Vermeer and the Camera Obscura: Some Practical Considerations

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ABSTRACT

The remarkable precision of linear perspective in Vermeer's paintings has led to the claim that he used a "room-type" camera obscura. However, the most readily available convex lenses available in the seventeenth century were those used for spectacles; these lenses had diameters of about 4 cm. The author shows that the use of such lenses in a large-scale camera obscura results in images of interior scenes that are too dim for effective visual inspection. Problems of inversion, reversal and depth of focus further complicate the images. It is concluded that Vermeer could not have traced his interiors directly at full size from the screen of a camera obscura. Vermeer's composition and approach to linear perspective could have been stimulated by use of a small camera obscura, but his final works must have been painted right-side up and in good light.

Toward the end of the nineteenth century, when photography was gaining in widespread use [1], J. Pennell pointed out that the paintings of Johannes Vermeer of Delft (1632–1675) exhibited a certain "photographic quality" [2]. This observation has been extended over the years, with several historians of art proposing that Vermeer was familiar with the camera obscura [3–10]. Generally, this proposal was accepted to mean that the artist could have been stimulated by the composition, coloring, perspective and other characteristics of the optical image. However, the end-point of the progression—the claim that Vermeer actually traced many of his works from the screen of a "room-type" camera obscura—was reached in 1995 by Steadman [11] and Williams [12].

Linear Perspective and the Camera Obscura

Perhaps the major characteristic that gives rise to the photographic quality noted in Vermeer's works is the remarkably perfect linear perspective displayed by many of his interior scenes. The orthogonals defined by floor tiles, window frames and beams converge very closely upon the point demanded by theory [13–15], as is illustrated in Fig. 1. Freehand painting and drawing, unless aided in some way, does not approach this accuracy. A photograph taken with a modern camera does, however, normally exhibit perfect geometric perspective [16,17], so nowadays we associate the phenomenon of photography with "realistic" planar representations of three-dimensional (3D) objects and scenes. There are, however, several graphical methods of creating a picture in true perspective, so its presence is no proof that a camera was used.

Silver-based photography was invented long after Vermeer's time [18], but some form of camera obscura with a directly viewable screen could have been available to him [19]. Certainly the science of optics was making great advances in the Netherlands around this time, with Constantine Huygens; his sons Constantine, Jr., and Christiaan; and Anthony van Leeuwenhoek as leading makers and users of lenses. (There is no evidence, however, that van Leeuwenhoek ever made more than tiny short-focus lenses for microscopy.)

Unlike the photographic cameras of the present century, the earliest camera obscuras incorporated only a simple single convex lens. It is the purpose of this article to examine whether such apparatus could have given images of sufficient quality to permit direct application to the production of works of art.

Orientation of Real Images

The history of the camera obscura is the subject of a book by J.H. Hammond [20]; technical treatments have been given by M. Kemp [21] and M.H. Pirenne [22]. The origin of the camera obscura is generally accepted to have literal accordance with its name: beginning with the use of a small hole to allow light from a sunlit external scene to enter a dark room to form an inverted real image upon a receiving screen (Fig. 2).

If a small image is thrown in this way upon an opaque white card, then the outlines of major objects in the exterior scene can be traced on the card. The image will be inverted top-to-bottom and backwards with respect to the real scene. A 180° rotation of the image will correct the inversion, but it will remain a mirror image of the real thing [23]. Only if the image is traced upon thin translucent paper (rather than an opaque white card), and the sketch is subsequently inverted and viewed from behind, will the image match the original object. (This procedure is analogous to the procedure followed when printing a negative produced by a modern camera.)

