927-48) stated that Levi's bold thinking and his being suspected of heresy probably affected what influence he might have had. While Levi apparently could not read Latin or Arabic, which adds to the puzzle of his own sources, his work was translated into Latin for the Pope. Although this might indicate that his work had importance, Lindberg (1970) reasoned that the translation was requested on the basis of Levi's reputation as an astrologer. Straker (1971) suggested that the translation was probably in connection with a calendar; in either case, the number of people who had access to the work was probably quite small.

Levi's methods spread, but his theory apparently made little impact on subsequent writers. Even Kepler was unaware of Levi's work on camera-formed images, although he
cited Levi in connection with other astronomical concerns. Apparently, Levi was known by his reputation rather than through the dissemination of his writing. Certainly, no evidence of influence can be seen on his contemporaries who addressed the problem of the camera obscura.

In the second quarter of the century, Egidius of Blaisiu wrote a "Refutation" to John Pecham's *De sphera* and his revised version of the *Perspectiva communis*. Although the work is extant only in a fragment found in a manuscript in Cracow, the discussion of image formation through a non-circular aperture is considerable. The work is entitled, "Refutation of a certain cause, customarily assigned, why a solar ray passing through a quadrilateral aperture produces a round figure on a wall, composed by Brother Egidius of Baisiu" (Lindberg 1970, p. 301). Here Egidius set out to refute the cause given; he was not really asking why or how the phenomenon happens.

Egidius first listed the two "causes" found in Book I Proposition 7 of the revised *Perspectiva communis*, that of light's natural tendency toward a circular shape, and of the intersection of rays as a result of rectilinear propagation. Then he included a long passage from Pecham's *De sphera*, without identifying the source, which was supposed to demonstrate the invalidity of the intersection
theory. He concluded, then, that the intersecting rays, as a result of rectilinear propagation, can not be the cause of a round image. He went further to support this conclusion with an argument apparently from Bacon's *De Multiplicazione specierum*, that is, that light does not assume a circular shape as quickly in the morning (since the light is weaker then) as it does at midday; since this is true, the cause of the circular image is not simply a matter of the intersection of rectilinear rays. However, according to Lindberg (1970), Egidius still recognized the crucial importance of this principle.

Egidius then proceeded to take issue with these arguments that he has just established. Using reason, sense, and Alhazen as his source, he set forth a rather traditional proof: if it is not the intersection of the light rays, then an innate virtue of light must be the cause. However, if this were true, he argued, then the light would be round directly behind the aperture, since it is closer to the light source which is more effective at a closer range. Besides, rays going through a bigger aperture should become round faster as there are more light rays present to form the image. Lindberg (1970) points out here that apparently Egidius thought there is strength in numbers; I would add that he also apparently believed that
bigger is better.

Going further, Egidius then stated that these light rays don't simply become round naturally, they assume the shape of the light source, as one can observe during a solar eclipse when the image becomes "horned." Driving this point home, Egidius noted that if a triangular portion of the sun were projected through a round aperture, the image would be triangular. Finally, he took issue with Bacon's and Pecham's erroneous observation regarding the eclipsed image by stressing that the sun and its image are eclipsed on opposite sides. The fragment ends with what Lindberg (1970) calls "a quantitative argument on the ratio of the sun's disk and the diameter of the solar orbit" (p. 303).

By apparently refuting Pecham's denial that the intersection of rectilinear rays was the cause of the circular image, Egidius diligently upheld one of the basic principles of geometrical optics, that of rectilinear propagation. In addition, Egidius correctly addressed two of the weaknesses found in 13th century arguments, that the image takes the shape of the light source, and that the image is inverted. As the discussion ends somewhat abruptly, one cannot say if Egidius went further. How the passage on the diameters of the sun's disk and orbit relate
to this refutation is not clear, but one could assume that Egidius had defended his argument to his satisfaction and had gone on to another matter.

With the one fragmentary manuscript extant, it is most probable that this discussion had little if any impact on the development of astronomy or optics. However, points similar to Egidius' refutation are found in the discussions of later writers in the 14th century. Lindberg (1970), in tracing the lines of influence on 14th century writers, has suggested that the existence of an additional but now unknown work might explain the similarity of ideas in these writings.

During the period from 1363-1373, the *Questiones super perspectivam* was written by Henry of Langenstein (1325-1397). Henry had what we might call a distinguished career as an administrator in Higher Education: he was made vice-chancellor at the Sorbonne sometime after 1376, then in 1389, he went to the University of Vienna, where he first served as dean of the theological faculty, and later as rector in 1393.

His treatise was made up of 15 questions from Pecham's *Perspectiva communis*, but Henry seems to have used other sources presenting views outside Pecham's which he attacked
or defended. On this point, Lindberg (1970, p.309) again suggests that apparently an optical tradition had developed in that 100 year period between Pecham and Henry which is now lost.

In his third question, "whether light incident through a triangular aperture is reduced to rotundity by nature. And it is argued that it is not" (Straker, 1971, p. 188), Henry more clearly demonstrated the shift towards philosophical issues and away from geometrical ones. While Pecham had questioned the geometrical validity of rectilinear propagation, Henry took a metaphysical approach by conceding that non-circular apertures somehow produce circular images, then asking if this occurs "by nature."

Henry first gave a list of arguments against why light is reduced to roundness naturally, most of which had nothing to do with rectilinear propagation. Comparing light to fluids, for instance, he argued that while water naturally assumes a spherical shape when unconfined, it assumes the shape of its vessel when confined. Therefore, a triangular body of water could be placed at the center of the universe, he stated, and the water would not run to one side or the other but remain triangular. This is a rather oddly stated argument which we will see repeated in a slightly different form by Blasius of Parma.
Another argument given here is that if light is round by nature, then it should be round immediately behind the hole, a point made more fully by Egidius. Finally, his last argument, which was directed a Pecham's *De sphera*, he stated:

Light does not radiate transversely to its line of action from the luminous body, and therefore the 'corners of a luminous triangle cannot radiate light toward the side' to produce the appearance of a circle" (Quoted in Lindberg, 1970, p. 310).

In other words, light cannot withdraw from angularity. With this statement made, Henry then introduced his defense of the principle of rectilinear propagation. He demonstrated two single cones or "pencils of light" radiating from either side of the sun and passing through a round aperture (Fig. 17).

This figure was more an observation than a theory in Henry's discussion, and he concluded by supporting Pecham, stating that these singular cones will produce an image of
the aperture, round if the aperture is round, angular if the aperture is angular.

He then took up the issue of image of a partially eclipsed sun, this time agreeing with Witelo that behind any aperture of any shape the image will be round. He went beyond Witelo, however, and clearly stated, where Witelo had inferred, that no matter what the shape of the source or the aperture, the image will be round at some distance from the aperture. This, he argued, was because some of the rays are weaker due to their length (i.e. the ones on the outer edges) and the shorter ones in the central portion are stronger. Therefore, the image is round. He ended this part of his discussion by noting that the round image would be smaller than geometry alone would indicate. Finally, he proposed a method for measuring apparent diameters of the sun and moon, but unlike Levi, Henry did not take into consideration the size of the aperture or the distance from the aperture to the screen. It is interesting, however, that Henry made reference to an astronomical technique in an optical treatise.

One last work which appeared toward the end of the century was the *Questiones super perspectivam* written by Blasius of Parma around 1390. Of the works discussed from this century, more copies apparently were made from
Blasius' treatise than the others, but his influence seems to have been confined primarily to Italy (Lindberg, 1970).

Blasius included twenty-four questions from Pecham's *Perspectiva communis*, and in Book I Question 4 is found his discussion of incident rays passing through angular apertures. He not only questioned the issue of the rays naturally becoming round, but also identified the question of the image becoming larger the further it is extended from the screen. Of his style of argumentation, Lindberg (1970) notes, "Blasius is no model of clear and consistent exposition -- a trait he and Henry share in generous quantity..." (p. 318). Nevertheless, it is possible to recognize a similarity in structure and reasoning with that of Henry, with reminders of Egidius and Bacon.

That he shared the same attitude as Henry in his approach to the problem is seen in the way his question was set forth, that is, can light become round by nature. He stated that the achievement by circularity was not natural, then presented a series of arguments or contrary opinions against natural rotundity, as Henry had done, repeating a number that been stated by earlier writers. If circularity is natural, he argued, then the image would be circular immediately behind the aperture as well as during a solar eclipse. He also reasoned, as Henry and Egidius had done,
that the image should be round immediately behind aperture because it is closer to the sun and that is when the rays are stronger.

Blasius not only rejected the theories of natural rotundity and of intersection, which Pecham had cited, but also rejected a third cause, that of the tendency of everything natural to achieve spherity in order to preserve itself. Here he recalled Henry's analogy of the triangular body of water:

But contrary to this, when you place water or earth or any element you please in a triangular or quadrangular vase, the water or earth ought never to be preserved in such a vase;...however, ...we see that earth can be preserved in a triangular vase for a long time (Quoted in Lindberg, 1970, p. 319).

After Blasius concluded that light does not approach roundness naturally, he refuted several other rhetorical arguments before presenting what apparently was his own. He argued that the shape of sun could not be the cause of a round image, as the rays are not always round behind the aperture. He presented a very confusing discussion of intersecting rays, and finally concluded that those rays outside the circle (i.e. the ones forming the angles immediately behind the aperture) are weaker because they have to travel further. Therefore, they become invisible leaving the central rays to form the circle. Here we see
Blasius reaching for Bacon's explanation in the *De speculis comburentibus*.

Where Henry demonstrated some confusion on the shape of an eclipsed image, Blasius recognized that the image became "boat shaped," as he described it. However, Blasius conceded this was true only for a certain distance behind the aperture, then the image became round. He concluded then, that eventually the image is round no matter what the shape of the luminous source. In arguing the second part of his question, Blasius stated that the rays behind the aperture get wider for a short distance, but then will get progressively smaller the further away the screen is moved. Do these rays eventually disappear, if one goes far enough? Blasius did not address the question, but one wonders what prompted this comment in the first place. Perhaps it was based on observation; the further the imaging screen is from the aperture the fainter the image, until it disappears. However, this observation clearly demonstrates that the image increases in size the further it is from the aperture.

By the end of the 14th century, in general only confusion had been added to the problem of image formation in the *camera obscura*. Levi Ben Gerson certainly came the closest to a clear and accurate explanation of image
formation, but Henry of Langenstein and Blasius of Parma, with their convoluted presentations, left the reader in a state of probable confusion. Egidius of Baisiu may have been on the right track, but the fragmentary evidence does not permit any firm conclusion.

Where Bacon and Pecham had recognized that the light projected through an angular aperture projects first an angular image then one the shape of the source, Henry, denying that the image conforms to the shape of the source, stated emphatically that the image is always round. Blasius admitted that in the case of an eclipsed image, the image will temporarily take on a crescent shape, but will become round regardless of the shape of the source. Where Bacon, Witelo and Pecham had used both geometrical and non-geometrical methods to prove what was in fact a geometrical problem, Egidius, Henry and Blasius had approached the problem philosophically. Levi had been successful in his reasoning because he approached the problem as a practicing astronomer, not as a natural philosopher of optics.

That 14th century writers did not visually perceive of the camera obscura in the same way that their 13th century counterparts had is obvious in their lack of geometrical proofs. Without illustration there is no clue to the way
in which they saw the camera. It is not until the 16th century that we find an illustration of a room-type camera obscura, which shows the room of a darkened house with a hole in the window projecting light onto the wall opposite (Plate III). Even Leonardo da Vinci did not regard the device in this way. However, a curious illustration is found in a 1341 Italian translation of Alhazen's *Perspectiva*. The manuscript, a translation from Latin preserved in the Vatican Library, is dated and signed by its translator, Guerruccio di Cione Federighi, court astronomer to Alfonso X of Castille. While the Latin versions of this work had few illustrations in Book I, Federighi added several of his own in the bottom margin of the pages. One is a typical and rather crude diagram of the sun entering a hole in the window and striking the "opposite body" (Fig. 18).

![Diagram of camera obscura](image.png)

FIGURE 18

The other diagram, unfortunately not an illustration of the camera obscura, shows a house with two internal walls, each
having a window. A hole has been made in the outside wall, and an eye looks through this aperture into the three rooms of the house (Plate II). The illustration augments an experiment Alhazen gave to demonstrate the rectilinear propagation of vision. This could easily be mistaken for an illustration of the camera obscura. How could a 14th century court astronomer make such a mundane diagram of the camera obscura on one page, and on another make such a beautiful and sensitive drawing of an experiment which had not traditionally been illustrated? Probably for that very reason; he had no tradition of preconception for the one, but had a geometrical tradition for the other. Even Leonardo drew the camera obscura as a scientist rather than as an artist. It was not a question of the scientists being unable to draw while the artists could; Federighi clearly demonstrated the folly of this generalization. Rather, it was a matter of traditional conditioned thinking. An accurate drawing of the phenomenon would not be made until the instrument was finally in the domain of the artists who had no knowledge of this medieval geometrical tradition of perspectiva. Nor would the problem or cause of image formation be considered again until the 16th century, when geometry had advanced, perception in thinking geometrically had changed radically,
and geometrical optics was changing with the advent of new inventions as the telescope. From the 14th century's disregard for geometry, oddly enough, came the birth of perspective in the 15th century. Along the way, the camera obscura was apparently forgotten in the 15th century by all except Leonardo da Vinci, who saw in this phenomenon the secret of human vision.
REFERENCES


CHAPTER IV

LEONARDO AND THE CAMERA OBSCURA

Leonardo began his notebooks about 1487, when he was around 35 years old, and continued them for the next thirty years until his death in 1519. The 5,000 extant pages constitute only a portion of Leonardo's known documented research (Richter, J. P., 1970). Pedretti (1965) estimates, for example, that only one third of the manuscripts used to formulate Leonardo's Trattato della Pittura still exist. Despite the missing manuscripts, what remains is a massive amount of confusingly organized and seeming unrelated information, in Italian, and for the most part in "mirror writing."

While Leonardo gave no reason for writing backwards, we find on folio 1 recto of the Codex Arundel, written around 1492, that he recognized the disorder of his notes and informed the reader of his plans to arrange them at a future date:

This is to be a collection without order, made up of many loose sheets which I have copied out in the hope of putting them in their proper order later, each placed according to its subject. But I am afraid that before I come to do this, I will have to repeat the same thing several times. Do not blame me, O reader, for the subjects are many and memory cannot retain
all and say: This I have written, I will not write it again (Quoted in Chastel, 1961, p. 41).

Even the individual pages are unorganized as often Leonardo wrote about several unrelated subjects on one sheet. On folio 2 verso of the Codex Leicester, written between 1506 and 1509, Leonardo again lamented the state of his notes:

...then I will get them in order, putting together those of the same kind, so that you will not wonder nor will you laugh at me, reader, if we jump from one subject to another (Quoted in Strong, 1979, p. 139)

It is difficult to imagine anyone laughing at Leonardo's breadth of thinking. Nevertheless, how others might regard his apparent disorganization of the notebooks was a very real concern to him. Leonardo eventually did manage to organize some of the notes, as some of the later manuscripts refer to completed books. In the meantime, Leonardo considered each page as a unit, trying to limit his discussion of a proposition to a single page. When his ideas carried beyond that page, he gave instructions to "turn over" or "This is the continuation of the previous page" (Richter, J. P., 1970, Vol. I, p. xv). Clearly Leonardo was aware of an audience as he wrote, even in his "rough draft," which would certainly dispel any idea of secrecy on Leonardo's part, a notion often used to justify the backwards writing.
Unfortunately, Leonardo could not insure that his notebooks would come down to us in the order in which he intended. The subsequent dispersal and mutilation of the notebooks after Leonardo's death only made the scholar's task more difficult, while at the same time adding to the myth of Leonardo's accomplishments.

This myth also has been supported in large part by Leonardo's own lack of clarity and structure throughout the manuscripts. Frequently, Leonardo used within the same context words which had significantly different meaning. One such example is his use of "simulacra," "eidola," "species," and "simulitudines" all to describe the image formed in the camera obscura or the eye. This indiscriminate intermixing of such words has contributed to the difficulty in understanding Leonardo's exact meaning in a passage. Many times he would draw the diagrams on the page first, then would go back and write in the proposition or discussion (Strong, 1979). Sometimes a drawing went unexplained and we are left with a tantalizing fragment of Leonardo's thinking which thus becomes a subject for speculation. His preoccupation with certain ideas over a span of years is often lost in the volume of pages which are now so difficult to date. In his habit of fragmenting repeated ideas, one can easily miss the subtle nuances of
his insight into a problem, or his maturation in thinking as a concept evolved. This inherent ambiguity of the manuscripts, perhaps, has encouraged a broader interpretation of his writings, with one reading more into the text than what might actually have been said. Thus, as with the case of Roger Bacon, Leonardo has often been credited with many visionary ideas and technological innovations, from predicting the wave theory of light to inventing the machine gun, the helicopter, and the camera obscura.

Leonardo's approach to the notebooks was clearly scientific and became much more mathematical in his later years. In the Windsor folio 19,118 verso of 1506-08, he stated, "Let no one who is not a mathematician read the elements of my work" (Quoted in Strong, 1979, p. 388). This statement reflects an attitude more prevalent in his notebooks after 1505, that is, his general distrust of the eye and observation as a means for discovering truth, and his shift towards geometry as a means of achieving perfection.

His attitude toward the methodology of scientific research, however, still maintained a healthy respect for nature and the natural experience. In the Madrid MS I, folio 51 recto of 1493-1497, he identified the desired
method: "Test it first, then state the rule afterward" (Quoted in Strong, 1979, p.XVI). By 1510, however, he had moved from the cause and effect approach toward the natural experience from which he mathematically deduced the cause, as seen in MS E folio 55 recto: "Nature begins with the cause and ends with the experience; we must follow the opposite course" (Quoted in Strong, 1979, p. XV).

By Leonardo's time the term "prospettivo" had a dual meaning, the traditional scientific one of optics, and the term used by artists to explain a geometrical system of depicting on a two dimensional surface the illusion of three dimensional space. Leonardo made a distinction between these, calling traditional optics natural perspective, and the drawing system artificial perspective.

Leonardo stated his philosophy of perspective and clearly defined its terms in a series of folios of the Madrid MS II, written between 1500-1510. On folio 67r, Leonardo defined perspective as a mathematical science and identified the place of astronomy:

Mathematical sciences are those which, through the senses, have a final degree of certainty. There are only two of them, of which the first is arithmetic, the second geometry. One deals with discontinuous quantities, the other with continuous ones. From them the perspective arises, which deals with all the functions and delights of the eye, with varied speculations, of these 3 mentioned: that is, arithmetic, geometry and perspective--and if one
of them is missing, nothing can be achieved—is born astronomy, which by means of the visual rays, with number and measure, establishes the distance and size of the celestial as well as terrestrial bodies (Quoted in Strong, 1979, p. XVIII).

This passage was a restatement of a similar idea on an earlier folio, 62 b, where Leonardo described a stronger relationship between geometry and perspective. Here he personified perspective as "the first child of geometry" which "gives birth to astronomy." This familial relationship is due to the fact that perspective deals with visual "lines" which connect the object and the eye and are continuous; as geometry deals in continuous quantities, the two are intimately related. Astronomy also deals with visual "lines," those used with the astrolab in measuring the distance of celestial bodies, and with lines of natural motions, "by which the world is measured" (Strong, 1979, p. XLII). Thus, for Leonardo a profound interrelatedness existed in optics, light, vision, color, "artificial" perspective, astronomy and geometry.

That Leonardo planned a book on perspective is repeatedly mentioned throughout the notebooks. In the Codex Ashburnham I folio 17 verso of 1492, he gave an outline of the contents: linear perspective, the perspective of color, and the perspective of "disappearance" or the representation of objects in
proportion to their distance from the eye. By 1510, in MS G folio 53 verso, he had identified that this was to be a perspective for the painter, and redefined the third part of the book, the perspective of "disappearance," as dealing with the diminishing definition of forms and outlines at various distances to the eye. Again in 1513, in MS E folio 79 verso and 80 verso, he was still discussing his book on perspective. This time he rearranged the order of the topics, listing the diminution of sharpness first, the diminution of size (linear perspective), second and the perspective of color as third. In the notebooks, however, Leonardo seems to have been compiling notes both on a perspective for the painter and on a more traditional optical treatise along the lines of John Pecham's *Perspectiva Communis*.

Leonardo was well acquainted with Pecham's book; he not only copied the introduction verbatim in the Codex Atlanticus Folio 203, but also listed both the first edition and the revised version of the *Perspectiva Communis* in his library. Pecham's treatise was first published in 1482-83 in Milan by Fazio Cardano, an acquaintance of Leonardo's. It is quite possible that Leonardo came by his copy through Fazio, and this might explain why Leonardo never mentioned Pecham by name in any of his notebooks.
Fazio's edition only cited Pecham's name once, at the very end of a rather long-winded introduction, and it is easily overlooked.

That Leonardo knew of Roger Bacon is evidenced in a memorandum found in the Codex Arundel folio 71 verso dating from 1517-18: "Roger Bacon done into print" (Pedretti, 1965, p. 20, note 32). This terse reminder is hardly evidence that Leonardo had access to any of Bacon's optical writings, none of which were "in print" that early. There was an incunabula edition of Bacon's *Opera Chemica Rogeri Bacconis* printed in 1485, but as Leonardo's vehemence for alchemy is clearly stated throughout his notebooks, certainly this was not the book he wanted. As this reference was made so close to Leonardo's death, it would hardly seem probable that Bacon was a source for Leonardo's optical writings. Lindberg (1976) argues that there is nothing in Leonardo's notebooks that could not be found in Pecham's *Perspectiva Communis*. This is probably true in the case of Alhazen as well; there is nothing in Leonardo's notes that could not be found in Witelo. Leonardo was acquainted with Witelo's book on optics and not only cited him by name, but also listed the number of propositions in Witelo's treatise. Alhazen is never mentioned in Leonardo's notebooks. Although Leonardo was concerned with
a number of points first raised in Alhazen's *Kitab fi-l'Manazir*, these were all transmitted through Pecham and Witelo.

Other possible sources for Leonardo include al-Kindi's *De aspectibus*, the Pseudo-Euclidean *De speculis*, Nicole Oresme's *De visione stellarum*, and Dlasius of Parma's *Questiones super perspectivam*. In addition to these works from the standard optical literature was a "trattato anonimo" *Della prospettivo*, written in the "vulgare" apparently for artist-craftmen, which is now attributed to Paolo Toscanelli (Parronchi, 1964).

Leonardo's treatment of the *camera obscura* is found in his discussions on astronomy and optics which included the nature of light and color, and the function of the eye in vision. While Leonardo often used a darkened room, even one with an aperture for admitting a controlled ray of light, these were not always imaging forming experiments. He also employed experiments that required looking through a hole, but in none of these did he utilize the *camera obscura*. However, Leonardo was usually quite specific in identifying this image forming phenomenon when discussing the camera. Unfortunately subsequent scholars have indiscriminately identified many of the experiments done with an aperture or in a dark room as the *camera obscura*.
when in fact they were not (Richter, 1970; Padretti, 1965). This has lead to some confusion in understanding Leonardo's grasp of the phenomenon as well as the extent to which he applied the camera in his scientific reasoning. It is evident from the discussion of Leonardo's proposed treatise on perspective that his interest in the camera obscura spanned the thirty years of his writing, from the earliest of his notebooks, the Codex Trivulziano dating from 1487, to pages in the Codex Atlanticus and Windsor MS dating from 1516-1518. While the discussion below is by no means an exhaustive study of every passage in which Leonardo dealt with the camera, it should be sufficient to demonstrate the breadth and depth of Leonardo's concern with the topic.

![Diagram](image)

**Figure 19**

The earliest evidence of Leonardo's knowledge of the camera obscura is found in a rather insignificant marginal drawing of the Codex Trivulziano folio 25 verso (Fig. 19). It shows Leonardo's standard visual notation for the sun projecting an inverted circular image through an aperture.
It is the least geometrical diagram seen so far illustrating the image forming phenomenon, with the sun's squiggly rays making the symbol less abstract than a mere circle. However, the realism stops there, for Leonardo did not indicate the enclosure in which the image is projected, and the image itself, while drawn in perspective, is merely a circle seen from an angle. There is no description or discussion accompanying the drawing, although on an earlier folio, Leonardo had discussed a method observing a solar eclipse:

A METHOD OF SEEING THE SUN ECLIPSED WITHOUT PAIN TO THE EYE.

Take a piece of paper and pierce holes in it with a needle, and look at the sun through these holes (Richter, J. P., 1970, vol. II, P. 153, no. 891).

Figure 20

This written comment about viewing the solar eclipse might lead one to believe that Leonardo was unaware of the camera obscura as an astronomical tool, even though his drawing depicted the formed image of the sun. His was a more immediate solution to viewing the eclipse. He was
certainly aware of the more traditional observation method, for in MS A folio 64 b of ca. 1492, Leonardo described the image of eclipsed moon formed through a slit:

No small hole can so modify the convergence of rays of light as to prevent, at a long distance, the transmission of the true form of the luminous body causing them. It is impossible that rays of light passing through a parallel slit, should not display the form of the body causing them, since all the effects produced by a luminous body are in fact the reflection of that body: The moon, shaped like a boat, if transmitted through a hole is figured in the surface it falls on] as a boat-shaped object...(Richter, J. P., 1970, vol. I, p. 118, no. 214).

In this passage it is almost as if Leonardo were making his own "refutation" of those 13th and 14th century optical works which questioned image formation in non-circular apertures. There was no question in Leonardo's mind about image formation as a proof of rectilinear propagation. He challenged Pecham's claim of natural rotundity with his emphatic statement that it was physically impossible for any aperture to modify the rays of the projected image in such a way to prevent rectilinear intersection; any aperture, even a slit, would form the image of the light source if the focal length were long enough. He answered Blasius of Parma and Henry of Langenstien when he declared without hesitation that the image formed was that of the light source. We recognize Blasius' description of the
"boat-shaped" moon, but unlike Blasius, Leonardo recognized that this image could never be altered to any other shape but that of the projected luminous body.

Leonardo's conclusions were founded on first hand experiences using the camera obscura for observing an eclipse. We also find in the Codex Leicester folio 1 a, a work primarily of scientific observations which dates from 1505-1509, a rather enigmatic memorandum about another application of the camera to astronomy:

Memorandum that I have first to show the distance of the sun from the earth and by means of one of its rays passing through a small hole into a dark place to discover its exact dimensions, and in addition to this by means of a sphere of water to calculate the size of the earth.

And the size of the moon I shall discover as I discover that of the sun, that is by means of its ray at midnight when it is at the full (MacCurdy, 1939, p. 294).

Obviously Leonardo knew the method used by astronomers to measure the diameters of the sun and moon. This information had been recorded in Bacon's *Speculum astronomiae*, Levi Ben Gerson's *De sinibus chordus et arcubus* and Henry of Langenstein's *Questiones super perspectivam*, although it is quite unlikely that Leonardo had access to any of these works. Leonardo gave no indication that he was aware of the need to measure the aperture size or the focal length in calculating the diameters of the sun and
moon as Levi had suggested. Elsewhere in Codex Arundel 78b, Leonardo reminded himself, "Take the measure of the sun at solstice in mid-June" (Richter, J. P., 1970, Vol. II, p. 153, no. 888), but there was no mention of what method he would use. Nor is there any indication that he made any mathematical calculations with the camera, as his notebooks do not contain the typical astronomical tables or data associated with this activity.

What is enigmatic about this passage is the first paragraph. Did Leonardo also intend to determine the distance of the sun from the earth with a camera obscura? How did he plan to determine the size of the earth? No firm conclusion can be drawn because he did not mention this in any of the other extant notes. His suggestion of using a sphere of water, a method which he often used in place of a large lens, is provocative and suggestive. In MS E folio 15 b written between 1513-1514, Leonardo described a similar method for seeing the moon enlarged:

...And so the moon will be seen larger and its spots of a more defined form. You must place close to the eye a glass filled with the water of which mention is made in number 4 of Book 113 "On natural substances;" for this water makes objects which are enclosed in balls of crystalline glass appear free from the glass" (Richter, J. P., 1970, vol. II, p. 144, no. 869).

In another instance, in the Codex Atlanticus folio 187 a, Leonardo reminded himself to "Construct glasses to see the
moon magnified" (Richter, J. P., 1970, Vol. II, p. 168, no. 910). Many scholars have interpreted these passages to signify Leonardo's invention of a telescope, but there is no evidence that he did construct such "glasses." The importance of the passages for this discussion, however, is to underline the fact that Leonardo preferred a direct approach to observation, even of the solar eclipse. His suggestion of an alternative means by which to see the sun directly, not vicariously through a projection of itself, is typical of his need for a first hand experience. He suggested these "glasses" for the eye, more like binoculars, perhaps, to give the eye more visual power. However, Leonardo never suggested adding these lenses to the "eye" of the camera obscura, either in conjunction with or in place of the small aperture, which in fact is exactly what happened with early telescopes. In addition, later astronomers used the telescope to continue their method of vicarious observation an eclipse by projecting the image of the sun through the tube of the telescope and onto a screen held below the eyepiece.

As we have seen, for Leonardo astronomy was the offspring of perspective. As such, astronomy was a philosophical science, one which became more of a discourse for him within the pages of his notebooks rather than a
practical method of collecting and analyzing relevant data. Of all the ways in which Leonardo discussed the camera obscura, it was for him as astronomer that the camera had the least significance, for here he was more concerned with discovering what were for him better ways in which to see the heavens.

It is in his work on optics that Leonardo's most important discussions on the camera obscura are found, usually as a demonstration of some theory of light or as a means to explain the workings of the eye. In his theoretical considerations Leonardo made several basic assumptions about image formation and seemed to argue with those writers before him, as we already have seen above. Time and again in these passages we encounter the same theme with subtle variations and emphases, used to prove a variety of propositions. He experimented with a variety of aperture shapes, even in image formation as seen with the slit in the passage above. It is interesting that in all of these, Leonardo never tried to explain why a non-circular aperture could form a round image. He knew that any small aperture, whatever its shape, would form an image of the luminous body, but apparently for him the phenomenon was so obvious that it needed no discussion. He did not mention any relationship of aperture size to focal
length or the fact that the image increases as the focal length increases.

For Leonardo, the *camera obscura* was the proof of rectilinear propagation, as well as that of image inversion and image dispersal, that is, that every luminous body projects from any one point on its surface an infinite number of images of itself in every direction throughout the air around it. Leonardo discussed this particular problem of image dispersal in two passages written at the same time as his discussion of the boat-shaped moon. In Codex Ashburnham I folio 22 b, Leonardo took up a problem discussed by John Pecham:

All bodies together, and each by itself, give off to the surrounding air an infinite number of images which are all-pervading and each complete, each conveying the nature, colour and form of the body which produces it.

It can clearly be shown that all bodies are, by their images, all-pervading in the surrounding atmosphere, and each complete in itself as to substance form and colour; this is seen by the images of the various bodies which are reproduced in one single perforation through which they transmit the objects by lines which intersect and cause reversed pyramids, from the objects, so that they are upside down on the dark plane where they are first reflected. The reason for this is---(Richter, J. P., 1970, Vol. I, p. 38, no. 61).

