# A simple and effective 'first' optical image processing experiment

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**Abstract**: Optical image processing experiments can contribute to an understanding of optical diffraction and lens image formation. We are trying to discover a highly effective way of introducing lens imaging and related topics, light scattering, point sources, spatially coherent light, and image processing, in a laboratory-based holography-centered introductory optics course serving a mixture of physics, chemistry, and science education sophomores and juniors. As an early experiment in this course, a microscope slide bearing opaque stick-on letters forming a word such as PAL is back-lighted by a point source of laser light. The surround for the letter A is transparent, while the surround for the letters P and L is made translucent with Scotch MAGIC$^{TM}$ tape. A 20-cm focal length converging lens forms a bright image of PAL on a screen, and also an image of the laser point source in a (transform) plane between the lens and the screen. Students are startled when they see that they can choose to pass only the image of the letter "A" or only the images of "P" and "L," by very simple manipulations in the transform plane. The interpretation of these experiments is challenging for some students, and the experiments can lead to a significant amount of discussion. Useful explanatory ray diagrams will be presented. Many demonstrations of optical image processing require long focal length lenses and precise manipulation of somewhat complex passing/blocking filters. In contrast these experiments are easy to set up and easy to perform. Students can fabricate the required objects in a matter of minutes. The use of zero-order laser light helps students discover the essential simplicity of the ideas underlying image processing. The simultaneous presence of both scattered (spatially incoherent) and not scattered (spatially coherent) laser light is thought provoking. Current explorations to further develop these and other closely-related experiments will also be described.

## 1. Introduction (Purposes, Related literature, related methods; outline of paper)

Our objective is to introduce students to lens imaging in the context of optical image processing. In addition students are introduced to light scattering (clean glass versus translucent tape), point sources. Better students discover basic ideas about depth of focus as influenced by aperture diameter. The experiments described were created for use in a laboratory-based holography-centered introductory optics course serving a mixture of physics, chemistry, and science education sophomores and juniors. The experimental apparatus and experimental procedures described introducing lens imaging in the context of optical image processing. The author believes the apparatus and procedures described are simpler than any described elsewhere. Because of this simplicity, they can be used with almost no previous experience with lens imagine. Despite this simplicity, they seem very effective as an introduction to optical image processing.

Optical image processing is introduced in most sophomore-junior level optics texts[1]. A second source of information on optical image processing and optical diffraction is a set of lab experiments authored by Arthur Eisenkraft, and distributed for many years by the Metrologic Corporation. These materials are still available through the company Industrial Fiber Optics[2]. A very attractive apparatus for teaching optical image processing is the house diffraction plate, an apparatus created by Ronald Bergsten, at the University of Wisconsin, Whitewater. The Bergsten diffraction plate is based on a diffractive method of color imaging first described by J. D. Armitage and A. W. Lohmann[3]. Our method is simpler to implement than any of the previously described methods. Also, since it uses zero-order laser light, and no diffraction grating, it is easier for the beginning optics student to grasp. In previous experiments, the distinction is between low-spatial frequency and high-spatial frequency diffraction gratings. In our method, the distinction emphasized is between scattered laser light (spatially incoherent laser light) and non-scattered spatially coherent laser light. The objects utilized are microscope slides with attached opaque letters, and Scotch Magic$^{TM}$ tape. A razor blade or thumbtack serves well filter. The manipulations are not 'critical' or stressful.

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The experimental arrangements, and the basic phenomena, are described in some detail in Section 2. In Section 3 diagrams that are useful for interpreting the results are discussed. In Section 4 comments are made on how this apparatus relates to previous experiments, and how the objects described in this report might be further elaborated.

