Prism experiments

After Newton's famous prism experiment was voted one of the top ten most beautiful experiments in science, we had to retry it and let you know what we found. In doing so, we discovered LSD.

Introduction

Every teacher of science has surely done the normal demonstration of splitting white light into a spectrum. Many will do this every year, and perhaps several times over with different classes. Given that it is one of the most commonly done experiments, it might seem so simple to do. Indeed, as a mark of this ordinariness, no-one has asked me about it in my 24 years at SSERC – until, that is, the recent Physics Summer Schools and IOP Stirling Meeting. There, teachers saw a spectrum produced with a white Lumiled source and prism in a SSERC experiment and commented: "That's a better spectrum than I've ever been able to produce. However do you do that?" That's one reason for writing about it. Another was the result of a poll conducted by the American philosopher and historian of science, Robert Crease, of readers of the journal *Physics World*, in which he is a regular columnist. Crease asked his readers to let him know which experiments they thought were particularly beautiful. (The question presupposes that beauty can be found in science or an experiment, but it seems that no one has disagreed with the presumptions.) The finding that an experiment by Newton with prisms was in their top ten is the second reason for writing about experiments with them.

So this article is about a very ordinary set of experiments and will show how spectra of great beauty can be made. The key is in knowing the role played by each of the optical parts. The highlight is the experiment Newton called his *experimentum crucis*.[1] Knowing that the experiment is not at all easy, Newton went at some length to give instructions on how it should be done. This is a third reason for writing this piece. And then there is LSD ...

How to get a spectrum

White light from an intense lamp illuminates a vertical slit, which becomes the source in the optical system (Fig. 1). A converging lens focuses the image of the slit on a temporary screen, *C*, placed at about the same distance from the lens (700 mm) as the spectrum will eventually be. A 60° prism is placed in the radiation and turned to get the angle of minimum deviation. The spectrum on screen *AB* is also an image of the slit, extended by the dispersion of the colours. The prism and perhaps the other optical elements are placed on an A1-sized sheet of white card to show the rays of dispersed light.

The lamp is sited level with, or just slightly above, the working plane, giving the desired effects. With some types of lamp, for instance the Compact Light Source (Harris, B6H76839, £112), the working plane has to be elevated to make allowance for the size of the lamp housing. We therefore made a prism table from an A1-sized sheet of MDF (839 x 592 mm) resting horizontally on separate supports at a height of about 100 mm above the benchtop (Fig. 2). A sheet of white A1 card sits on the table on which the coloured rays from the prism are cast. Another white card is placed vertically along one side to show the spectrum.

1 In spite of the experiment's Latin title – it means the crux or crucial experiment - it is noteworthy that Newton's *Opticks* was written in English – unlike his other magnum opus *Principia*.