In Book I Propositions 6 and 7 of Pecham's first edition *Perspectiva communis*, "Every point of a luminous body irradiates the medium hemispherically," and "Rays of
visible objects illuminate the medium without intermingling" (Lindberg, 1970, p. 83), Leonardo had first found the theory of image dispersal. Pecham had used the radiating light of a candle to demonstrate this concept, but Leonardo realized that the camera obscura was a much better demonstration of the principle. Yet, in this passage he did not quite bring the full force of his argument to focus. Not only did he stop before explaining the cause of image formation and its inversion, he also did not fully demonstrate just how the camera could be a proof. Similarly, a second passage of this same period, 1492, found in the Codex Atlanticus folio 135 b, described a scene projected in the camera obscura, which to Leonardo's thinking apparently demonstrated the theory of image dispersal sufficiently:

PROVE HOW ALL OBJECTS, PLACED IN ONE POSITION, ARE ALL EVERYWHERE AND ALL IN EACH PART.
I say that if the front of a building—or any open piazza or field—which is illuminated by the sun has a dwelling opposite to it, and if, in the front which does not face the sun, you make a small round hole, all the illuminated objects will project their images through that hole and be visible inside the dwelling on the opposite wall which may be made white; and there, in fact, they will be upside down, and if you make similar openings in several places in the same wall you will have the same result from each. Hence the images of the illuminated objects are all everywhere on this wall and all in each minutest part of it. The reason, as we clearly know, is that this hole must admit some light to the said dwelling, and the light admitted by it is derived
from one or many luminous bodies. If these bodies are of various colours and shapes the rays forming the images are of various colors and shapes, and so will the representations of the wall (Richter, J. P., 1970, Vol. I, p. 44, no. 70).

In this wonderfully rich passage is the first description of a projected scene other than that of a light source—a candle or the sun—being formed in the camera obscura. The entire scene is formed with each object reflecting its image in full color and in the smallest detail. This description alone is enough to support the image dispersal theory, but Leonardo went further. He introduced the concept of multiple apertures forming multiple images, noting that there are as many images as there are holes. Like that of the image of a scene, the idea of multiple imagery had not been recorded before Leonardo. He took up this problem again between 1490 and 1505, as part of a long discussion of the camera obscura in the Windsor folios 19,149 recto through 19,152 verso. The Windsor folios reflect a more mature reasoning in the camera discussion, and were probably written closer to 1505.

On folio 19,149 recto Leonardo began what seems to be a fairly sequentially argued set of propositions on the camera problem:

THE PRINCIPLE ON WHICH THE IMAGES OF BODIES PASS IN BETWEEN THE MARGINS OF OPENINGS BY WHICH THEY ENTER.
What difference is there in the way in which images pass through narrow openings and through large openings, or in those which pass by the sides of shaded bodies? by moving the edges of the openings through which the images are admitted, the immovable objects are made to move. And this happens, as is shown in the 9th which demonstrate: the images of any objects are all everywhere, and all in each part of the surrounding air. It follows that if one of the edges of the hole by which the images are admitted to a dark chamber is moved it cuts off those rays of the images that were in contact with it and gets nearer to other rays which previously were remote from it &c. (Richter, J. F., 1970, vol. I, p. 46, no. 77).

Figure 21

Leonardo again had taken up the problem of image dispersal, citing what probably refers to the 9th proposition in the revised edition of *Perspectiva communis*. Pecham had given the demonstration of a stylus casting as many shadows as there were candles in a room. Leonardo began his discussion by asking what relationship exists in the way that images are projected through small or large apertures or those which cast shadows. The object will seem to move, he said, if the edge of the aperture is
moved. Although Leonardo did not say it, this is also true of cast shadows. This happens he said, refering to the Pecham proposition, because of image dispersal. Therefore if the hole is moved, it will block the rays of one projected image of the object, but will project the rays of a slightly different view. Leonardo continued, exploring the idea of the moving aperture further:

OF THE MOVEMENT OF THE EDGE AT THE RIGHT OR LEFT, OR THE UPPER, OR LOWER EDGE.

If you move the right side of the opening the image on the left will move [being that] of the object which entered on the right side of the opening. This can be proved by the 2nd of this which shows: all the rays which convey the images of objects through the air are straight lines. Hence, if the images of very large bodies have to pass through very small holes, and beyond these holes recover their large size, the lines must necessarily intersect (Richter, J. P., 1970, vol. I, p. 47, no. 77).

![Diagram](image)

Figure 22

Leonardo restated his belief in image inversion and the intersection of the light rays in the aperture, although these never were doubted by him, by noting that when the aperture is moved on one side, the image is blocked on the...
opposite side. To prove this Leonardo cited another proposition, although not referring to Pecham here, which is a proof of rectilinear propagation, the cause of the intersecting rays.

He reintroduced the problem of multiple images on folio 19,150 verso, again in the context of image dispersal:

The images of objects are all diffused through the atmosphere which receives them; all on every side in it. To prove this, let $abc$ be objects of which the images are admitted to a dark chamber by the small holes $np$ and thrown upon the plane $fi$ opposite the hole. As many images will be produced in the chamber on the plane as the number of said holes (Richter, J. P., 1970, Vol. I, p. 41, no. 66).

![Figure 23](image)

This text and diagram demonstrate how any image from various points on the surface of the object can enter one of several apertures. The drawing shows the several projected images of body $a$ being projected into the two apertures, demonstrating most clearly the concept of image dispersal. The diagram also clearly depicts the multiple imagery of the three bodies projecting their respective
views into the two apertures, although in aperture Leonardo did not complete the cones of light from the bodies to the aperture.

After some discussion on the similarity of the eye and the camera, Leonardo continued a very long and thorough discussion of image formation on folios 19, 152 recto and verso. He began by explaining how the projected rays come to a point without intermingling as they intersect in the aperture:

HOW THE INNUMERABLE RAYS FROM INNUMERABLE IMAGES CAN CONVERGE TO A POINT.

Just as all lines can meet in a point without interfering with each other—being without breadth or thickness—in the same way all the images of surfaces can meet there; and as each given point faces the opposite to it and each object face an opposite point, the converging rays of the image can pass through the point and diverge again beyond it to reproduce and re-magnify the real size of the image. But their impressions will appear reversed—as is shown in the first, above; where it is said that every image intersects as it enters narrow openings made in a very thin substance (Richter, J. P., 1970, Vol. I, pp. 49-50, no. 81).

Figure 24
Leonardo once again took up Proposition 7 of first edition of *Perspectiva communis* to discuss not only image dispersal but also that each image maintains its own integrity as the rays pass through the point aperture. He argued that the light rays were identical to geometrical lines, with no measurable dimension except length, and that the object reproduces itself point for point in the inverted image. Leonardo realized that this was true only for point apertures, and clearly stated the need to make a very narrow opening in a very thin material; a large aperture, as we have seen, can only present problems with the geometrical proof, and a thick aperture material would cut off the light rays causing a tunneling effect. We have an indication that Leonardo realized the image enlarged itself conceivably to the original size of the object, but he does not state this fully or clearly enough to indicate that the enlargement is in direct relationship to the focal length. At the very end of this passage, Leonardo instructed the reader to "Read the marginal text on the other side." Turning the folio we find the text written in long narrow columns in the spaces between three large diagrams (Fig.25). Only two of the diagrams are clearly discussed in the text, where Leonardo explained how the images overlap in relation to the aperture size:
In proportion as the opening is smaller than the shaded body, so much less will the images transmitted through this opening intersect each other. The sides of images which pass through openings into a dark room intersect at a point which is nearer to the openings in proportion as the opening is narrower. To prove this let \( ab \) be an object in light and shade which sends not its shadow but the image of its darkened form through the opening \( de \) which is as wide as this shaded body; and its sides \( ab \), being straight lines (as has been proven) must intersect between the shaded object and the opening; but nearer to the opening in proportion as it is smaller than the object in shade. As is shown, on your right hand and your left hand, in the two diagrams \( abce \) [and] \( nmio \) where, the right opening \( de \), being equal in width to the shaded object \( ab \), the intersection of the sides of the said shaded object at the point \( c \). But this cannot happen in the left hand figure, the opening \( o \) being much smaller than the shaded object \( nm \). It is impossible that the images of objects should be seen between the objects and the openings through which the images of these bodies are admitted; and this is plain, because where the atmosphere is illuminated these images are not formed visibly.

When the images are made double by mutually crossing each other they are invariably doubly dark in tone. To prove this let \( deh \) be such a doubling which although it is only seen within the space between the bodies in \( bi \) this will not hinder its being seen from \( fg \) or \( fm \); being composed of the images \( abik \) which run together in \( deh \) (Richter, J. P., 1970, Vol. I, pp. 51-52, no. 81).

In this demonstration Leonardo compared the overlapping cones of light projected from two shaded objects and entering a finite aperture with the cone of light from one shaded object which enters a point aperture. It was the
image of these objects and not their cast shadows which were projected through the apertures. In the finite aperture, which has a diameter equal to the width of one of the shaded bodies, the two projected cones are inverted prior to entering the aperture. In the point aperture, the rays intersect in a point within the aperture opening. In the first diagram of the finite aperture, the light from the two cones overlap prior to entering the aperture, but as Leonardo noted, this overlap is not visible since none of the images dispersed from the object are visible until formed through the aperture. This overlap continues in an area beyond the aperture, where Leonardo noted they become twice as dark. However, as the purpose of this demonstration was to illustrate, this darkened area does not prevent the correct formation on the screen beyond the image of the two objects and the space between them. That space is seen even though the central area of the rays immediately behind the aperture is so dark. Leonardo stated that the size of this overlap depends upon the size of the aperture. However, in the demonstration between diagrams I and III, he showed the difference as being the distance between the object and the aperture. This is an indirect implication of his written statement, as theoretically the aperture is smaller the further away it
is from the object.

This discussion, which is a continuation of his proof on the convergence of rays to a point in the aperture, is the closest Leonardo came to explaining image formation in a finite aperture. He had before him at least one model of optical argumentation, that of John Pecham, but Leonardo was not influenced by the traditional method of proof. While he used geometrical diagrams to support his reasoning, often more effectively in fact than many of his predecessors, Leonardo selected a few theorems from Pecham's treatise and repeatedly argued each minute aspect of that point with subtle nuances clearly and logically considered. His demonstrations were uniquely his own. No element of metaphysics crept into his reasoning, yet what he assumed as given fact apparently he did not feel obligated to prove. Pecham's brief consideration of image dispersal even in the revised version of his treatise was only several short paragraphs. Leonardo managed to see much fuller implications in the problem and turned to the camera obscura as a scientific demonstration which had the potential for an indepth investigation.

In 1508-09, Leonardo once again considered the theoretical implications of the camera obscura in his treatise on human vision and the function of the eye. In
Leonardo once again addressed the problem of image formation and image inversion in a very direct statement of his belief in rectilinear propagation:

Of the species of objects which pass into dark places through narrow holes. It is impossible that the species of bodies which penetrate through the hole into dark places do not reverse themselves. This is proved by the third [proposition] of this which says: "the dark or luminous particles of any given ray are always rectilinear;" (sic) therefore, part b of the objects a b passes through the hole n into the darkened place o p q r and is imprinted in the wall p r at point c and the opposite extremity a of the same object a b passes through the same small hole and imprints itself in the same wall p r in point d. And thus the right extremity of such an object becomes left and the left become right etc. (Quoted in Strong, 1979, pp. 89-90).

This simple demonstration was only part of a much more complex discussion on human vision. He knew that the image that entered the eye was like that of the camera obscura, in full color but inverted and reversed from left to right. Leonardo realized however, that unlike the camera, we see the image in its correct orientation. Over the years Leonardo searched for some mechanical explanation for how
the image might be inverted again in the eye. On a folio from the Codex Atlanticus, 337 recto a, from around 1490-1505, are two drawings without any text. One shows the **camera obscura** admitting four rays through its aperture; inside the **camera** the inverted image strikes the front surface of a glass globe, where they are then reinverted at the center of the globe. The rays of this corrected image proceed through the back of the globe and into an eye behind. It would seem that Leonardo was comparing the function of the **camera obscura** to that of the eye.

![Diagram of camera obscura and eye](image)

**Figure 27**

A more explicit comparison of the **camera obscura** and the eye is found in his treatise on vision, MS D folio 8 recto:

> How the species of objects received by the eye intersect inside the albugineous humor.

The experience which shows how objects inside the eye in the albugineous humor is demonstrated when species of illuminated objects penetrate through some small round hole into a very dark habitation. Then you will receive these images
on a sheet of white paper placed inside this habitation somewhat near to this small hole, and you will see all of the mentioned objects on this paper with their true figure and colours, but they will be smaller and they will be upside down because of said intersection. These simulacra if they proceed from a place that is illuminated by the sun will actually seem painted on this paper, which should be very thin and seen in reverse; and the said hole should be made in a very thin plate of iron. Let a b c d e be the said objects illuminated by the sun, o r the front of the dark dwelling in which is the said hole n m, s t the said paper where the rays of the species are cut so that a right becomes f right, and e left becomes f right, and so it is with the pupil (Quoted in Strong, 1979, p. 78)

Leonardo made a clear connection between the way images are formed in the camera obscura and the way they enter the pupil of the eye. Furthermore, he gave a rather detailed description of the image inside the camera, suggesting the use of a translucent sheet of paper for the viewing screen through which one viewed the image. While movable viewing screens had been suggested before, Leonardo was the first to conceive of a transmitted image seen through the screen, in the same way that the image is projected onto the ground glass of a photographic camera. His statement that the
image seems painted on the paper is provocative, but nowhere did Leonardo suggest tracing the image formed by the camera.

Leonardo developed several theories over the years to explain how the eye sees the image correctly rather than upside down as in the camera obscura. A clue to his early thinking is found in the second drawing of the Codex Atlanticus folio 337 recto a of 1495-1500 (Fig. 27), which shows four rays entering the pupil of eye and striking the surface of the cornea forming an inverted image. The rays of this inverted image then pass through the crystalline sphere or lens where they are inverted again, thus sending a correctly oriented version of the image through the optic nerve and to the brain. This idea is reiterated in the Windsor folios of about the same period, as is seen on folio 19, 150 verso:

Necessity has provided that all the images of objects in front of the eye shall intersect in two places. One of these intersections is in the pupil, the other in the crystalline lens; and if this were not the case the eye could not see so great a number of objects as it does. This can be proved, since all the lines which intersect do so in a point. Because nothing is seen of objects excepting their surfaces and their edges are lines, in contradistinction to the definition of a surface. And each minute part of a line is equal to a point; for smallest is said of that than which nothing can be smaller, and this definition is equivalent to the definition of the point. Hence it is possible for the whole circumference of a circle to transmit its images
to the point of interception, as is shown in the 4th of this which shows: all the smallest parts of the images cross each other without interfering with each other. These demonstrations are to illustrate the eye. No image, even of the smallest object, enters the eye without being turned upside down; but as it is once more reversed and thus the image is restored to the same position within the eye as that of the object outside the eye (Richter, J. P., 1970, Vol. I, pp. 47-48, no. 78).

Reinforcing the similarity between the camera and the eye, as well as reasserting his theory of double inversion, Leonardo then demonstrated just how the image of a large object could enter such a small place as the eye. He went to geometry, with its dimensionless point, and stated that the image is in fact made up of countless points which can intersect in the aperture without intermingling. It is an argument we have already seen above on folio 19, 152 recto "How the innumerable rays from innumerable images can converge to a point," but here it is better reasoned. His statement that the eye is capable of seeing so many objects recalls his eloquent praise for the eye, written about the same time in the Codex Atlanticus, folio 345 verso b:
...The eye is the window of the human body through which the soul views and enjoys the beauties of the world...Who could believe that so small a space could contain the images of all the universe? O mighty process!...Here the figures, here the colours, here all the images of every part of the universe are contracted to a point. O what point is so marvelous! O wonderful, O stupendous Necessity thou by thou law constrainest all effects to issue from their causes in the briefest possible way...(Quoted in Strong, 1979, pp. 348-349)

Leonardo's exuberant endorsement for the eye, however, did not last; toward the end of his career he had become distrustful of the eye's "truthfulness," and turned to the truth of geometry instead. His ideas about double inversion also changed, and by 1508-09, when he was working on MS D, Leonardo had developed a radically new theory of how the eye sees a correct image of the scene in front of it. On folio 7 verso, Leonardo compared the retina with a very dark mirror which reflected the inverted image onto the back of the crystalline sphere where the image was corrected and sent to the optic nerve. On folio 8 recto, he proposed that the light rays are inverted behind the pupil, transverse the crystalline sphere, and are then somehow reinverted in the space behind the crystalline sphere before entering the optic nerve. Leonardo never found a suitable explanation for the problem, nor did he ever realize that the lens was not a large sphere in the center of the eye.
As Leonardo struggled with understanding the mechanics of the eye, he searched for some instrument to help him determine where the visual sensitivity lay inside the eye. One might assume that because he had compared the eye to the camera obscura, that this would be the logical instrument for what he called his "oculus artificialis." However, the camera could only demonstrate what happened to the light rays as the image was projected through an aperture. By 1508-09, Leonardo had become more involved with binocular vision, with the curvature of the eye, and with the fact that the eye was not immobile as a camera eye or the eye of "artificial" perspective. Thus, while he continued the analogy of camera and eye in MS D, Leonardo chose other methods for constructing his artificial eye.

As much as Leonardo utilized the camera obscura in his proofs of rectilinear propagation, image dispersal, and human vision, it is surprising that he supported anything other than the intromission theory, that is, of the rays traveling from the body to the eye. In his early notebooks, Leonardo embraced the emission theory exclusively, but as early as 1490, he had already begun to adopt a platonic viewpoint of both emission and intromission. With the light rays and the sight rays traveling the same line, Leonardo developed a theory which
would not contradict image formation in the *camera obscura*, but rather had the *camera* admitting and projecting images just as the eye did. We find the first hint of this compromise approach in the Codex Atlanticus folio 270 recto b:

**Opinions**
All these instances are given in order to prove how all things or certainly many things transmit the appearances of their powers together with the images of their forms without any injury to themselves; and this also may happen with the power of the eye.

**Contrary opinion**
Furthermore if anyone wished to say that the eye was not adapted to receive like the ear the images of objects without transmitting some potency in exchange for these, this may be proved by the instance of the small hole made in a window which gives back all the images of the bodies which are opposite to it; therefore one may say that the eye does the same.

**Refutation**
If the small hole cited as an example without sending forth anything except its form without incorporeal power gives back to the house the images of objects in their colours and forms and there inverts them, the eye would have to do the same so that everything seen would appear there inverted (MacCurdy, 1939, pp. 236-237)

On Codex Atlanticus 270 verso c, Leonardo gave a series of examples, the "instances" cited above, which supported the idea that the eye has an active visual power (i.e., that the wolf has the power by its look to make men have hoarse voices, that the spider makes its eggs hatch by looking at them, that a young woman has the power in her
eyes to attract the love of a young man). He went on to argue the power of the visual ray, saying that every body in nature fills the air around it with its images, and the eye has the same power to fill the air around it with its visual power. In the argument above, Leonardo debated the emission-intromission theory, without really coming to any clear cut resolution. In the "opinion" Leonardo stated that all objects can send out the "apparences of their powers" in conjunction with their images without causing any damage to themselves. In the "contrary opinion" he argued that the camera obscura was the evidence of the intromission theory with the rather peculiar wording that the Camera "gives back all the images of the bodies which are opposite." By this he meant that the images are formed reproducing the scene. He ended this section with the observation that the eye does the same thing. In the "refutation" however, he concluded that if indeed the object can form an image through the aperture—an image that is in full color and inverted—the eye would have to do the same thing, and we would therefore see everything upside down.

Later, in the Windsor folios, written before 1505, Leonardo explains his dual direction idea more clearly. On folio 19, 148 verso we find:
...Lines from the eye and the solar and other luminous rays passing through the atmosphere are obligated to travel in straight lines. Unless they are deflected by a denser or rarer air, when they will be bent at some point, but so long as the air is free from grossness or moisture they will preserve their direct course, always carrying the images of the objects that intercepts them back to their point of origin. And if this is the eye, the intercepting object will be seen by its colour, as well as by form and size. But if the intercepting plane has in it some small perforation opening into a darker chamber—not darker in colour, but by absence of light—you will see the rays enter through the hole and transmitting to the plane beyond all the details of the object they proceed from both as to colour and form; only everything will be upside down...(Richter, J. P., 1970, Vol. I, pp. 78-79, no. 130)

Leonardo clearly equated rays from the eye with light rays which are directly from or reflected by the sun, and unless these rays are refracted or deflected somehow in the atmosphere (i.e. in fog) these rays will always travel in straight lines. He then proceeded to explain how this happens with the camera and with the eye. We already understand that the camera "intercepts" through its aperture those images dispersed by the luminous body. In the case of the eye, however, it is the object that intercepts the rays of the eye. So in this argument, the camera obscura and the eye are not comparable. Leonardo carried his discussion of the camera further to explain that the size of the image formed depended on the distance the object is from the aperture and the distance the
aperture is from the imaging screen. However, he did not carry the idea any further to explain just what this ratio might be.

A more important theme introduced here is that of the "central ray." Earlier on folio 19,148 verso Leonardo stated:

...I say that the projects an infinite number of lines which mingle or join those reaching it which come to it from the object looked at. And it is only the central and sensible line that can discern and discriminate colours and objects; all the others are false and illusory...(Richter, J. P., 1970, Vol. I, p. 78, no. 130).

There is little doubt from this statement of Leonardo's belief in the theory of emission. The eye sends out an infinite number of rays, but only one of these is discriminating; the rest are peripheral. Further on in this same passage, Leonardo declared that the central ray was the only one that "carries truth in its testing of shadows." This theme of the sole veracity of the central ray became more prevalent in Leonardo's thinking as he became more disillusioned with the general trustworthiness of the eye.

On folio 19,152 recto of the Windsor manuscript, Leonardo addressed the issue of the central ray in relation to the inverted image:
OF THE CENTRAL LINE OF THE EYE.

Only one line of the image, of all those that reach the visual virtue, has no intersection; and this has no sensible dimensions because it is a mathematical line which originates from a mathematical point, which has no dimensions.

According to my adversary, necessity requires that the central line of every image that enters by small and narrow openings into a dark chamber shall be turned upside down, together with the images of the bodies that surround it (Richter, J. P., 1970, Vol. I, p. 48, no. 79).

The adversary was Leonardo's way of identifying another point of view not necessarily his, but in this instance, the adversary was correct. By turning to geometry instead of reason based on logic, Leonardo incorrectly concluded that the central ray was not inverted. Mathematically, how could that one central point invert itself in the aperture when it only continued as a straight line to the screen beyond? By the laws of geometry it could not, yet if this were true, one point of the image would not be in correct orientation with the rest of the image. Leonardo's faulty reasoning was a direct result of his changing attitude toward the veracity of human vision.

The notes on optics and vision were part of his proposed treatise to the painter. The treatise was never completed during Leonardo's life time, as far as is known. While there were several reports that he had completed parts of it as early as 1498 (Strong, 1979), Francesco
Melzi, who inherited the notebooks, prepared a compilation from the notebooks for the Trattato della Pittura around 1530. This manuscript, which apparently was intended for publication, survives today in the Vatican Library (Codex Urbinas 1270). From the Melzi manuscript and the surviving notebooks, we have some sense of how Leonardo applied his scientific research to painting. The camera obscura is mentioned in only a few instances, and only in relation to statements about color. These passages, which are primarily found in the earlier folios of the Codex Atlanticus, concern color mixing, intensity and contrast. However, according to Blunt (1968, p. 29), color theory was not a topic which held much interest for Leonardo, and his general disinclination to develop the argument is seen in three passages which include the camera obscura.

On folio 181 recto a of the Codex Atlanticus, Leonardo discussed how the surface of objects take on the color of its surroundings:

OF PAINTING.
The surface of a body assumes in some degree the hue of those around it. The colours of illuminated objects are reflected from the surface of one to the other in various spots, according to the various positions of those objects...And the rest will be set forth in the book on painting. In that book will be shown, that, by transmitting the images of objects and the colours of bodies illuminated by sunlight through a small round perforation and into a dark chamber onto a plane surface, which itself is
quite white, &c.

There is an interesting relationship of reflected light and projected light implied in this passage. In the omitted section of this passage, Leonardo demonstrated how a blue object on one side and a yellow object on the other side of a white sphere can reflect their colors onto the surface of the sphere; where the two reflected colors overlap on the sphere's surface, they mix to make green. The intensity of this reflected color is dependent, of course, on how close the object is to the surface on which it reflects its light. Leonardo implied that the projected colors of an image formed in the camera is a similar situation, but the explanation of the relationship is promised elsewhere. This explanation, however, never found its way into Melzi's compilation.

Technically, the light and colors of the camera image are from sunlight which is reflected off the surface of the scene opposite the aperture. However, the distance between the scene and the aperture is so great, that the colors of the formed image are not merely a result of simple reflection. If the white screen were placed outside and just in front of the aperture, the colors of the scene would have no visible effect on the white surface. It is
the image formation in the aperture that colors the white surface of the screen with the hues of the scene.

Another rather interesting notion deals with where the color seems the most intense. On folio 190 recto b, Leonardo described a perceptual phenomenon of the color intensity seeming greater at the edges than in the center, as demonstrated by the colors of objects projected into the camera obscura. This idea is part of a larger, rather common notion that the colors in the camera obscura are more intense than in the scene. The colors seem more intense because they are surrounded by a non-color or a neutral, that is, black. The phenomenon is a result of contrasting color with a neutral. What Leonardo observed with his incredible eyesight, was that the point of contact between color and non-color seems more intense than the central area of color surrounded by more color.

This idea of contrast was carried further, with the aid of the camera obscura, in the concept of maximum contrast, that is, white and black. On folio 192 b Leonardo wrote:

Since black, when painted next to white, looks no blacker than when next to black; and white when next to black looks no whiter than white, as is seen by the images transmitted through a small hole or by the edges of any opaque screen... (Richter, J. P., 1970, Vol. I, p. 150, no. 279)
Leonardo gave as examples the camera as well as cast shadows to illustrate that black and white make for the greatest contrast achievable, whether next to themselves or next to each other. How the camera or cast shadow illustrate this concept is not explained; it is apparent through observation, and at the time this was written, observation was still a viable method of proof for Leonardo.

The camera obscura was a real, working proof, one which provided observational information as well as mathematical substantiation. Leonardo made full and innovative use of the camera as experimental tool and as a proof for his theories of light and vision. He had a clear understanding of the phenomenon of image formation, knew the importance of a point aperture, understood the relationship of aperture size to focal length and of image size to focal length.

In spite of his innovative applications with this tool, there are two "improvements" on the camera hinted at but not fully resolved in the notebooks. The first was the application of a lens in place of or in conjunction with the aperture. This would let in more light, and provide a much brighter image. The drawing of the eye as camera obscura in all probability is a result of a direct experiment with a glass globe of water behind the aperture,
but once he had done this experiment, was it necessary for him to continue to repeat it? Leonardo eventually abandoned this theory of double inversion in the eye, and the camera equipped with glass globe no longer functioned as his "artificial" eye. We also saw him concerned with making glasses to see the moon, but again these were for the eye, not the camera. In Leonardo's day, generally lenses were regarded with a great deal of suspicion, as they were not well made and often distorted "the truth." Leonardo's search for truth lead him away from the eye, and as a result, away from the camera as well.

The second aspect of the camera obscura which Leonardo might have improved but did not was that of the inverted image. He wrote almost apologetically time and again, "but the image is upside down." Again, it was in his search to find out how the eye sees the scene correctly that Leonardo provided a potential solution, that of the retina as a mirror. His concern, however, was image inversion in the eye, not in the camera; the camera was only a tool, one which worked well for him and one which needed no improvements. He used the camera obscura as a method of solving a variety of problems; he never thought of the camera as a problem needing any solutions.
There is little agreement among historians on what influence Leonardo's notebooks had upon subsequent writers. The general state of the notebooks, even during Leonardo's time, would lead one to believe that they were of little use to anyone other than Leonardo, and from what we have seen, even he could not recall what he had already addressed in his writings. However, there is evidence that some of the works were completed, and that some of the notebooks were seen by others, if not during Leonardo's lifetime, then certainly during Melzi's and afterward. Steinitz (1958, p. 6) supports this theory and argues that there were those intelligent enough to appreciate the content of Leonardo's writings.

In 1542, Benvenuto Cellini acquired from an impoverished nobleman in the court of Francis I a book on painting and sculpture copied from Leonardo's manuscripts. This he loaned to the architect Sebastiano Serlio, who, Cellini recorded, wanted to use them in his book on perspective but apparently was not successful in completely assimilating the information in them (Pedretti, 1965, p. 167). In 1584, Giovanni Paolo Lomazzo, in his Trattato dell'arte de la pittura, mentioned having seen a Leonardo manuscript written at Ludovico Sforza's request, which compared painting and sculpture (Pedretti, 1965, pp. 4 and
9, note 2). Nor were all of the comments about Leonardo's notebooks positive. Baldassare Castiglione in his Il Cortegiano of 1514, and Frederigo Zuccaro in his L'idea dei scultori, pittori e architetti of 1609, both criticised Leonardo's neglect of painting for an over emphasis on scientific studies (Strong, 1979, p. 266, note 138).

In the 16th century works written after Leonardo's death, only a few which discussed the camera obscura show any relationship to ideas expressed in Leonardo's notebooks, and only in the case of one of these can the author, Girolamo Cardano, be linked with Leonardo through circumstantial evidence. However, it is in these 16th century writings that we find a realization of Leonardo's implied improvements to the camera, that is, the lens and mirror, and the first examples of these are remarkably similar to Leonardo's own spherical glass globe and concave mirror.
REFERENCES


CHAPTER V

DIVERSIFICATION OF A TOOL:

THE 16TH CENTURY

The 16th century saw an increased interest in optics, lenses, and the study of human vision. While very few new optical works that discussed the camera obscura were written during the century, many of the traditional works were published for the first time. One such work was Alhazen's Perspectiva or De Aspectibus, the Latinized version of the Kitab fi-l'Manazir included in Frederic Risner's edition of Opticae Thesaurus. This work also included Witelo's Perspectiva which had already been published in 1535 and 1551 (Lindberg, 1972). John Pecham's Perspectiva communis went through nine publications during the 16th century, with the Hartman edition of 1542, which included numerous "improvements," influencing those to follow (Lindberg, 1970). Even a commentary of Johannes de Sacro Bosco's 13th century astronomical treatise, Tractus de sphera, appeared in 1531, which included a description of the camera obscura as an observational tool where the original text had made no mention of this device.
The contemporary works that appeared continued the traditional discussions of the camera obscura in its application to astronomy, its comparison to the eye in demonstrating human vision, and its theoretical implications in image formation. Most important in this literature, however, were the physical modifications to the camera including lens and mirror, and the application of the tool to picture making. In addition, we see in all but one of these works genuine expressions of amazement and wonder at the phenomenon of image formation. The change in emphasis found in these works began a new tradition of camera obscura literature which was to continue into the 19th century.

The first contemporary publication to include a discussion of the camera obscura appeared in 1521, two years after Leonardo's death. This was Cesare Cesariano's venacular annotation and edition of Vitruvio de Architectura published in Como. Cesariano was born in Milan in 1483, and worked in Bramante's workshop until he was 16, when Bramante left Milan for Rome in 1499. Cesare was 18 when Leonardo left Milan, and while he mentioned Leonardo in his book, there is no evidence that Cesare ever had any contact with Leonardo. Cesariano's edition of Vitruvius is a curious blend of personal anecdotes supplemented, when his
own experience was lacking, with information from ancient sources, which were liberally interspersed in his word-by-word commentary of this classical work on architecture. Reaching a wide audience, even through some plagiarized versions, Cesariano's work was valuable primarily for popularizing this revered source book for architects (Krinsky, 1969).

