Public domain optics: Experimental gems from pre-1923 textbooks

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ABSTRACT

The basic concepts of theoretical and experimental optics have remained largely unchanged since the 1890s. With the exception of the existence of the ethereal medium, interpretations and explanations of classical optical phenomena contained in introductory optics textbooks of the late 1800s and early 1900s are essentially modern, and textbooks from this era can provide a valuable source of teaching and learning material which can be adapted for modern coursework free of fear of copyright infringement. In surveying a number of such textbooks, a trove of interesting "chiefly by the lantern" experiments which would prove useful to any student of today have been found. This talk will describe a selected few such experiments which can be done without significant materials cost, perhaps involving minerals such as mica, tourmaline, and selenite.

Keywords: Talbot effect, mica, birefringence, textbooks

1. INTRODUCTION

There is an increasing number of free-for-download textbooks and textbook-like lecture notes in the field of optics and optoelectronics readily available. A survey of such materials conducted in early 2019 by the author found a large number of such learning materials readily available [1-47]. The copyright terms of such recent works vary considerably, sometimes allowing free use and rights of re-distribution, sometimes allowing free use but with restrictions on distribution and re-use, and sometimes unclear or complex rights. In any case, for the learner of optics, these materials can be invaluable. (The author took reasonable care to ensure that only legally available texts were counted.) In addition to the large number of recent efforts by authors and publishers to make more work available, pre-1923 textbooks are special because these works are now in the public domain in the U.S. (and in the vast majority of other localities as well). Many of these books have been scanned and are available for download or print-on-demand. Since the field of classical optics, including concepts such as geometrical optics, introductory physiological optics, interference, birefringence, and other topics which are usually taught to beginners is unchanged, these textbooks can provide a valuable source of teaching and learning materials without fear of breaching copyright; moreover, some experiments useful for learning basic optics which were painstaking in the late 1800s are significantly easier now, and are perhaps not widely known. Some experimental texts from the late 1800's are especially interesting, because optics experiments were described without significant equipment needs. The books *Light: A Course of Experimental Optics (Chiefly with the Lantern)* by Lewis Wright (Macmillan, 1892) [20] and *Practical Exercises in Physiological Optics* by George J. Burch (Oxford, 1912) [23] are especially useful, along with an 1836 article by Talbot introducing what's now known as the Talbot Effect [47].

2. THREE SAMPLE EXPERIMENTS

2.1 Polarization

Imagine the following scenario in an introductory optics class: Teach first the concept of polarization, and then use two pieces of Polaroid to explain polarization in the standard way. But for students to truly understand polarization, ask the following question in an introductory optics class: How many ways can you think of to polarize light? And explain how each method works! For example, if no Polaroid film is available, explain how tourmaline can be used as a polarizer. Explain the Nicol Prism, Foucault's Prism, Iceland Spar (calcite), Ahren's Prism, the Glan Prism, the Rochon Prism, a "stacked-glass" polariscope or explain how a polished mahogany table can function as an analyzer. Wright [20] recommends 10-12 glass plates in the stack, with the bottom of the lowest plate blackened, as shown in Figure 1.

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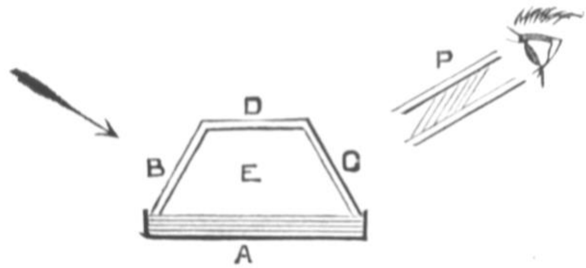

Figure 1. The stacked glass polariscope, reproduced from Ref. [20], Fig. 167. Understanding of this polarizer is slightly more difficult for students than other types of polarizers.

