Newton's missing experiment

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Some characteristics of Newton's philosophical method relevant to his works *First Paper on Light and Colours* (1672) y *Opticks* (1704) are discussed. It is shown from his prism experiments using different materials described in those works that it is possible that he may have carried out experiments with air prisms in water. This would have questioned the inductive conclusion that red rays are always less refracted than blue ones. Finally, and with a pedagogical intention, an experiment is reported to illustrate the result obtained depending on the material of the prism and of the medium.

Keywords: Optics; light; colours; Newton experimental philosophy.

Se discuten algunas características del método de filosofía de Newton particularmente relevantes a sus trabajos *First Paper on Light and Colours* (1672) y *Opticks* (1704). Se muestra que, a partir de los experimentos con prismas de diferentes materiales descritos por Newton en esas obras, es muy probable que haya realizado experimentos con prismas de aire inmersos en agua. Esto último hubiera cuestionado la conclusión inductiva de que los rayos rojos son siempre menos refractados que los azules. Finalmente, y con un propósito pedagógico, se reporta un experimento que ilustra el resultado obtenido dependiendo del material del prisma y del medio.

Descriptores: Óptica; luz; colores; filosofía experimental de Newton.

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One of the most important results of Newton's *First Paper on Light and Colours (1672)* and *Opticks* (1704) is that 'the light of the Sun consists of Rays differently Refrangible', or that sunlight is a 'heterogeneous mixture' of 'Rays differently Refrangible'. In agreement with his '*hypotheses non fingo*' assertion, Newton claimed to prove this form 'phenomenon' in his one and two prism experiments. In the first experiment, a ray of sunlight was passed through a prism. On the other side of the prism, the colour spectrum is shown and the different degree of refrangibility (or wavelength in modern terms) for each colour can be observed. In the second experiment, Newton used two prisms. In the first prism starting from a ray of sunlight the colour spectrum is obtained and, using a screen with a hole at the exit of the first prism, all colours are blocked but one, which is passed through the second prism, obtaining no new colours but the original one. From the first experiment, Newton claimed that sunlight is made up of a mixture of differently refrangible rays, and from the second one that the degree of refrangibility is an intrinsic property of each ray and cannot be modified. For Newton, this result is a theorem (Theorem II, Book, I, Part I of the *Opticks*) and he states that "the provof follows from experiments". The second experiment was crucial to rejecting objections according to which the colour spectrum from the first prism could have been <u>created</u> within the prism. Here there are two interesting points[1]:

i) The observation that red rays are less refracted than blue ones was obtained in prisms of different material *e.g.* flint glass, water, crown glass. Does it follow that this holds for any transparent medium? Is this just enumerative induction? And,

ii) What if there were a transparent medium -call it "magic glass"- that Newton had not investigated and which reversed the order of refraction? That is, a medium in which red rays are more refracted than blue rays.

Due to some experiments using optical elements in water that we know Newton conducted, the last question may have indeed been investigated by Newton and is what we call here "Newton's missing experiment"[2].

As we know [3], in any substance the index of refraction n is a function of frequency ω, and the change of refractive index with frequency $dn/d\omega$ is called dispersion. In 'normal dispersion', the index of refraction $n(\omega)$ increases with frequency ω (or diminishes with wavelength λ, since $2\pi v = \lambda\omega$, where v is the speed of light in the substance). In normal dispersion, if white light passes through a glass prism, the blue constituent will have a higher index than the red and will therefore be deviated through a larger angle. However, due to their internal structure, all materials exhibit absorption at certain resonant frequencies. For glasses, these resonant frequencies typically occur at wavelengths of about 100 nm (well in to the ultraviolet region and beyond the detection capability) of the naked eye, and this is the reason why we are used to dealing mostly with normal dispersion. In the regions immediately surrounding the resonant frequencies, called absorption bands, the dispersion $dn/d\omega$ is negative and the process is spoken of as anomalous (*i.e.* abnormal) dispersion. That is, in normal dispersion (within a region of normal dispersion), shorter wavelengths (larger frequencies) have a greater index of refraction whereas in anomalous dispersion (within a region of anomalous dispersion), longer wavelengths (shorter frequencies) have a greater index of refraction. Since all substances possess absorption bands somewhere within the electromagnetic frequency spectrum, the term anomalous dispersion is certainly a misnomer. As already mentioned, for glasses and many other substances, the absorption bands lie outside the visible region; some exceptions to this are iodine vapour and fuchsine dye. It is known[4] that anomalous dispersion was first observed in about 1840 by Fox Talbot and the effect was christened in 1862 by Le Roux; however, his work was forgotten and eight years latter rediscovered by C. Christiansen.