In the commentary on Vitruvius' use of the word "spectaculum," Cesariano attempted to give a contemporary example, but was not certain whether Vitruvius had meant a small tube or sight used on astronomical dioptrers and astrolabs or referred to the more common use of a public show. Combining the two meanings in his example, Cesariano related how as a student traveling to Milan, he and his friends had stayed in a monastery and was there shown a spectacle by one of the monks:

A beautiful law of optics may well be mentioned which was found out and verified by the Benedictine monk and Architect Don Papnutio. If a circular concavity, about two inches in diameter, is cut with a lathe in a piece of wood, about four to six inches in size, and in the center of the concavity a small and very short tube (spectaculum) or aperture, which is also called a sight (scopos) is placed; and if it be properly fixed in a leaf of a door, or in front of a window, shut, so that no light may enter, and if you have a piece of white paper or other material upon which everything passing through the aperture may be represented, you will see everything contained in the earth or the sky according to the pyramid formed through the
aperture, and with their colours and forms (Quoted in Waterhouse, 1901, p. 273).

Cesariano tied the commentary more closely to the text by referring to Vitruvius' comments on the great and frightful qualities of the heavenly winds and the laws of nature. He concluded the passage with the comment that to this end, this would be excellent for illustrious painters, astronomers, and opticians, like having money placed in the bottom of a water filled sphere.

At first glance this passage adds little new to what we already have seen described, but we must remember that this was the first real description of the *camera obscura* to be published; the theoretical discussions in the reprinted optical works of Pecham, Witelo and Alhazen did very little to make known this phenomenon of image formation. We see from this passage that Cesariano was aware that this demonstration was one traditionally associated with optics, "a beautiful law of optics," he noted. Whether this information was gained through his encounter with Don Papnutio or on his own is not clear, but in all probability the monk explained this aspect of optics when he demonstrated the phenomenon to Cesariano and his friends. Don Papnutio, unknown except in this reference, perhaps was university trained and had studied optics. Regardless of how he came upon the information, however,
Papnutio apparently had not been satisfied with just knowing optical principle; instead he had put it to the test and "verified" this law of rectilinear propagation.

Cesariano's description of making the aperture is fairly detailed. Inside the two inch hole is place a sight or scope. As Cesariano had already referred to the astronomical diopter and the astrolab, it could well be that Don Papnutio was also versed in making astronomical observations. Once the room is dark enough, Cesariano continued, the image is projected onto a sheet of white paper or other material. The image, seen in full detail and color, included everythin in both the earth and sky ("tutula terra et Coela"). Missing in this description, however, is Leonardo's refrain "but the image will be upside down." As Cesariano's description is so carefully accurate, it is difficult to think he just forgot to mention that the image was inverted. It is more probable that Cesariano either assumed that the reader understood this optical law which illustrated image inversion, or that he deliberately omitted what might be construed as a negative aspect to this spectacle. Describing the light entering the aperture, Cesariano used the term "pyramid," a word that in medieval optics was synonomous with "cone" and in Renaissance perspective signified the visual angle. In
medieval optics, as we have seen, this term did not imply a specifically shaped base (i.e. in a triangle or rectangle), but could be a pyramid with a circular base (i.e. the shape of the sun). In this case the base of the pyramid is the shape of the scene projected on the paper.

His concluding statement was, like some of Leonardo's comments, provocative both in implication and in similarity to an idea already seen in Leonardo's notebooks. The implication that illustrious painters, astronomers and opticians could benefit from this device—that it was excellent for them—prompts the question of how these individuals might use the camera obscura. Astronomers and opticians historically had already made full use of this device, but artists had not. Was Cesariano suggesting that illustrious artists could use this tool as a drawing instrument? He did not elaborate. How they could use the camera would be as clear to them as "having money at the bottom of a water filled sphere." If they could see the application, they could seize the opportunity. The water filled sphere analogy, reminiscent of Leonardo's optical studies, was a well known Renaissance device used as a magnifying lens. Cesariano made no connection of this lens to the camera obscura, not even an implication as strong as that of Leonardo, yet one reading this passage and
understanding the capabilities of the sphere as lens could easily make a connection between the analogy and the experience of image formation.

The next suggestion of some physical modification to the camera is found in Girolamo Cardano's *De Subtilitate Libri XXI*, published in Nuremburg in 1550. Cardano, born in Pavia around 1501, was the illegitimate son of Fazio Cardano, professor at the University of Pavia who had published Pecham's *Perspectiva communis* in 1482-83. Girolamo's colorful and checkered career as physician, mathematician, university professor and compulsive gambler is recorded in his autobiography *De Vita Propria Liber* published in 1643, 67 years after his death. He also was a compulsive writer, producing enough work to fill seven thousand pages, almost all of which was in Latin (Stoner, 1930). He seems to have lifted freely from many sources for his publication, and there is strong evidence that he had even seen Leonardo's notebooks. Cardano's word associations for dream interpretation in his *De Somnis* is similar in method to Leonardo's work lists in the Codex Trivulziano, and his book on water, *Di Mondo et Acque*, also bears similarities to Leonardo's studies (Stites, 1970). He also seems to have been aware of Leonardo's anatomical studies (Bilancioni, 1929). His discussion of the camera
*camera obscura*, however, bears only the most superficial resemblance to Leonardo's many passages. Cardano's discussions of the *camera obscura* are found in Book IV of his *De Subtilitate*, in a section entitled "De Luce et de Lumine" (p. 107):

> If you want to see the things which go on in the street, at a time when the sun shine brightly, place in the window shutter a bi-convex lens (*orbem e vitro*). If you then close the window you will see images projected through the aperture on the opposite wall, but with rather dull colours; but by placing a piece of very white paper in place where you see the images, you will attain the eagerly awaited result in a wonderful manner (Quoted in Gernsheimer, 1969, p. 20).

While the majority of historians have translated this problematic phrase "*orbem e vitro*" as a bi-convex lens, Waterhouse (1901) interprets this as glass concave mirror which was placed outside the closed window and reflected the street scene through the aperture and onto the screen opposite. As Cardano, like Cesariano before him, makes no mention of an inverted image, Waterhouse's translation would certainly make sense in this context. Waterhouse apparently concluded that Cardano meant a mirror because after he placed it in the window he closed the shutters, implying that the mirror was outside. As we shall see in later descriptions, however, most writers described preparing the lens in the window first, then closing the
room to the light, a much more sensible way of going about things than working in the dark.

It is also possible, although not very probable, that Cardano was influenced by Cesariano's description, using it as a model for his own. However, his comment that "you will attain the eagerly awaited result in a wonderful manner" would seem to indicate a first hand experience of the phenomenon. This "orb that is glass" is very much like the descriptions already given by Leonardo and Cesariano of the popular magnifying lens, a glass sphere filled with water, or indeed could have been a solid glass ball. While this translation seems more accurate, it does not account for Cardano's failure to mention the inverted image.

That Cardano was fully aware of the optical problem of the camera is seen in his attempt to explain image formation through non-circular apertures (Book IV, pp. 107-108):

The reason for this is twofold...For lines which earlier converge, the farther they proceed, to that degree the more they will approach parallelity, by which it is accomplished that the more they recede from the nature of angles the more they approach the nature of rotundity...The other reason is that the more the figure recedes [from the aperture], the more it grows, and that part of the object is weaker...becomes lost to sight as we have assumed from the beginning. When the ample and more round part overshadows the edges by its light it is necessary that the parts of the weaker strength, that is, the angular parts, cease to move vision before the
parts in the middle into which parts rays are emitted copiously, and therefore, these figures will appear round... But if these things which I put forward do not turn out well for anyone, let him accuse himself of ignorance not me of deceit (Quoted in Straker, 1971, pp. 282-283).

Cardano's argument is like a recurring nightmare of Bacon, Witelo and Pecham all thrown into one theorem, the only thing missing is Pecham's humility when he said that he would venerate anyone as teacher who could explain this better than he. Cardano offered nothing new; the image is round because of the parallelity of rays which naturally move toward rotundity the further the screen is from the aperture, or the image is round because of weak rays which become invisible the further the screen is from the aperture. Straker interprets Cardano's closing statement as confident optimism, but it could also be seen as hostile defensiveness expressive of his inability to contribute something new to this discussion. Nevertheless, from this passage we can assume that Cardano was aware of image inversion, for he noted the convergence of the rays through the aperture. As his overall description of the camera in the earlier passage was rather brief, perhaps his omission of image inversion was an oversight.

In 1558, just eight years after Cardano's book, Giovanni Battista Della Porta, a Neopolitan nobleman, published his first edition of Magia Naturalis Libri IIII.
One of the most colorful and controversial figures in the 16th century, Della Porta's biography has been somewhat obscured by "public" statements recorded by family and friends after Della Porta had a rather frightening brush with the Inquisition. Della Porta's own accounts of his life are even less clear, often giving conflicting dates for his birth, and claiming that he was only fifteen years old when he published *Magia Naturalis*; actually, he was twenty-one. Della Porta was a showman, a wizard, and the founder of the academy of I Segreti. It was in fact his dabbling in magic that led to his investigation by the Inquisition. He was a highly popular figure, it being said that the two greatest tourist attractions of his day in Naples were the baths of Pozzuoli and Giambattista Della Porta (Clubb, 1965). He wrote seventeen books ranging from optics, cryptography, physiognomy, horticulture, mathematics, meteorology, and mnemonics, to fortification. One of his last works left unpublished was *Del telescopio*, an attempt to substantiate his claim to having invented the telescope. In his spare time Della Porta was a playwright.

The material for his book on Natural Magic was accumulated from the members of I segreti who were required upon entry to the academy to "discover a secret unknown to the rest of mankind" (Clubb, 1965, p. 12). Thus, the book
became an encyclopedia of trivia, some harebrained and some completely unbelievable, mixed in with useful and sometimes important scientific information. Many historians of science in the past have regarded Della Porta as a charlatan, or at best an interesting curiosity. However, as other of his scientific work have come to light, such as the rediscovery in the 20th century of his De telescopio, Della Porta's importance as a 16th century scientist is being reassessed.

*Magia Naturalis* was the least scientific of Della Porta's work, but certainly the most influential, being published six times in Latin and translated into Italian, French, English, Dutch, and, according to Della Porta, Spanish and Arabic. In 1589, the work was re-issued in an expanded 20 book edition. Containing such valuable information as how to remove warts, grow hair, and remove the ill scent from the arm pits, this work did more than any other to popularize the *camera obscura* as a spectacular toy. As a result, Della Porta is still often regarded as the inventor of the *camera obscura* (Clubb, 1965).

The 1558 edition had a rather brief description of the *camera* found in Book IV, Chapter II, page 143:

The manner in which one can perceive in the dark the things which on the outside are illuminated by the sun, and with their colors.
If one would see this, it is necessary to closely shut the windows and door down to the smallest possible aperture, lest even a little daylight entering the interior should cause the demonstration to fail. The light should be admitted only through a single conical hole bored through the wall, the base of the cone being turned to the sun and the pointed end towards the interior. The wall opposite should be kept white or covered with a sheet or paper. One will then perceive everything that is lighted by the sun, and the people passing on the street will have their feet in the air and what is on the right will be on the left side. Everything will be reversed. The images will be much larger as the paper will be farther away from the opening; but nearer the paper is placed, the smaller they will become. I will now reveal a matter which I have always hidden and believed it best to conceal: if one would see all these things in their colours on the paper, one uses a mirror. Not a mirror which disperses the rays, but one which collects them. Move it farther away or place it nearer until you find the proper distance where the image is in the center of the mirror and the observer, looking attentively, can recognize the faces, the gestures and movements of the passerby [the clouds, the blue sky and the birds flying]...This will make it possible for anyone ignorant of the art of painting to draw with a pencil or pen the image of any object whatsoever (Quoted in Potonniee, 1972, pp. 6-7).

He mentioned the need of having to let the eyes adjust to the dark before seeing the image on the screen, which is an indication that at best, the image was not very bright. He then compared the eye to the camera, saying that the pupil was like the window aperture, and the image formed in the mirror was like that formed in the major sphere (crystalline sphere) in the eye where the seat of vision is located. This should prove to philosophers and physicians
("medicis"), he argued, how vision takes place and should settle the discussion of intromission. Della Porta also commented that "you will rejoice not a little to see the marvel" (Waterhouse, 1901, p.274).

Della Porta, ever the showman, set the stage for the spectacular event with his heading, how you perceive in the dark the full colored view of the scene outside in the sun. His choice of the word "conspicias," that is, "perceive," rather than the word "see" added a bit more drama to expectation of witnessing this event. His description is very detailed, even to the point of explaining which way the conical opening should be oriented in the window. The type of opening was necessary in permitting the light rays to spread out again after intersecting in the aperture, and to prevent them from being blocked by the thickness of material in which the aperture was made. His novel description of people with their feet in the air ("antipodes") certainly demonstrates his awareness of the reversed and inverted image, and to correct this Della Porta introduced his great secret, a concave mirror. While not stating the optical principle, Della Porta was aware of the relationship between focal length and image size, even with the concave mirror. His last statement, naively made as a useful tip, may have done
more harm in the long run to the acceptance by the art world of the camera obscura as a legitimate drawing device, for he recommends it to those who cannot draw--those ignorant of the art. This work, in fact, was not for the artist or scientist; it was for the edification and entertainment of the general populace. No serious artist could take this advice to heart; and if he did, would he ever admit it?

While Della Porta had corrected the problem of the inverted image, he still used an aperture without a lens. For those trying to use Della Porta's camera, they would find the images were not very bright and thus difficult to trace. Cardano's description was not clear enough to interpret definitely as including a lens. It was not until Daniele Barbaro published his Practica della Perspectiva in 1569 that we find a clear description of the camera obscura with a lens.

Barbaro (1514-1570), a Venetian nobleman and Patriarch of Aquileia, had attended the University of Padua in the 1530's where he worked with Giovanni Zamberto in publishing Zamberto's 1537 editions of Euclid's Elements and Optics. He was trained as a Euclidean scholar, but had been exposed to the Aristotelean-Averroist philosophy of vision currently prevalent at the University of Padua. He was
primarily a humanist scholar, rather than artist or art theorist, and his strength as a writer lay in his ability to compile and edit original source material. He had published three editions of Vitruvius' *De Architectura*, and drew upon this experience and information for his edition of *La Practica della Perspectiva*. This influential treatise drew upon the perspective works of Piero della Francesca, Durer, Serlio and Vitruvius in a effort to demonstrate not only the theory of perspective, but also to demonstrate the wide range of subjects, such as architecture, theatrical scenery, astronomy and human proportion, to which perspective could be applied. He tried to bridge the growing gap between perspective theory and theories of vision by attempting to prove that perspective was indeed a valid means of recording visual impressions. In his discussion of vision, Barbaro finally concluded that no matter whether the eye emits or receives rays, the image is impressed upon the eye with a point to point correspondence with the scene. He said that vision is not just based on geometrical laws, but also on the laws of natural science (i.e. physics) which must consider the natural phenomenon of light making the scene visible.

However, Barbaro did not go as far as to compare the eye with the *camera obscura*. 
Barbaro began his book with an analysis of theoretical optics and the geometrical theory of vision and ended with the practical application of optics to perspective. In between, he explained how to project spherical objects which had application to scenography and cartography, discussed human proportion, and included a discussion on mechanical drawing devices which could augment perspective construction. In Part IX Chapter V (pp. 192-3), Barbaro described a camera obscura which included a lens and diaphragm:

Nature delights in teaching us the various proportions of objects and helps us to define the precepts of art, provided that we are diligent observers on every occasion. Now I will describe a most beautiful experiment concerning Perspective. If you wish to see how nature shows us the various aspects of things not only the outlines of the whole but also their parts as well as of their colors and shadows, you must make a hole of the size of a spectacle lens in the window shutter of a window of a room where you wish to observe. Then take a lens from spectacles used by old men, that is to say a lens which is fairly thick at the center and not concave like the spectacles for younger men who are shortsighted, and fix this lens in the hole you made. After that close all the windows and doors of the room, so that no light is present except that which enters the lens. Take a sheet of paper and hold it behind the lens and you will see on the sheet of paper every detail however small of everything outside the house and this will happen most distinctly at a given distance from the lens. By moving the sheet of paper towards or away from the lens you will find the most suitable position. Here you will see the images on the paper as they are, and the variations, colours, shadows, movements, clouds,
the rippling of water, birds flying, and everything that can be seen. For this experiment you should choose the glasses which do best, and should cover the glass so much that you will leave a little of the circumference in the middle, which should be clear and open, and you will see a still brighter effect. Seeing, therefore, on the paper the outlines of things, you can draw with a pencil all the perspective and the shading and colouring, according to nature, holding the paper tightly till you have finished the drawing (Quoted in Wheelock, 1977, pp. 137-138).

Barbaro went on to suggest that the camera could be used for making exact copies in any size one desires of maps and the dials of waterclocks. He instructed the reader to set the map or drawing that is to be copied in the direct sun opposite the aperture and let the rays be projected onto the paper inside the dark room, placing the paper at whatever distance to get the desired size. Then all that was necessary was to trace the image.

Barbaro's introduction to this passage reflects his philosophy that the "secret" to perspective was not the geometrical principles of linear perspective, but rather an understanding of nature (Straker 1971). His emphasis on the proportion of objects and his concern for color and shadow reflect that break with mathematical perspective. For Barbaro, the camera became a most beautiful demonstration of a natural phenomenon applicable to perspective.
His description of the camera is, of all the published ones so far, the most thorough. He gave explicit details on what kind of lens to use, that is, a simple magnifying lens either plano-concave or bi-convex. He described it as the type used in eye glasses for "old men," or in other words, reading glasses. The type of lens used for myopia (shortsightedness) was concave and would not form an image properly. He suggested fixing the lens in the shutter before closing up the room. Further on he suggested making a diaphragm, that is, a small aperture placed behind the lens to make the image "brighter." The diaphragm better focused those rays entering the lens and prevented any spherical aberration of the image around the edges of the lens. In actuality, the image was sharper, not brighter. It is important to note, too, that Barbaro took no credit for the innovation of this type of lens or for the diaphragm. The sharp, bright image was necessary for Barbaro's other suggestion of using the camera as a drawing tool. This description was, after all, in a section on mechanical drawing devices, along with a reproduction of Durer's perspective instrument. Barbaro's advice to hold the paper up while at the same time trying to draw seems awkward at best. As he had suggested moving the paper back and forth in order to focus the image, obviously the paper
was not against the wall opposite the aperture. Apparently it was up to the artist to work out a viable system for tracing the image. Barbaro also emphasized using the camera as a copying machine for reproducing maps and designs at whatever scale needed. He seems to have had a complete understanding of the need of a well-lit original from which to copy, although the difficulty of actually making the tracing could indicate that Barbaro had never used the camera in this way.

Barbaro's description is quite convincing and gives the impression, for the most part, of his having experienced the camera phenomenon first hand. However, given the way Barbaro relied on other sources for his writing, the question of influence should be considered. There are phrases in the passage that would perhaps betray a knowledge of earlier descriptions, and the fact that Barbaro, like Cesariano and Cardano, had failed to include any mention of the inverted image would certainly hint at more than coincidence.

That Barbaro knew of Cesariano's edition of Vitruvius is almost certain, as he would have used all available sources for his own commentaries. While Barbaro made no mention of the camera obscura in his own commentaries on Vitruvius, he would have known that Cesariano had, and he
would have known Cesariano's quandary in interpreting the word "spectacle." However, the similarity in English between "spectacle" (i.e. show) and "spectacles" (i.e. glasses) does not exist in Latin or Italian. Barbaro had used the Italian word "occhiale" for the spectacles of old men. Cesariano had used the word "spectaculum" for the aperture or sight. Barbaro, on the other hand, implied a spectacle of nature, that is "how nature shows the various aspects of things." For Cesariano, the experience showed the "colours and forms," for Barbaro it was the "colors and shadows." Another link may be found in the similarity between Barbaro's phrase "a most beautiful experiment concerning perspective" and Cesariano's statement "a beautiful law of optic." Cesariano had used "optica" rather than the traditional Latin work "perspectiva," but Barbaro, who had studied optics at the University, would have known the word he used, 'perspective," had a double meaning.

Barbaro also knew of and had cited Cardano's De Subtilitate in his 1567 edition of Vitruvius. From Cardano came the idea of the lens, although Barbaro improvised and used a lens from eye glasses, which indeed could have been construed as an "orb of glass." As Cardano's description is so brief, it is difficult to find similarities in a work
that Barbaro definitely knew. It is significant, however, that none of these three writers mentioned that the image was upside down. Della Porta had been so aware of the inverted image that he employed a mirror to correct it. If Barbaro had mentioned of Della Porta's description, certainly he would have known of Della Porta's work. However, the similarity in phrasing between the two descriptions of the image, Della Porta citing "the faces, the gestures and movements of the passerby, the blue sky and flying birds," and Barbaro mentioning "the variations, colours, shadows, movements of the passerby, the blue sky and flying birds," makes it difficult to totally discount the idea that Della Porta's work was unknown to Barbaro. Barbaro seems to have just filled in Della Porta's list a bit more, adding something close to home, i.e., the rippling water of Venice. While Cesariano had hinted that the camera would be excellent for artists, he had failed to state how it might be used. Della Porta, on the other hand, had clearly explained its use for drawing and could have served as a source for Barbaro. Della Porta's book had already undergone several printings by this time, and it is hard to believe that Barbaro did not know of it. Yet, if he did
know it, he ignored the problem of the inverted image.

So where did Barbaro get the idea of the diaphragm? Most probably, Barbaro accidently happened upon this. Having had university training in optics, Barbaro was acquainted with the traditional optical literature, and knew about image formation through apertures. Misreading Cardano, who implied that the "orbem e vitro" went outside and projected the images through the aperture, Barbaro could well have understood that the aperture referred to was the traditional small one, not the opening for the lens. It would be quite natural to give the camera obscura "glasses," that is to add a lens to the aperture, rather than to replace the pinhole "optic" with a glass lens. We will see in Della Porta's second edition that he did just that, added the lens to the already existing aperture.

By 1585, the camera obscura equipped with both lens and mirror was apparently fairly well known in Italy. In a book of physical observations and mathematical data, Diversum Speculationum Mathematicum et Physicum Liber, published in Turin that same year, Giovanni Battista Benedetti, the author, included a letter he had written to Pirro de Arzonis. In the course of the letter, Benedetti had discussed how a bright light can "extinguish" a less intense light, and had used as a proof of this the camera
obscura. The images projected through a round aperture are obliterated when the sun light is permitted at the same time to enter the darkened room. In other words, the image is still projected, but when one of the windows is opened and the ambient light enters, its intensity cancels out the lesser light of the projected image.

Benedetti continued as an aside to tell his friend about a wonderful improvement to the camera obscura, the use of a bi-convex spectacle lens in the opening, but not the type for shortsighted persons. The images will be projected onto the paper at the proper distance, and "nothing more beautiful can be seen, though they are reversed" ("ut nihil pulchrior delectabiliusque viserit, poterit inversa tamen" p. 270). The image can be corrected, he added, with any kind of mirror.

Four years after Benedetti's account, in 1589, Della Porta published his expanded second edition of Magia Naturalis Libri XX, filled with even more exciting bits of information the common man needed for his comfort, edification and entertainment. Della Porta's section on the camera was greatly expanded, drawing upon all the information that had been published on the camera since his first edition some 31 years before. Della Porta again included the description in the section on mirrors and
burning glasses, this time with an emphasis on how to make an "image hang in the air." The section on the camera incorporated much of the original version, but with some important changes and additions. His first modification, as seen in the 17th century English translation, was the addition of a diaphragm for which Della Porta uncharacteristically did not take credit:

To see all things in the dark, that are outwardly done in the Sun, with the colours of them.

You must shut all the Chamber windows, and it will do well to shut up all the holes besides, lest any light breaking in should spoil all. Onely make one hole, that shall be a hands breadth and length; above this fit a little leadened or brass Table, and glew it, so thick as paper; open a round hole in the middle of it, as great as your little finger...(Natural Magick, 1658, p. 363).

Rather than suggesting a conical opening this time, Della Porta instructed the reader to make a large hole, hand sized, over which is glued a thin metal sheet in which is a smaller aperture, finger sized. The large hole guaranteed that the light rays would not be blocked while the thin metal aperture would produce a sharper picture than the method he had originally proposed.

He continued with a description almost exactly as the first version. The image of those in the streets walking upside down and reversed would be seen on the paper or sheet opposite the aperture. The image could be made
clearer by moving the paper back and forth, although it will not be seem immediately, as the eyes must adjust to the dark. Then he revealed his secret, which originally had been the use of the concave mirror to correct the image:

...Now I will declare what I ever concealed till now, and thought to conceal continually. If you put a small lenticular Crystal glass to the hole, you shall presently see all things clearer, the countenances of men walking, the colours, and all things as if you stood by; you shall see them with so much pleasure, that those that see it can never enough admire it... *(Natural Magick, 1658, p. 363-364)*.

In this passage we can see the method that led to the diaphragm; first you make the aperture then you add a lens. This was what Barbaro had done, and his description was probably the source for Della Porta. The use of the diaphragm was not a conscious innovation as that of later opticians, who started with the lens, then added the diaphragm for optical resolution. As the idea of replacing the aperture in the camera with a lens caught on, the diaphragm was rarely used.

Della Porta described the image much the same as he had before, adding the mountains in the distance to the list of things seen. He also noted that "...in a small circle of paper (that is put over the hole) you shall see as it were an Epitomy of the whole world, and you will much rejoice to see it..." (p. 364). The "small circle of paper" referred
to the fact that with the lens the image of the scene was formed in a circle of light. Della Porta then reiterated his suggestion for using the camera as a drawing tool. However, while Della Porta repeated the phrase "for anyone ignorant of the art of painting," the 1658 English edition made the suggestion more palatable:

If you cannot draw a Picture of a man or anything else, draw it by this means;

If you can but onely make the colours. This is an Art worth learning. Let the sun beat upon the window, and there about the hole, let there be pictures of men, that it may light upon them, but not upon the hole. Put a white paper against the hole, and you shall so long fit the men by the light, bringing them neer, or setting them further, until the Sun cast a perfect representation upon the Table against it; one that is skill'd in painting, must lay on colours where they are in the Table, and shall describe the manner of the countenance; so the Image being removed, the Picture will remain on the Table, and the superficies it will be seen as an Image in a Glass. (Natural Magick, 1658, p. 364)

This description is more explicit than that in his first edition, although he had explained the need for putting the subject in the sun. In this second edition, however, Della Porta suggested moving the paper back and forth to find the best resolution of the image and using a table or support as one applied the colour and traced the outlines. When the drawing was complete, Della Porta remarked, its surface would look like a mirror reflecting the image. Of course, the convincing quality of this "mirror like image" depended
upon one's skill in painting.

Della Porta then introduced the matter of the concave mirror to correct the inverted image. This had been his big secret in the earlier version, and while that book had already been through a number of publications and was quite well known, Della Porta implied that its successful use was still relatively unknown. Many people had tried it, he said, but had not able to make it work. They probably had been unsuccessful because Della Porta's earlier description had not been clear or detailed enough. In the second edition Della Porta explained how to focus the light rays in the mirror and to project them onto a sheet of paper set at an angle above the aperture.

...Put against the hole a convex Glass [bi-convex lens]; from thence let the Image reflect on a Concave-glass [mirror]; let the Concave-glass be distant from the Centre, for it will make those Images right, that it receives turned, by reason of the distance of the Centre. So upon the hole and white paper, it will cast the Images of the Objects so clearly and plainly, that you will not wonder a little. But this I thought fit to let you understand, lest you fail in the work, that the Convex and Concave-glasses be proportionable circles: how you shall do this, will be here declared often (Natural Magick, 1658, p. 364).

Della Porta gave no illustrations of the camera obscura, but the figure below gives an idea of how he reflected the image off the curved surface of the concave mirror and onto the paper surface above the aperture.
Della Porta was almost apologetic for anyone's earlier failure and explained that to be successful, both the mirror and the lens must have similar focal lengths ("proportionable circles"). Like Leonardo, Della Porta promised an explanation of this elsewhere ("will be here declared often"), but he did not discuss it in the section on the camera obscura.

As this section of Della Porta's book is filled with advice on how to thrill and frighten your friends and neighbors, he drew upon his dramatic skills as a playwright in describing how to create scenes and events for the camera obscura:

*How in a Chamber you may see Hunting, Battles of Enemies, and other delusions.*

Now for a conclusion I will add that, then which nothing can be more pleasant for great men, and Scholars, and ingenious persons to behold; That in a dark Chamber by white sheets objected, one may see as clearly and perspicuously, as if they
were before his eyes, Huntings, Banquets, Armies of Enemies, plays, and all things else that one desireth. Let there be over against that Chamber, where you desire to represent these things, some spacious Plain, where the Sun can freely shine: Upon that you shall set Trees in Order, also Woods, Mountains, Rivers, and Animals, that are really so, or made by Art, of Wood, or some other matter. You must frame little children in them, as we use to bring them in when Comedies are Acted; and you must counterfeit Stags, Bores, Rhinocerets, Elephants, Lions, and what other creatures you please: Then by degrees they must appear, as coming out of their dens, upon the Plain: The Hunter must come with his hunting Pole, Nets, Arrows and other necessaries, that may represent hunting: Let there be Horns, Cornets, Trumpets sounded: Those that are in the Chamber shall see Trees, Animals, Hunters Faces, and all the rest so plainly, they cannot tell whether they be true or delusions: Swords drawn will glitter in at the hole, that they will make people almost afraid. I have often shewed this kind of Spectacle to my friends, who much admired it, and took pleasure to see such a deceit; and I could hardly by natural reasons, and reasons from the Opticks remove them from their opinion, when I had discovered [revealed] the secret (Natural Magick, 1658, pp. 364-365).

This spectacle was not wasted on the common man; Della Porta made it known that he delighted in fooling educated, distinguished individuals, not only to entertain them, but to frighten them and confound them with the phenomenon. Even after he revealed how the image was formed and the optical reasoning behind it, it was difficult to convince these observers that the spectacle was not occult magic, but derived from the laws of nature. It was this very point which had brought him under scrutiny by the
Inquisition.

Lest the reader lack creativity, Della Porta provided a script and listed all the props needed. He failed to explain how one went about getting or making such exotic things as mountains, trees and rivers, or elephants and rinocerets. In the next chapter, Della Porta returned to this same theme of creating with the camera obscura fantastic scenes and plays to terrify the audience. This time he suggested waiting until a very stormy night, then projecting through the lens and onto a sheet in the dark chamber a frightening torchlit scene located in the adjacent room. Leonardo had created a similarly frightful event of a dragon painted on a shield and lit in a darken room.

Della Porta also repeated his analogy of the eye and the camera:

From this it may be clear to philosophers and students of optics where vision is effected; and if the question of intromission discussed for so long is broken off, both can be demonstrated by no other device. The image is sent in through the pupil, as by the opening in the window, and the part of the crystalline sphere located in the middle of the eye takes place of the screen; something that I know will greatly delight ingenious people. It is described more fully in our optics (Quoted in Crombie, 1967, p. 46).