## 2. Experimental procedures and results

### *2.1. Objects used*

In Figures 1 and 2 examples of objects used are shown. Figure 1 shows the word ALE affixed to a 25 mm by 75 mm microscope slide. The three letters are formed by opaque stick-on (or dry-transfer) figures. Words containing a 'pointing' letter, like the letter A, work well to highlight when an image has, or has not, been inverted. In our experiments two of the letters had a translucent surround, and one had a transparent surround[4]. The translucent surround was fabricated by covering the letters L and E, and the surrounding region, with Scotch MAGIC$^{TM}$ tape. See the L and the E in Fig. 1 and the W and the G in Fig. 2, as examples. However, the letter 'A' had a transparent surround. The transparent surround was arranged simply by placing no tape over the letter or its surrounding region, and by keeping the glass clean, to minimize light scattering. See the letter 'A', in ALE in Fig. 1 and the letter 'A' in WAG, in Fig 2, as examples.

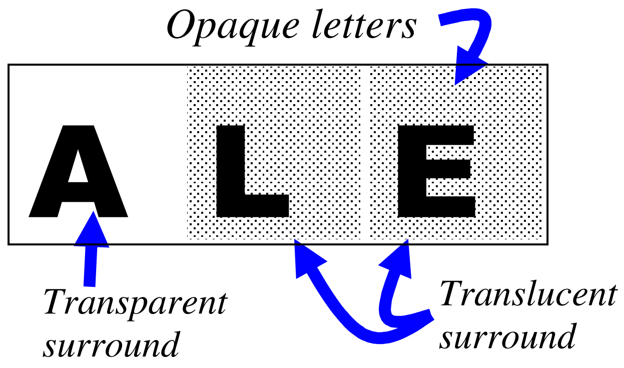


Figure 1 An example of a translucent-transparent object.

The strong scattering characteristic of the Scotch MAGIC$^{TM}$ tape, and the lack of scattering by the clean microscope slide, are demonstrated in Fig. 2. A photograph is shown of a back-lighted transparent-translucent microscope slide, bearing the three figures W, A and G, formed by placing a camera at a slightly off-axis location. The letters with a translucent surround are highly visible, while, in a darkened room, the letter "A," which has a transparent surround, has low visibility.

Fig 2. Photograph of the back-lighted translucent-transparent object shown on right.

### *2.2. Experimental arrangement*

Figure 3, below, shows the basic experimental arrangement. For clarity, the system is shown twice in Fig. 3. In 3a), the light rays that have been scattered by the translucent tape on the microscope slide are emphasized. In 3b the light rays that pass through the transparent regions of the slide are emphasized.