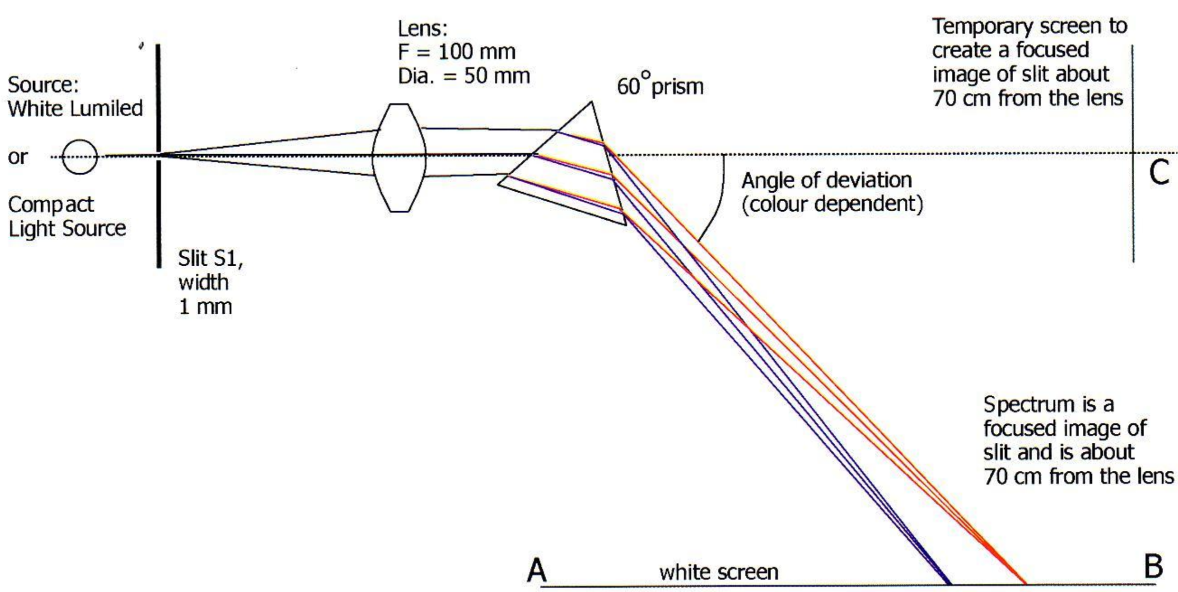

Figure 1 *Producing a spectrum with a prism: Ray diagram and the optical parts. Procedure: (1) With prism removed and a temporary screen at C adjust the lens to get a sharp image of slit S1 at C. (2) With prism in place, rotate the prism until the spectrum is as far towards B as possible, such that the angle of deviation is a minimum.*

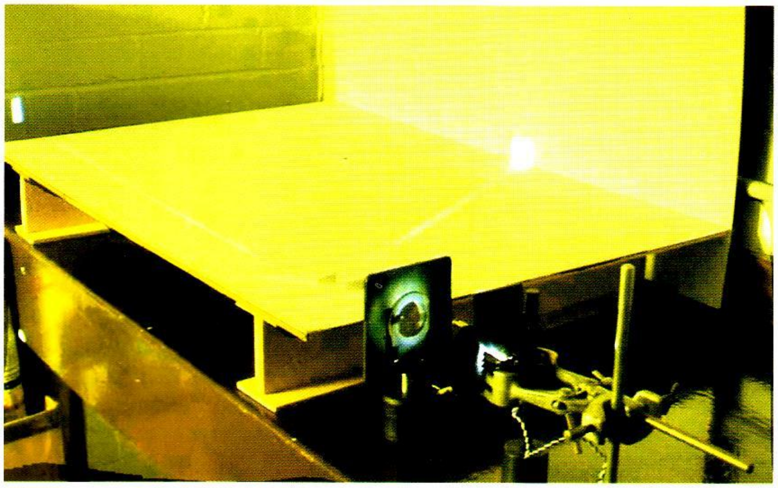

Figure 2 *The prism table with white, A1-sized card showing rays of light.*

The light source should be white with a significant blue-violet element. The new 1 W white Lumiled with optics is excellent for this job. Being physic-ally small, it can be operated on the worktop, there then being no need for a prism table. The radiation emitted by this source has a circular cross-section of about 12 mm in diameter and is roughly collimated, diverging only a little. Another suitable source is the *Compact Light Source*, which has a 12 V, 100 W quartz halogen lamp inside a large, rect-angular box. This needs to be used with a prism table because of its physical size.

The slit should be mounted vertically right in front of the light source. The best width is 1.0 mm, rather smaller than the width on some raybox slits (commonly 1.5 mm). If the slit width is wider than 1.0 mm, there is too much overlapping of colours resulting in the centre of the spectrum appearing as yellow and cyan, or even white, the green having merged with red and blue.

In fact the quality of the spectrum is a pragmatic compromise. The choice of lens (f = 100 mm) and image distance (700 mm) results in the slit's image being 6 mm wide at *C* (Fig. 1). The orthogonally transverse width[2] of the rays at screen *AB* is 50 mm, so, whilst there is some overlapping of colours, the amount does not noticeably spoil the spectrum. You would get greater colour purity with either a narrower slit or longer focal length of lens, but the colours would be less bright.