2.2 Birefringence

The use of mica or other minerals such as selenite, which are expensive, can offer interesting hands-on activities to students to demonstrate both thin film interference and birefringence. The idea was beautifully implemented in Ref. [20] but can be reproduced much more easily with two pieces of Polaroid (linear polarizing film). Figure 2 outlines the procedure of a simple experiment. Firstly, a book of muscovite mica can be very easily divided into very thin and transparent leaves. Since mica is birefringent, the method of using crossed polarizers can be used to illustrate a beautiful interference effect. With a single leaf of mica sandwiched between non-crossed polarizers, there is a small effect, but when the polarizers are crossed, an interference pattern resembling thin-film interference is set-up which depends on both the thickness of the film and the birefringence of the sample. This method may be useful in teaching both concepts, and may not be readily understood at first glance. The result from the author may not resemble the beauty of the 1892 work in which a vast assortment of beautiful patterns were designed using only mica sheets, but is fast and easy.

2.3 Talbot Effect

The Talbot Effect was first described in 1836 in *Philosophical Magazine* [47]; an excellent modern description of the effect (with a 2-dimensional grating) is available by Belin and Tyc [48]. The essence of the effect is that a collimated (or quasi-collimated) beam of monochromatic light shone through a grating with a lateral surface feature size of a will produce self images at periodic distances of $2a^2/\lambda$, the Talbot length. Intermediate distances produce beautiful patterns which make the effect interesting in an educational setting.

Although the effect may have been more difficult to observe in the 1800s without a laser, it can be now easily created with a single laser pointer and a pair of binoculars, and any 2D stencil pattern with a reasonably small a to give reasonable Talbot distances for visible light. (However, a should not be too small so as to be similar to the wavelength.)

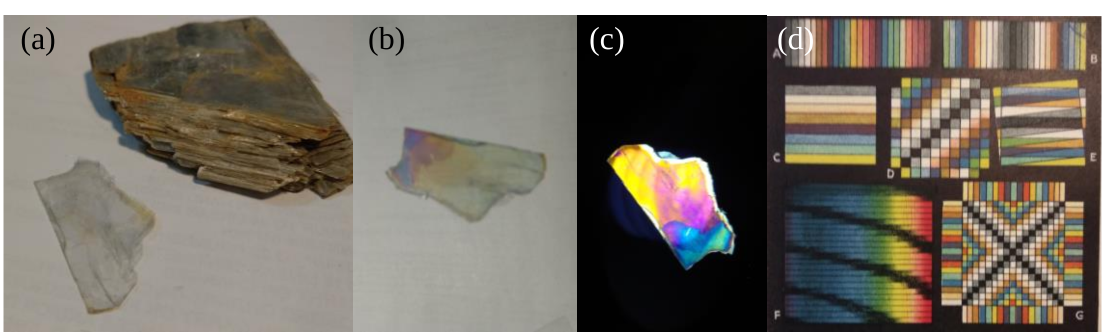

Figure 2. Experiment by the author: (a) A book of mica with one leaf cut away, (b) the leaf between parallel Polaroid pieces, (c) the leaf between crossed Polaroid pieces (illuminated from behind). (d) A similar setup with a more elaborate design in the 1892 reference [20].