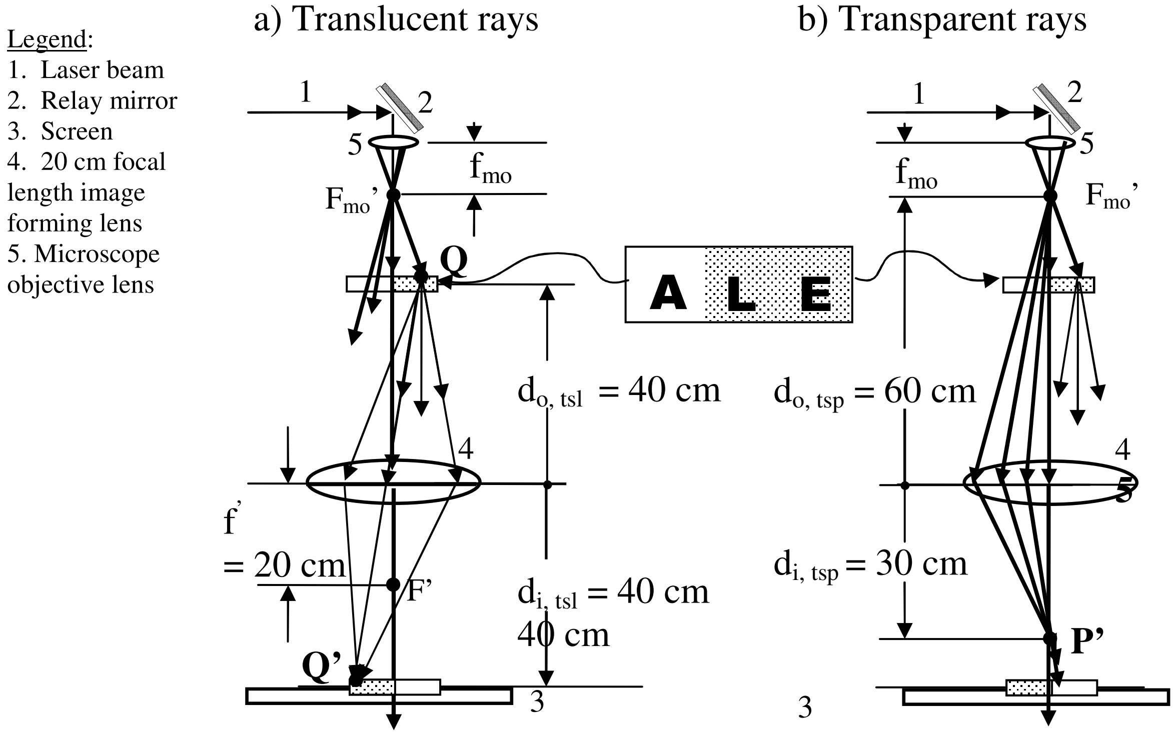


Figure 3. Translucent light rays (3a) and transparent light rays (3b) are shown. Both types of rays transit the system simultaneously. For the purpose of clarity, two drawings are introduced.

We will refer to light that has been scattered by the translucent tape as "translucent light." We will refer to light that has not been scattered by its passage through the microscope slide as "transparent light," because it has passed through one of the transparent regions of the microscope slides.

Two different object distances are involved in this optical system. The point source of the transparent light is at a different distance from the lens than the point sources of the translucent light. In Fig. 3, the point source of the transparent light is the focal point ($F_{mo}$') of the beam spreading microscope objective lens. $F_{mo}$' might be $d_{o,\,tsp} = 60$ cm from the image forming lens (or usually even more). In contrast, the point sources of the translucent light are distributed over the surface of the tape that covers portions of the microscope slide. The tape is two focal lengths ($d_{o,\,tsl} = 40$ cm) from the 20 cm focal length image forming lens. We might think of the translucent tape as consisting of a large number of tiny "point-sized" randomly oriented and randomly sized prisms, Each of these tiny prisms directs its portion of the incident light in a different direction. Thus each part of the tape sends light out in all directions (like a tiny pinhole), but accomplishes this without absorbing or blocking much of the light.

Because there are two different object planes, one at 60 cm and one at 40 cm from the imaging lens, there are also two different conjugate planes.

- For the translucent light:
    - The object plane is the surface of the translucent scattering tape, at $d_{o,\,tsl} = 40$ cm[5].
    - The conjugate image plane is at $d_{i,\,tsl} = 40$ cm. This assumes a converging imaging lens with a focal length of 20 cm.
- For the transparent light:
    - The object plane is at the focal point of the beam spreading microscope objective lens, $d_{o,\,tsp} = 60$ cm from the imaging lens in our example. This is the point $F_{mo}$' in Fig. 3b.
    - The conjugate image plane is at $d_{i,\,tsl} = +15$ cm, in our example. This is Point P' in fig. 3b.

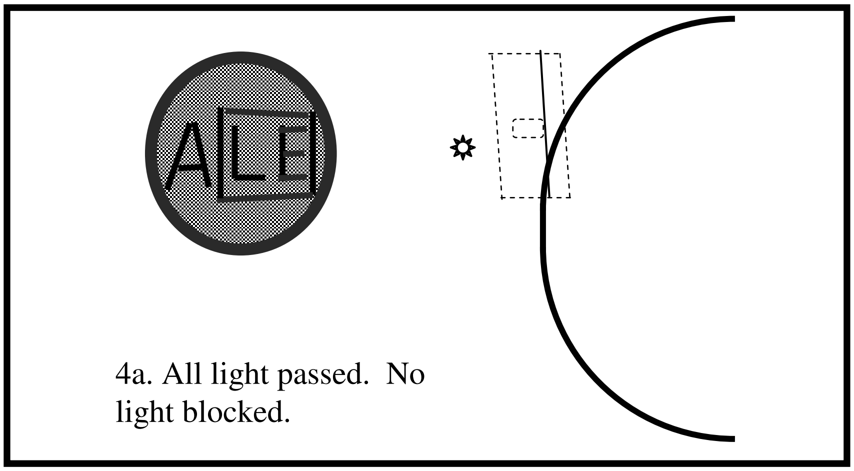
Students perform this experiment twice, first back-lighting the object with parallel rays from a laser collimator, and second for a situation like that shown in Fig. 3, with the point source of the spatially coherent laser light at a non-infinite distance from the imaging lens ($d_{o,\,tsp} = +60$ cm in our example). When the laser point source is at infinity (collimated laser beam), the conjugate image plane for the transparent light is at the imaging lens focal length, i.e. at 20 cm in our example. On the other hand, if the point source of the laser beam is moved closer to the imaging lens (to $d_{o,\,tsp} = 60$ cm in our example), then the conjugate image plane moves further from the imaging lens, to a distance greater than 20 cm (to $d_{i,\,tsp} = 30$ cm in our example).