The "reflex" camera obscura incorporates a plane mirror at an angle (usually 45°) to the optical axis and was commonly made in a portable box-like form [24]. It was first illustrated by Zahn [25] in 1685, but he does not claim to have invented this version. Such an obvious modification could well have been known in Vermeer's time [26]. This apparatus produces an image the right way up, but reversed left to right. Again, a sketch of the image must be viewed from the rear or in a mirror to give a correct orientation. Thus, if Vermeer's pictures were conceivably painted upside down, they would still exhibit left-to-right mirror inversion when turned 180°. The maps and recognizable pictures hanging on the far wall in many of his works are, however, correctly oriented.

The Purpose of Lenses

Images Produced by Pinholes

The light that creates the camera obscura's image must enter through an aperture. The smaller this hole and the larger the inverted image, the lower will be the intensity of the image. Making the hole larger will increase the brightness of the image, but also reduce its definition because a large hole acts as a spatially distributed set of smaller holes. In early engravings

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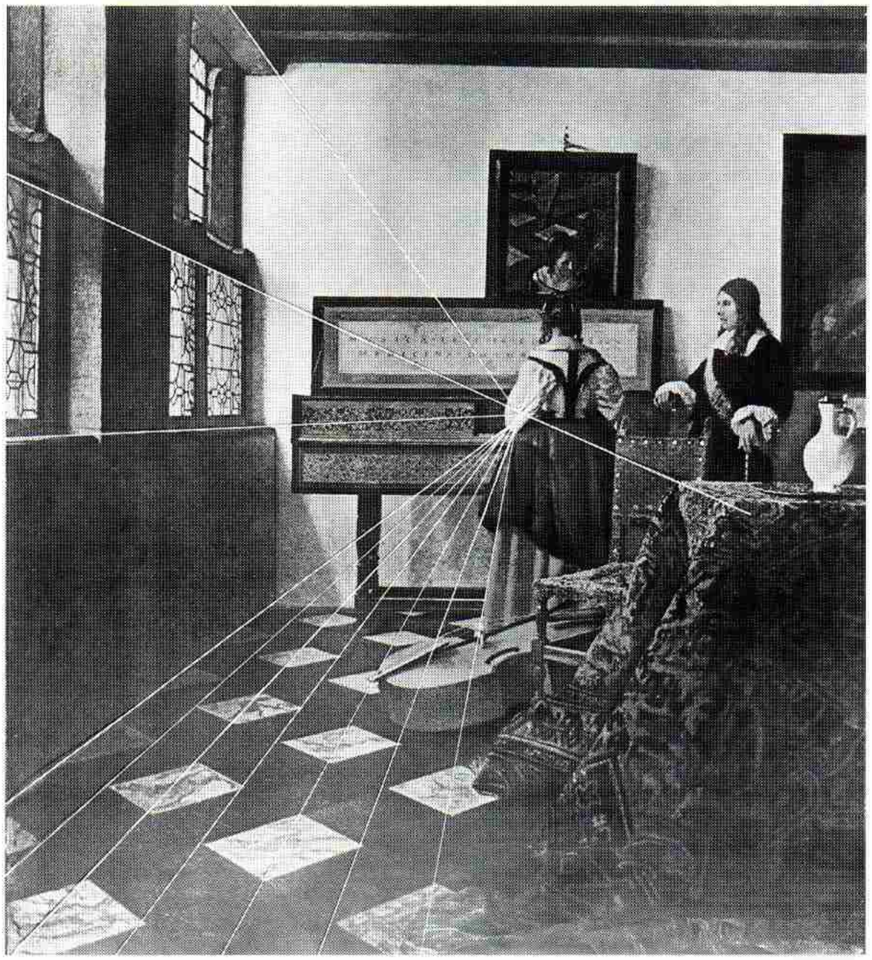


Fig. 1. Johannes Vermeer, *The Music Lesson*, sometimes entitled *A Lady at the Virginals, with a Gentleman*. Orthogonals have been superimposed upon a photograph of the original painting, which hangs in Windsor Castle (Catalog No. CW 230). (The Royal Collection ©, Her Majesty Queen Elizabeth II.)