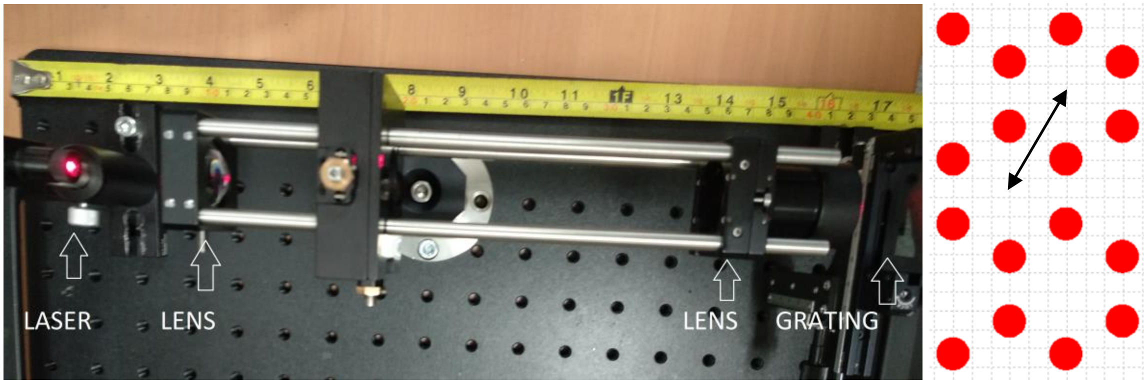

Figure 3. The beam is first expanded with a 2-lens telescope and then passes through the pattern. (One unit cell of the pattern used is shown to the right, where the red circles are open and the rest is opaque with chromium). The spacing between centers of the hexagonal array illustrated by the arrow is 0.72 mm and the radii of the red openings are 0.10 mm.

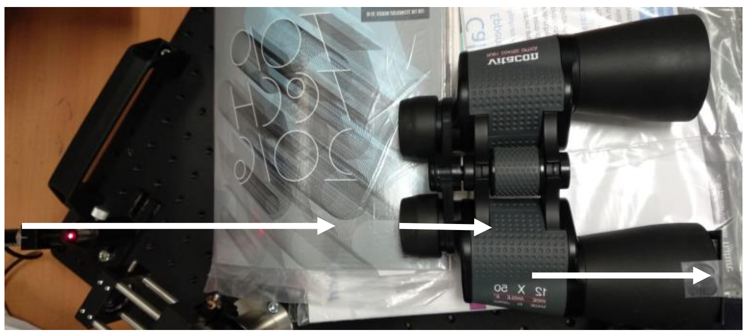

Figure 4. No optical table is necessary and no beam expander is necessary. In this case, a 12x50 binocular half acts as a beam expander.

A simple setup of an experiment to observe the effect is shown in Figure 3 built on an optical breadboard, consisting of a red collimated laser diode, followed by a beam expander (in this case, a Keplerian telescope configuration of two convex lenses), followed by a grating. The beam expander ensures a collimated beam, although it is possible for the setup to still function with a single lens which would cause the beam to diverge, although in that case the Talbot distance will be altered and the Talbot image will be magnified (and less bright). A Nikon D7100 DSLR camera with the lens removed was then used to capture images beyond the grating. The image sensor is 23.5 mm x 15.6 mm in size. These images are labeled with the approximate distances from the grating to the camera image sensor and are shown in the collection of Figure 5 (corresponding to the Figure 3 setup and a collimated beam). The images are low quality compared to those in reference [48] and the binoculars setup—the periphery of the patterns show diffraction (probably due to the size of the grating relative to the expanded beam), and there are beam artifacts caused by the [modal quality of the] laser itself. If the laser would be first filtered to improve the beam, it would look better, but this shows that a very simple setup is useful in educational settings. The images shown in Figure 6 correspond to the setup in Figure 3, but with the lens adjacent to the grating moved inwards to create a diverging beam and a magnified set of images. The images shown in Figure 7 correspond to the setup in Figure 4.