### *2.3. Phenomena observed*

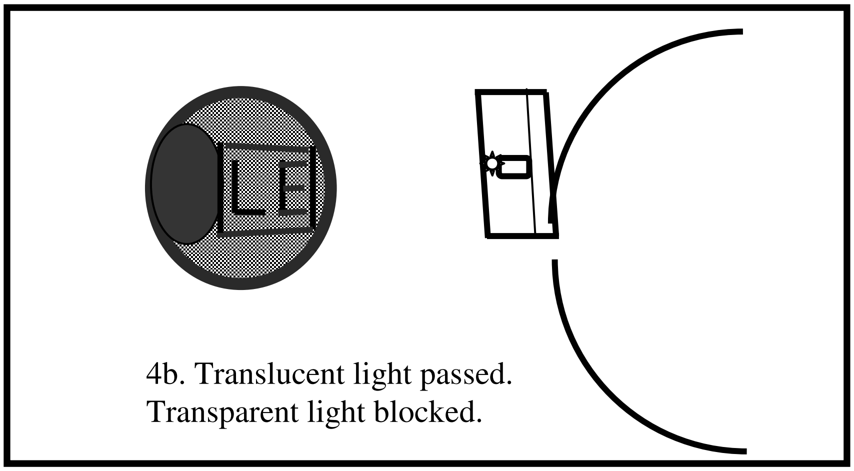
This relatively simple experimental arrangement provides a rich environment for exploration. Two main types of phenomena observed are shown in Figure 4 and in Figure 5.

Figure 4 (below) shows optical image processing in action.

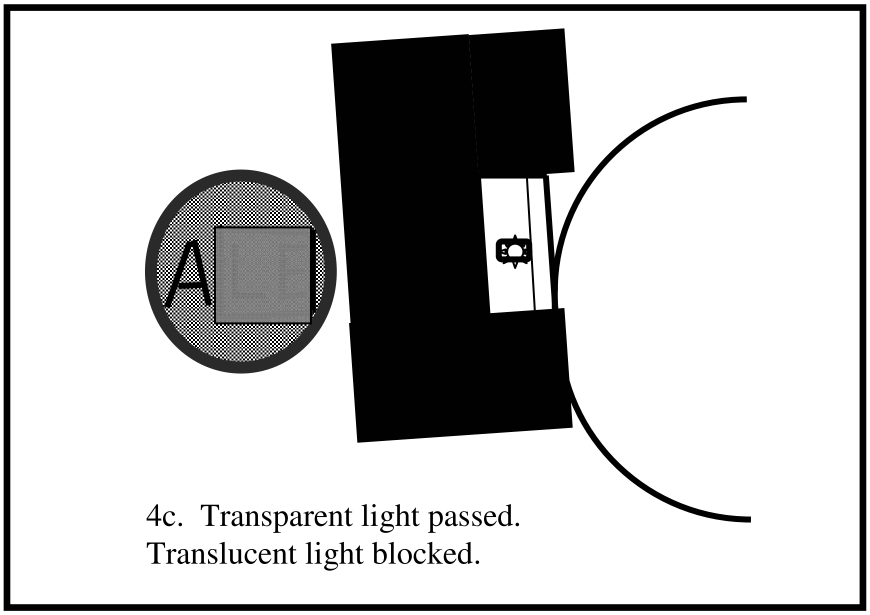
- Case 1. Images of all three letters A, L and E are seen on a screen 40 cm past the imaging lens. In Fig. 4a, the razor blade is not utilized, and none of the light passing through the imaging lens is blocked. A clearly resolved image of the letters L and E results. These are focused images formed by translucent light, on a screen at 40 cm from the imaging lens. Also, an image of the letter A appears.
- Case 2. The image of the letter A is blocked/filtered. Images of L and E are seen. In Fig. 4b, the razor blade metal acts as a blocking filter for transparent light. At the same time, most of the translucent light passes around the razor blade. The clearly resolved images of the letters L and E, formed by translucent light, are seen on a screen 40 cm from the imaging lens. However, the transparent light is blocked if any small opaque object is placed at P' in Fig. 3b. The letter A does not appear. The region on the viewing screen surrounding the 'black letter A' turns dark, making the image of the 'black letter A' not visible.
- Case 3. The image of the letter A is passed; the images of L and E are blocked. In Fig. 4c, the small hole in the razor blade is placed at Point P' in Fig. 3b, and this hole passes most of the transparent light. The solid part of the razor blade is extended by black construction paper, causing most of the translucent light leaving the imaging lens to be blocked. Only the image of the letter A appears on the screen.