It is interesting to note that, in order to observe in a prism 'something somehow looking like anomalous dispersion' (*i.e.* that the red rays will be deviated through a greater angle than the blue rays), it is not necessary to have a prism made out of a fancy anomalous absorption material. This can easily be done for example with an air prism immersed in water (or - more difficult to build - an air prism inside a glass medium). What is important for the sake of the effect we wish to observe is not only the kind of absorption we have (normal or anomalous) but the *quotient* of the refractive index n_{medium}/n_{prism}. In most circumstances, we have air as the medium (n = 1) and a glass prism ($n > 1$); however, in order to observe an results looking like "anomalous dispersion" we only need to reverse the situation, having for example a water or glass medium ($n > 1$) and an air prism (n = 1). It is known that Newton used to keep many results of his research to himself, so even if he did not know about materials presenting anomalous dispersion, he may or may not have conducted the sort of experiments just mentioned with air prisms in water. What would have been the difference for Newton's conclusions if he had also done an experiment in air with a fuchsine-filled prism or in water with an air prism? We can only speculate about this question and about "Newton's missing experiment". I believe that in any case Newton's conclusion 'from phenomena' would have been the one previously stated by Worrall [1], *i.e.* that "the degree of refrangibility would instead be a *relational* affair between a type of ray and a type of transparent material", which is consistent with today's scientific knowledge. On the other hand, the implications of these experiments for Newton's scientific methodology are very important[1,2].

Conducting Newton's experiments with water prisms, as well as "Newton's missing experiment" (air prisms in a water medium), can be a very instructive and interesting experience for any student, both from the scientific and the historical point of view. These experiments are reported as follows. Figures 1a and 1b show the experimental set-up. The purpose of the experiment is to observe the results obtained when refraction takes place from a glass prism in air and from an air prism in water. The equilateral triangular glass prism used has sides measuring 20 mm wide and 12 mm high. The equilateral triangular air prism was built using three glass plates 1 mm thick, 25 mm wide and 18 mm high glued togethet and also glued to a 20 $\times$ 20 cm glass base with 18 mm high glass walls along the perimeter of the base as shown in Fig. 1b. The light beam used can be obtained from the Sun or from a battery operated lamp with a 3 mm carton diaphragm. Figure 1a shows the well-known result obtained using a glass prism having air as the medium; red rays are less refracted than blue ones. This experiment can also be carried out using a water prism in an air media obtaining the same qualitative result. On the other hand, Fig. 1b shows an air prism in a water medium; in this case, red rays are more refracted than blue ones. Students should verify that glass, water, plastic or any transparent medium with an index of refraction greater than one (air) will produce the qualitative result shown in Fig. 1a whereas, when the prism is made of air and the surrounding medium has an index of refraction greater than one, such as water, the "normal" refraction result is reversed. This is what we call here "Newton's missing experiment".

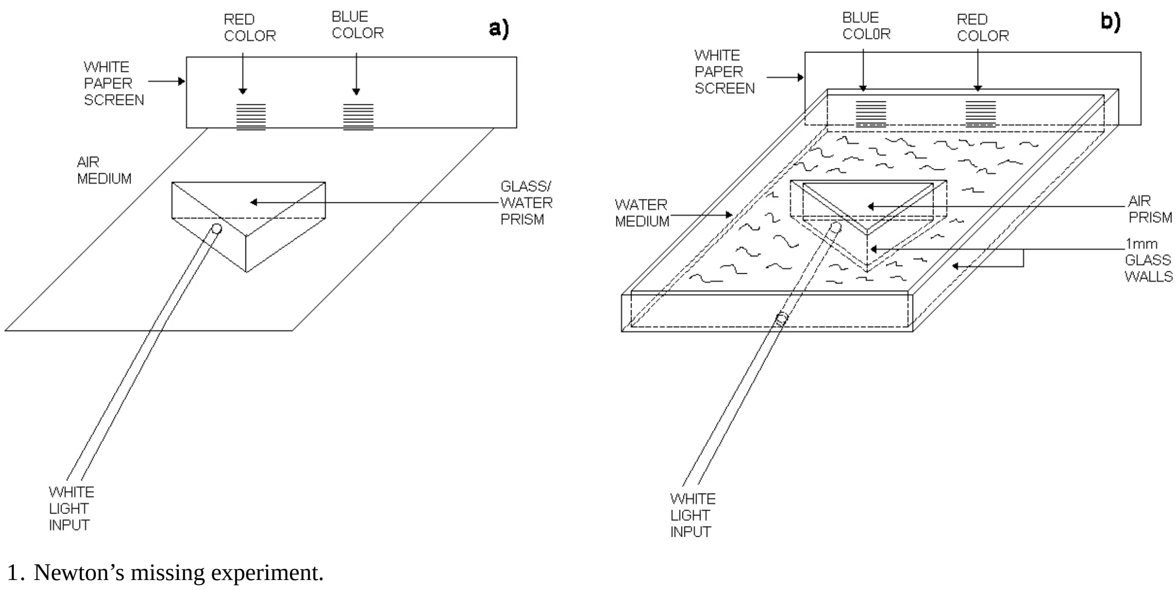

FIGURE 1. Newton's missing experiment.

The direct reading and discussion of Newton Opticks together with the simple experimental work described here has been found very instructive for university and high school students. This may be a very useful experience for any student takin a physics or history of science course.

1. J. Worrall, *British Journal for the Philosophy of Science* **51** (2000) 45.
2. V. Aboites, *British Journal for the Philosophy of Science* **53** (2003) 455; *History of Physics Group Newsletter, Institute of Physics* **18** (2005) 59.
3. M. Born and E. Wolf, *Principles of Optics*, Sixth Edition (Pergamon Press, 1993) p. 90.
4. E. Hecht and A. Zajac, *Optics* (Addison-Wesley, 1974) p. 42 and 58.