The analogy is more fully developed in this statement. Della Porta did not see the retina and the mirror or screen...
as being similar, but rather, like Leonardo, believed that the image was in the crystalline sphere. Unlike Leonardo, however, Della Porta did not discuss the problem of the inverted image in the eye. He also referred to "our opticks" where this matter is discussed, presumably in more detail. The work he cited was eventually published as *De Refractione* in 1593. This work was an attempt to explain refraction in all of its aspects, from general ramifications, refraction in glass spheres (i.e. lenses), refraction in the visual process and finally refraction in eye glasses and meteorological phenomena. In Book IV Propositions I-II (pp. 87-95) Della Porta discussed the camera obscura as an analogy of the human eye. According to Lindberg (1976), however, Della Porta did not derive any new insight into understanding the visual process; he merely made the analogy again and added nothing new to his comments in *Magia Naturalis*. On page 91 of the *De Refractione* Della Porta stated:

I say that just as light [passing] through the narrow opening of a window portrays bodies illuminated by the sun on paper placed opposite, so also does it, proceeding through the aperture of the pupil, portray the images of things seen on the crystalline [humor] (Quoted in Lindberg, 1976, p. 186).

Della Porta never compared the crystalline sphere to the lens behind the aperture forming the image on the curved
retina, nor did he see the retina comparable to the concave mirror.

In 1583, just six years before Della Porta's enlarged version of *Magia Naturalis*, Egnatio Dante had published his *Le Due Regole della Prospectiva Practica di G. B. Vignola* in Rome. Dante was the Vatican astronomer and cartographer, who, as mentioned earlier, had used a camera obscura to prepare the Gregorian calendar. Dante, who had been entrusted with Vignola's perspective treatise after the architect's death, published a commentary on Vignola's two perspective rules, one a variation of Alberti's "construzione legittima," and the other derived from Viator's treatise *De Artificialis Perspectiva*. Dante, however, was far more interested in optics than in the artist's problems of perspective, and he included in his commentary a long discussion on vision and the human eye. Dante drew from the traditional optical sources in this section, but perhaps knew of Della Porta's analogy of the eye and camera in the 1558 edition. Dante also made this comparison, stating that the rays "which arrive at the eye or at a mirror or wall must impress an image of the object that it is carrying" (Wheelock, 1977, p. 153), and Dante's mention of the mirror recalls Della Porta's earlier version. In this case, Della Porta is probably a source
for Dante even though Dante's work was published shortly before Della Porta's second edition of *Magia Naturalis*.

In the 1589 edition, Della Porta concluded the chapter on the *camera obscura* with short discussion on using the *camera* for observing an eclipse:

**How you may see the Sun Eclipsed.**

Now I have determined to shew how the Suns Eclipse may be seen. When the Sun is Eclipsed, shut your chamber windows, and put the paper before the hole, and you shall see the Sun: let it fall upon the paper opposite from a concave glass, and make a circle of the same magnitude; do so at the beginning, middle, and end of it. Thus you may without any hurt to the eyes, observe the points of the diameters of the Suns Eclipse (*Natural Magick*, 1658, p. 365).

Della Porta had made no mention in his earlier edition of using the *camera obscura* to observe an eclipse, although several contemporary astronomical works had been published prior to 1558, which included the *camera* as observational tool (below). However, it was quite unusual to find any mention of lens or mirror in connection with the astronomical *camera*.

In 1573, Egnatio Dante had also published *La Prospectiva di Euclide* where he had mentioned an eclipse in a section on Catoptrics (mirrors). The direct application of the mirror to the *camera*, however, was described in projecting a scene outside into the darkened room. Dante even included a geometrical diagram of the optical
principle. He then mentioned another experience of the camera, that of the solar image being cast through the aperture in the roof of the Duomo in Florence, Santa Maria de Fiore, and projecting its image on the pavement below. Dante made no direct reference, however, to the mirror in the solar camera, and again, rather than Dante being a source for Della Porta, Della Porta's first edition was probably the inspiration for Dante's "wonderful experience."

Della Porta apparently incorporated information from other astronomical works which referred specifically to making solar measurements during the eclipse, for he mentioned observing the "points of the diameter." He gave directions for reflecting the image onto a sheet of paper and then tracing the shape and size onto the paper surface ("make a circle of the same magnitude"). His description did not include a lens, and could well have been included in his first edition. However, serious astronomers using the camera to make mathematical measurements would have ignored Della Porta's suggestion of using a mirror. His suggestion of tracing the solar image, however, was something astronomers already did quite frequently, and it is not surprising to think that astronomers had been using the camera obscura as a drawing tool long before it use was recommended to artists.
An implication that astronomers made drawings of the solar image with the camera is found in Reinerus Gemma Frisius' *De radio astronomico et geometrico liber*, published in Antwerp in 1545. Gemma Frisius referred to a work which had been published three years earlier, Erasmus Reinhold's edition of George Peurbach's *Theorica novae planetarum*. Reinhold, a student of George Peurbach, had included in Peurbach's original text, a description of using the camera for making astronomical measurements during the eclipse.

His comments were similar to those in Roger Bacon's *Speculum astronomiae*, for Reinhold implied that an aperture of any shape would suffice. In fact, he tried to make the construction of the camera as simple as possible:

In the same way also, the quantities, respective paths [of the sun and moon], the [times of the] beginnings and ends of eclipses of the sun could be observed without any damage to the eyes since you do not even look at the heavens...Lest I detain you longer, it is done in this way. At the time when by computation a solar eclipse is expected, either go up under the beams of an old building, go into a less humble place, or go under any structure or roofing or boards that your please, which to the degree [the boards are higher], will be more suited for this undertaking. Finally, in that place in which you will make the observation exclude as much outside light as you can. Although you will have shut and sealed all openings, there will easily remain a chink or aperture of some shape or other into which the solar rays will be able to fall. But if not, make a small aperture open to the impinging rays. Having done this, if you look at the light of the sun falling on an area of the floor or on a surface opposite the aperture, you
will see, mirabile dictu, it represents [there] straightforwardly an image [effigiem] of the sun, and whatever the size of the piece missing from the bright circle [on the floor or tablet], so much has the moon itself interceded [between us and the sun as seen] from our viewing place. Wherefore, if you divide the diameter of the bright circle into 12 digits, as they are called, all those remaing skilful (sic) things which I mentioned earlier will be set down before your very eyes. But an ingenious observer will from this brief recommendation discern much more, reveal much more, and so forth (Quoted in Straker, 1971, pp. 311-312).

We see from this passage that in astronomy the camera obscura had changed very little since the 13th and 14th centuries. Reinhold certainly was unaware of Levi Ben Gerson who had demonstrated that the size and shape of the aperture had a relationship to the projected image. Nor did Reinhold comment that the eclipsed image was both reversed and inverted. However, Gemma Frisius in his reference to the camera recognized that the aperture needed to be both round and small, and noted the reversal of the image which was a demonstration of optical theory. In Chapter 19 (p. 31) Gemma Frisius gave "another way" for observing the solar eclipse, one he considered "the easiest and most certain of all:

Erasmus Reinhold recommended it to us in his 'Commentaries' on Peurbach's Theoricae. All the openings and windows having been closed, the ray of the sun is admitted inside some room through a narrow round aperture, and the ray is received on a flat tablet. There certainly the degree to which the sun is eclipsed can be seen exactly
without any visual difficulty as perfectly as if you were present in the heavens yourself. If anyone, therefore, first noted on the tablet with a pencil the shape of the sun and marked the diameter of the sun ([which is the same] either before or after the eclipse received on the same tablet equally distant from the aperture through which the ray is admitted) and therefore had divided that very diameter into 12 equal parts with a compass, then you will see how many 12th of the sun are eclipsed. But it is generally necessary to recognize that the eclipse appears on the tablet by means of the solar rays opposite to the way it occurs in the heavens. That is, if in the sky the upper part of the sun suffers the eclipse, in the rays it will appear to be eclipsed from below, as optical theory insists.

Thus we observed a solar eclipse exactly, at Louvain in 1544, and we discovered it to be slightly more than 5/6ths, that is [slightly more than 10 units or 'digits,' as they are called]...By this method, therefore, observations of the sun, moon, and even the motion of other stars and the longitudinal positions can be set down correctly (Quoted in Straker, 1971, pp. 315-316).

Gemma Frisius made no mention of the inaccuracies in Reinhold's description; instead he gave a more accurate account of the camera required for precise observation and measurements. As Reinhold had before him, Gemma explained how to find that fraction of the sun which is eclipsed. This statement indicates that the majority of eclipses observed were partial ones, as a total eclipse was just as infrequent then as it is today. However, Gemma stated that the effect of the eclipse could be seen so perfectly this way, that it is almost as if you were "in the heavens yourself." Apparently, the event was so astonishing that
it was easy to forget what you were doing, for Gemma told
the reader if anyone forgets to make the measure of the sun
before the eclipse, you can still do it afterward,
providing that the focal length of the image is the same as
it had been at the outset of the eclipse. Gemma
mentioned marking with a pencil the diameter of the sun, an
indication that astronomers did use the camera as a kind of
drawing tool for making visual records as part of their
scientific observation and mathematical measuring.

Gemma then stated that he had used this very method to
observe an eclipse at Louvain in 1544, and he included an
illustration with a caption which further documents the
event as having taken place on January 24 of that year.
This illustration is the first published representation
that attempts a literal visual description of the camera
phenomenon (Plate III). The illustration shows a
Renaissance building in proper perspective, complete with
the grid floor, which has the partially eclipsed image of
the sun being projected through a small round hole in the
wall and forming an inverted image on the wall opposite.
The face of the moon which is personified as well as darker
and smaller that the sun also is inverted in the image, and
we see the "horned" or "boatshaped" crescent image refered
to in traditional astronomical literature.
PLATE III

Sec. Decemvirum Anno Christi
1544. Die 24: Januarj

Lenanij
One final work, Francesco Maurolico's *Phototismi de Lumine et Umbra*, written during the middle of the 16th century but published posthumously in 1611, was an optical analysis of image formation through point apertures, non-circular apertures, and lenses. In Book I Theorem 22 and Corollaries, Maurolico proved with the aid of geometrical diagrams why the image of any light source can be formed in any shaped aperture:

![Diagram](image)

**Figure 31**

Furthermore let there be any source of light AB and an aperture CD of any form whatever; suppose the rays ADE and BCF to be produced as far as the plane EF and to intersect at the point G; likewise ACH and BDK. Then FCH and KDE may be considered as pyramids of light, having their vertices at C and D, and their bases in PH and KE respectively. Thus it happens that, if the plane FE is placed parallel to AB, both the bases, PH and KE, appear similar to the source AB, because of the similarity of the pyramids.
Since now the angles FCH and KDE are larger than the angles FBK and HAE, it happens that when the rays are produced to the length of the bases FH and KE do not increase proportionally with FK and HE; for if the rays are produced still farther, the ratio of the lengths FH and KE to those of FK and HE increases. When the rays are produced, it is therefore entirely possible for the spaces FK and HE to become negligible in comparison with FH and KE. Evidently the lengths FK and HE are the distances apart of the bases FH and KE of the pyramids which have the shape of the light source, AB. Therefore, it follows that, in proportion as the rays are produced, the bases FH and KE will acquire similarity to one another and to the light-source AB, since FH and KE are figures similarly situated. And by a preceding Corollary [Theorem XXI] these produced rays make it possible that both figures, FH and KE, may be thought of as one. This phenomenon will be all the more marked as the aperture CD becomes smaller in comparison with the source AB. So also in proportion as the source AB recedes from the aperture will FK and HE become smaller in comparison with FH and KE. Similarly we may show that the shape FE which is the largest, built up from the Pyramid FGE, and the others without number built up from an infinitude of pyramids step by step come together and fuse into a form similar to the Source AB, until they acquire a shape almost identical with it (Crew, 1940, pp. 28-29).

In other words, when the distance between the aperture and the image plane is relatively close, the two lines FK and HE will be formed, taking on the shape of the aperture, but as the focal length is increased, FH and KE begin to merge and FK and HE disappear.

Maurolico's solution was probably not known even in Italy before it was published. In the introductory notes of the published edition, the printer, Tarquinus Longus,
remarked that while there were manuscripts in existence, these were rare and often error-filled (Crew, 1940). There is no evidence, however, that Maurolico's solution was known to subsequent writers. In the early 17th century, Kepler, in solving this problem of cameraformed images, made no mention of Maurolico in his survey of the literature on the camera obscura.
REFERENCES


Neo-Platonic Hermeticism of the late 15th century continued into the 17th century with marked influence (Kearney, 1971). This was particularly true in astronomy where the Copernican heliocentric system of the universe continued to spark great controversy with the Aristotelian dominated church. Copernicus had first circulated his theory about 1530 in hand written copies to his friends. The first printed account appeared in 1540 and was written by a student of Copernicus, George Rheticus; Copernicus finally published his own account in 1543 (Mason, 1976). The theory, however, was slow to be accepted, in part because it refuted church teachings, both Catholic and Protestant, and in part because there seemed no way to prove it. Astronomers such as Tycho Brahe regarded the Copernican view as absurd since it stated that the earth was a heavenly body spinning on its axis and rotating around the sun in a circular path. Others who supported the notion, such as Michael Mastlin at the University of Tubingen, were obliged to teach the strongly established
Ptolemaic view that the sun moved around the earth (Baumgardt, 1951).

Tycho had devised a variety of instruments, including a modified pinhole diopter (Plate IV), which permitted astronomical observations with an accuracy that had not until then been attained by the naked eye. He amassed a private collection of data which was an outgrowth of his obsession with astrology, believing as he did that "more accurate knowledge of the stars led to more accurate horoscopes" (Kearney, 1971, p. 130).

Mastlin also used the traditional astronomical camera obscura for observations. In July of 1590, Mastlin led his students high up under the cathedral's roof to demonstrate how to observe and record a solar eclipse. Through a small aperture in the roof, Mastlin let the image fall onto a tablet below and calculated the diameters of the sun and moon. One of Mastlin's students that day was Johannes Kepler who recorded the results (Straker, 1971). Kepler, who had prepared himself in theology and hoped to be an orthodox Lutheran minister, was appointed professor of Mathematics at Graz in 1594. In addition to his lectures there, Kepler was expected to publish calendars with astrological forecasts, and as a result he adopted the Catholic Gregorian calendar introduced in 1582. Needless
to say, this action won him no support from his Protestant superiors (Baumgardt, 1951).

During this time, Kepler wrote his first book, *Mysterium cosmographicum*, a strange work blending geometry and mysticism together in attempt to explain why there were only six planets (including the earth) in the Copernican system, and how these planets corresponded to the five perfect solids of Euclid (Kearney, 1971). He also maintained a steady correspondence with Mastlin, and wrote to Galileo, sending him a copy of this first book. Kepler also asked Galileo to make some specific astronomical observations for him over the course of a year as Kepler lacked the quadrant he needed to make them himself (Baumgradt, 1951).

While Kepler's book was criticized for its Copernican sympathies, it impressed a number of leading men of the day for its mathematical inventiveness. One who was impressed was Tycho Brahe, and in 1600 Kepler began an assistantship with Tycho. However, the time spent with Tycho was frustrating for Kepler; Tycho was secretive with his data and unwilling to share it freely with Kepler. At one point, Kepler wrote Mastlin:

Tycho is very stingy as to communicating his [astronomical] observations. But I am allowed to use them daily. If I could only copy them quickly enough! I must, however, be content with
making selections from them and ask you to tell me what, in your opinion, is mainly to be noted and selected...If you should send him [Tycho] some of your observations, he would, I think, send some to you, too, if you ask. For in spite of all the instability of his character, he is, after all, a man of great benevolence. All [his observations] are accessible to me but first I had to promise solemnly to keep them secret. I have complied with this as far as it befits a philosopher (Quoted in Baumgradt, 1951, pp. 64-65).

Kepler spent the first five months of 1600 in Prague with Tycho; by June he was back in Graz, making preparations to observe a partial solar eclipse. By August he was expelled from Graz in a purge of Protestants. In October he was back in Prague, this time with his family, again as Tycho's assistant.

Prior to going to Prague, Kepler had compared his data with Tycho's for an eclipse of 1599. Tycho's data showed that the moon "retreated," as Tycho said, or got smaller during an eclipse. While in Prague the first time, Kepler realized that Tycho's method of solar observation was different from his own or Mastlin's. While Tycho took into consideration the size of the aperture (Kepler did not) in addition to the focal distance and image size, he failed to recognize the ratio of aperture size to the focal distance. Tycho had never observed a total solar eclipse, yet his data seemed more accurate than Kepler's. Kepler, however, could not discover the cause of Tycho's "enigma,"
which caused the moon to appear smaller during an eclipse. Kepler began to question Tycho's method of observation. (Straker, 1971)

Kepler went back to Graz during the summer to make preparations for observing an eclipse, this time using Tycho's method. Kepler constructed a portable dioptral camera obscura which he used several days prior to the eclipse for solar observation (Plate V). This large wooden diopter, with sturdy base, pivoting rule and two pinnules was set outside in the market place and covered with heavy black cloth. The sun entered the aperture in the thin metal upper pinnule and projected the image onto a white tablet attached to the sliding bottom pinnule. Of the device Kepler remarked:

...And the apparatus which I had set up did not provide as much darkness as I would have liked so that I was not able to delineate the extremities of the rays accurately (Quoted in Straker, 1971, p. 380).

Using this instrument with Tycho's method of calculation, Kepler confirmed Tycho's "enigma," and his observations showed that the moon diminished in size during the eclipse. Kepler realized that the moon appeared smaller only on the screen; when viewed by direct observation, the moon did not appear to be diminished. He concluded that the problem was an optical one, and he turned to the
"perspectivi" of Witelo, Alhazen, and Pecham for help. His frustration with the obscure 13th century reasoning and the flat geometric diagrams is understandable. As he explained later in his book *Ad Vitellionem Paralipomena*, quibis *astronomia pars optica traditur* ("Additions to Witello in which the optical part of Astronomy is given") of 1604, Kepler needed a three dimensional way to visualize image formation in the *camera obscura*. The demonstration Kepler chose derived from Durer's perspective experiment of drawing a lute:

...since I could not comprehend the obscure sense of the words [of the opticians] from the diagram on the page, I had recourse to a personal observation in three dimensions. I placed a book on high to take the place of the shining body. Between it and the floor I set a tablet having a many-cornered aperture. Next, a thread was sent down from one corner of the book through the aperture and onto the floor; it fell on the floor in such a way that it grazed the edges of the aperture; I traced the path produced and by this method created a figure on the floor similar to the aperture. Likewise, by means of a thread attached from another, a third, a fourth corner of the book, and finally to an indefinite number [of points] along the edge, there resulted on the ground an indefinite number of traced figures [having the shape] of the aperture, which together produced a great and four-cornered [figure having the] shape of the book. And so it became possible for solving the problem to bring in circularity, not the rays of vision, but the sun itself; not because the circle is the most perfect figure, but because it is the figure of the shining body (Quoted in Straker, 1971, p. 390).
From this first insight during the summer of 1600, Kepler went on to develop an accurate theory of image formation, as well as theories of light and color, reflection and refraction, and vision. These made up a significant part of his *Ad Vitellionem Paralipomena*. Also included were a history of the theories of image formation, specific information on the astronomical *camera obscura*, an illustration of Kepler's portable dioptral *camera*, and the recommendation to use his corrected method for observation of the 1605 eclipse. Kepler used this new method in 1605 and in the same year published his results of the eclipse data.

In 1601, Tycho died, leaving all of his data to Kepler. Kepler then replaced Tycho as "Mathematicus" in the Court of Rudolph II. Using Tycho's data to substantiate his own work on the motion of Mars, Kepler developed two radical innovations which he published in his *Astronomia Nova* (1609): that the planets traveled in elliptical orbits (rather than in the Copernican circular ones) around the sun, and that the velocity of these orbits was not uniform (Kearney, 1971). Later, he published a third law in his *Harmonice Mundi* (1619) which stated "that there is a constant ratio between the square of the planetary period of revolution and the cube of the planets'
mean distance from the sun" (Kearney, 1971, p. 138). While these works had little immediate influence on his contemporaries, it is these laws which have subsequently overshadowed Kepler’s significance for astronomical optics and the camera obscura.

Kepler’s *Ad Vitellionem Paralipomena* was, in a sense, the last great treatise of the western medieval optical tradition of rectilinear propagation. Having established both an accurate theory and method, Kepler’s work became the basis for future studies where light does deviate from a rectilinear path, as in Grimaldi’s work on diffraction in 1665. However, Kepler’s method of solar observation was already becoming obsolete. In his *Ad Vitellionem Paralipomena*, Kepler had avoided any discussion of lenses with the camera obscura except in comparing the eye with a camera obscura using a glass globe. Kepler later recalled that his opinion of Della Porta had, in part, influenced any serious consideration of lenses:

> After I began to work on my 'Optics,' the Emperor questioned me frequently about della Porta’s...devices written of above [tubes containing lenses]. I must confess that I disparaged them most vigorously, and no wonder, for he obviously mixes up the incredible with the probable. And tht title of Chapter 11 [of the *Magia Naturalis*] ('To Extend Vision to Unimaginable Distances') seemed to involve an optical absurdity; as though vision took place by a process of emanation, and lenses sharpened the ejaculations of the eye so that they would travel
farther than if no lenses were employed; or if vision takes place by a process of reception, as della Porta acknowledges, as though in that case lenses supplied or increased the light to make things visible. Rather it is true that no lens can ever detect objects which do not of themselves impart to our eyes some degree of light...

For these reasons, reinforced by other obstacles besides, I refrained from attempting to construct the device...

[Johannes Pistorius] steadfastly declared that someday somebody would come along who would devise a more exact procedure [than Tycho's] with the help of lenses [for astronomical observations]. I objected on the ground that their refractive qualities made lenses unsuitable for reliable observations. But now I see that Pistorius was in part a true prophet (Rosen, 1965, pp. 18-19, 21).

What changed Kepler's mind was the publication in 1610 of Galileo's little book *Sidereus Nuncius*. While visiting Venice in July 1609, Galileo had heard from friends about a "Dutch Tube" which a Frenchman had bought as a novelty; the year before Hans Lippershey of Middleburg had applied for a patent for just such a device. Galileo rushed back to Florence without having seen the "spyglass" and worked out several versions of his own based on his understanding of lenses—that convex lenses make objects larger but blurred, while convex lenses reduce the object but are sharp. Using a convex lens for the objective and a concave lens for the eye piece, Galileo produced a telescope that gave an erect image with a magnification of about eight times. He took this to Venice in August, but by November he had fabricated
a telescope that magnified twenty times, and by January 1610, he had produced his finest instrument which magnified thirty times. In March Galileo published the first report of his observations made over that four month period (Hall, 1983).

Kepler immediately published his Dissertatio cum Nuncio Sidero, an enthusiastic support of Galileo's treatise, and was just as quickly chided by his friends for being so effusive in his comments. In August, Kepler wrote to Galileo, asking to see his telescope:

I have received your observations on the Medicean stars from the Ambassador of his Highness the Grand Duke of Tuscany. You have aroused in me a passionate desire to see your instruments, so that I at last, like you might enjoy the great performance of the sky. Of the oculars which we have here the best has a tenfold enlargement, the others hardly a threefold; the only one which I have gives a twentyfold enlargement, but the light is very weak. The reason for this is not unknown to me and I see how the intensity could be improved, but one hesitates to spend the money... (Quoted in Baumgardt, 1951, p. 84).

The last statement above was no indication that Kepler was a tight-wad. In fact he spent much of his career trying to collect from the Court of Ruldoph the 11,817 gulden owed him in back salary.

Kepler undertook an intensive investigation of the optical workings of the telescope, and by September he had completed a treatise on theoretical optics entitled
Dioptrice. This work, a supplement to his Ad Vitellionem Paralipomena, is a thorough study of lenses which continued his study of human vision, introduced telescopic lenses to the dioptral camera, and presented innovative lens combinations for maximum telescopic effect. The discussion of the camera obscura included for the first time that specific term, and showed a diagram of the rays passing through a convex lens (Figure 32):

**XLIII PROBLEM.**
To paint visible objects on a white wall with a convex lens.
Let a convex lens block the single opening in a dark chamber [camera obscura]. A sheet of paper is placed at the focus [of the lens]. Now by all its rays which radiate onto the lens, a single point of the visible thing is collected again into a single point. Visible objects actually consist of infinitely many points. Therefore, infinitely many such points are painted on the paper, that is, the entire surface of the visible object [is depicted there].

**XLIV PROPOSITION.**
The picture formed by the lens is inverted.
For the lens is the base on which two cones rest; the vertex of the one is in a point of the visible object, the vertex of the other in a point of the picture on the paper.

**XLV DEFINITION.**
For the sake of instruction, we shall call such a pair [of cones] a 'pencil.' For truly all pencils of all points come together on the lens just as in the common base of the cones, and passing through the lens, diverge again and are sorted out into opposite regions...(Quoted in Straker, 1971, pp.475-76).
In Problem CV Kepler demonstrated how to depict the image through both a convex and then a concave lens, giving a brighter, sharper picture, although reversed (Figure 33). For telescopes Kepler recommended using three lenses.

Kepler's two works, *Ad Vitellionem Parlipomena* and *Dioptrice* would become the standard for astronomers through the rest of the 17th century. In 1611, the same year as Kepler's *Dioptrice*, Johannes Fabricius, perhaps the first to observe sunspots, published his *De Maculis Sole Observatis*. Fabricius and his father attempted to observe sunspots through a telescope, but soon realized it was too dangerous to the eyes. They reverted to the "old method" of projecting the image through an aperture in a darkened room in order to make their observations (Waterhouse, 1901).

In 1617 Christopher Scheiner published *Refractiones Coelestes*, a work in which he claimed to have observed sunspots in 1612 by projecting the image through a telescope and onto a tablet below. He illustrated his device and gave instructions on how to build what he called the Helioscope (Plate VI). The influence of Kepler's dioptral camera can be seen in the basic construction of Scheiner's model. In 1630, Scheiner published his *Rosa Ursina*, a massive and handsomely illustrated work on solar observations. He included three different illustrations of
Macula et facula ex uaris obseruandis modis stabiluntur.
PLATE IX

LIBER III.

Heliotropii Telescopici sua Telescopii Heliotropii figura sua
Machina Macularum Curius aequa ule pependicula aut suspensa
Elliptica ad verticalem Corolum inclinatione aequitur.
the helioscope in this work. The first illustration is similar to his 1617 version (Plate VII). In the second illustration (Plate VIII) we see a portable frame over the back of the telescope and the imaging screen. This could be covered with a dark cloth when the ambient light was too great for drawing the image on the screen. Thus, the instrument could be used at an open window or outside, although Scheiner did not mention using the device in the field. The third illustration showed an elaborate but more flexible stand which included a scale for measuring the angle of inclination. The telescope was covered with a rectangular tube (Plate IX).

Scheiner cited seven different ways to observe sun spots, remarking that the helioscope produced the most brilliant, surest and easiest result. He included a drawing of sunspots made with the helioscope (Plate X). Scheiner discussed the use of the more traditional camera obscura with an aperture and with a convex lens, and like Kepler, considered both the advantages and disadvantages of such arrangements. The problem with the convex lens, he noted, was the smallness of the image, unless a very large lens was used, and the difficulty in keeping the light rays perpendicular to the front and rear surfaces of the lens. As Kepler had done, Scheiner discussed the effects of
PLATE XI

Arte et Natura Tubi et Oculi in speciebus claribus, presentandis confederis. N. 3.


various lens types and lens combinations, but he included an illustration comparing the lenses to the eye (Plate XI). Other than mentioning the fact that the helioscope could be used for observing terrestrial objects as well, Scheiner added little to Kepler's discussion. However, Scheiner's work is an important indication that Kepler's work had some impact, and is more important for graphically illustrating points Kepler had already made. It was Scheiner's rather than Kepler's book which disseminated this information to subsequent writers, and we see an number of important astronomical works making use of the telescopic camera or helioscope.

On November 24, 1639, Jeremiah Horrocks used the telescopic camera to observe the transit of Venus across the sun. In 1647, the French astronomer Pierre Gassendi published his Instituto Astronomia, a work dealing with Copernican and Tychonian theories of the universe. Gassendi used an instrument similar to Scheiner's for observing not only sun spots, but also the transit of Mercury across the sun on November 11, 1631. Kepler had already published a similar account, Mercurius in Sole, in 1609, and in 1662 Johannes Helvelius published his version, Mercuris in Sole. While Kepler had used the dioptral camera for his observations, some fifty years later, Helvelius, a
PLATE XII

[Image of two people operating a large telescope and other astronomical equipment]
wealthy brewer in Danzig, made use of his very fine observatory (Plate XII). Earlier, Helvelius had discussed the problem of image formation and the principle of the camera obscura in his book Selenographia of 1647. With the exception of some interesting published illustrations, then, little innovation or change is found in the astronomical camera after 1630. The persistent use of the helioscope can be found as late as 1745, in Marinonius' De Astronomica Specola Domestica.

The invention of the telescope "proved almost at a stroke how inadequate all philosophical (and popular) accounts of the universe had been" (Hall, 1983, p. 124). Yet, the telescope was not without its difficulties. While its defects were less serious than those of the microscope during this century, image distortion and chromatic aberration in the telescope were problematic. Isaac Newton was led to his study of optics because of the imperfections in 17th century telescopes. He realized these imperfections were a result of the light being bent through the curved glass lens; in a beam of light emanating from a point source, not all of the rays which fall on the spherical surface of the lens will pass through the lens and form again at a point. Newton concluded that these defects could not be remedied in the standard telescope.
with a lens, the refracting telescope. In 1668 Newton
designed and built the first reflecting telescope which
used a concave mirror instead of a lens to concentrate the
light rays.

Newton's conclusion was challenged by David Gregory, a
17th century professor of Mathematics at Edinburgh.
Gregory, whose uncle had worked out a design for a
refracting telescope in 1663, argued that the human eye was
also a lens system, but that it did not suffer from
chromatic aberration. It should therefore be possible to
make achromatic lenses for the telescope, he reasoned.
However, it was not until the mid 18th century that these
achromatic or color corrected lenses were made.

Lenses had existed for a long time, and were part of
the trades and crafts tradition before scientists like
Kepler began to formulate the theories of what has become
modern scientific dioptrics. As part of this theoretical
investigation, Kepler was also the first to correctly
explain vision in the human eye, which he had expounded in
his Ad Vitellionem Paralipomena, and which was demonstrated
by the camera obscura. Kepler was compelled to tackle the
problem of vision because of the discrepancy between what
he saw during an eclipse and what was projected through the
aperture and onto the screen. He began a study of the
literature dealing with vision, both ancient and contemporary. On the basis of his demonstration of image formation in the *camera obscura*, Kepler discarded all but Felix Plater's *De Corporis humani structura et usu*, first published in 1583 and reprinted in 1603, which he compared with the *Anatomia Pragensis* by his friend Johannes Jessenius (Crombie, 1964). Plater had argued that the sensitive organ of the eye was not the crystalline humour (lens), as other anatomists including Jessenius believed, but that the retina was the sensitive organ while the crystalline humour acted inside the eye just as a spectacle lens acted outside the eye.