4a. All light passed. No light blocked.



4b. Translucent light passed. Transparent light blocked.



4c. Transparent light passed. Translucent light blocked.

Figure 4. Optical image processing in action.

Figure 5 shows another dramatic phenomena, which quickly catches student's attention. Students see that the image of the letter A appears everywhere past the imaging screen.

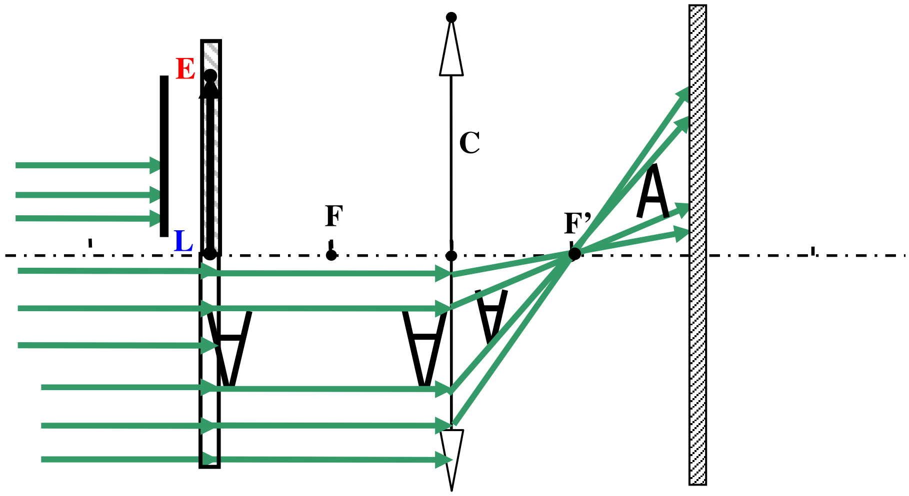


Figure 5. Transparent (unscattered) light is shown for the case of a collimated laser beam backlighting the object. The shadow of the opaque figure A is visible on a sheet of white paper placed anywhere between the microscope slide and the lens, and also anywhere between the lens and the viewing screen.

## 3. Ray models and discussion questions

Figure 5 serves both to describe an important observation, but also helps to explain this phenomena (the letter A is visible at many view screen locations). A main question then arises: Why is the letter A visible at essentially all locations of a screen, while the L and the E form clear images only for a very narrow range of screen locations. To move the discussion forward, a diagram like that shown in Fig. 6 can be introduced.