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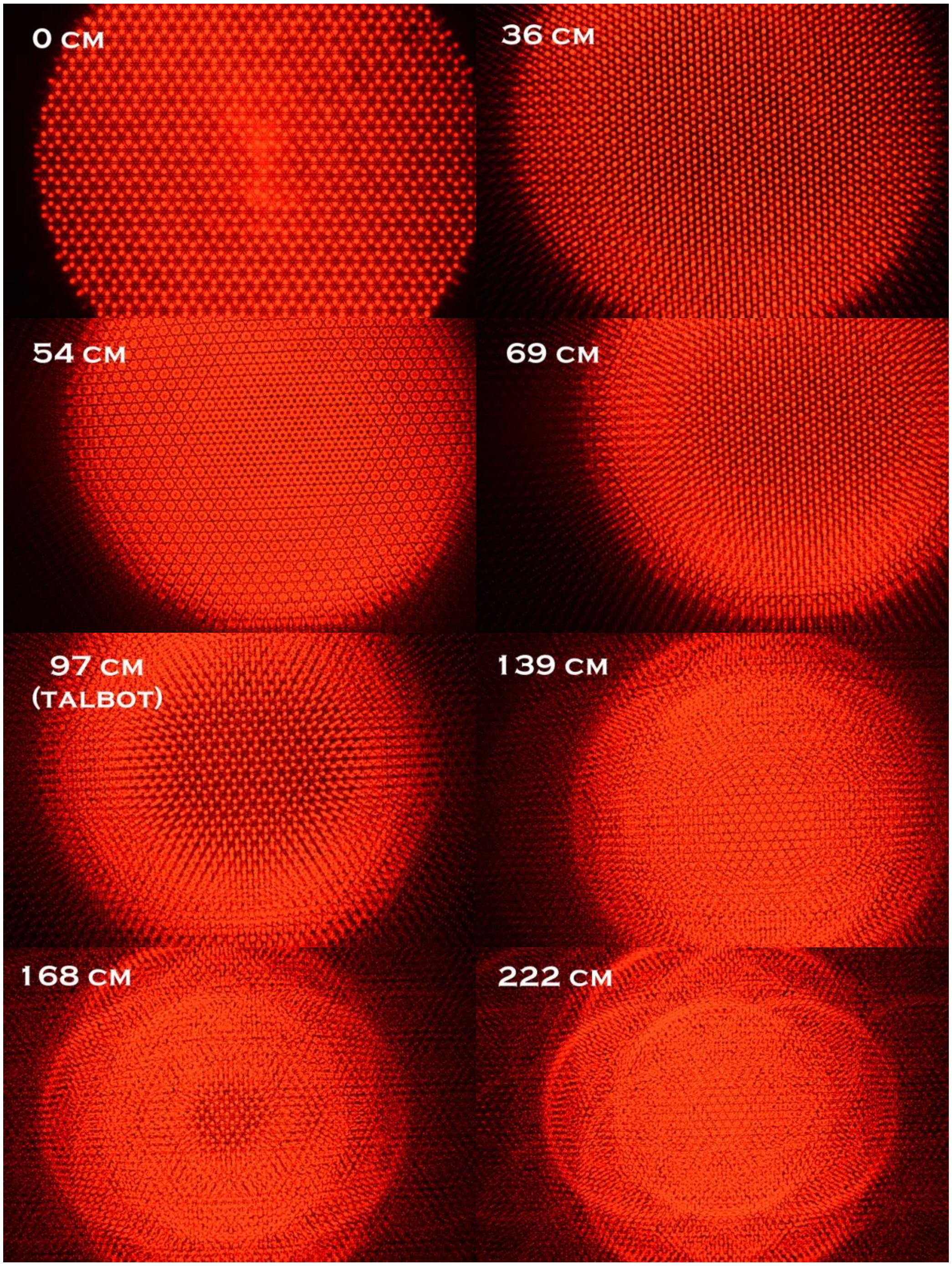

Figure 5. Direct observations at the image sensor with approximate distances from the grating marked with an expanded, collimated beam. Exact calculation of the Talbot distance for such a grating is described in detail in [48].