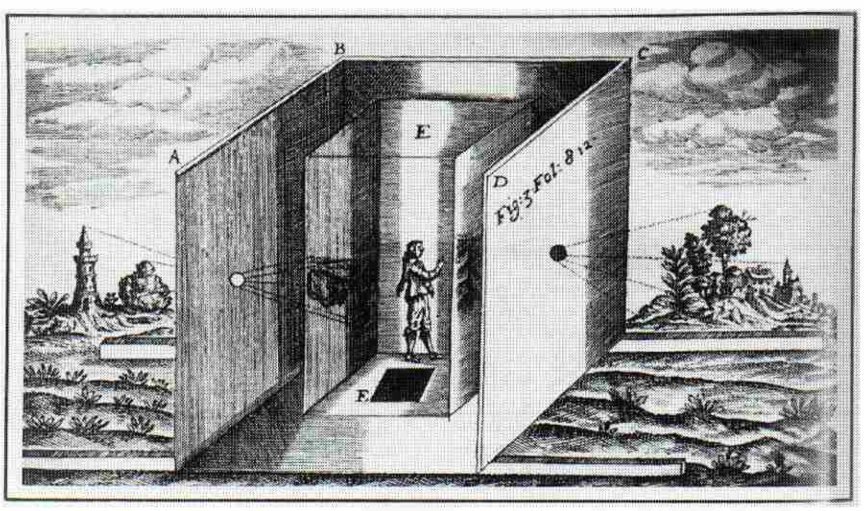


Fig. 2. The room-type camera obscura, as illustrated in Kircher's *Ars Magna* of 1671 [53]. The extremely low intensity of light associated with such a large image has been ignored by the illustrator.

depicting the camera obscura, the apparatus is always shown as a small hole in the wall of a totally blacked-out room, throwing an image of a brilliantly sunlit scene or exterior object. However, the life-sized images featured in many engravings (for example, as shown in Fig. 2) must not be taken literally: at such a scale they would have been too dim to be seen.

To quantify this point, I conducted tests in a blacked-out attic room to which light from a brightly sunlit landscape and sky could be admitted by holes of various sizes punched in pieces of black paper. I found that a true pinhole (0.8 mm in diameter) allowed so little light to enter that it was necessary to receive the inverted real image upon tracing paper and view it from the rear by transmitted light. (This results in less loss of light than scattering from opaque paper.) Definition was quite good, but little could be perceived when, at a distance of a few centimeters, the image exceeded 10 cm in diameter on the tracing paper. This is equivalent to an increase in area relative to the pinhole of some 15,000 times. The exception was the image of the sun itself, the brilliance of which enabled the production of a reasonable 25-mm-diameter image of its disc at a distance of 2.5 m from the pinhole (a pinhole has no specific focal length).

As expected, increasing the size of the aperture enhanced the intensity of the image at the cost of resolution. A hole 4.5 mm in diameter seemed the best compromise, producing a slightly fuzzy image about 60 cm wide upon a white card held 40 cm away. Vermeer's *View of Delft* is 117 cm wide and thus would have been very dim if imaged at this size, and all fine detail would have been lost. To summarize, pinhole images of interior scenes are impracticably dim, even if very small in area.

Images Produced by Lenses

A brighter image requires a larger aperture to allow more light to enter, the resulting illumination being proportional to the square of the diameter of the hole. A convex lens must, however, be fixed within the aperture to restore definition by directing the light coming from any given element of the scene to a corresponding point of the inverted real image.

LENSES

Extensive research conducted by E. Rosen [27] led him to conclude that spectacles were first used in Tuscany be-

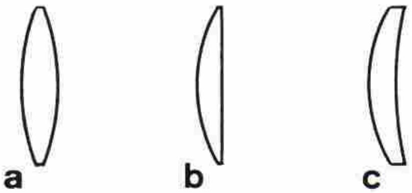


Fig. 3. Sections of simple spherical converging lenses: (a) biconvex, (b) plano-convex, (c) convex meniscus.

tween A.D. 1280 and 1285. A trade soon sprang up to manufacture a range of lenses for spectacles. Lenses depend on the refraction of light through transparent media bounded by curved surfaces. Curves that are parts of spheres are the easiest to generate in quantity [28], so the vast majority of lenses were spherical in nature.