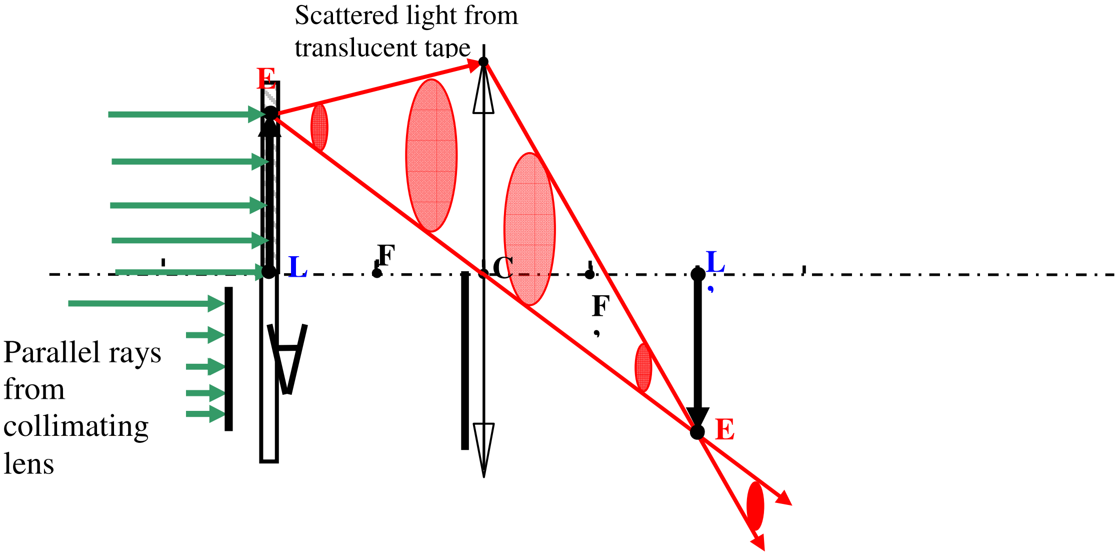


Fig. 6. Translucent light, i.e. light scattered from translucent "Magic" Scotch tape is emphasized. Transparent light is omitted from this diagram.

For a person experienced in optics, the theory underlying the formation of the focused image, as depicted in Fig. 6, should be familiar, and will not be discussed in detail here. We simply note that the quantitative part of the image location involves only the lens image position equation (1/do + 1/di = 1/f). The image size is treated by the lateral magnification equation m = hi/ho = (-1)(di/do). The theory of 'depth of focus' can also be introduced, because it comes natural to try to explain why the screen position has some tolerance for error, which forming the positions of the L and the E. However, the 'image' formed by the light passing through the transparent surround of the letter A, in ALE, for example, is not a conventional focused image. Explaining the behavior of the image of the letter A, and putting it in a proper perspective can challenge even the experienced student of optics.

In this author's opinion, one should avoid stating that the image of A is always 'in focus.' The image of the letter A is not a focused image. Focused images, both real and virtual have, as a main characteristic, that they have a definite location. The letter A, in the example being discussed, does not have a restricted image location. It is not a focused image of the type usually encountered in beginning imaging experiments.

Rather, what appears to be an image of the letter A is, in fact a 'shadow' analogous to the shadowing action of a pinhole in a pinhole camera. The opaque letter A, affixed to the microscope slide, and back-lighted with laser light is like a large aperture 'pinstop' camera. The shadow formed by the opaque letter A is carried wherever the transparent rays go, and so, quite dramatically, appears on a white sheet of paper moved to various locations on either side of the imaging lens. A dramatic indication of the presence of diffraction around the edges of the opaque letter A shows up on the screen in an experiment like that depicted in Figure 4b, if the transparent light is blocked by a push pin, rather than by a razor blade. Then the edge diffracted light is not focused into the same small region as the undiffracted light, and this edge diffracted light is not blocked by the push pin. Then, the shape of the letter A is outlined by a thin red line. In traditional optical image processing, this is regarded as a demonstration of 'optical differentiation.'

Several specific discussion questions have been formulated and presented to students to stimulate them to develop their thinking about the observed phenomena. Several are listed next, with brief answers.

Q1. Is the image of the letter 'A' a focused image? (Answer; No, because it has not definite location, unlike the letters of the L and the E.)