Kepler also discarded the metaphysical notion of pyramid or cone action of light that implied only certain rays, those perpendicular to a point on the source, could be formed on the screen. His demonstration had proved that all rays from one point formed an image. Discussing this same point in the *dioptrice*, he specifically used the term "pencilli" or "pencils" which in his day refered to the artist's pencil or brush (Straker, 1971). Finally, he concluded that these rays entered the pupil and were refracted by the crystalline humour which, acting as a lens, bent the rays to a single point again on the retina. The picture formed on the curved surface of the retina was
So that I may go on to treat this process of depiction [pingendi] and prepare for a demonstration of it, I say that this picture [picturam] consists of as many cones of equal size as there are points in the thing seen, in pairs always with the same base, namely the width of the lens (crystallinus) or part of it. Thus while one cone of each pair has its apex at the point seen and its base on the lens (nothing is altered by refraction through the cornea), the other has the same base on the lens as the first one and the apex at a point in the picture [picturae] depicted on the retina; this cone undergoes refraction on passing out of the lens. All the outer cones meet in the pupil, so that they intersect in that space, and right becomes left... (Quoted in Crombie, 1967, pp. 58-59).

Kepler clearly discarded the use of the word "image," choosing to stress how the picture is literally painted onto the retina by "pencils" of light. To demonstrate his point Kepler placed a glass sphere behind the aperture of the camera obscura and projected the inverted image onto the paper beyond. The demonstration with the glass globe is reminiscent of Leonardo, but Leonardo, Della Porta and others who had made a similar demonstration saw the globe either as the screen itself, or in the center of the eye reinverting the image correctly on its rear surface.

Kepler earlier had also tried to prove that the glass globe (crystalline humour) reinverted the image, but realized that this could not be:

And so I truly and dutifully tortured myself in order to show that the cones intersecting when
the pass through the aperture of the uvea intersect again behind behind the crystalline humour in the middle of the vitreous humour, so that another inversion is produced...And there was no end of this useless labor until I came upon Propositions 11 and 12 above, by which this opinion is plainly refuted (Quoted in Lindberg, 1976, p. 189).

The problem was, we do not perceive an inverted image. Kepler's response to the anticipated argument was that how the image is formed is an optical problem but how it is perceived by the brain is not, and therefore, not his to address:

I say that vision occurs when the image of the whole hemisphere of the world that is before the eye...is fixed on the reddish white concave surface of the retina. How the image or picture is composed by the visual spirits that reside in the retina and the [optic] nerve, and whether it is made to appear before the soul or the tribunal of the visual faculty by a spirit within the hollows of the brain, or whether the visual faculty, like a magistrate sent by the soul, goes forth from the administrative chamber of the brain into the optic nerve and the retina to meet this image, as though descending to a lower court--[all] this I leave to be disputed by the physicists. For the armament of opticians does not take them beyond this first opaque wall encountered within the eye (Quoted in Lindberg, 1976, p. 203).

Kepler again drew on the analogy of the camera obscura to defend his proof of an inverted retina image: "Nam ut pictura, ita visio" (As is the picture, so is vision) (Straker, 1971, p. 468), and reasoned:

...Therefore, if it were possible for that picture on the retina to remain after being taken
outside into the light, by removing the anterior portion [of the eye],...and if there were a man whose vision was sufficiently sharp, he would perceive the very shape of the hemisphere [i.e., the visual field] on the very narrow surface of the retina (Quoted in Lindberg, 1976, p. 200).

While Kepler was not the first to compare the camera obscura to the eye, he was in fact the first to explain the analogy correctly. Subsequent writers continued to repeat the camera/eye analogy. Some, like Scheiner and Descartes, expanded Kepler's ideas, but not all who came after Kepler accepted his theory of vision. Crombie (1967, p. 60) notes that Kepler's influence was felt almost immediately. In 1619, Christopher Scheiner in his book Oculis used the camera obscura to make a "model eye" complete with cornea, lens, curved retina, and two glass spheres duplicating the vitreous humour and the acqueous humour. Scheiner used this to study refraction of light through the lens and to reaffirm the formation of an inverted image on the retina. In his illustration of the eye, Scheiner showed a

![Figure 34](image-url)
lenticular lens (MN), placed in the front of the eye close to the pupil, the cornea (E), the optic nerve (O) entering to the side of the eye, and the central point of vision (D) on the retina directly behind the lens (Figure 34). In his *Rosa Ursina* of 1630, Scheiner, who took Kepler literally, described how in Rome during 1625 he carefully removed the backs of freshly dead animal eyes in order to observe the retinal image formation.

This experiment was repeated in 1636 in Daniel Schwenter's *Deliciae physio-mathematici*. Schwenter, a professor of mathematics and oriental languages at the University at Altdorf, used an ox eye to repeat Scheiner's experiment. Schwenter also constructed a "model eye" camera obscura which was a large wooden ball with a hole bored through the axis and a lens mounted at each end of the opening. The ball swivelled in specially designed frame that fit into the window shutter of a darkened room. The
ball, rotating in its "socket," greatly extended the view of the camera obscura (Figure 35). Variations on what became known as the "scioptric ball" were repeated into the 18th century. Caspar Schott, who wrote three different works that included discussions of the camera obscura, recorded similar ox eye experiments in his Magia universalis naturea et artis of 1657. Towards the end of the century, the telescope and scioptric ball had been combined for ease in solar observation, as Johannes Zahn illustrated in his 1685 Oculis artificialis teledioptricae sive telescopium (Plates XIII, XIV). In Plate XIV one can see how sophisticated the astronomical camera had become by the end of the 17th century. Telescopes of differing focal lengths could be used in the scioptric mount. A rod was attached to the mount in order to position the image from the floor and make certain that the light rays were truly perpendicular to the screen. The screen could be placed on an adjusting shelf and/or angled on a saw-tooth bracket which could be attached to the shelf. Images of longer focal length lenses could be projected through the inside "window" to the adjoining room.

While this mechanical eye was modified for astronomical purposes, theorists continued to debate human vision. In 1637, a year after Schwenter had first illustrated the
PLATE XIII

[Image of a medieval scene with sun rays and Latin text: "Macules chiam celo dedixit ab alto."]
scioptic ball, Rene Descartes published his *La Dioptrique*, where he, too, took up the problem of ocular dioptrics. Like Kepler and Scheiner, Descartes introduce his discussion of vision by comparing it with image formation in the *camera obscura*. Thirty-three years after Kepler's *Ad Vitellionem paralipomena*, Descartes illustrated Kepler's theory (Plate XV), stating:

Take the eye of a newly dead man or, failing that, an ox or some other large animal; carefully cut away the three enveloping membranes at the back, so as to expose a large part of the humour (M) without shedding any; then cover the hole with some white body, thin enough to let daylight through, for example a piece of paper or eggshell (RST). Now put this eye in the opening of a specially made window (Z), so that its front (BCD) faces a spot where there are a number of objects (V, X, Y) lit up by the sun, and the back, where the white body (RST) is, faces the inside of the room (P) you are in. No light must enter the room except through the eye, of which you know that all the parts from C to S are transparent. If you now look at the white body (RST), you will see, I dare say with surprise and pleasure, a picture representing in natural perspective all the objects outside (VXY), in due proportion to their distance. You must of course see that the eye keeps its natural shape, for if you squeeze it never so little more or less than you ought, the picture becomes less distinct. And it should be noticed that the eye must be squeezed a little more, and made proportionately a little longer, when the objects are very near than when they are farther away. Now when you have seen this picture in a dead animal's eye, and considered its causes, you cannot doubt that a quite similar picture is produced in a living man's eye...(Quoted in Crombie, 1967, p. 73)
Descartes reiterated Kepler's idea that rays form a "picture" of the retina; in the same year, Pierre Herigone in his Cursus Mathematici had also described vision as "the perception of the image of an object painted on the retina" (La vision est la perception de l'image de l'object, peinte en la retina" V, p. 9).

While the image may have been painted on the retina, Daniel Schwenter refused to believe that the picture was inverted. In the 1677 edition of his Deliciae physio-mathematici, Schwenter omitted the illustration of the scioptic ball, and instead illustrated his argument for a correctly seen image on the retina. He first illustrated a camera obscura where the image of a potted tree was projected through a hole in the wall (Figure 36).

Figure 36
At the point where the rays would form an inverted image on the screen, a large convex lens is placed to reinvert the image. A second large convex lens is placed between the first and the imaging screen to magnify and brighten the image.

Schwenter's diagram of the eye (Figure 37) shows the lens somewhat centrally located in the interior hemisphere. The light lays enter the pupil (MN) where they are inverted. The rays pass through the lens or crystalline humour (B) and are reinverted in the vitreous humour before forming a corrected image on the retina.

Figure 37
This concept of introducing one or more lenses behind the aperture is rather common in the 17th camera literature, and came probably indirectly from Kepler via Scheiner in their discussions on lens types and lens combinations, particularly with regard to the telescope. Having a "correctly oriented" image when one looked through lenses in tubes (telescopes) was, of course, a necessity. Placing a lens behind the aperture of the camera obscura, or using a second lens beyond the first, to reinvert the image would seem a logical advancement. In the 16th century, before the theory and technology of lenses were developed, a mirror was used to correct the image. In the 17th century literature, however, it becomes difficult to discern when the phrase "concave glass" refers to a mirror or a lens.

One of the earliest illustrations which showed the camera obscura with a second lens to correct the inverted image is found on the title page of Scheiner's Oculus of 1619 (Plated XVI). Four demonstrations of image formation were depicted within a craggy landscape. Two of these examples showed the inverted image while two showed the projected image corrected. In one example of the corrected image, in the upper right of the illustration, the correcting lens can clearly be seen. In the other example,
that of a church and campanile, the image is vertically corrected but laterally reversed. This second example could demonstrate image formation with a mirror, although no such device was apparent. Cryptic phrases referring to the relationship of the eye and vision to the hand appeared throughout the page. The illustration depicting the correcting lens was reproduced in a greatly modified form by Leurechon in his *Recreations Mathematiques* of 1626. This same figure reappeared in 1633, when William Oughtred, an amateur mathematician and inventor of the slide rule, published Leurechon's book in English, with his own additions (Figure 38). Unfortunately, Scheiner's handsome etching was reduced to what subsequent historians have interpreted as being a portable *camera obscura* (Waterhouse, 1910 and Hammond, 1981). The drawing apparently was copied onto the etching plate from Scheiner's book, as the picture
is reversed from left to right. Oughtred's translation, published under the pseudonym of Henry van Etten, was the first work in English that dealt with the camera obscura. The book was very cheaply printed with especially poor quality illustrations, but was, nevertheless, extremely popular. While the illustration derived from Scheiner, Leurechon's text was straight from Della Porta:

Problem II. How to represent to those which are in a chamber that which is without, or all that which passeth by.

This is one of the finest experiments in the Optiques, and it is done thus, chuse a Chamber or place which is toward the street, frequented with people, or which is against some faire flourishing object, that so it may be more delightfull and pleasant to the beholders, then make the Roome darke by shutting out the light, except a small hole of sixe pence broad, this done all the Images and species of the object which are without, will be seen with in: and you shall have pleasure to see it not onely upon the wall but especially upon a sheete of white paper or some white cloth hung nere the hole: and if unto the hole you place a round Glasse, that is, a Glasse which is thicker in the middle that at the edge: of such which old people use, for then the Images which before seeme dead, and of a darkish colour, will appear and be seene upon the paper, or white cloth, according to their naturall colours, yea more lively than their naturall; and the appearances will be so much the more beautifull, and perfect, by how much the hole is lesser, the day clear and the sun shining. It is pleasure to see the beautifull and goodly representation of the Heaveans, intermixed with clouds in the Horizon, upon a woody situation, the motion of Birds in the Aire, of Men and other Creatures upon the ground, the trembling of Plants, tops of Trees, and such like, for every thing will be seene within even
to the life, but inverted; notwithstanding this beautifull paint will so naturally represent it selfe in such a lively perspective, that hardly the most accurate Painter can represent the like. Now the reason why the Images and objects doe intersect one another in the hole: so that the species of the feete ascent these of the head descend.

But heere note, that they may be Represented right two manner of wayes; first with a concave glasse. Secondly, by helpe of another convex glasse; disposed or placed betwene the paper and the other Glasse; as may be seene here by the figure.

Now I will adde here onely by passing by, for such which affect painting, and portraiture, that this experiment may excellently helpe them, in the lively painting of things perspective wise, as Topographickal cards, etc. and for philosophers, it is a fine secret to explaine the organ of the sight, for the hollow of the eye is taken as the close Chamber, the balle of the Aple of the eye, for the hole of the Chamber, the Crystalline humor at the small for the glasse and the bottome of the eye, for the wall or leafe of Paper (Oughtred, 1633, pp.6-8).

Here we have the 16th century convex spectacle glass augmented with a diaphragm, Porta's and Barbaro's flowery description of the scene including the feet in the air (Della Porta's "antipods"), and the use of a concave glass, this time a mirror, to correct the inverted image. Even the description of the eye is pre-Keplerian. The only suggestion of 17th century innovation is the short reference to the illustration derived from Scheiner. Oughtred, in his "Examination" at the end of this passage, added little clarity to the matter. He first explained correctly, but somewhat obscurely, what Leurechon had
omitted in his explanation, that is, Kepler's notion that each point on the object reflects its rays not just to the one hole in the window, but in all directions:

It is false that the species being pressed together or contracted doth perform it upon a wall, for the species of anything doth represent it selfe not onely in one hole of a window, but in infinite holes; even unto the whole Spheare, or at least unto a Hemispheare (intellectual in a free medium) if the beames or reflections be not interposed, and by how much the hole is made less to give passage to the species, by so much the more lively are the images formed (Oughtred, 1633, p. 8).

After he explained that the smaller hole gives a sharper or "more lively" image, Oughtred discussed the problem with using lenses, that is, only one point on the focal plain is ever "focused," either the center or the edges. It is not clear whether he was suggesting that instead of the lens, the best results would be obtained by using a "pinhole" aperture made in thin brass. If this were the case, then Oughtred had in effect taken the camera obscura back to the thirteenth century! In all probability, however, he meant this pinhole aperture to be used as a diaphragm, as had been suggested earlier. He incorrectly recommended that the sun light should be on the hole instead of on the scene opposite, and suggested that lifelike drawings could be made in this manner. The problem with using a pinhole aperture instead of a lens, of
course, was that while the small aperture could produce better overall sharpness, the image was rather dim. A diaphragm this small would hardly be any better. Finally, Oughtred suggested using either another pinhole aperture (rather than a second lens) or a concave glass or mirror to correct the inverted image:

In convexe, or concave Glasses the Images will be disproportionable to the eye, by how much more concave, or convexe, and by how much the parts of the Image comes neare to the Axis, for these that are neare are better proportionated, that these which are farther off.

But to have them more lively, and true, according to the imaginairie conicall section, let the hole be no greater than a pins head made upon a peece of thinne Brasse, or such like, which hole represents the top of the Cone, and the Base thereof the terme of the species: this practice is best when the Sunne shines upon the hole, for the the objects which are opposite to that plaine, will make two like Cones, and will lively represent the things without, in a perfect inversed perspective, which drawne by the Pensell of some artificial Painter, turne the paper upside downe, and it will be direct, and so to the life.

But the apparences may be direct, if you place another hole opposite unto the former so that the spectator be under it; or let the species reflect upon a Concave Glasse, and let that Glasse reflect upon a paper, or some white thing (Oughtred, 1633, pp. 8-9).

As the first English description of the camera obscura, this passage left much to be desired. In 1630, Leurechon's book had been criticized by another French mathematician, Claude Mydorge, in his Examen du Livres des Recreations Mathematiques. Mydorge said that Leurechon had merely
compiled a lot of worn out information on optics, which was beneath a great mathematician (Wheelock, 1977). The English had to contend with the worn out information, for Oughtred's translation went through several additional printings, the second in 1653, and another in 1674. Della Porta's *Magia Naturalis* was published in English in 1658, and Scheiner's *Oculus* had a limited English edition in 1652.

Francis Bacon was the first Englishman to make mention of the the camera obscura. In his book, *Of The Advancement and Proficiencies of Learning, or the Partitions of Science* printed in London in 1640, Bacon set forth his philosophy of scientific knowledge and of things in nature. In the second chapter of Book V, Bacon discussed the nature and need for experiment, and gave the camera obscura as an example of what he called the "Inversion of Experiment":

Inversion of Experiment is when the contrary to that which is by Experiment manifest, is tried; for example, Heat by Glasses is intended, is cold so too? So Heat when it diffuseth it selfe is yet rather caried upward: is cold likewise in diffusing it selfe caried rather downwards?...So the Beams of the Sun rebound from a white, upon a black congregate; whether are shadows also dispersed upon white, and unite upon black? The experiment we see made in a dark room, the light being let in throw a narrow chinck only, where the Images of things are without, are taken upon white paper, not upon black (Bacon, 1640, pp. 232-33).

While Bacon was using the camera only as a demonstration to his argument, it is evident that he had only a primitive
concept of a device with a "narrow chinck." Bacon's reference here sheds no great insight into the phenomenon, but was repeated, this time as part of an actual experiment, by a follower of Bacon's, Robert Boyle. To Boyle, Robert Hooke, Christopher Wren, Henry Oldenburg and other members of the Royal Society, Bacon, through his writings, was the inspiration for scientific experimentation, even though Bacon himself actually did little in that area.

Boyle, a well-to-do physicist and chemist, with the help of Robert Hooke, designed and constructed wonderful pieces of equipment with which to carry out his experiments. His work in optics was not as involved as his studies on air and water pressure, vacuum, heat and circulation. His earlier writing which discuss the camera obscura reveal a rather cursory knowledge of the device. In 1663, Boyle compared the eye to the camera obscura in his treatise Some Considerations Touching the Usefulness of Experimental Natural Philosophy. Boyle discussed how to take the severed eye of a cat or a dead man, holding it up:

...at a convenient distance betwixt yours and a candle, you may see the image of a flame lively express upon that part of the back side of the eye at which the optick nerve enters the above mentioned Sclerotis. Something of this kind we have also shown our friends with the eyes of dead Men, carefully sever'd from their heads; and with the (dexterously taken out) cristalline
humor of a Human Eye, we have after read, as with a Lens or Magnifying glass... For having held some of these eyes at a convenient distance betwixt my eyes and the window, I found them to be transparent, that the rays proceeding from the Panes of Glass, Iron Bars, etc. of the window, passing through the cristalline humor, and in their passage refracted, did on the Retina exhibit an inverted posture, according to the Optical laws; the contracted, but lively Pictures of those external Objects... became visible through it to my attentive eyes: As in a darkened Room the shadows of objects without it project on a fine sheet of paper, may, by reason of the thinness of the Paper, be seen thorow it by those that stand behind it. By Candle light we could see little in the bottom of these eyes, but lucid objects, such as the flame of the Candle, which appear'd tremulous, though inverted, but by Daylight we could manifestly discern in them both the motions of very neighboring objects, and the more vivid of their colours (Boyle, 1663, pp. 95-97).

It is difficult to know what sources were available to Boyle, if in fact he was aware of Kepler or Scheiner directly. While both had discussed the camera as an astronomical tool, Boyle may not have had any direct knowledge of them, for the following year, in his Experiments and Considerations Touching Colours, Boyle commented on a method he used to observe the sun:

... when the sun was veil'd over as it were, with a thin white cloud, and yet was too bright to be look'd upon directly without dazling, by casting my eyes upon a smooth water as we sometines do to observe eclipses without prejudice to our eyes, the sun then not far from the Meridian, appear'd to me not red, but so white, that 'twas not without some wonder, that I made the observation (Boyle, 1664, pp. 98-99)
The work in which this passage appeared was a rather systematic study of color, and much of it was conducted in a camera obscura, either in observing the colours of the images projected therein, or studying the effect of a sun beam through a prism, through a colored piece of glass, or onto different colors of paper. Much of this work proceeded Newton's experiments with a prism in the camera obscura, and he was well aware of Boyle's investigations. We can gather from Boyle's comments that he was aware of using a lens in the aperture, but the camera obscura remained for him a rather elementary device. However, in Boyle's hands the camera became a creative tool which he used to understand the additive and subtractive aspects of color.

In the following passage, after commenting on the colors of light formed by a prism, Boyle compared the perception of colors in a camera-formed image with those reflected in a concave mirror. When the "true colors" of the outside image are projected onto a surface, those colors mix with the color of the surface. Until Francis Bacon, that surface had always been a wall, or a white cloth or paper. If the wall were a color rather than white, the colors projected onto it would mix with the wall color. Boyle argued that we assume the colors on the wall
to be correct, whether they are or are not, because the wall is where the image is formed:

...consider what usually happens in Darkned Rooms, where a Wall or other Body conveniently Situated within, may so Reflect the Colours of Bodies, without the Room, that they may very clearly be Discern'd and Distinguish'd, and yet 'tis taken for granted, that the colours seen in a Darkned Room, though they leave no traces of themselves upon the Wall or Body that Receives them, are the True Colours of the External Objects, together with which the Colours of the Images are Mov'd or do Rest. And the Error is not in the Eye, whose Office is only to perceive the Appearances of things and which does Truly so, but in the Judging or Estimative faculty, which Mistakingly concludes that Colour to belong to the Wall, which does indeed belong to the Object, because the Wall is that from whence the Beams of Light that carry the Visible species, do come in Straight Lines directly to the Eye, as for the same Reason we are wont at a certain Distance from Concave Sphaerical Glasses, to perswade ourselves that we see the Image come forth to meet us, and Hang in the Air betwixt the Glass and Us, because the Reflected Beams that Compose the Image cross in that place, where the Image seems to be, and thence, and not from the glass, do in Direct Lines take their Course to the Eye and upon the like Cause it is, that divers Deceptions in Sounds and other Sensible Objects do depend, as we elsewhere declare (Boyle, 1964, pp.82-83).

With Francis Bacon in mind, Boyle then experimented with letting the image fall on a white cloth and on a black velvet cloth. The white cloth not only showed the colors as they were formed, but also projected the light across the room to the wall and floor opposite. Boyle noted that the black cloth absorbed the projected light rays as
well as the ambient room light:

...In a Darkned Room, I purposely observ'd, that if the Sun-beams, which came in at the Hole were receiv'd upon White or any other Colour, and directed to a Convenient place of the Room, they would Manifestly, though not all Equally, Encrease the Light of that Part; whereas if we Substituted, either a piece of Black Cloth or Black Velvet, it would so Dead the Incident Beams, that the place...would be Less Enlightned than it was before, when it recev'd its Light but from the Weak and Oblique Reflections of the Floor and Walls of a pretty Large Room, through which the Beams that came in at the Hole were Confusedly and Brokenly Dispers'd (Boyle, 1964, pp. 125-126)

Elsewhere, Boyle discussed observing the specular light reflected off smooth and rough surfaces of water where the intensity of the sun's reflection was intensely white. Making this same observation with a camera obscura, Boyle was able to see distinctly the many images of the sun projected onto the wall:

And I have sometimes for Tryals sake brought in by a Lenticular Glass, the Image of a River, shin'd upon by the Sun, into an Upper Room Darkn'd and Distant about a Quarter of a mile from the River, by which means the numerous Declining Surfaces of the Water appear'd so Contracted, that upon the Body that receiv'd the Images, the whole River appear'd a very White Object at two or three paces distant. But if we drew Near it, this Whitemess appear'd to proceed from an Innumerable company of Lucid Reflections, from the several Gently wav'd Superficies of the Water, which look'd Near at hand like a Multitude of very Little, Shining Scales of Fish. of which many did every moment Disappear, and as many were by the Sun, Wind, and River generated anew...(Boyle, 1964, p. 105-106)
Boyle's associate Robert Hooke worked closely with Boyle on many of his experiments. As the Royal Society's Curator of Experiments, Hooke was responsible for providing all of the instruments needed for the members' investigations. This often meant that Hooke had to invent and fabricate this equipment (Nicholson, 1965).

In 1680 Hooke gave a series of Cutlerian Lectures to the Royal Society. In his lectures on light, Hooke discussed vision and told how he had constructed an artificial eye. He then demonstrated the principle of image formation in the eye with a rather novel camera obscura he had constructed (Plate XVII):

Now because the Structure and Making of such an Artificial Eye is very difficult, and the use thereof notwithstanding, very necessary for a thorough Knowledge of Opticks; I having only mention'd this at present, that such as have a Mind to be curious in it, may, if they please, prepare the like.

I shall rather as a Supplement to it, make use of a darkned Room, or Perspective Box, in which all the Appearances that are made in the Eye are in some manner represented. Prepare therefore a Box in the shape in the seventh Figure, let it be four or five Foot long from A to DB, and make the bottom of it BC, Concave towards the End A, and the bottom of the Box BDEC, being made Cylindrical, and not tapering, as the part AFG is, that the movable bottom BC, may be placed nearer to or farther from the End A. At A place a convex Glass of the length of the Box in a Hole as large as the Glass, which the larger it is the better, because of several Tryals that may be made with it, which cannot be made with a smaller. To this Hole cut several, as eight or ten Pieces of Pastboard that may each
PLATE XVII
of them serve to cover it, and in every [one] of
them cut a Hole of a Round or other Figure you
would use, and either in the middle of it, or out
of the middle of it, and of a greater or less
Figure, according to the Tryals you design by
them; let the inside of the Concave bottom be
made very White, to receive and reflect the
Points of Light, and make a Hole in the side of
the Box H, covered about with Leather, or thick
Woolen Cloth, with a Hole large enough to put
ones Face into it, so as to see the Species or
Picture of Outward Objects upon the bottom, then
turning the end A where the Glass is placed
toward the Object (if the Sun shines upon it, it
is the better, because of the great Reflection of
Light from such Objects,) slide the moveable
bottom BC, to or fro, 'till by looking in at the
Hole H, you perceive the Representation of the
outward Objects very perfect, then take notice of
the distance of the Object, and likewise the
distance of the bottom; the Position, Magnitude,
Brightness, Colour, and all the other Remarks
that appertain to the explaining the several
Appearances that may happen to the Eye, then fit
it for representing Objects at a greater
distance, and take notice of the distance of the
bottom, and all the other Remarks necessary for
explaining your inquiry: The like may be done
with the various apertures of Pastboards, which
may serve to explain all that might happen to the
Eye, by the contracting and dilating the Pupil,
by observing the definedness of the Species on
each side the Axis, and where they are most
distinct; and so for all other Questions that may
happen concerning what Light is in the Eye, and
what Effects it there produced. It may be
convenient to fix a Ball and Socket underneath it
to make it more easy to be managed. It may also
be made square as well as Cylindrical, provided
the bottom of it, BC, be a Concave part of a
Sphere of the length of the Boxes Radius (Hooke,

Hooke's ingenuity of design can been seen in the
description of this portable camera obscura. He suggested
using a lens with a focal length of about 4 to five feet
(to determine this, one would hold a lens up towards the sun, focus the image of the sun on a perpendicular surface below, and measure the distance from the lens to the image). The lens was mounted into a cone which was then attached to a main tube or cylinder the same length as the focal length of the lens. A second tube with a white concave end slid back and forth in the main tube, focusing the image much like a telescope. An observation hole on the side of the main tube permitted one to see the projected image.

Hooke suggested making a variety of cardboard apertures to use as diaphragms simulating the pupil. In a preceding section, he had discussed the variation of pupil shapes in animals, i.e. the verticle oval of a sheep, the slit of a cat. Focusing on both near and far off sunlit objects, the observer not only saw an image formed, but was instructed to try the various apertures to see how they affected the image sharpness, brightness, size and color saturation. With near objects, the tube would be extended; with far objects the tube would be more compressed, demonstrating Scheiner's and Descartes theory of lens accommodation. Large apertures would permit more light, but give a less sharp, less saturated image. In each instance the area of critical sharpness would be in the center of the image at
the optical axis. Finally, Hooke suggested the use of a ball and socket fitting at the bottom, making the camera eye as mobile as the human eye.

Hooke was insistent that the imaging plane be concave, even if one were to build a box version instead of a tube. Not only was the concave back necessary for duplicating the retina surface, but it also guaranteed a better overall focused image, as the imaging plane conformed to the surface shape of the lens. Gernsheim contends that Hooke's "Perspective box" might easily have been used for drawing, if there were a place for the artist's hand (1969, p. 26). However, drawing on the concave surface would not have been particularly easy. Boyle had apparently designed an earlier box-type version, with sliding boxes and a viewing hole, before 1669 (discussed below), but gave no suggestion for using it for drawing. Hooke did design and illustrate a camera obscura for drawing, but not until 1694.

While Boyle and Hooke made some interesting studies with and novel designs of the camera obscura, neither investigated the theoretical optical aspects of image formation. In the last half of the 17th century, two other Englishmen, Sir Isaac Newton and William Molyneux, were to take up that challenge. In the Keplerian tradition, Newton developed a mathematical study of optics, while Molyneux
was the first Englishman to develop a theory of dioptrics.

As mentioned (page 224), Newton took up the problem of light and optics in the 1660's because of his general dissatisfaction with telescope lenses, namely chromatic aberration. He drew on Kepler's work, not only for his Opticks, which was published much later in 1704, but also for his Principia (1687), Newton's theory of the universe.

In his early experiments, Newton was drawn to a wave theory of light, first suggested by Francesco Maria Grimaldi in 1665. Grimaldi, in his Physico Methesis De Lumine, had used a pinhole aperture in the camera obscura to prove that light rays are bent into the shadow areas of the image as these rays passed through a very small aperture (Figure 39). This is known as diffraction. Grimaldi had gone on to suggest that light was a fluid capable of wave-like motions.

Figure 39
Newton also knew of Marcus Marci's 1650 *Disertatio in Propositiones Physico-mathematicus natura Iridos*, which established that white light was indeed a composite, while colored light could indeed be simple. Marci used the *camera obscura* to refract the white light as it entered the aperture, thus creating a rainbow effect. Newton, influenced also by Boyle and Hooke, went on to experiment with breaking up white light as it passed through non-parallel pieces of glass as a prism. Using the *camera obscura*, or what he referred to as an *obscuration cubiculi*, Newton placed a prism directly behind the aperture, letting the rays of the sun pass through it before forming an image on the wall beyond (Figure 40).

![Figure 40](image-url)
In the end, Newton developed his "corpuscular" theory of light, which stated that light consisted of particles traveling in a rectilinear motion. Newton's theory was in direct opposition to the wave theory of Christiaan Huygens, published in 1690. Huygens had taken the wave front idea of Grimaldi a step further into "wavelets." Huygens had also used a camera obscura to study light refraction in the eye. However, Newton's influence was more immediately felt.

In 1692 William Molyneux, a tutor at Trinity College in Dublin, published his Dioptrica Nova. This was the first English treatise dealing with image formation in the camera obscura, both with and without a lens. Patterned along the lines of Kepler's Dioptrice and benefiting from the work of Scheiner, Descartes, Zahn and others, Molyneux presented a thorough theoretical and mathematical study of lenses for telescopes and microscopes, as well as an analysis of vision. While he added nothing new to Kepler's analysis of the camera obscura or of image formation through lenses, his general discussion was an up-to-date evaluation of optical literature. This work is important for the reference works cited, and the critical comments about those works, as well as for preserving for an English audience Kepler's significant work. Yet, it was probably through Scheiner, rather than directly from Kepler that
Molyneux drew his information. Schiener remained the model for many 17th century writers as the disseminator of Kepler's ideas. While most of these writers failed to acknowledge their sources, occasionally an author gave credit where it was due, as did Molyneux. Another such writer was Johannes Christophor Kohlhans who in his *Tractus Opticus* of 1663, cited Scheiner as his source for the application of the camera obscura to the study of optics and the artificial eye, while using Kepler's term "camera obscura" for the phenomenon (p. 257). Descartes and Newton also had drawn upon Kepler's work to advance their own ideas. Newton's influence was far reaching, and little advancement was made in optics beyond Newton until the 19th century (Mason, 1976). As a result, little theoretical consideration of the camera obscura is found after the 17th century. During the 18th century more attention was given to popularizing the camera and more emphasis was placed on its practicality in drawing.
REFERENCES


CHAPTER VII
THE PORTABLE CAMERA OBSCURA IN
17TH AND 18TH CENTURIES

The camera obscura underwent far more during the 17th century than theoretical scrutiny. Optical "technology" began to emerge during the 17th century from the craft tradition of glass making. Theoretical studies in dioptrics brought some improvement in the quality of lenses used for telescopes, but microscope lenses remained fairly simple during the 17th century, with improvements coming in the 18th century. While the camera obscura benefited from the developing technology, 17th century writers expressed little concern for or consistency in discussing lens quality or use of a diaphragm to guarantee an optimum result. In the 17th century, the more "popular" camera literature followed Della Porta's Natural Magic. Only in the 18th century did an accurate and more scientific description of the camera obscura become widespread.