Our compromise depends on (1) the focal length of the lens, (2) the width of slit and (3) the refractive index *n* of the prism glass (Table 1) (Fig. 3 - opposite). For best results, so that all of the colours are vividly bright and well dispersed to be readily distinguishable, the slit width should be narrow (1.0 mm) and the refractive index high (1.7). We found that if the refractive index of the prism glass is only 1.5, as is the case with crown

2 The oblique width of the spectrum as seen at *AB* is about 60 mm with an SF-18 prism.

Prism glass	Slit width (1.0 mm)	Slit width (1.5 mm)
SF-18 glass, n = 1.7	Colours well spread out. The best results.	Slight overlapping noticed.
Flint glass, n = 1.6	Colours fairly well spread out.	Colours merge giving red-yellow-white-cyan-violet
Crown glass, n = 1.5	Colours merge giving red-yellow-white-cyan-violet	Colours merge giving red-yellow-white-blue. The poorest result.

Table 1 *The dispersion of colours in a spectrum is improved by having a narrow slit and high refractive index.*

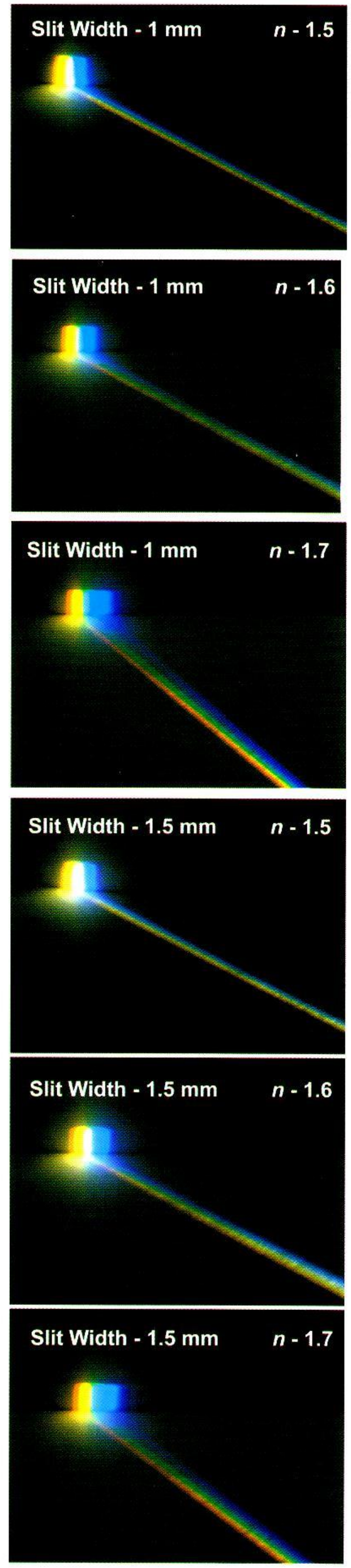

Figure 3 *Sets of spectra with various slit widths and refractive indices.*

glass, and the slit width is 1.5 mm, then there is so much overlapping of colours that the centre of the spectrum is white. We therefore recommend getting an expensive prism in SF-18 glass for a demonstration experiment.

The crucial experiment

Light is focused on a second slit, S2, placed about 100 mm from screen *AB* such that the path length from the lens to S2 is about 600 mm. Only one colour is transmitted through S2 (Fig. 4). When a second prism – an inexpensive crown-glass one is fine - is placed in this narrow beam (which is, of course, the refracted radiation of the first prism), no additional colours are produced (Fig. 5). What you see with the first prism is all you get. Refraction does not produce colours by magic. The experiment shows that it does not alter the nature of light. The colours seen are seen to come from the decomposition of white light. Thus white light, or sunlight, is a mixture of rays of different colours.

Please note that there are several other prism experiments requiring the use of two 60° prisms of the same refractive index:

1. If the second prism is placed in the refracted radiation from the first one, the colours can be recombined causing them to mix. This results in white light.
2. If the second prism is placed next to the first prism on the prism table, both with the same orientation, then when the experimenter looks through it at the spectrum on the screen, the colours have recombined producing white. What the viewer sees is a vertical white line.