Q2. What is the image plane conjugate to the object plane occupied by the letters L and E? (Answer: The plane for which the letters L and E have the sharpest appearance. The point here is to introduce/review the concept of conjugate planes.)

Q3. What is the image plane conjugate to the laser point source? (Answer: It is the transform plane, the plane where the blocking/passing filters must be located to perform image processing[6]. This is a more sophisticated use of the concept of conjugate planes.)

Q4. What can we do to increase the range of variation of the viewing screen that is permitted when obtaining a clear viewing of the images of L and E? (Answer: Decrease the diameter of the imaging lens. An additional diagram that is an extension of Fig. 6 is useful here, to explain 'depth of focus.' Light scattered from two different points on the tape must be displayed, and discussed. The circle of confusion can be introduced.)

Q5. Identify a plane in which the images of L and E would be <u>least</u> well resolved. (Answer: The plane just after the image forming lens.)

Q6. Specify the location and form of a blocking filer for the letter A, given the lens focal length and the distance of the laser point source from the imaging lens. For the letters L and E. Similar for passing filters. (Answer: For the form, see Fig. 4. For the location, use the lens image position equation.[7])

Q7. What will happen to the image of the L and the E if one-half of the lens is blocked, say the upper half? (Answer: The images will become dimmer, but no single point on the L or the E will be completely blocked.)

Q8. What will happen to the image of the letter A if one-half of the upper half of the lens is blocked? (Answer: if the 'A' is well centered vertically, then one-half of the letter 'A' image will be blocked, while the other half will appear on a viewing screen anywhere past the lens.)

## 4. Conclusions

These experiments are a fun way to get started with imaging, and optical image processing. However, they are challenging for some beginning students. The next time I teach this experiment, I will try breaking the experiment down into three separate parts. 1. Give students a microscope slide having three opaque letters, and no translucent tape. 2. Give students a slide with three opaque letters, with all surrounding regions covered by tape. (No transparent light.) 3. Give students the translucent-transparent object, like those shown in Figures 1 and 2.

To further elaborate the object, it is very attractive to then proceed to the introduction of weak holographically formed diffraction gratings, for example with vertically spaced lines, to serve as a surround for the opaque letters. This would move these experiments in the direction of more traditional optical image processing experiments. Additional interesting filtering operations would become available, and this object could be used to introduce the basic properties of non-focusing diffraction gratings.

Another interesting variation would be to replace the opaque 'A' with transparent surround. Instead make the surround opaque, and the letter A, itself, transparent. The figure A would then more obviously resemble the hole in a pinhole camera.

Because my optics course emphasizes holography, I require students to form records on holographic film of their processed images. Thus familiarizes students with film handling, and film chemical processing. Also students are sometimes surprised to see characteristics of the light pattern recorded in the film that they had not noticed while looking directly at the light beams. I would appreciate receiving feedback from anyone who tries this type of experiment.

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[1] A classic treatment is available in the text by Eugene Hecht, Alfred Zajac (1987) Optics, 2nd edition, Addison-Wesley, Reading, Massachusetts. Most other sophomore-junior level optics texts will also introduce the subject of optical image processing.

[2] The Metrologic Corporation has been purchased by Industrial fiber optics: http://www.i-fiberoptics.com/
This website makes readily available Arthur Eisenkraft's laboratory manual *Physical Optics Using A HeNe Laser*

[3] J. D. Armitage and A. W. Lohmann, "Theta modulation in optics," Appl. Opt. **4**, 399- (1965)

[4] The author has demonstrated the value of such translucent back-lighted objects for transmission holography. See Dale W. Olson, "Real and virtual images using a classroom hologram," *Phys. Teach.* **30**, 202-208 (1992); D.W. Olson, "The Abramson ray-tracing method for holograms," *Am. J. Phys.* **57**, 5 (1989), pp. 439-444; also "The elementary plane-wave model for hologram ray tracing," pp. 445-455.

[5] We use the Physics Sign Convention: Real objects and real images have positive distances from the lens.

[6] This point is less easily established in traditional image processing experiments.

[7] This question makes a good quiz question.