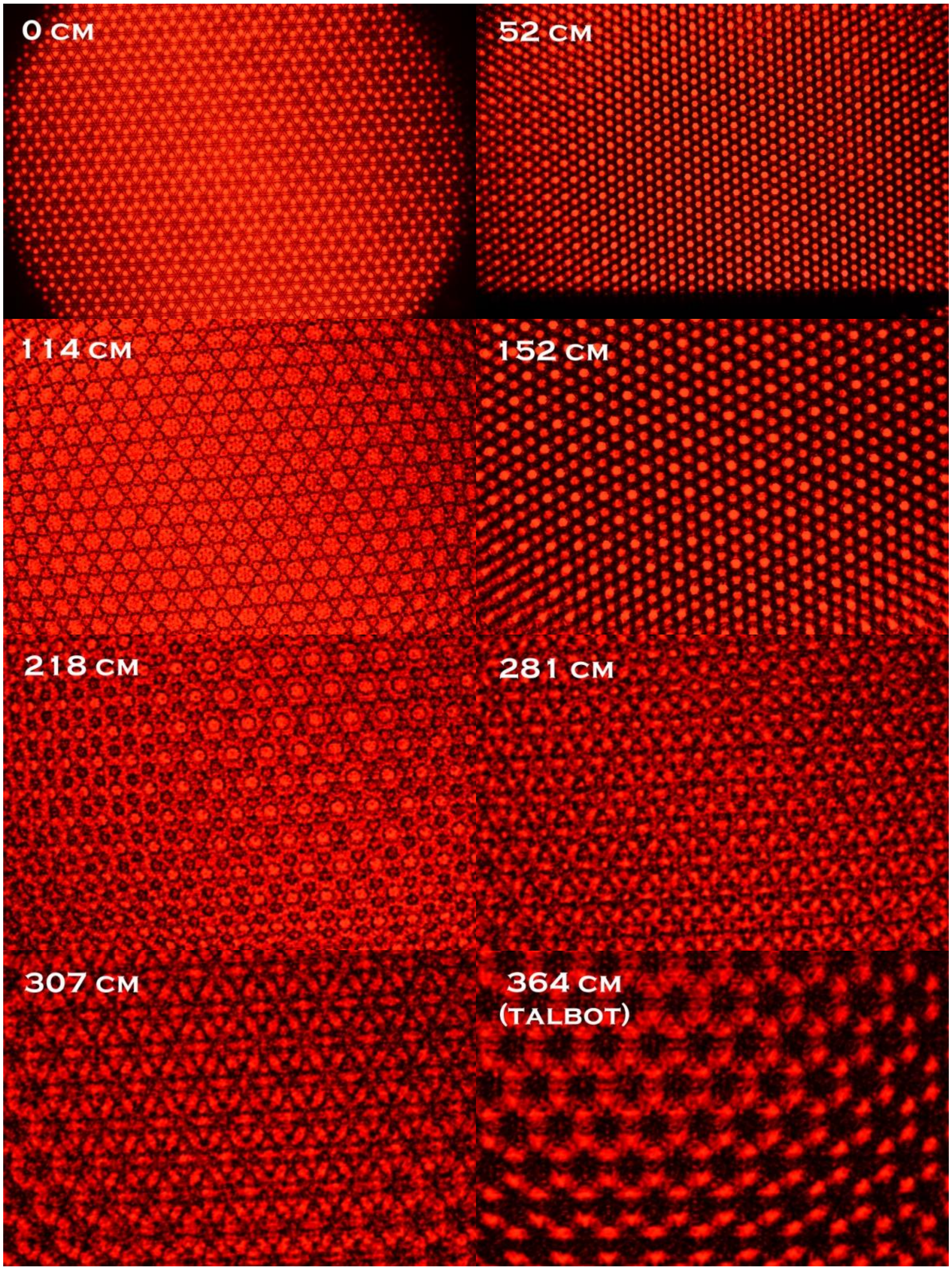

Figure 6. The diverging beam shows increasing magnification, and an increased distance to the Talbot image.