One very important trend occurring in the 17th century was to make the camera obscura a more practical and portable tool for drawing. A room was fine, even one with a scioptric ball, but the number of views one could draw
from the same location was limited. A variety of portable versions appeared during the 17th century, but it was not until the later part of the century that the size of the camera began to be reduced. Even in the 18th century the size was often cumbersome. After 1758, when John Dollond introduced an achromatic lens which corrected image and color distortion, a smaller camera obscura with the new lens became more readily available. This was the first really practical camera for drawing. Quite naturally, then, during the latter half of the 18th century, evidence is readily found of the camera obscura in use by such English artists as Paul and Thomas Sandby and by such English "explorers" as James Bruce in Egypt and Africa, Thomas Daniell in India, and Edward Dodwell in Greece (Hammond, 1981).

While recommendations for using the camera as a drawing tool had been made by Della Porta and Barbaro in the 16th century, these were limited to copying either the scene outside the room, or an arranged subject such as a portrait (Della Porta) or map (Barbaro). Early in the 17th century, both Kepler and Scheiner had made portable cameras for astronomical "drawing". However, copying a flat subject, or drawing the diameter of the sun or even its sunspots, not only permitted less drawing skill but also poorer-
quality optics than drawing from a three dimensional scene.

In 1606, two years after Kepler's *Ad Vitellionem Paralipomena*, Frederick Risner's *Opticae* was posthumously published. Risner, who died in 1580, had published the 1572 edition of Alhazen and Witelo, and was well acquainted with the camera phenomenon of image formation. In his *Opticae*, Risner included as short passage on the camera obscura with a diagram of a triangle projecting its inverted image through a round hole. He cited Pecham, Reinhold, Gemma Frisius, his own *Astrologia*, and Maurolyco's *Cosmographia* as already having discussed image formation and the use of this method for solar observation. None of these works, of course, correctly explained image formation, nor did Risner attempt it in his *Opticae*. While copies of Maurolico's correct analysis in his *Phototismi de Lumine* were available prior to its publication in 1611, there is no indication that Risner ever saw this particular work.

What is important about Risner's rather brief discussion is his suggestion of using the camera obscura for drawing. As Barbaro had done, Risner suggested using the camera to make enlargements or reductions of drawings or maps. However, Risner went one step further and suggested that the camera could be used to make maps or
topographical drawings. To do this, one would need a portable *camera*, what Risner called a little house (domunculam). This was a lightweight "multiangular" wooden construction, with the support beams joining at the top and spreading out towards the base. A conical hole was made in any one of the wooden sides, and the image of the scene was projected inside. Risner did not indicate how large this "house" was, nor did he indicate using a lens in the aperture.

It is important to remember that this is a 16th century work, written sometime between 1572 and 1580. Risner cited only medieval "perspectivi" and contemporary astronomy works as sources on the *camera obscura*. Barbaro's *La Practica della Perspettiva*, Della Porta's *Magia Naturali*, and Cardano's *De Subtilitate*, works which mentioned the use of a lens, were all missing. Risner had encountered the same difficulty as Kepler would later, that the astronomical literature did not deal with optics. Both Risner and Kepler wrote books on optics; both devised portable versions of the "pinhole" *camera obscura*. Kepler had omitted the lens because he distrusted lenses and put no faith in Della Porta's claims about them. Risner also omitted a lens, although it is difficult to think he did so because he was ignorant of the works of Barbaro, Cardano,
or Della Porta. There is no indication that Kepler knew of Risner's *Opticae* before it was published in 1606. By that time, Kepler had already dealt with the optical problems discussed by Risner in his own *Ad Vitellionem Paralipomena*. Kepler's *Dioptice* of 1611 was a theoretical work on lenses, a topic Risner did not address. Nor is there any indication that Scheiner was familiar with Risner's *Opticae* for his *Refractiones Coelestes* of 1617 or his *Oculus* of 1619. In fact, there is no evidence that Risner's work had any impact; by the time it was published, its concepts were already obsolete. Thus, it would appear that Risner's remarkable suggestion of a portable *camera obscura* for drawing was virtually unknown.

In 1612, after the death of Rudolph II in Prague, Kepler was sent to Linz, Austria. He was still the "Imperial Mathematicus," but his duties also included once again teaching mathematics and being in charge of drawing new maps of Upper Austria. In 1620 Sir Henry Wotton, an English diplomat with an avid interest in science, visited Kepler. Wotton observed several of Kepler's experiments and wrote his friend Francis Bacon about the meeting:

...Therefore, for a beginning, let me tell your Lordship a pretty thing which I saw coming down the Danuby, though more remarkable for the Application, then for the Theory. I lay a night at Lintz, the Metropolis of the higher Austria...There I found Keplar, a man famous in
the Sciences, as your Lordship knowes...In this
tans study I was much taken with the draught of a
Landskip on a piece of paper, me thoughts
masterly done: Whereof enquiring the author, he
bewrayed with a smile it was himself, adding that
he had done it non tanquam Pictor, sed tanquam
Mathematicus. This set me on fire: at last he
told me how. He hath a little black tent (like a
windmill) to all quarters at pleasure, capable of
not much more than one man, as I conceive, and
perhaps at no great ease; exactly close and dark,
save at one hole, about an inch and an half in
Diameter, to which he applies a long
perspective-trunke, with the convexe lense fitted
to the said hole, and the concave taken out at
the other end, which extendeth to about the
middle of this erected Tent, through which the
visible radiations of all the objects without are
intromitted, falling upon a paper, which is
accomodated to receive them, and so he traceth
them with his Pen in their natural appearance,
turning his little Tent round by degrees till he
hath designed the whole aspect of the field; this
I have described to your Lordship, because I
think there might be good use made of it, for
Chorography: for otherwise, to make Landskips by
it were illiberall; though surely no Painter can
do them so precisely...(Wotton, 1651, p. 413).

Given the task of producing accurate maps, Kepler could
have turned to a variety of sources for help, from current
written works to friends in the "business" of map making.
One such acquaintance was Willebrord Snellius who had
studied with Kepler and Tycho at Prague. Snellius,
Professor of Mathematics at the University of Leiden, is
known primarily for his mathematical equation for the law
of refraction which was based on Kepler's Dioptrice (Mason,
1976). After his death in 1626, Snellius' formula was
lost, but Descartes reportedly incorporated it into his own
work in 1637 (Pledge, 1966). Snellius also was involved with surveying an area in the northern Netherlands, publishing his results in 1617 (Struik, 1981). In addition, Snellius had a copy of Risner's Opticae in which he made detailed annotations; this annotated version was published posthumously in 1918. No correspondence between Snellius and Kepler remains, however, concerning Kepler's mapping project or Risner's work. Kepler did record Wotton's visit in a letter of August 1620, but he made no mention of his mapping project (Baumgardt, 1951).

From Wotton's description, Kepler's "tent" more closely resembled Risner's model rather than being a modification of his own dioptral camera or of Scheiner's helioscopes. Wotton remarked that it was like a "windmill", a description remarkably similar to Risner's own instructions of attaching the wooden strips together at the top and spreading them out towards the bottom. Wotton's phrase "tent" has generally been interpreted to mean that Kepler's camera was covered with cloth, similar to Nollet's design of 1733 (Gernsheim, 1969). However, such a solution would have made mounting the telescope tube in the side difficult. Wotton was unclear in explaining exactly how or where the tube was placed. It is clear that Kepler modified a telescope by removing the eye piece (concave lens) and
leaving the objective lens (convex lens) for the projecting element. He probably resorted to this solution from necessity, as the only lenses of any quality available to him were those in telescopes. Yet, we have already seen that even these were poor inadequate.

The device was large enough to accommodate one man rather uncomfortably, it seems. It was also lightweight and movable enough that Kepler was able to make panoramic or 360 degree views. While Wotton did not specifically state that Kepler was using this device for "chorography," that is for mapping, he did make that suggestion to Bacon. However, Wotton's comments about the suitability of its use in drawing is puzzling. He had been attracted to a drawing of a landscape which he thought "masterly done," yet he remarked that making landscape drawings this way was "illiberal." This last comment may have been a reflection on Kepler's skill in tracing, that it was too "tight." He did acknowledge, however, that no painter could make a landscape as precisely.

Another type of drawing camera is found on one of Kepler's notebook pages now in Leningrad (Plate XVIII) (Gerlach and List, 1951). This device was quite different from any of the earlier cameras and certainly did not fit Wotton's description of Kepler's tent. The drawing showed
a large wooden ball at one end, much like a scioptic ball, with a large lens mounted on the outside end. The other end of the ball fit into a long rectangular tube within which were two smaller lenses, an arrangement Kepler had recommended in his Dioptrica for telescopes. At the far end was an imaging screen which slid back and forth in a track for focusing. This whole system was mounted on a tripod. On the notebook page a sketch of a church and campanile is shown projecting its image onto the viewing screen. Alpers has suggested that this drawing was based on a design by Scheiner and sent to Kepler by Melchior Stolze in 1615, when Kepler himself was working on a similar type of device (1983, p. 246, n. 51). It is possible that the wooden lens element might have derived from Scheiner's artifical camera eye which Scheiner used for the experiments published in his Oculus of 1619. Even the drawing of the church and campanile are reminiscent of the example found on the title page of that work. While Scheiner did not illustrate his mechanical eye, his description was accurate enough for Daniel Schwenter to reproduce it as a scioptic ball in 1636. However, the telescopic lens arrangement is that recommended by Kepler in his Dioptrice. Whatever the source of this drawing, it is highly unlikely, as has been suggested by Alpers (1983,
pp. 49-50), that this particular instrument was the one Kepler used during Wotton's visit. Wotton's specific description of the modified telescope does not correspond to the lens system depicted in the notebook drawing.

About this same time in England, another reference to a portable camera obscura appeared which was just as enigmatic as those to Kepler's cameras. In a series of letters written by Constantijn Huygens, a young Dutch nobleman in England, we learn of another such camera belonging to Cornelius Drebble. Drebble was a Dutch inventor who was a technical advisor to the English navy and served as "artificer" in the court of James I. He was said to have navigated his submarine in the river Thames and produced elaborate productions with air and water driven beasts for the delight of the English court (Bachrach, 1980). Drebble also experimented with explosives, thermostats, microscopes, telescopes, and invented the "bow scarlet" dye used so long in for the British army's uniforms (Hall, 1983). Unfortunately, Drebble's affinity for what was interpreted as sorcery and his preoccupation with a perpetual motion machine meant that he was not taken seriously by very many of the English intelligentsia. However, young Constantijn was immediately taken with Drebble and all of his intriguing instruments,
including the camera obscura. In a letter to his parents written April 13, 1622, Constantijn described the deep impression made on him by Drebble's camera:

I have at home Drebble's other instrument, which certainly makes admirable effects in painting from reflection in a dark room; it is not possible for me to reveal the beauty to you in words; all painting is dead by comparison, for here is life itself or something more elevated if one could articulate it. As one can see, the figure and the contour and the movements join together naturally and in a grandly pleasing fashion...(Quoted in Wheelock, 1977, p. 93).

This observation was made by one knowledgeable in the arts. Constantijn had studied drawing with Henrich Hondius, the author of an important Dutch perspective manual. While Constantijn had once remarked about the rigidity of Hondius' drawing style (Alpers, 1983), he noted that the animated image of the camera obscura made all art seem stiff and lifeless. So taken with the effect, Constantijn could not find the words to adequately describe the image which to him seemed more noble than life itself. Unfortunately, Constantijn's actual description of Drebble's apparatus was also lacking, stating that the camera was:

a lightly constructed instrument so arranged that when the subject that is held outside and before it is illuminated by strong sunlight, its image will be projected in a carefully closed chamber. It used to be thought that Drebble was the first to employ a round lens, but even this he attributed to a deserving improvement by his
predecessors...This can be said, that Drebbale alone has introduced the placing of the movement, the pushing of it forewards and backwards and the easy turning to all sides. Now may the instrument, that produces such extraordinary pleasure and usefulness when it is seen, be called perfect, when my friend Drebbale finally knows how to correct the images that stand reversed, because the emitted rays cross each other, and the debt, that he had already long taken upon himself, will finally be paid back (Quoted in Wheelock, 1977, p. 99).

Earlier, in March of that same year, Huygens had mentioned that the camera produced a "brown" picture (Wheelock, 1977, p. 93). However, Huygens saw the monochromatic image as less of a problem than the fact that Drebbale had not figured out how to correct the inverted image. Drebbale did not take credit for introducing the lens, but rather attributed the use of a "round lens" to his predecessors. Of the printed works available to Drebbale which mentioned a lens but omitted any method of correcting the image? From the 16th century only Cardano's De Subtilitate and Barbaro's La Practica della Perspectiva meet that requirement. It is surprising that Drebbale would not have known of Della Porta's Natural Magic, as the two men shared similar interests. Della Porta's book had even been published in Dutch, although Drebbale was multilingual, publishing his own books in Latin. Della Porta had mentioned the use of a mirror to correct the image long before he mentioned the use of a lens in his second
edition. From the 17th century, only Scheiner's *Oculus* included a detailed description of the camera obscura equipped with a lens but mentioned nothing of correcting the inverted image. Drebble probably knew of the general camera principle from earlier works, perhaps even from his own countryman Gemma Frisius who had published the first illustration of the camera obscura.

Huygens' comments most closely follow those of Cardano. Cardano had discussed the problem of image inversion, mentioning that the rays emitted were reversed, but was unable to explain why. He noted that the objects outside need to be in bright sun. He suggested that the colors of the image would be rather dull when projected onto the wall and recommended the use of white paper. His description of the lens, "orbem et vitrum," was vague but no more so than Huygens' own phrase, "round lens." It is not clear from Huygens' description just how much he and Drebble understood about the camera obscura, but it does seem to have been limited, particularly as Drebble did not know how to correct the inversion. Drebble used both microscopes and telescopes; had he understood the optical principles of these, he should have been able to figure out a way to right the camera image. Huygens' statement that the camera produced a "brown" picture is rather peculiar. Most
writers commented about the objects being depicted in their natural colors. Only Risner in his *Opticae* had mentioned a monochromatic picture. Wheelock has suggested that Huygens "may have been responding to the image with the eyes of an art critic aware of the most recent advances in landscape painting" (1977, p. 101, n. 3). It seems more likely, however, that the lens was inferior, perhaps made of tinted or impure glass, or that the image was projected onto a nonwhite surface.

Huygens' description of the *camera* itself gives even fewer clues. It was lightly constructed and had a carefully closed chamber. Huygens gave Drebble credit for introducing "the placement of the movement, the pushing of it forwards and backwards, and the easy turning to all sides." This description could apply to several things, such as Risner's portable room, Kepler's and Scheiner's astronomical *camera*, or even a scioptic ball. "Pushing of it forwards and backwards" could refer to the means of focusing (whether moving the imaging surface back and forth) or to the size of the projected image by moving the *camera* box back and forth. "The easy turning to all sides" recalls Wotton's description of Kepler's tent which was "convertable (like a windmill) to all quarters at pleasure." It would also describe the action of the
scioptric ball as it moved inside its wooden collar. "Introducing the placement of the movement" would seem to mean that the camera was portable enough to chose what animated scene was to be projected.

Drebble's camera obscura apparently made little impact in England, for Sir Francis Bacon's description in 1623 indicated only the most basic understanding, while Leurechon's translation by Oughtred in 1633 and Della Porta's translation in 1658 added little significant information. Only in the latter part of the century did England see any significant contributions in the work of Hooke and Boyle. Nor did the presence of Drebble's camera back home in Holland make any documented impression. Huygens showed the device to several of his artist friends to their "great amusement," and remarked that the camera was "familiar to everyone," but could not understand by what negligence on the part of our painters it happens, that so pleasant and useful an aid to them in their work should have so far been neglected by them or be unknown to them...(Quoted in Wheelock, 1977, p. 95).

Germany produced the greatest number of works on the camera obscura during the 17th century, many by Catholic clergy including Scheiner, Kircher, Schott, and Zahn. France also had its share of works, but Italy seems to have already made its contribution in the preceding century. Most of
these works were "scientific" or mathematical in nature, although Kircher and Schott reflected the continued interest in "magic." Most of these works also suggested using the camera obscura for some type of drawing. Even Scheiner in his Oculus listed the "ars pingendi" as one of several uses for the camera obscura. Leurechon, and Oughtred in the English translation, had reiterated the 16th century suggestion that the camera could be used for painting, portraiture and perspective drawings. Daniel Schwenter, in 1636, mentioned that the German painter Johann Hauer and his son had used a camera obscura equipped with a scioptric ball to make a panoramic view of Nuremberg.

The following year, 1637, Pierre Herigone published his multi volume Cursus Mathematicus, a thorough summary of Kepler's work in a general mathematical instruction manual. In volume V, Herigone discussed optics and perspective, following Kepler's theories on vision ("La vision est la perception de l'image de l'object, piente en la retina" p. 9), and gave a rather traditional Euclidean approach to perspective. In 1642, Herigone wrote an updated edition, Supplementum Cursus Mathematicus, which included a novel camera obscura to be used for perspective drawing. Herigone had not previously mentioned the camera in his discussion of perspective, and his inclusion here
suggested that the idea originated with someone else:

Various methods of obtaining the perspective of an object which one wishes to see before his eyes.

...the others figure that one can obtain an object in perspective in its colours by means of its replica which records itself on a piece of white paper stretched taut at the bottom of a chalice-shaped cup and on the opposite side of the tube through which the images entered, a convex lens; the right portions of the perspective will, however, represent the left portions of the object (Quoted in Potomniee, 1973, pp. 26-27).

Hergone did not illustrate the device, but an illustration appeared in much later work by Johannes Zahn in 1685 (Plate XIX). Zahn's versions were a bit more sophisticated than what Herigone had described. The lens was placed at the bottom of the chalice and projected the image onto a screen inside the cup. One model had a mirror placed in the stem which corrected the image. Neither Herigone's or Zahn's chalice cameras seem of much use for drawing. In Hergone's version, the tautly stretched paper would easily be punctured while drawing. In Zahn's version, trying to draw in the base of the chalice would be awkward at best. Both would require a lens with an extremely short focal length, and necessitate a very steady hand to hold the camera in position. In reality, this ingenious concept probably never got off the drawing board. That it was repeated by Zahn late in the century indicates a continued interest
in the novel design. Another rather bizarre solution was illustrated in Athanasius Kircher's *Ars Magna Lucis et Umbra* of 1646. Kircher was a German Jesuit who would have felt more at home with someone like Della Porta than with the scientists of his own day. He supported the Tychonian theory of the universe (that the planets rotated around the sun, but that the sun and moon rotated around the earth), and was a true follower of Hermetic studies, believing in magic, the occult, and astrology. His writings tended to be encyclopedic in nature; the inscription on the title page of his *Ars Magna Sciendi* may well have been his motto: "Nothing is more beautiful than to know the All" (Godwin, 1979, p. 9).

His *Ars Magna Lucis et Umbra* was a massive work which included such topics as comets, eclipses and other astrological influences, sundials, optics, colors, and phosphorescence, to name a few. Where the *camera obscura* was applicable to the discussion, such as eclipses, or optics, it was included. Kircher apparently tried to include as much as he could find from other sources, as long as they fit his mystical philosophy. Thus, Kepler and the Copernican theory were ignored. In the first chapter he described Scheiner's method of using a telescopic *camera* for observing sun spots. However, in his general "theory"
about the image formation, Kircher relied for the most part on Della Porta, particularly in his discussion on correcting the inverted image. The book was richly illustrated with handsome engravings of the *camera obscura* as well as many other devices of phantasmagoria.

In Chapter IV, Book X Part II, in his discussion of the *camera obscura* with a lens, Kircher included a portable version for drawing. (Plate XX). Kircher introduced what he called a "conclave," a device he had seen used in Germany, used to copy objects and to produce likenesses. This consisted of a large box mounted on top of two long poles. The artist entered through a trap door at the bottom of the box. Lenses were placed in the middle of two opposing external walls of the box. Inside, thin paper was stretched across wooden supports, creating in internal "box" parallel to the walls. When the artist entered, he was inside the paper "box" and saw the image through the back of the paper (much as Leonardo da Vinci had described). This still produced an inverted image, but one corrected from left to right. In this fashion, the artist was able to make more than one drawing at a time without having to move the "conclave." While the illustration showed lenses in only two of the four walls, it is conceivable that all of the walls would have lenses, thus
creating a full panorama, as Kircher's heading had suggested. In Kircher's 1671 edition of this work, he told how a group of Jesuits in Paris had built a similar "conclave" in the form of a chair; they had been delighted with it but informed him that the construction was costly (p. 714).

Gaspar Schott, professor of mathematics at Wurzburg and a former student of Kircher's, published most of Kircher's work for him after 1670 (Godwin, 1979). Schott included Kircher's "conclave" in his own 1677 edition of *Magia Optica* (Plate XXI). Schott omitted the artist and the poles in his illustration, but gives Kircher's description, citing Kircher's *Lucis et Umbra*. This device was also included in Schott's 1657 *Magia Universalis* which was based on Kircher's notes. In the 1677 edition of this work, Schott told of having heard from a traveler in Spain of a smaller version of Kircher's "conclave," that was small enough to carry in the arms (p. 200). It was Kircher's version that remained popular, however, and we see variations of it reproduced as late as 1692. Daniel Schwenter continued the emphasis on magic in his illustration included in a rather late edition of his *Deliciae Physio-mathematici* (Plate XXII). The illustration depicted a less pleasant scene than Kircher's.
Schwenter included the two poles which implies that the box was still large enough to be carried by two people. Rather than showing the artist standing inside, Schwenter indicated the "eye level" with a dotted line, and included only the artist's eye. This illustration might suggest that while the box was still large, it need not include more than the artist's head and shoulders.

A French perspective manual, which included a description of a portable camera obscura for artists, appeared shortly after Kircher's *Ars Magna Lucis et Umbra*. Jean-Francois Niceron's *La Perspective Curieuse* of 1652 discussed a number of traditional "machines a dessiner". The first edition of this work (1638) had not included any mention of the camera obscura, but in the third, Niceron gave a rather full account not only of the visual effects and its use for drawing, but also the optical theory and use in magic. Niceron also commented on the deception of the eye:

After a room has been shut on all sides so that no perceptible light can enter, a hole is made in one of the walls or in the shutter, in front of which hole a paper or blank sheet is placed at a certain distance, perpendicular to the horizon, which serves as the canvas upon which the exterior images are received. This reception is so perfect that the eye is completely deceived by this natural image so that, if science and reason did not correct the deception, one would believe
PLATE XXIII
that the eye sees the actual objects, especially if one inserts in this hole, about the size of a twenty sol piece, a convex lens of long focus; because these exterior objects project not only their real size, the figures and colours, but also their movements which is always lacking in the painter's work...(Quoted in Potonniee, 1979, p. 27).

Niceron then illustrated how the subject distance would affect image size (Plate XXIII). He commented on the eye's deception of so natural an image, yet he accepted the inverted image and gave no indication of how to correct it. It is only the scientific explanation and one's reason (i.e. a realization that this is only an image, an impression) that correct the deception. Using a lens, Niceron said, only heightened the deception. Niceron echoed Huygens' observation about the appearance of the image, but added one important aspect: that the objects were their "real" size. It is improbable that Niceron would have a lens that provided a 1:1 ratio, an exact size projection. It would be more accurate to interpret this to mean the objects were proportionately correct to each other. Where Huygens had noted that the "figure, contour, and movement come together naturally," Niceron added color and emphasized the animated effect, an aspect lacking in painting. Under the heading "An optical experience which shows perspective perfectly" ("Experience optique qui enseigne parfaitement la perspective" p. 21), Niceron
instructed the artist:

It is sufficient to remark...that if a painter in a transportable camera makes four drawings and joins them together where he can put the matter to a test, he will have the kind of perspective which he seeks...A painter must have a sort of portfolio or lantern pierced in such a manner by a hole...that he will see below everything projected by the light-rays through this hole on a very white piece of paper. Now looking through another opening made on the side of the portfolio, he will trace all on the same place on the paper in order to carefully reproduce an immobile painting from the mobile picture which latter, however, will vanish as soon as the first hole is covered or when he changes his position (Quoted in Potonniee, 1979, p. 28).

The beginning of this passage recalled Kircher's "conclave," one that is both transportable and permits making four drawings or panorama of a scene. Niceron's camera was a bit different, however. He described it as a portfolio, a portable case for carrying drawing sheets, or a lantern, a portable case carrying a light. The lantern analogy for the camera obscura is a rather intriguing one, where here the light filling the case is projected from the outside rather than filling the case and projecting it to the outside. Unfortunately, the phrase later would lead to confusion with the Magic Lantern, the forerunner of the modern day projector. In addition, the actual description was not particularly clear should one wish to construct such a device. He described this case as having an aperture for projecting the image, but did not mention a
lens in this context. Apparently, the artist was to make the connection from the earlier passage. Where one placed the aperture or lens was not specifically stated, but one assumes it was somewhere above, as the image was seen below. The artists then looked through a second hole in the side of the case to observe the projected image. Somehow he was to insert his hands inside the case in order to trace the image.

Niceron again emphasized the animated image, and perhaps his disappointment in the drawing of it, for while the image is mobile (thus difficult to trace if there is too much motion), the tracing, or the end result—a painting from this drawing—will seem static. The image was also fleeting or transitory, for if the aperture were covered, or the artist changed his position, the image vanished. Certainly the image would vanish if the light rays were blocked. However, if the artist changed his position slightly, i.e., moved his head a bit, his angle of view would change, but the projected image would not. The artist had more flexibility in head and eye movement with the camera obscura than with drawing devices that presumed an immobile head and eye. Should the artist change the position of the camera, then obviously the image would change; the original image would "vanish." With Niceron's
description, however, an artist would find it difficult to fully utilize this instrument as a drawing tool.

In 1658, the year of Della Porta's debut in English, Sir William Sanderson published a little handbook on drawing and watercolor entitled *Graphice, or the Most Excellent Art of Painting*. Part I included the history and philosophy of painting, while Part II had more practical information about composition, perspective and use of color. On the last page of the book, following a section on how to draw a landscape from life, Sanderson included a discussion on "The draught of a Landskip Mathematicall." Sanderson repeated almost verbatim the description of Kepler's tent found in Wotton's 1622 letter to Francis Bacon. This letter had been included in *Reliquiae Wottonianae* published in London in 1651. During the intervening seven years, few artists had been made aware of this portable *camera* for drawing. Sanderson apparently had not used the device, for he added no additional comments of his own experience. Nor, evidently, had he seen a drawing done with a *camera obscura* as he repeated Wotton's reference to chorography as well as his criticism of "illiberall" landscape drawings. Sanderson included the passage so that those readers who "have leasure and desire thereto, may make an experiment" (Sanderson, 1658, p.86).
The book offered little of value to a practicing artist, being aimed more for the "dilettanti". This this tent-type camera did not become popular as drawing tool, however, until 1733 when it was patented by J. C. Nollett.

The box or "little room," first mentioned by Gaspar Schott in 1757, was also included in J. C. Kohlhans' treatise of 1663. Influenced by Scheiner's Oculus, Kohlhans published his own work on vision entitled Tractus opticus. Kohlhans, as had others before him, repeated Scheiner's experiment with the artificial eye camera obscura, with his version being a small box ("cistellula parva"). He also introduced a camera in the shape of a book which he called the "liber opticus" (Gernsheim, 1969). This book-type camera became popular in the 18th century, with examples being found today in the collections of Yale University and the Science Museum in London.

In England, Robert Boyle also introduced a box camera obscura sometime during the late 1660's. In his Of the Systematical or Cosmical Qualities of Things (1669), Boyle described an portable camera and made reference to an earlier version already shown earlier to the Royal Society:

I need not perhaps tell you, that if a pretty large box be so contrived that there may be towards the one end of it a fine sheet of paper stretched like leather of a drum head at a convenient distance from the remoter end, where there is to left an hole covered with a
Boyle used the camera obscura as a demonstration for some scientific notion, such as vision (1663) or his study of color (1664). This time he used the device as part of his developing theory of light, prefiguring Newton in the concept of a corpuscular nature. To test this theory in the field, Boyle needed a portable camera, one that could be turned every direction all day long.

Boyle's reference to his earlier model shown several years earlier apparently was not recorded. Boyle was still using a room in his house as a camera in 1664. On February 21, 1666, Samuel Pepys recorded in his diary Robert Hooke's comment that for drawing "nothing doth like squares, or,
which is best in the world, like a dark room which pleased me mightily" (Pepys, 1963, p. 80). It would seem, then, that Boyle (and Hooke who would have actually constructed it) thought of a portable camera no earlier than March 1666. Also it would appear from Boyle's comments that his device had been copied by others, although just who these "diverse ingenious men" were is unknown. Boyle had not been the first to suggest a design employing two boxes, one fitting inside the other and sliding back and forth to focus the image. In 1657 Gaspar Schott described a similar albeit smaller design (Gernsheim, 1969). In fact, Boyle and Hooke made no new discoveries about the camera obscura; rather they generally offered better designs to implement already existing solutions in a scientific setting of the Royal Society.

Only the year before, in 1668, Robert Hooke had demonstrated to the Royal Society Della Porta's method of projecting via mirror and lens a scene from another room. Hooke made no mention of Della Porta or his book, which had appeared in English ten years earlier. Della Porta had referred to this spectacle as "How in a Chamber you may see Hunting, Battles of Enemies, and other delusions," which had included such props as the rinoceret. The full title of Hooke's presentation pretty well summed up his device:
"A contrivance to make the picture of anything appear on a wall, cupboard, or within a picture frame, etc. in the midst of a light room in the daytime, or in the night time in any room which is enlightened with a considerable number of candles" (Quoted in Gernsheim, 1969, p. 26).

Unlike Della Porta's example, however, Hooke's image was projected into a well lit room. Hooke's presentation to the Royal Society, few of whose members were "professional" scientists, was given as a new optical experiment, but was, in fact, more accurately entertainment. Hooke made no attempt to relate this to any scientific principle of optics, as Boyle did, although he, as Boyle, had previously demonstrated this "experiment."