Spherical and planar surfaces may be combined in lenses in a number of ways (Fig. 3). A section that is thickest at the center is generically a positive, converging or convex lens. It acts as a magnifying glass and produces a real inverted image by projection. Shapes that are thinnest at the center are negative, diverging or concave lenses; these act as diminishing glasses and give rise to exit rays diverging from a virtual focus.

The earliest spectacle lenses appear to have been biconvex lenses, perhaps approaching plano-convexity in the lowest powers. These would be needed to correct the lack of accommodation (presbyopia) associated with age, their convergence supplementing that produced by the cornea and natural lens of the eye to allow the wearer to see near objects distinctly—a necessity for reading, for example. These spectacles would be removed at other times. The opposite condition—short-sightedness or myopia—is relieved by spectacles containing concave lenses. Concave lenses appear to have been manufactured in Florence from at least the middle of the fifteenth century [29].

The meniscus lens is convex on one side and concave on the other (see Fig. 3c). Its genesis is unclear. An application of a lens of this form is mentioned in a matter-of-fact manner by Leonardo da Vinci [30] in a note in the Codex Windsor, written circa 1506–1508. However, it was claimed as an invention by Wollaston [31] in 1803, when he recommended it as the best shape for spectacles, naming it the "periscopic" lens. This claim was immediately challenged by Jones [32], who wrote that it was no more than the "common meniscus" and was no better than the usual biconvex or concave product. That Wollaston was at least right in stating that the meniscus is better adapted to the movement of the eyeball is borne out by the fact that modern spectacle lenses are normally of this form.

Focal Length and Depth of Focus

We have seen that a convex projection lens is essential to overcome the lack of definition in the image produced by a small hole. However, unlike a pinhole, a lens possesses a definite focal length, to which it directs parallel light rays coming from an object at a great distance (theoretically infinity). Nearer objects will be focused at a distance greater than the focal length.

Perspective reconstructions of scenes represented in a number of Vermeer's interiors have been drawn by P.T.A. Swillens [33] and P. Steadman [34]. In these, the position of the lens of a hypothetical camera obscura is indicated by the point where lines defining the angular field of view intersect. Swillens states in his text [35] that the marble floor tiles depicted in Vermeer's interiors may be taken to have an actual diagonal dimension of 40 cm, so the focal length of a simple lens placed at the intersection point and assumed to be focused on the rear wall may be calculated by the standard thin-lens equation:

$$1/f = 1/u + 1/v$$

where f is the focal length, u is the distance from lens to object, and v the distance from the lens to the image. Values for f found in this way are shown in Table 1: they vary from 60 to 113 cm. It seems unlikely that Vermeer would have access to, or have chosen to use, so many different lenses. The perspective reconstructions also show a wide range of angular fields of view varying from 28° to 50°.

A related problem is that it is impossible to focus on all parts of a 3D scene at the same time. No matter how good the lens, foreground objects would be out of focus if the lens were focused on a far wall. Re-focusing the lens on differ-

Fig. 4. Planar image formed by a symmetrical biconvex lens, the type of lens most likely to have been available to Vermeer.

Table 1.Optical characteristics calculated to apply if lenses were used to image, at full size, some of the scenes painted by Vermeer.

Title	Angle of view (degrees)	Derived focal length (cm)	f number
From Steadman [54]:			
The Music Lesson	48	60	15
The Concert	38	71	18
Lady Writing a Letter with her Maid	28	92	23
A Lady Standing at the Virginals	28	77	19
A Woman and Two Men	35	73	18
The Glass of Wine	35	73	18
From Swillens [55]			
The Music Lesson	50	65	16
The Love Letter	44	61	15
Allegory of the Faith	38	113	28

ent areas in a scene would lead to changes in magnification and therefore of apparent size.