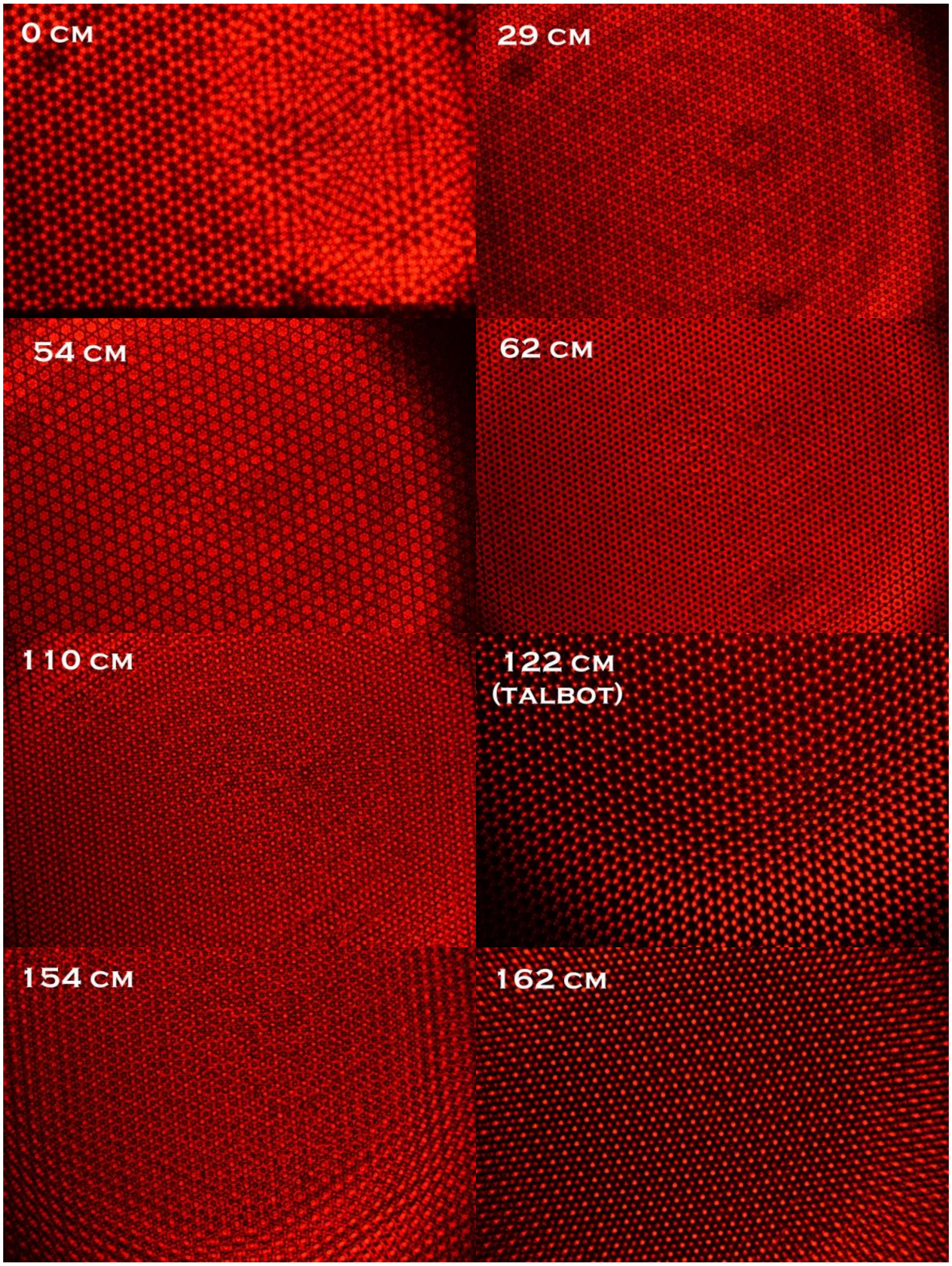

Figure 7. The aperture of the binoculars was more than twice the diameter of the expanded beam of the setup in Figure 5 resulting in improved images.

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