One of the German scientific societies, Collegium curiositum sive Experimentale, was also aware of the camera obscura. This group was founded in 1672 by Johan Christoph Sturm, a professor of mathematics at Altdorf. The group was similar to Della Porta's group "I Segretti," but lacked the importance that the Italian societies had (Mason, 1976). Along the lines of Della Porta, who had published an accumulation of his society members secrets, Sturm published a compendium of contemporary scientific inventions discussed by his own members. This Collegium experimentale sive curiosum of 1676 included information on such instruments as telescopes and air pumps. Sturm included a section on light and optics, and in his
tentament vii had compared the eye to a small camera obscura. In tentamen xvi Sturm described a portable reflex camera as a demonstration of how the eye functions. This camera was a box with a mirror positioned inside behind the lens and at a 45 degree angle, which reflected the image onto a sheet of oiled paper stretched across the top of the box. Around the paper was a three sided shield or hood which blocked out the surrounding light. Oiling paper made it translucent so that the image could be seen through the back of the sheet (Plate XXIV). Leonardo and Kircher also had suggested viewing the image through the paper, but had not suggested oiling the paper. While this method made the image easier to see, and corrected the inverted image, the oil made drawing much more difficult. This problem was resolved in 1685 when Johannes Zahn published his Oculis Artificialis Teledioptricae sive Telescopium.

Zahn collected information from a variety of sources for this work, but not always from the best available. Molyneux complained that Zahn frequently copied information from others including their errata which "shews that Zahn was either very careless, or else that he understood nothing of the matter, as he seems to do very little for he is a mere blind transcriber from others" (Molyneux, 1692,
Much of what Zahn included on the camera obscura originated with earlier writers such as Sturm, but he did give a more detailed description with illustrations, and gathered into one place much of what had been written on the camera over the past century. This included Scheiner's artificial eye and Schwenter's scioptic ball, Niceron's comments on the use of the camera by charlatans including Herigone's magic chalice, Della Porta's room for battle scenes, Auzout's chart on the focal length of lenses (which had been presented to the Royal Society in 1665), and Sturm's portable reflex camera obscura.

Of particular interest are two versions of the portable box camera, which are about two feet long and a little less than a foot high and wide. The first had sliding tube lens at one end and a sliding back at the other. The back was raised and behind was a sheet of paper or thin wood with a hole in the center large enough for both eyes to look through. Further inside the box a taut sheet of oiled paper served as the imaging screen. (Plate XXV bottom). This model, then was only for viewing, as there was no way to trace the picture. The second version was based on Sturm's camera. Inside the box a mirror was placed at a 45 degree angle opposite the lens. However, between the lens and the mirror, a thin sheet of oiled paper was placed for
the imaging screen. The mirror reflected the image on the paper upward to the viewer, and a three sided hood blocked the extraneous light. Zahn replaced the oiled paper that had been stretched across the top of the box in Sturm's model with a thick piece of glass ("vitrum parastaticum") (Plate XXV top). Both illustrations showed a dotted circle drawn on the imaging screen. This indicated that the lens was not large enough to "cover" the imaging area, thus the image was small and circular. Had the lens been large enough to project a circle larger than the size of the paper, the entire screen would be filled with an image just as in modern cameras.

Zahn's second model also was impractical for drawing. Had Zahn removed the oiled sheet of paper inside the camera, then placed a thin sheet of paper on top of the glass letting the mirror reflect the image directly onto the drawing surface, he would have designed the type of reflex camera popular at the beginning of the 19th century and which was adapted for use in the early years of photography. Unfortunately, a number of historians, Waterhouse and Eder among them, have suggested that Zahn's solution was like the early photographic reflex camera. This error coupled with an erroneous publication date of 1665 given by Eder have been used as evidence that a
practical portable drawing tool was available to artists in the mid 17th century. Zahn's illustrations were, like Boyle's portable camera obscura, a means to demonstrate optical principles. Zahn's cameras were not intended for drawing.

A portable camera that was made for drawing was designed by Robert Hooke in 1694 (Plate XXVI). In December of that year Hooke presented a paper to the Royal Society entitled "An Instrument of Use to take the Draught or Picture of any Thing." Hooke saw the instrument being particularly useful to navigators and travelers for drawing

...not only the Prospects of Countries, and Coasts, as they appear at Sea from several Distances, and several Positions, but of divers In-land Prospects of Countries, Hill, Towns, Houses, Castles, and the like; as also of any Kind of Trees, Plants, Animals, whether Birds, Beasts, Fishes, Insects; nay, of Men, Habits, Fashions, Behaviors; as also, of all Variety of Artificial Things, as, Utensils, Instruments, Engines, ships, boats, Carriages, Weapons of war, and any other Thing which an accurate Representation, and Explanation, is desirable (Hooke, 1967, p.292-293)

Hooke realized that he was not the first to suggest the use of the camera obscura for topographical drawings, but he also expressed concern about how poor and exaggerated many of the illustrations were in "Wagoners," a collection of topographical coastal drawings used by sailors. His criticism of these and illustrated books on foreign
PLATE XXVI
countries and people was both sharp and witty. Hooke's
design seemed to be a modification of the model he had used
fourteen years earlier to demonstrate the eye, but rather
than putting one's face inside a large hole on the side,
this drawing camera fit over the head and shoulders. One
would suppose that Hooke, in his role as Curator of
Experiments for the Royal Society, actually constructed one
of these and put it to the test. Hooke has been described
as

...fertile, ingenious and assiduous; the variety
of material he produced was fantastic, but it can
hardly be said that as a 'director of research' he showed consistency or persistence. He was
brilliant in ideas, low in concentration of effort (Hall, 1983, p. 224).

Given the above statement and Hooke's design, it might be
best to assume that this was a clever idea that never came
to fruition. This notion is supported by Hooke's own
comment that he had shown a similar device earlier, a small
picture box for drawing a man, and thus did not even feel
the need to describe the present instrument. It seems that
the earlier model was built, and Hooke believed himself to
have been the first to suggest such a camera. In addition,
he lamented the fact that it had been omitted from the
record written by Sir John More and thus was not utilized.
The problem with Hooke's second design was one of
feasibility. Should the construction have been made of
light wooden frame and covered with canvas or dark cloth, the weight of the front end would make it difficult to maintain the camera position; a support of some kind would be necessary. In addition, the draftsman’s arms and shoulders surely would have been extremely uncomfortable, even if the camera were placed on a table and the draftsman seated. Most difficult, however, would have been trying to use this on the deck of a ship, as Hooke suggested; the roll of the ship would make it practically impossible to trace the image. Unfortunately, Hooke did not pursue the problem further during the last nine years of his life.

Hooke’s design was abandoned by early 18th century writers on the camera obscura, who fared a bit better with their models than Hooke had. During this period little optical innovation was made, but modifications on the physical shape continued. This century, however, was primarily a time for popularizing what had already been written. Writers of the 18th century borrowed heavily from one another, and this was especially true with the emergence of the encyclopedia. Diderot’s *L’Encyclopédie ou Dictionnaire raisonne des Sciences, des Arts et des Métiers*; the *Encyclopedia Britannica*; *Chamber’s Cyclopedia*; *Crocker’s Dictionary of Arts and Sciences*; and Busch’s *Encyclopaie Der Historischen, Philosophischen und Mathematic*
were just a few with entries on the *camera obscura*. A number of these, including *Chamber's Cyclopedia* (1741) and *Diderot's L'Encyclopedia* (1753), attributed the invention of the *camera obscura* to Della Porta. All mentioned the visual phenomenon of the room-type *camera* in much the same terms as Diderot:

The *camera obscura* furnishes a very amusing spectacle because it presents perfect images resembling objects; because it imitates all the colours and even the movements which no other representation can produce (Quoted in Potonniee, 1973, p.35).

With the exception of *Chamber's Cyclopedia*, most did not include a discussion of portable *cameras* until after mid-century. Popular literature during the 18th century also reflected a growing interest in the *camera* phenomenon. In the first half of the century, newspapers and magazines such as *Post Boy* (March 122, 1709), *The Tatler* (Dec. 29, 1709), and the *Spectator* (June 1712) included articles on the *camera obscura* which tended to emphasize the "spectacle" aspect. The second half of the century, articles as "The Method of drawing Landscapes, etc. by help of a Camera Obscura," in the *Oxford Magazine* of May 1769 (pp. 160-170) placed more emphasis on drawing as well as on portable *cameras*. This type of article, however, was less frequent than those references to the *camera obscura* found in encyclopedia articles. By the end of the century,
references were found in books and poetry, including Samuel Richardson's *The History of Sir Charles Grandison* (1754), Lawrence Sterne's *Tristram Shandy* (1781), and John Gay's three-volume poem *The Fain* (Hammond, 1981). In 1747 John Cuff, a London optician, published a pamphlet with a poem about the room-type camera, entitled "Verses, Occasion'd by the Sight of a CHAMERA OBSCURA" (Schwarz, 1975). By the first quarter of the century Alexander Pope's famous grotto at Twickenham included a camera obscura (Pope, 1806), and by 1777 Horace Walpole, a member of Parliament and one of London's social elites, had purchased a portable camera obscura made by William Storer (Walpole, 1926).

Early in the century several different styles of portable camera obscura appeared which remained quite popular and were frequently illustrated and discussed by subsequent writers of optics and mathematics, by encyclopedists, and by the periodicals. The most often illustrated and discussed during the 18th century were cameras in the shape of sedan chairs, tents, and tables. The 18th century reflex camera obscura, a variation on Zahn's viewing camera, appeared as early as 1734 in Pierre Poliniere's 4th edition of *Experiences De Physique*, but was not commonly seen in the literature until the second half
of the century. Opticians' trade cards also began to illustrate this reflex *camera obscura* among their instruments around 1750 (Victoria and Albert Museum, 1971).

In 1711 Willem Jacob van s'Gravesande published a drawing manual for artists, *Essai de perspective*, in which he discussed the use of the *camera obscura* for drawing. This work was quite popular, not only in its 1724 English edition, but also in its repetition in Jombert's *Method Pour Apprendre Le Dessein* (1755) and in Hutton's *Recreations in Mathematics and Natural Philosophy* (1803). Gravesande designed a sedan chair *camera obscura*, complete with drawing table, bench and light proof breathing tube (Plate XXVII). On the roof of the device, mirrors directed the scene into the *camera* from all sides without having to move the chair. One mirror was positioned at a 45 degree angle directly over a lens in the top of the *camera* projecting the light rays onto the paper inside. When used by itself, this mirror depicted the scene immediately behind the draftsman's back. The second mirror could be placed in front of and at an angle to the first to reflect the scene on either side of the chair. To project the view directly in front of the draftsman, the first mirror was slightly raised but still at a 45 degree angle, while the second was placed at a 45 degree angle towards the scene.
PLATE XXVII
The camera could also be used for copying drawings by attaching them to the removable drawing board mounted on the brackets at the top of the chair. Jombert's illustration (Plate XXVIII) showed not only Gravesande's chair and breathing tube, but also a light framed drawing table with a small camera using a similar mirror arrangement mounted on top of the table. The draftsman stood at this model and pulled a black cloth down around his head and shoulders. A third version was a collapsible box which folded into the shape of a book.

Nicholai Bion's drawing camera for copying engravings was published in his *Construction and Use of Mathematical Instruments* in 1723 (Figure 41) while an improved version was published in 1727 (Plate XXVIX).

Figure 41
The earlier version employed a mirror to reflect the drawing onto the copper plate below. The drawing was placed vertically in front of a mirror which was tilted at a 45 degree angle towards the engraving plate. The improved version used a lens to project the imaged of the drawing attached to a board opposite, while a mirror reflected a beam of light onto the drawing. This device was to be used in a darkened room with the only light being that illuminating the drawing. In the 1758 supplement to this work, Bion also included designs for two portable camera obscuras. These designs had first appeared in 1738 in Robert Smith's *A Compleat System of Optics*. One of these was a horizontal reflex model to be used for drawing (Figure 42).

![FIGURE 42]
The camera was a large wooden box with a plano-convex lens fitted in a sliding square wooden tube. A mirror was positioned inside the box and reflected the image onto sheet of "rough glass." When not in use, the glass and mirror were stored in a drawer in the bottom of the camera. The lid, which was illustrated separately, had "wings" which spread out to block out extraneous light.

FIGURE 43

The second portable drawing camera was a vertical cabinet which was to be placed on a table or stand. This version employed an improvement of Gravesande's mirror and lens system. The mirror was angled above a lens positioned in an upright wooden tube. Unlike Gravesande's lens, however, the sliding tube permitted the image to be focused and made the device much more practical. The draftsman looked at the projected image through a hole (K) and placed
his hand and arm through the lower hole (L). This hole was in a sliding board that moved left and right, permitting the draftsman to draw the scene across the entire page. Bion, in his supplement, also discussed Gravesande's sedan chair camera, and remarked that it was necessary to keep the mirrors on the outside of the camera as the draftsman's breath would fog them.

One of the most popular portable drawing cameras was patented in France by the abbot J. C. Nollet in 1733. This was a tent-type camera obscura, and variations on this design could be found into the 19th century. Nollet included a discussion of the design in his Leçons De Physique Experimentale first published in 1743. In Book V of the work, Nollet discussed several portable cameras including the reflex type. He illustrated this and a version which was a mechanical demonstration of the human eye (Plate XXX). He commented that he had designed the tent camera because of the limitations he found with the reflex box camera (Plate XXXI):

The camera obscura which was also in the form of a box, whether demountable or not, is not so portable as one would have desired; moreover, one is reduced to obtaining only very small images, because if a long focus lens is used, the box must be proportionately longer. It is now about twenty-five years since I have thought of a camera which is light, takes up very little room
and of which the objective have a focus of thirty inches and even more. This is a pyramid composed of four strips of wood ABCD meeting at the top in a collar of the same material EF, and at the bottom joined by a baseboard at the four corners of the chassis GHIK. These boards are hinged, and each side of the chassis folds towards the center, so that when the four hooks are opened to give free play at the hinges GHIK, they fold and open and close like the ribs of an umbrella and, on each side, are the crossbars which form the chassis. The top piece EF is pierced in order to receive a cardboard tube L equipped with a lens focused towards the base of the pyramid. The part L which turns like the rest, is equipped with another collar MN which turns upwards when desired, carrying on its circumference two small copper tubes N, n, split lengthwise, so that they can fly back. In these tubes, gliding up and down, are two small metal uprights which carry a cap o, at the bottom of which a plane mirror is adjusted...The whole is covered with a heavy green cloth, again enclosed inside of black taffeta, on all three sides and part of the fourth. At the lower part of the two uprights a thick black curtain is attached, for the purpose of covering the head and shoulders (Quoted in Potonniee, 1973, pp. 33-34).

Nollet's camera could easily be used to make panoramic drawings, as the lens swiveled inside its collar. He still recommended using the device in a poorly lit room, placing it on a table near the window, with one's back towards the view.

In 1734, just a year after Nollet's patent and nine years before Nollet's publication, Pierre Poliniere included a tent camera obscura in his fourth edition Experiences De Phisique. Poliniere gave a very thorough discussion of image formation and the comparison of the
camera obscura to the eye. He illustrated a reflex camera (Figure 44), and discussed its use in drawing. In discussing the camera image, he remarked on the novelty of the animated picture, a thing no painter could do. He said that those knowing how to draw would find that the camera would help to perfect their picture, while those not "knowing how to draw a dot" would be able to trace exactly all of the objects including houses, the view or the landscape.

Poliniere also saw the tent camera as more portable than the heavy wooden box cameras. His design was slightly different from Nollet's, in that the mirror was more simply fabricated, and required a more truncated pyramid. The whole was covered with cloth, with a hole (M) pierced in one side for the hand. A curtain was attached to the top at NA and was draped over the head and shoulders of the draftsman. Poliniere explained how a short focus lens
could be used to convert the camera into a large solar microscope to view and draw microscopic objects.

FIGURE 45

The idea of making a microscopic drawing camera was again suggested by Martin Froben Ledermüller in 1760. His *Microscopischer Gemuths und Augenergotzung* explained how to adapt the solar microscope to a *camera obscura* for making drawings of small insects (Plate XXXII). While the telescope had been adapted to a drawing *camera* almost one hundred and fifty years before, this is one of the earliest published attempts to combine the *camera obscura* with the microscope. In Ledermüller's illustration, the camera and microscope tube were fitted into a plate in the window where a mirror projected light into the lens. The
PLATE XXXIII
top figure showed a reflex **camera** projecting the microscopic image onto the glass above; the second figure showed the **camera** without a mirror projecting the image onto the back of the **camera**. It is not clear from the perspective of the illustration and the dismembered arm whether this took place in a darkened room or in an elaborate canopy placed over the **camera** body.

A rather gargantuan reflex **camera** for copying objects was included in Georg Brander's *Beschreibung dreyer Camera Obscura* of 1769 (Gernsheim, 1969) (Plate XXXIII). Brander, a maker of scientific and surgical instruments, illustrated a large drawing table with a multi-sectioned lens tube for enlarging objects. The draftsman was shown drawing just the head and shoulders of the statuette. In the original illustration Brander also showed a hood which was to be fitted over the top of the glass so that the image could be seen. One would imagine that the image would have been rather dim even with the large lens, when the tube was so greatly extended. Nor would this camera have been particularly portable.

A reference to a smaller type of drawing table **camera** was published the following year in E. G. Guyot's *Nouvelles Recreations Physiques et Mathematiques* (1770) (Plate XXXIV). Guyot's **camera** was similar to Brander's
in principle, in that the mirror was below the glass table top and a tent was placed on the frame to block the extraneous light. Guyot's *camera* was smaller and more portable, but had one disadvantage. The vantage point of the lens was extremely low. This was fine for copying objects which could be placed on the floor in front of the *camera*, but would not work as well for drawing views. Guyot's design, however, was included in William Hooper's second edition of *Rational Recreations* in 1782. Hooper gave Guyot credit for the design and commented that this *camera* had the advantage over the tent version in that the draftsman's hand did not block the light as the image was projected onto the paper. Its disadvantage, Guyot observed, was that it was not as portable as one might desire:

> This camera is, indeed, something more combersome than those that have been hitherto invented; and yet, if properly made, it will not weigh more than twenty to five and twenty pounds" (Hooper, 1787, p. 30)

In 1733 William Cheselden, Surgeon to Queen Caroline and physician to Alexander Pope, published an important medical book, *Osteographia, or the Anatomy of the Bones*. Accuracy of the illustrations was particularly important to Cheselden, and none of the various methods he tried in making them seemed satisfactory. In the introduction
to the work, Cheselden related how he came upon a method which conveniently solved his problem, which he illustrated on the title page (Plate XXXV):

Then we proceeded to others, measuring every part as exactly as we could, but we soon found it impossible this way; upon which I contrived (what I had long before meditated) a convenient camera obscura to draw in, with which we corrected some of the few designs already made, throwing away others which we had before approved of, and finished the rest with more accuracy and less labour, doing in this way in a few minutes more than could be done without in many hours, I might say in days (Quoted in Hammond, 1981, p. 57).

Cheselden's illustration showed a large box camera mounted on two tripods. The type of lens and focusing systems were not apparent. This was not a reflex type as the inverted image was projected onto the vertical screen at the back of the camera. An inverted image appeared more abstract, and as accuracy was of utmost importance, the subject was inverted to make the draftman's job easier. Cheselden was not the first to place the inverted subject before the camera lens. Robert Hooke had suggested this in 1668 in his address to the Royal Society on projecting a scene into a lighted room. Hooke admitted that inanimate objects worked best, as trying to hang living animals or candles upside down was certainly difficult. Cheseldon had a perfect subject for this method. Cheseldon never mentioned being aware of the portable reflex camera. Apparently, his
solution was based on his knowledge of the conventional camera obscura. Cheseldon apparently felt the need to justify his use of the camera for making these illustrations by pointing out that artists frequently use tools such as compass and ruler for accuracy in drawing.

In 1778 William Storer patented a new design for a portable reflex camera. Storer, a London instrument maker, called his device the "Royal Accurate Delineator." The patent model and instruction booklet, Storer's Syllabus, to a course of optical experiments, on the syllepsio optica; or the new optical principles of the Royal Delineator Analysed, are today housed in the Science Museum in London. A catalogue entry for an exhibition at the Victoria and Albert Museum in 1972 described this instrument as

A reflex box form of camera obscura which is notable for the large aperture of the lenses employed. Two rectangular sections of lenses are mounted in sliding boxes on the front of the instrument. A third rectangular section of a lens is mounted immediately below the ground-glass screen. Because of the large aperture of the lenses, the image on the ground-glass screen is bright enough for indoor use. The lenses are not achromatic...The device was the most useful camera obscura of its day for producing indoor portraits...As a result of the large aperture the depth of field is small. In order to facilitate focusing rackwork is fitted to each of the sliding boxes on the front of the camera (Victoria and Albert, 1972, p. 20).
Storer's Delineator was much smaller than the earlier reflex cameras and was much easier for travelers to use in documenting their excursions. The Delineator was mentioned as late as 1803 in Hutton's *Recreations in Mathematic and Natural Philosophy*, but just how popular the instrument was or how many were made is unknown.

An earlier reference to "pocket sized" reflex cameras appeared in 1775 Joseph Harris' *A Treatise on Optics*. These were six to eight inches long by two to three inches wide, and were available in London optical shops. Harris suggested this camera for those people able to draw free hand. He also mentioned a miniature version fitted into the head of a cane. This had an extremely short focus lens with a focal length of about two inches. This type was certainly not intended for drawing, but rather for the optical novelty.

The most significant design innovation for the camera obscura, however, appeared in the early 19th century. This was William Hyde Wollaston's periscopic or meniscus lens of 1812 which was discussed in Charles Chevalier's *Notice sur L'usage des Chambres Obscures et des Chambres Claires* of 1829 (Figure 46). Wollaston's lens, which was applied to the tent camera and replaced the bi-convex lens, had a concave back surface and a convex front surface which faced
the drawing board. A diaphragm was added between the mirror and the lens. The advantage of this lens design was that it produced an image that was sharp at both its center and its edges. Thus, the camera obscura became a most practical drawing instrument and was used in this manner long after the invention of photography in 1839.

Since the 16th century it had been suggested that the camera obscura be used as a drawing tool. How the camera compared to other available drawing devices, who made use of it, and how it was utilized will be considered in the following chapter.
REFERENCES


Boyle, Robert. (1671). Of the Systematical or Cosmical Qualities of Things. London: Royal Society.


Hooper, W. (1787). Rational Recreations, in which the Principles of Numbers and Natural Philosophy are Clearly Elucidated. (3rd Ed.). London: Davis & Robson.


CHAPTER VIII

THE CAMERA OBSCURA AS DRAWING TOOL

The camera obscura was only one of a number of devices, both mechanical and optical, that were recommended for use in drawing. These instruments appeared in the 16th century, after the development of perspective in Italy, and conformed to the limitations of plane geometry implicit in this system of rendering upon a two dimensional surface the illusion of three dimensional objects existing in space. They presupposed a single, fixed eye position with the visual rays subtending at vanishing points located on the horizon line opposite the viewer's eye (Plate XXXVI). The devices ranged from a viewing frame with very simple grid, to the pantograph, to image forming devices as lenses, mirrors and the camera obscura.

The mechanical devices, such as the viewing frames, first appeared in 16th century perspective and drawing manuals. Durer's designs from his Unterweysung der Messung (1525) are probably the best known examples (Plate XXXVII). These drawing aids remained fairly standard in design and were generally constant in the repertoire of
PLATE XXXVII
instruments recommended for perspectival drawing. They were still found in 17th century perspective treatises, often presented as a new discovery or as an improved version. An example of this is found in Jean Dubreuil's two variations on the drawing frame, or his "Machine a Dessiner," in his La Perspective Practique of 1642 (Plate XXXVIII and XXXIX). Dubreuil was aware that the frame itself was not a new concept, but believed that he was the first to incorporate the eye sight. In fact, his design was similar to Durer's two examples with the exception of the sighting device. Both Durer and Dubreuil showed an artist tracing the scene directly onto the plane glass frame, while copying the scene of the grid frame onto a sheet of paper with a grid. In Durer's examples the sighting device was always directly in front of the artist's eye. In Dubreuil's examples, however, it is not clear from the illustrations how the sight was to be used. The text made it clear that the sight was used in both cases, although in the illustration with the grid, the sight was too far away from the artist to be of much value. Dubreuil described his sight as an adjustable ruler having at the top a thin circle of tin three to four inches in diameter with an aperture in the center the size of a pea. This sight was not much different from those found in diopters used by
astronomers for astronomical sightings. Dubreuil confidently observed

everyone knows how to take, or copy off, what is designed on the glass. 'Tis best to draw the lines and figures on the glass with pen and ink; then wetting the backside of the glass a little, and laying a moist sheet of paper on the side that has the design; rub or press the paper gently thereon with the hand, and the whole draught will be impress'd or transfer'd from the glass upon the paper (Dubreuil, 1726, p. 120).

A similar method would be recommended in the late 18th century for tracing the image on the ground glass of the camera obscura. The grid frame was also recommended for drawing portraits as is seen in an illustration from Abraham Bosse's *Divers manières de dessiner et de peindre* of 1667 (Plate XXXX). However, no sighting device was employed in Bosse's method. The grid frame was placed as closely as possible to the subject, while the artist drew within a proportionately larger, smaller or identical grid on his paper.

This type of mechanical drawing device was consistent with one of the earliest treatises on perspective, Leon Battista Alberti's *Della Pittura*, written about 1435. Alberti first described how the artist might consider the painting as a window on the scene, and then introduced the practical technique of a grid, or what he called a "velo" or veil:
they should only seek to present the forms of things seen on this plane as if it were of transparent glass. Thus the visual pyramid could pass through it, placed at a definite distance with definite lights and definite position of centre in space and in definite place to the observer...He who looks at a picture, done as I have described, will see a certain cross-section of a visual pyramid...Nothing can be found, so I think, which is more useful than that veil which among my friends I call an intersection. It is a thin veil, finely woven, dyed whatever colour pleases you and with larger threads [marking out] as many parallels as you prefer. This veil I place between the eye and the thing seen, so the visual pyramid penetrates through the thinness of the veil (Alberti, 1973, pp. 51-52, 68-69).

Thus, this type of drawing device fit into the traditional conventions of perspective. While simplifying the mathematical demands of perspective on the artist, the drawing frame still required an ability to draw. This was a tool, much like ruler and compass, which required skill and sensitivity on the part of the user, and as such was wholly acceptable to artists.

Other mechanical drawing devices such as the pantograph did more of the work for the artist. These instruments became more frequent in the 17th century, a time when a Cartesian mechanical world began to replace the Neoplatonic one. Drawing instruments such as the pantograph, however, appeared not in the traditional perspective literature, but rather in works by non-artists including Christopher Scheiner. In his *Oculus* of 1619 Scheiner had cited drawing
as one of the uses for the **camera obscura**; in 1630 he depicted the **camera** as an astronomical drawing tool in his **Rosa Ursina**. One year later, in 1631, Scheiner published his **Pantographice sev ars delineandi**. This was a work for non artists presenting a practical mechanical method for copying drawings and objects in nature (Figure 47).

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**Figure 47**
This consisted of four wooden rods joined to form a parallelogram. A stylus (RO) was used to trace around the original drawing or object (Z) while a pencil (SP) mounted at the far side mechanically redrew the picture (T) at whatever scale desired. Scheiner also devised a way of mounting the pantograph onto a vertical drawing board so that objects in a scene might be copied (Plate XXXXI). The stylus (M) traced around the objects in the air while the pencil traced them onto the drawing paper. The draftsman maintained a constant eye position by placing his head against a support (FDHI). Scheiner's pantograph had many practical applications for the mechanical arts for copying maps, drawings, designs, and the like.

In 1669 a similar but more sophisticated design by Sir Christopher Wren was presented to the Royal Society (Figure 48). Wren was both an important architect and scientist, distinguishing himself in the fields of astronomy and anatomy; in 1657 he became professor of astronomy at Gresham College, and from 1680-82 he served as president of the Royal Society (Philosophical Transactions, 1669, p. 310-11). His drawing instrument "for drawing the Outlines of any Object in Perspective," which had been invented a number of years earlier, was in principle very much like Scheiner's. The parallelogram rods were replaced with two
Figure 48

Cords of equal length (aaa, bbb) which were attached to pulleys at the top of the vertical drawing board. At the end of each cord was a lead weight (Q). The other end of the cord was attached to a horizontal rod (H) which moved up and down and left to right, always remaining horizontal. A pencil (I) traced the picture as the draftsman outlined the objects in the air with a small pin attached to the end of the horizontal rod. Wren's device was quite popular and variations of it are found into the early 19th century. There is no evidence, however, that
"serious" artists employed such a device that was so mechanical in its method to record.

Optical devices were also used by artists and draftsmen, but, it would seem, to a lesser extent than the drawing frame. Of these, the mirror had been known since Roman times. Roger Bacon in the 13th century had discussed image formation with a mirror outside a window projecting a scene into a room. Della Porta in his *Magia Naturalis* of 1558 had also discussed mirrors, image formation with mirrors and lenses, and had suggested using a concave mirror for correcting the inverted image of the *camera obscura*. In the 13th century the polished metal plane mirror was replaced with a lead-backed flat glass mirror, which by the next century was an object of interest to optical scientists, artists and poets including Dante Alighieri. The 14th century chronicler Filippo Villani recorded Giotto's use of mirrors for painting (Edgerton, 1975). Alberti also discussed the use of the mirror in his *Della Pittura*, observing:

A good judge for you to know is the mirror. I do not know why painted things have so much grace in the mirror. It is marvellous how every weakness in a painting is so manifestly deformed in the mirror. Therefore things taken from nature are corrected with a mirror. I have here truly recounted things which I have learned from nature (Alberti, 1973, p. 83)
In the early 1460's Antonio Averlino, known as Filarete, noted that the mirror demonstrated the convergence of parallel lines in vision, and suggested that Filippo Brunelleschi had developed his perspective method with the aid of a mirror:

If you want to see this more clearly, take a mirror and look into it. And you will clearly see that this is so, but if the same were opposite to your naked eye, [the orthogonal lines in the room] would seem parallel to you...And so I believe that Pippo di Ser Brunellescho the Florentine found the way to make this plan [linear perspective] which truly was a subtle and beautiful thing, which he discovered through considering what a mirror shows you (Quoted in Edgerton, 1975, pp. 125, 135).

In 1425 Brunelleschi had used a plane mirror in his demonstration of perspective, a panel painting of the Baptistery in Florence.

By the 17th century many of the optical, mathematical and natural magic treatises such as those by Leurechon, Kircher, Schott, Schwenter and Zahn included a discussion of mirrors as drawing aids (Plate XXXII). A few perspective treatises of this period also mentioned the use of plane and convex mirrors as drawing aids, including Samuel van Hoogstraten's *Inleyding tot de Hooge Schoole der Schilderkoonst* (1678), and C. A. du Fresnoy's *L'Art de Peinture* (1673) (Wheelock, 1977).
The plane mirror, like the viewing frame, represented reality itself, and was the only optical device which functioned this way:

A plane mirror, or to be quite exact a system consisting of two plane mirrors suitably arranged, sends to the eye the actual light flux which comes from the real scene. Consequently, what we see in the mirror is reality itself. The illusion produced in the mirror is thus of a very special kind. The mirror does not represent reality, it presents to us reality (Pirenne, 1970, p. 11n)

Thus, the plane mirror was similar to the viewing frame in that it had traditional ties to perspective development, depicted a real, although reversed, view of the scene, and required some drawing skill to use.