Luminosity of the Image

The lenses available to the impecunious Vermeer would almost certainly have been spectacle lenses around 4 cm in diameter, although a few skilled craftsmen were capable of making larger lenses as objectives for expensive telescopes. A positive spectacle lens of 66 cm in focal length (+1.5 diopters in modern terminology) would be representative of those listed in Table 1 and would be a likely stock item for spectacle makers of any period.

The intensity of the image produced by a lens is controlled by its *f number*, defined as the ratio of focal length to effective diameter. The lower the f number, the brighter the image of a given scene. In the above example this parameter would be close to f16. I experimented with an early photographic lens incorporating a calibrated iris diaphragm, throwing an image upon the ground glass of a plate camera that was then viewed from beneath a black cloth. At f16, the image of an exterior scene in bright sunlight was just about visible, but that of an interior (where the illumination was reduced by a factor of between 30 and 100) was hopelessly faint. Neither Vermeer nor anyone else would have been able to see it clearly. Most of the deduced f numbers in Table 1 would have resulted in even more unfavorable conditions for tracing images. It must be remembered that photographic emulsion integrates, or builds up, light, allowing the exposure of an image to be lengthened to compensate for the weakness of a light source, but the eye does not work in this way.

Vermeer would not have had a carefully designed multi-element lens available to him. While a simple lens can fairly easily be made with a large diameter to gather more light, its low f number results in reduced depth of focus and an increase in a host of aberrations and distortions.

Fig. 5. Planar image formed by a plano-convex lens, curved side out. This form of lens might have been known to Vermeer.

Aberrations of Simple Lenses

The spherical and chromatic aberrations produced by a simple lens acting as the objective of a refracting telescope are well known. However, this primitive telescope has such a narrow field of view that its images are almost on axis. A simple lens used to image a wide field, where peripheral incoming rays are at appreciable angles to the optic axis, can exhibit many additional defects: these include coma, astigmatism, field curvature and vignetting [36]. All contribute to degradation of the image and were thus of great concern to the makers and owners of camera obscuras [37–39] and, to an even greater extent, the first photographic cameras [40–42]. Wollaston's 1812 recommendation [43] of a convex meniscus lens, placed hollow side out and preceded by a diaphragm, was adopted by Chevalier [44] for his first daguerreotype cameras.

Modern photographic and video camera lenses are far from simple, embodying at least two sets of lenses grouped around an adjustable iris diaphragm [45–47]. This arrangement reduces image distortions. The near-perfect image produced by such a highly evolved system is no guide to the performance of a simple lens, so I adopted an experimental approach to determine what the various forms of the latter could do.

Simple Lenses and the Portable Camera Obscura: Image Quality

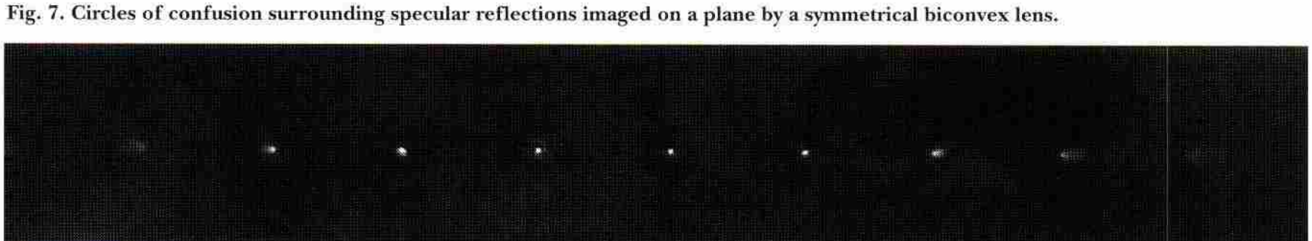
The requirement of transportability limits the focal length of the lens in a portable camera obscura to about 30 cm, for the minimum distance between an object and its real image is 4 times the focal length. A simple lens with a diameter of 4 cm would then give an f number of f7.5. The ground-glass receiving screen might be around 25 × 20 cm (10 × 8 in), leading to an angular field of 56°. My replica camera obscura using these parameters produced an image of a sunlit exterior scene that was impressively superior in brightness to that observed when the lens was stopped down to f16 (see above). Even interiors were now viewable if the sun was shining brightly through nearby windows and a black cloth was placed over the head to exclude extraneous light. A problem, however, was that the definition of the image degraded with distance from its center.