The convex mirror was also used by artists, and occasionally appeared in paintings such as Jan Van Eyck's Arnolfini Wedding of 1434 or Parmigianino's self portrait in a convex mirror from the early 1520's. In 1707 Gerard de Lairesse described in his Het Groot Schilderboek how he employed a convex mirror for drawing the Stadthuis in Amsterdam:

I chuse a Station or Distance of eight feet, more or less, from the Building, as Occasion requires. Then, I take a Convex Looking-glass, of about a Foot Diameter...and place it against the Inside of my Drawing-board, or Porto-folio: I contrive it in such Manner, that it may either stand upright, or leaning back, according as I would see Things either from beneath, or higher. Thus I approach with the open Porto-folio, and my back towards the Object, till the Building, Tree,
Etc. appear as I would have it, and then design it from the Looking-glass, on white or blue paper. This Method is very convenient for drawing all sorts of large Works in narrow Places or Streets; even, a view of twenty or thirty Houses. 'Tis also useful to Landskip-painters in their country views: They may take whole Tracts of Land, with Towns and Villages, Waters, Woods, Hills, and Sea, from East to West, without moving either Head or eyes. 'Tis likewise proper for those who are ignorant of perspective (Quoted in Wheelock, 1977, pp. 160-161).

In the late 18th century, a type of convex mirror known as a "Claude Glass" became popular. Named after the French landscape painter Claude Lorraine, this slightly convex blackened mirror produced a subdued and rather dark reflection of the scene, similar in mood to Lorraine's paintings.

The use of lenses by artists was not quite as widespread, in part because of their rather late appearance (17th century) in relation to the development of perspective, and in part to their generally poor quality until the 18th century. Nevertheless, magnifying glasses and convex and concave lenses for both viewing and projection were mentioned as drawing aids, primarily in treatises on optics and natural magic. In the 16th century Della Porta mentioned the artist's use of a concave lens:

The painter will be able with the greatest of ease and proportion, for with the concave lens placed up, it draws into a small circumference objects which are in a very large plain. Thence the painter, who looks at these things, with a
small amount of effort and skill, paints all things accurately in proportion (Quoted in Wheelock, 1977, pp. 161-162).

In the 17th century Kircher, Leurechon, Schott and Schwenter included various types of lenses for image projection in drawing. One such example is found in Gaspar Schott's *Magia Ottica* of 1677 (Plate XXXIII). Here a large plano convex lens is used to project an image onto a wall in room similar to a camera obscura.

All of these mechanical and optical devices, including the *camera obscura*, conformed to perspectival depiction with its single fixed viewpoint, its frame or window on the scene, and its representation nature in geometrical space. None left any physical trace on the final painting, and most left no physical evidence on the drawing itself; the exceptions were the grid and a page which had been varnished to make it more translucent for tracing the image on a glass frame or the ground glass of the *camera*. All of these devices would have been used to record some existing object, scene or perspective; none were suitable for creating an imaginary perspective space. While the optical devices could cause visual distortion, such as curving straight lines, the artist could easily correct these. Not all pictorial distortion, however, was due to an optical device. Marginal distortions were possible both optically
and mathematically by having an angle of view more or less than 30 to 60 degrees. Distortion could also occur when a rigidly constructed perspective was viewed from other than the intended "ideal" point. Finally, all of the optical devices capable of image formation, including projecting lenses, the concave mirror and the *camera obscura*, would evidence problems with focus, spherical and chromatic aberration and highlight distortion.

What kind of drawing tool was the *camera obscura*? One would assume that tracing an image projected onto a wall or screen would be fairly uncomplicated, as indicated by the lack of much direction in 16th and 17th century descriptions. Provided one had access to a lens, and hopefully one of good quality, the biggest difficulty with a conventional *camera* would be not blocking the image as it was traced, and not obliterating details with the drawn lines. The image needed to be large enough and bright enough to see. A screen would permit the most critical focusing, but chromatic aberration would show colored halos around highlights and in areas of strong contrast. In general, the central areas of the projected image would be the sharpest with the edges blurred. Without a diaphragm only one plane in the scene could be in focus. Thus, a flat object such as a map would be the most suitable
subject to copy.

With the introduction of portable reflex cameras, 18th century authors gave more specific instructions for tracing the image. Since Kircher's portable "conclave" in 1646, draftsmen had been advised to oil the taut paper to make it translucent and trace the image with a black lead pencil. As late as 1772, James Ferguson still advocated that process, but still did not explain how one drew easily on the oily paper. Ferguson recommended copying this tracing onto a clean sheet of paper. One could also draw directly on the glass, but Ferguson made no mention of how to transfer the drawing from the glass. In 1787, W. Hooper gave those specific instructions, as he discussed Guyot's table model camera obscura. Rather than oiling the paper, Hooper suggested varnishing it, making a much better drawing surface. This paper was held in place on the glass with bits of wax at each corner. This method was suggested for drawings which were to include the shading. For line drawings, Hooper suggested drawing directly on the glass with soft black pencil and carmine. When finished, a damp sheet of paper was spread over the glass and rubbed, transferring the drawing onto the paper. This last method reversed the drawing. Hooper noted that if a drawing made this way were used for an engraving, the drawing would be
corrected in the print.

Such specific references to the camera obscura, like those to other optical devices, are found most frequently in the optical, mathematical and natural magic treatises. The greatest proponents of the camera as a drawing tool, it seems, were non-artist authors. Of all the works discussed in this study, relatively few were intended specifically for artists. This is not to suppose that artists were unaware of or uninterested in the scientific literature. It is to suggest that the camera obscura was not regarded as a viable drawing tool for the serious artist. In the 16th century only two perspective manuals, Barbaro's La Practica della Prospectiva and Egnazic Dante's edition of Vignola's Le Due Regole, addressed the camera. Neither of these authors had any real practical experience in the visual arts; they functioned primarily as editors of others' work. Barbaro's account was important for its technical innovations. While he was impressed with the spectacle of the camera-formed image, he primarily saw the device as a copying machine applicable for the mechanical arts. Dante, on the other hand, was purely interested in the optical ramifications of the camera, in particular its implications to understanding vision, and made no connection whatsoever to any drawing application.
The 17th century also had only two perspective works which specifically dealt with the camera obscura. The Dutch painter Samuel van Hoogstraten, in his Inleyding tot de Hooge Schoole der Schilderkonst of 1678, discussed the camera in a very brief passage and indicated his intrigue with the animated image. This moving quality, which had attracted Barbaro, Huygens and others before van Hoogstraten, made the picture seem more life-like, but made tracing difficult. Van Hoogstraten concluded that all such optical devices give the same effect although with varying degrees of acceptability:

I am certain that vision from these reflections in the dark can give no small light to the sight of the young artist; because besides gaining knowledge of nature, so one sees here what main or general [characteristics] should belong to a truly natural painting...But the same is also to be seen in diminishing glasses and mirrors, which, although they distort the drawing somewhat, show clearly the main coloring and harmony (Quoted in Wheelock, 1977, p. 165).

Father Niceron, in his third edition of La Perspective Curieuse (1652), discussed a number of drawing devices including the camera obscura. While he made no theoretical connections of the camera to perspective, he did discuss the technical use of a portable camera by artists. He, too, was taken with the animated aspect of the camera-formed image, but was also concerned with its deceptive quality. In fact, much of his discussion on the camera
dealt with a "perspective show" or spectacle in the Samaritaine on the Pont-Neuf. There charlatan showmen used the camera obscura to dupe a naive and ignorant audience into believing that through magic the spirits in the apparition on the wall had stolen their purses and counted out their money.

Some perspective writers certainly were aware of the camera obscura as a drawing tool yet chose to ignore it in their own treatise. Jean Dubreuil referred to the works by Barbaro, Dante and Niceron, yet made no mention of the camera in his La Perspective Practique necessaire a Tous Peintures. In the second half of the 18th century a more diverse response to the camera appeared, due in part to the increasing awareness by artists of the tool. One very supportive passage is found in Count Francesco Algarotti's Saggio della Pittura from the early 1760's. Algarotti was a Venetian nobleman, patron of Titian and writer on science and art. In a section entitled "Dell'uso Della Camera Ottica" Algarotti expressed his enthusiasm for the camera image:

We may well imagine, that could a young painter but view a picture by the hand of Nature herself, and study it at his leisure, he would profit more by it than by the most excellent performance by the hand of man...[this artificial eye presents] a picture of inexpressible force and brightness; and as nothing is more delightful to behold, so nothing can be more useful to study, than such a
picture. For, not to speak of the justness of the contours, the exactness of the perspective and of the chiaroscuro, which exceeds conception; the colours are of a vivacity and richness that nothing can excel...the shades are strong without harshness, and the contours precise without being sharp...an infinite variety of tints, which, without this contrivance, it would be impossible to discern...the best modern painters among the Italians have availed themselves greatly of this contrivance; nor is it possible they should have otherwise represented things so much to the life...Every one knows of what service it has been to Spagnoletto of Bologna...[to revive the art of painting an academy needed no more than] the book of da Vinci, a critical account of the excellencies of the capital painters, the casts of the finest Greek statues, and the pictures of the camera obscura...Let the young painter, therefore, begin as early as possible to study these divine pictures, and study them all the days of his life, for he never will be able sufficiently to contemplate them...Painters should make the same use of the camera obscura, which Naturalists and Astronomers make of the microscope and telescope; for all these instruments equally contribute to make known, and represent Nature (Quoted in Scharf, 1968, pp. 22-23)

As an awareness of the **camera obscura** as drawing tool became more widespread in the latter half of the 18th century, some artists having experimented with the device were not as enthusiastic about its use. William Hogarth, in a passage originally part of his *Analysis of Beauty*, chose to commit images to memory, which to his way of thinking were more truly a picture than those formed in a **camera obscura** (Burke, 1955). Sir Joshua Reynolds took up the problem of the **camera** in the thirteenth of his
Discourses on Art. Reynolds has been acknowledged as having owned a camera obscura, now in the collection of the Science Museum in London. There is no evidence, however, that he used this device to make drawings or paintings, nor would his painting style suggest any influence of an optical tool as the camera obscura (Waterhouse, 1973). Reynolds gave his camera to Lady Yates (Victoria and Albert Museum, 1972), probably after experimenting with it. In his lecture Reynolds expressed his concern that the optical precision of the camera image would confine the artist's expressive abilities:

If we suppose a view of nature represented with all the truth of the camera obscura, and the same scene represented by a great Artist, how little and mean will the one appear in comparison of the other, where no superiority is supposed from the choice of the subject. The scene shall be the same, the difference only will be in the manner in which it is presented to the eye. With what additional superiority then will the same Artist appear when he has the power of selecting his materials, as well as elevating his style? (Quoted in Scharf, 1968, p. 21).

In 1711 Willem Jacob van s'Gravesande, designer of the sedan chair camera obscura, had also expressed some reservations with the limitations of the tool. His comments were repeated in 1755, by Charles Antoine Jombert in his Methode pour Apprendre le Dessein:

It can be noticed regarding the camera obscura, that several Flemish painters (according to what is said about them) have studied and copied, in
their paintings, the effects that it produces and the way in which it presents nature; because of this several people have believed that it was capable of giving excellent lessons for the understanding of that light, which is called chiaro-oscuro. It cannot be denied that certain general lessons can in fact be drawn from it of broad masses of shadows and light; and yet too exact an imitation would be a distortion; because the way in which we see them naturally. This glass interposed between objects and their representation on the paper intercepts the rays of the reflected light which rendered shadows visible and pleasantly coloured, thus shadows are rendered darker by it than they would be naturally. Local colours of objects being condensed in a smaller space and losing little of their strength seem stronger and brighter in colour. The effect is indeed heightened but it is false. Such are the picture of Wouermans. A painter should bring before the eyes of all men nature as they normally see it and not with a heightened effect (as is seen in the camera obscura) but which in fact only a few know (Quoted in Scharf, 1968, pp. 21-22)

Historically the camera obscura had been associated with understanding and explaining the principle of light. Jombert noted, however, that this device was not accurate in helping the artist understand the quality of light except in its broadest tonal generalities. The problem was a discrepancy between the way we see and the way light formed an image in the camera. It is the same problem that photographers face, having to learn to see like the photographic camera. The human eye automatically adjusts not only to focus but also "exposure" and can discern detail in the shadow as well as the highlight. Jombert
noted that the camera gave a false rendition of the scene with an increase in contrast between light to dark, or what he referred to as a darkening of the shadows. While he did not note it, the camera also eliminated detail in the highlights due in part to flare.

Jombert also cautioned the artist of the false intensity of color in the camera image, a quality that some writers such as Algarotti found particularly attractive. Jombert was correct in this observation, but not quite correct in his explanation of why the colors seem more intense. Yet his reasoning has persisted and repeated by contemporary historians considering optical qualities in 17th century Dutch painting.

A number of factors could contribute to the apparent intensity of color. First, the camera image is seen in the dark, hence the color is surrounded by black rather than white. When surrounded by white, the light is diffused and dilutes the color intensity. Both the Autochrome process, an early 20th century photographic color method, and the RCA Triniton color television employed this technique for color enhancement. Second, the camera image is darker and more contrasty than the original scene, hence the color appears more saturated. Third, chromatic aberration would affect some light waves more than others intensifying those
particular colors. Fourth, in a reflex camera the transmitted light of the image seems richer than that seen with reflected light. A contemporary example is the comparison of a color photographic transparency or "slide" which has been printed. The reflected light image of the print will never equal the intensity of color saturation seen in the transmitted image. Fifth, perception of the viewer, based on his own accustomed standards of what a color image should look like, will certainly influence his response to the camera-formed image. Because the camera image did not conform to the standard of reference, i.e. painting, it was different. To a contemporary American viewer accustomed to seeing color images in magazines, movies and television, an autochrome seems rather colorless, while the four color carbro prints of the 1930's and 40's seem rather artificial and exaggerated. Few viewers today would probably detect any noticeable difference between the color of the camera obscura image and that of the scene. Nevertheless, Jombert found the exaggeration undesirable, although he did admit that few people were aware of the discrepancy. His advice was that artists should paint what they know, not what they see in the camera obscura. Jombert, like Algarotti, specifically cited an artist using the camera in his work. Such
references add to the intrigue that important artists were indeed using the camera obscura, but no hard evidence remains to support these suggestions. In the reference to certain Flemish painters incorporating the effect of the camera in their work, Jombert was actually repeating Gravesande's own observation of the art of his countrymen. Sir Joshua Reynolds had also remarked on the similarity between the camera image and a painting by Jan van der Heyden. Writing in his Journey to Flanders, Reynolds included an annotated list of Dutch painters and their subjects. Of the van der Heyden he noted:

A View of a church by Vander Heyden, his best; two black friars going up steps. Notwithstanding this picture is finished as usual very minutely, he has not forgot to preserve, at the same time, a great breadth of light. His pictures have very much the effect of nature, as seen in a camera obscura. (Quoted in Apers, 1983, p. xvii).

This aspect of Dutch painting as well as what seemed the vulgar nature of subject matter did not impress Reynolds. Dutch preoccupation with what Reynolds called the "naturalness of representation" was for him less than art:

...as their merit often consists in the truth of representation alone, whatever praise they deserve, whatever pleasure they give when under the eye, they make but a poor figure in description. It is to the eye only that the works of this school are addressed; it is not intended solely for the gratification of one sense, succeeds by ill, when applied to another (Quoted in Alpers, 1983, p. xviii).
Reynolds' bias against this kind of representational art was not uncommon. Leonardo da Vinci was a great believer in understanding and copying nature, but to him the painter was also:

a creator; he can draw 'not only the works of nature, but infinitely more than those which nature produces', and he excels nature 'by the invention...of endless forms of animals and herbs, plants and landscapes' (Quoted in Blunt, 1968, p. 37)

Michelangelo shared Leonardo's and Reynolds' opinion that Art was more than skill in imitating nature. Michelangelo's bias was due in part to an attitude of Italian superiority in painting, a view still prevalent today. Nevertheless, he, too, found Dutch painting too mimetic and unselective for his taste:

Flemish painting...will...please the devout better than any painting of Italy. It will appeal to women, especially to the very old and the very young, and also to monks and nuns and to certain noblemen who have no sense of true harmony. In Flanders they paint with a view to external exactness or such things as may cheer you and of which you cannot speak ill, as for example saints and prophets. They paint stuffs and masonry, the green grass of the fields, the shadow of trees, and rivers and bridges, which they call landscapes, with many figures on this side and many figures on that. And all this, though it pleases some persons, is done without reason or art, without symmetry or proportion, without skillful choice or boldness and, finally, without substance and vigour (Quoted in Alpers, 1983, p. xxiii).
This was a strong bias, one which made it difficult for an artist to use the camera obscura, although its use had been recommended by Algarotti because of the precision in imagery, exactness of perspective, and accuracy in representing nature. Algarotti suggested that the young artist do what Jombert said the Flemish had already done, that is, study and copy this effect into their work. Yet, the effect was apparently not without flaws, as Jombert noted. One of these was the fact that the camera obscura did not represent an image the way the eye perceived it. The cause for the discrepancy lay in the fact that the camera was an optical device, and there was historically a distrust of the "truthfulness" of lenses (Ronchi, 1957).

Part of the difficulty lay in the fact that visual deception, particularly by means of lenses and the camera obscura, was such an integral part of natural magic, including Della Porta's outlandish claims which seemed to border on fantasy. Many of the 17th century treatises followed Della Porta's model, although they seemed less exaggerated. These included Kircher, Schott, Schwenter, Heregone, and Zahn, to name a few. Even Robert Hooke presented a Della Porta-type spectacle to the Royal Society in 1668, while Niceron emphasized the deceptive aspect of the camera in his book on perspective. Another aspect was
tied to the increasing chasm between perspective theory developed in the 15th century and the optical theory of vision developed in the 17th century. Alberti's method, which ignored the theory of vision, was based on Euclidean geometry and presupposed a visual pyramid emitted from a point on the surface of one eye. The angle of this visual pyramid was between 30 to 60 degrees. Leonardo abandoned this artificial perspective system as a result of his study of vision, but in the end, also began to distrust the veracity of the eye's optical system. As a more accurate theory of vision developed, particularly in regards to binocular vision, the theories on which perspective had been founded became more glaringly antiquated. The angle of human vision was 45 to 55 degrees; the image was formed inside the eye, on the retina, and was inverted. That the eye received an inverted image caused problems for some writers on perspective. Either they ignored vision altogether in their treatises, which many did; they demonstrated vision but with a corrected image being formed in the eye, which Schwenter did; or they compared the eye to the camera obscura but avoided any connection between the camera and perspective, which Dante did. The fact that the eye was so regularly compared to the camera obscura by optical writers may have be a major factor in understanding
why 17th century perspective writers all but ignored the device. In spite of such biases against its use, surely there were artists who experimented with the camera obscura in spite of its technological limitations. A good deal of attention, although speculative, has been given to the use of the camera by certain Dutch painters, particularly Vermeer, and to the Venetian view painters Canaletto, Bellotto and Guardi. Much of the evidence cited in these arguments has been circumstantial, while "evidence" of optical qualities in paintings by these artists has been contradictory. Issues become even more clouded as references to the photographic image are applied to pre-photographic paintings. In addition, other types of image-forming optical devices including projecting lenses, the concave mirror, and even the ocular system of the artist, have generally been ignored. Optical qualities, for example in Vermeer's painting, could have been caused a number of optical devices besides the camera.

The case of Vermeer is particularly difficult in relation to the technical development of the camera obscura. There is some disagreement among historians not only in dating Vermeer's work but also with attribution. Of the approximately 37 paintings thought to have been done during a twenty year period, from the early 1650's to the
early 1670's, only two were dated by Vermeer. Those paintings assigned to the period of the 1660's, historians have suggested, were influenced in some way by the use of optical aids. Of the optical devices cited, it is the portable reflex camera obscura most often associated with Vermeer's paintings.

While Vermeer could have known about the conventional room device or the portable "conclave" or "lantern" camera, it is doubtful that he could have known about and utilized the box-type reflex camera. The two earliest published works which mentioned this type of reflex camera, Sturm's Collegium experimentale sive curiosum and Zahn's Oculis artificialis telediopicae sive telescopium, were both published after Vermeer's death in 1675. Both of these works used the reflex camera to demonstrate the function of the eye.

It is possible that Vermeer used a "conclave" camera for the interior views, but this would seem unlikely, as there is little evidence to support the notion that he traced or painted directly from the camera-formed image. Regarding the optical qualities in Vermeer's paintings attributable to the camera, it has been noted:

Of the list of ten phenomena put forth by the most comprehensive study of this kind only one has been generally accepted. It would appear that those small globules of paint that we find
in several works...are painted equivalents of the circles of confusion, diffused circles of light, that form around unfocused specular highlights in the camera obscura image (Alpers, 1983, pp. 31-32).

Such an optical effect, the blurring specular highlights or circles of confusion, would occur with any image-forming instrument including the camera, but this effect can only occur where bright highlights reflect off mirror-like surfaces such as polished metal. In Vermeer's paintings, however, these globs of paint are found in cloth, bread, mortar, wood, that is, on objects where specular highlights cannot be optically formed. This effect of globby highlights is not unique to Vermeer. A similar painting treatment can also be found in works by Rembrandt, Willem Kalf, Abraham van Beyeren, and Nicolas Maes. None of these artists, however, have what can be called an "optical" style of painting. Another Dutch artist, Carel Fabritius, is thought to have used some optical device to paint A View of Delft, with a Musical Seller's Stall, signed and dated 1652. This work demonstrates an unusual optical perspective but has no evidence of Vermeer's globby highlights (Wheelock, 1977).

It would seem, however, that Vermeer did incorporate an optical effect in his painting, deliberately using some type of faulty optical system and exaggerating those faults
to the extreme. Wheelock (1977), in his study of Dutch painting during this period, has suggested that both Vermeer and Fabritius made use of a double concave lens.

Historians of photography in this century have generally tied the invention of photography to the development of linear perspective in the 15th century Italian Renaissance. Technically, "photography is nothing more than a means for automatically producing pictures in perfect perspective" (Galassi, 1981, p. 12). This premise has lead to the notion that the popularity of the camera obscura was indicative of a desire for pictorial realism, which in turn culminated in the invention of photography. This popular use of the camera by artists, however, also indicated that "photography was not a bastard left by science on the doorstep of art, but a legitimate child of the Western pictorial tradition" (Galassi, 1981, p. 12). Photography was, as perspective, a blending of both science and art, but in the case of photography, it has been imperative to firmly establish photography's role in art.

Since the history of the camera obscura has traditionally been approached as a chronology of the technical developments of the tool, it has been relatively easy for a paranoia to develop on the part of photographic historians regarding the schizophrenic nature of
photography. At first glance, the implications of this study might be seen as reinforcing that "either/or complex" and undermining the circumstances surrounding the legitimacy of photography's "birth." It is hoped, however, that the broader implications of this study will lead to a reassessment of photography's development, both preceding and after its invention, to permit a more rational understanding of the medium in all the roles it performs.

The *camera obscura* was a drawing tool of the astronomer long before the invention of linear perspective. It functioned in many roles in the history of science long before it was suggested as a drawing tool for "those ignorant of the art." While it is mentioned often in the optical and popular literature of the 16th through 18th centuries, there is very little hard evidence to support the broad and generally accepted claims that the *camera obscura* was widely used by artists since the 16th century. Numerous biases against its use as a drawing tool existed, including a mistrust of optical devices, due in part to the poor quality of the optics as well as their deceptive nature; the precision and ease in which the *camera* so readily represented nature; and a theoretical discrepancy between the principles of perspective and the nature of vision, which the *camera* demonstrated. This study suggests
that the technology of the camera obscura was not adequately developed until the later half of the 17th century, and was not perfected until the early 19th century. By the time the camera became a viable tool for drawing, it was adapted to the photo-chemical process of image making called photography. Who knows what might have happened to the camera as a drawing tool had it been perfected earlier or the chemical part of photography had been developed much later. Gernsheim has observed:

Considering that knowledge of the chemical as well as the optical principles of photography was fairly widespread following Schulze's experiment [the darkening of silver salts by light, done in 1725]—which found its way not only into serious scientific treatises but also popular books of amusing parlour tricks—the circumstances that photography was not invented earlier remains the greatest mystery in its history (Gernsheim, 1969, p. 13).

The difficulty with this thinking is in assuming that because something is in print people know about it, understand its ramifications or see greater implications. Very simply, much of the pre-history of photography was tied to spectacular entertainment, parlour tricks, deception, amusement. That the chemical and optical aspects were indeed finally brought together in the invention of photography may be the greatest mystery. This study suggests that the camera obscura may never have been an integral part of the artist's tool box. Rather, it
began as a drawing tool of the astronomer, continued as a drawing tool in the mechanical arts and drawing crafts, and finally, was popular with 18th century "pictorial tourists," the equivalent of today's Instamatic and Disk camera toters. The fact that other drawing devices continued to be developed, including Wollaston's camera lucida in 1806—a very popular device with the "dilettante"—may further support the notion that the camera was not as convenient or easy to use as previously thought.

If this is indeed the case, that the camera obscura did indeed lie outside the mainstream of "high art," it does not necessarily follow that the camera was an insignificant or second rate tool, or that photography must therefore be an outsider. Proof that a recognized artist utilized the camera obscura neither lessens the importance of that artist's work nor adds validity to the tool in the tradition of picture making. That the camera had an important role in the history of optics and astronomy prior to the invention of photography, does not necessarily mean that the photographic camera has no importance in art today. The camera obscura was only a tool, but importantly, one that did not reach it full potential in the visual arts until after the invention of photography.
REFERENCES


APPENDIX

Chronology

<table>
<thead>
<tr>
<th>Century</th>
<th>Event</th>
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<tbody>
<tr>
<td>4th Century BC</td>
<td>Earliest recorded description of image formation through an aperture found in Aristotle's <em>Problemata</em>.</td>
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<tr>
<td>9th Century AD</td>
<td>The Arabs and Chinese speculate about image formation.</td>
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<tr>
<td>11th Century</td>
<td>The Arab Alhazen correctly explains image formation; however, the West is deprived of his theories.</td>
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<tr>
<td>13th Century</td>
<td>Western scholars Roger Bacon, Witelo and John Pecham theorize about image formation through multi-angular apertures.</td>
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<tr>
<td>14th Century</td>
<td>The <em>camera obscura</em> becomes a standard tool for solar observation; 13th century writings are questioned.</td>
</tr>
<tr>
<td>15th Century</td>
<td>Leonarño da Vinci utilizes the <em>camera obscura</em> in his studies on light, vision and color.</td>
</tr>
<tr>
<td>16th Century</td>
<td>Earliest published account of the <em>camera obscura</em> (1521); physical modifications include the addition of a lens (Cardano, 1550) a mirror to correct the inverted image (Della Porta, 1558) and a diaphragm (Barbaro, 1569); the <em>camera</em> is recommended as a drawing tool; earliest published illustration of the <em>camera obscura</em> (1545).</td>
</tr>
<tr>
<td>17th Century</td>
<td>Johannes Kepler and Francesco Maurolyco theorize correctly on image formation through apertures; astronomers adapt the telescope to the astronomical <em>camera</em>; writers on optics demonstrate the theory of vision with the <em>camera</em>; earliest portable <em>camera</em> recorded in Risner's <em>Optica</em> (1606); portable reflex viewing <em>cameras</em> available by 1676 (Sturm).</td>
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18th Century Viable portable drawing cameras such as the sedan chair (1711) and reflex boxes (1723) become popular; "pocket" cameras available (1775); mention of the camera obscura is found in encyclopedias and in popular literature such as poetry and novels; achromatic telescopic lenses become available (1758); Thomas Wedgewood experiments with chemically recording the camera formed image (1799).

19th Century Wollaston introduces the camera lucida (1807) and the meniscus lens for the camera obscura (1812); Niepce (1820's), successfully records the image of the camera obscura by chemical means; Talbot, Herschel (England), Daguerre and Bayard (France) invent a photographic process in the late 19th's; August 1839 the daguerreotype process is made public; 1840 the camera is manufactured for photographic purposes.
BIBLIOGRAPHY

I. PRIMARY SOURCES

A. MANUSCRIPTS


B. PRINTED WORKS


Bacon, Roger (1750). Opus Majus ad Clementem IV. Venetiis: Franciecum Pitteri.


Bacon, Roger. See Bridges, Burke.


Boyle, Robert. (1663). *Some Considerations Touching the Usefulness of Experimental Natural Philosophy*. Oxford: Oxford University.


Cardano, Girolamo. (1559). *De Subtilitate Libri XXV.* Lugduni; Gulielmo Rouillum.


Della Porta, Giovanni Battista. (1558). Magia Naturali, sive de miraculis rerum naturalium libri IIII. Neapoli: M. Cancer.


Fabricius, Johann. (1611). *De Maculis Sole Observatis.* Wittenbergae: Laurentij Seuberlichij.


Hooke, Robert. (1668). A contrivance to make the picture of anything appear on a wall, cupboard, or within a picture frame, etc. in the midst of a light room in the daytime, or in the night time in any room which is enlightened with a considerable number of candles. In *Philosophical Transactions of the Royal Society.* (No. 38) 2, 269-70.

Hooke, Robert. (1726). An instrument of use to take the draught or pictures of anything (Dec. 19, 1694). In *Philosophical Experiments and Observations of the Late Eminent Dr. Hooke.* London: Innys.

Hooper, William. (1755). *Rational Recreations, in which the Principles of Numbers and Natural Philosophy are Clearly Elucidated*. London: Davis and Robson.


London: Senex.

Firenze: Pagani.


Roma: Istituto di Storia della Medicina dell'Università di Roma.


Leurechon, Jean. (1626). *Recreation Mathematique.*
Font-a-Mousson: Jean Appier Hanzelet.

Vinezia: Domenico Giglio.

Parisiorum: Thomam Blasie.


Martin, Benjamin. (1742). *Micrographia Nova, or a new Treatise on the Microscope & Microscopic objects, to which is added, an Account of the Camera Obscura*. Reading: J. Newbery.


Maurolico, Francesco. See Crew.


Porta, Giovanni Battista della. See Della Porta.


Storer, William. (1782). *Storer's Syllabus to a course of optical experiments, on the syllepsia optical: or the new optical principles of the Royal Delineator Analysed*. London.


Walpole, Horace. (1762). *Anecdotes of Painting in England with some accounts of the principal artists; and incidental notes on others Arts; collected by the late Mr. George Vertue*. Strawberry-Hill: Thomas Farmer.

Witelo. (1535). *Vitellionis mathematici dotissimi...id est natura, ratione e projectione radiorum visus, luminum, colorum...quam perspectivam*. Norimbergae: I. Petreium.


**II. SECONDARY SOURCES**


Bacon, Roger. (1816). *Famous Historie of Fryer Bacon, containing the wonderful things that he did in his life, also the manner of...death*. London: Francis Grove.


Daniel Matteo Barbaro. In the Enciclopedia Italiana Biographica. (pp. 89-95). Roma.


The Camera Obscura. (1903, January). In *The British Journal of Photography* (pp. 18-20).


Court, Thomas and Von Rohr, Moritz. (1935, Feb.). On Old Instruments Both for the Accurate Drawing and the Correct Viewing of Perspectives. In *The Photographic Journal*. (pp. 54-66).


Narducci, Enrico. (1871). *Intorno ad una Traduzione Italiana fatta ne secolo XIVo del Trattato d'Ottica d'Alhazen*. In Bullettino di Bibliographica e di Storia di Scienza, Mathematiche e Fisiche. IV, 1-5.


Thorndike, Lynn. (1955; 1958). Notes upon some medieval Latin astronomical, astrological and mathematical manuscripts at the Vatican. In Isis. 47(150); 49(155).


Wiedemann, Eilhard Ernst Gustav. (1910b). Über die Erfindung der Camera Obscura. In Verhandlung der deutschen physikalischen Gesellschaft. 12, 177-182.