To obtain a record of this, one would ideally replace the ground glass with a photographic plate. Unfortunately, such plates are no longer made, and cut film of this size, and its processing, is expensive. Therefore, I used modern biconvex, plano-convex and meniscus glass lenses (see Fig. 3) of 15-cm focal length to form images upon standard 12.7 × 10.2 cm (5 × 4 in) cut film to capture the same angle of view. I fixed each lens in turn over a 2-cm aperture (to give f7.5) in the lens board of a technical camera and adjusted each for optimum focus at the center of the ground glass before inserting a film holder and making an exposure. One of the test objects I photographed was a brightly lit commercial color reproduction (49 × 42 cm) of *The Music Lesson*. The use of this two-dimensional object allowed me to avoid the potential focusing problems that would be presented by a real scene.

Fig. 6. Planar image formed by a meniscus lens mounted concave side out with an external diaphragm as recommended by Wollaston in 1812 [56]. This is the best image possible with a simple lens, but of a form that was not available to Vermeer.

The results obtained with symmetrical biconvex, plano-convex and meniscus lenses are shown in Fig. 4, Fig. 5 and Fig. 6 respectively. Of these, I believe Fig. 4 approaches most closely that which Vermeer might have seen through a portable camera obscura of his time. Note how the various aberrations (particularly the curved nature of the image field) give rise to an out-of-focus effect that increases radially toward the perimeter of the image. A similar out-of-focus appearance of the lion's head finials in Vermeer's *Girl With a Red Hat and Girl With a Flute* has frequently attracted comment, as have the out-of-focus foreground threads in *The Lacemaker*. In other tests with the same set-up, I also generated specular reflections by shining a compact-source lamp (simulating the sun) upon small ball bearings glued across a piece of black-painted hardboard. The result is shown in Fig. 7, in which comet-like "circles of confusion" resulting from imperfect imaging are apparent. Claims have been made that such circles appear in some of Vermeer's works (e.g. *View of Delft*).

Fig. 7. Circles of confusion surrounding specular reflections imaged on a plane by a symmetrical biconvex lens.



CONCLUSIONS

It would not have been possible for Vermeer to have painted his interior scenes directly, at full size, from images produced by a room-type camera obscura incorporating the lenses of his time. Such images would have been much too dim and in any case would have been mirror images of the real scene. However, Vermeer could have observed—and even been stimulated to sketch—the more brightly illuminated images produced at a smaller scale by a portable camera obscura. Aberrations are inevitable with simple single lenses imaging a wide field, and phenomena associated with such aberrations appear to occur in some of the artist's works. The veracity of his perspective would not have necessitated a camera—in fact, Vermeer's accurate perspective argues against his use of a camera, for single-lens aberrations also cause blurring and distortion of the orthogonals.

I believe that Vermeer painted his canvases right-side up and in good light, first laying out a perspective grid according to the graphical methods then taught by his fellow countrymen de Vries [48] and Hondius [49]. These conclusions agree with the most recently published opinions of Vermeer specialists [50] and with recent x-ray evidence [51]. This technique shows signs of local overpainting and the presence of tiny (filled) holes in the foundation layer at the vanishing points of several of his interiors, where temporary pins may have held taut threads to define the orthogonals of the scene.

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