Beauty in science

"Is science beautiful?" That was the question put by Crease. A well-made spectrum is indeed beautiful. But beautiful effects are superficial. And many scientific effects would not be beautiful to look at. Many experimental scientists work by guddling around in the laboratory, trying one thing after another. The more practised the experimenter, the more artful becomes his craft. This would seem to have been the way with Newton as he played with his prisms and lenses in an upstairs' room of his mother's house. He clearly got a thrill from solving the problem of the formation of the spectrum – the idea that it is an image of the slit extended by the spreading out of colours. He was also excited by seeing that what he had found out about the refraction of sunlight could be shown by one demonstration, the *experimentum crucis*. And from what he had discovered, he was able to explain the formation of the rainbow, and he was able to apply his knowledge in the design and construction of optical instruments. If there is beauty in science then it is because of the sequence of events, the artfulness of the work and the thought processes as much as anything.

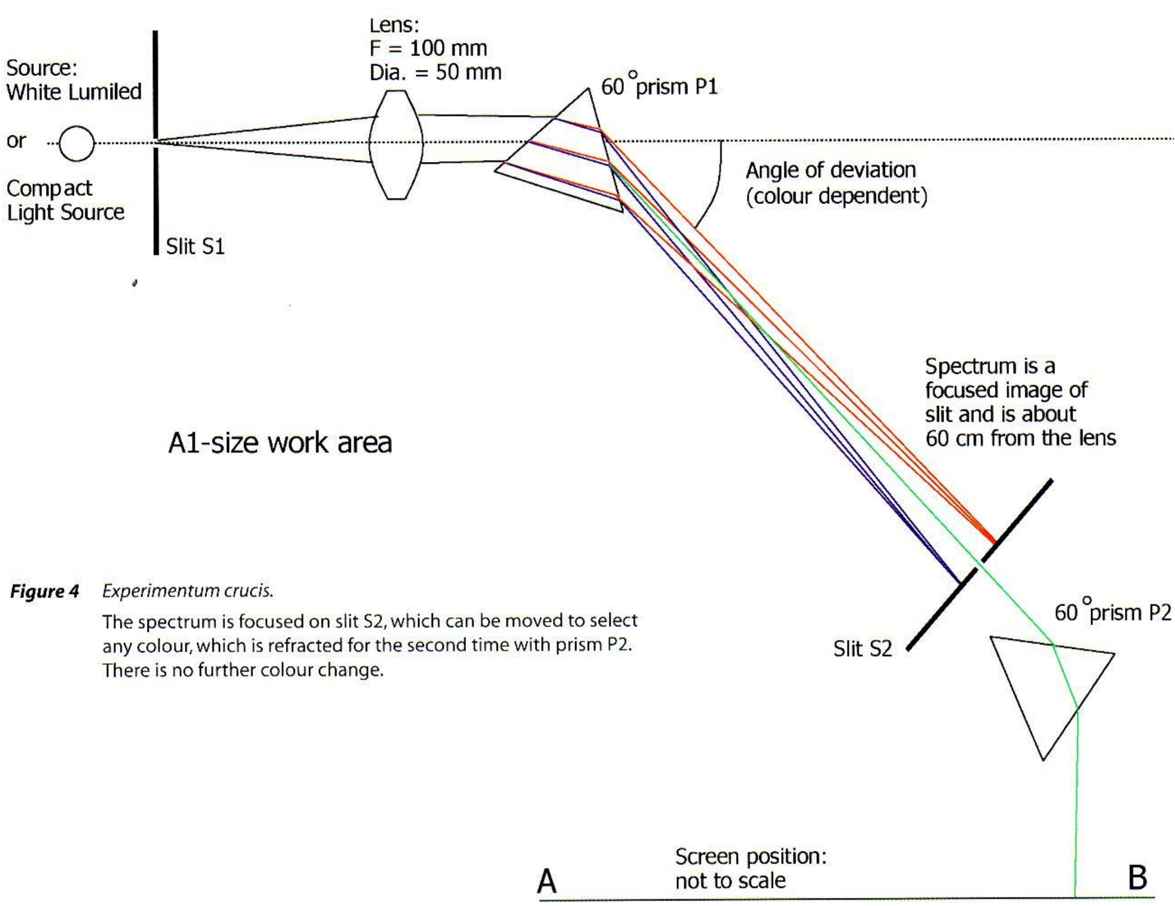

Figure 4 *Experimentum crucis.*

The spectrum is focused on slit S2, which can be moved to select any colour, which is refracted for the second time with prism P2. There is no further colour change.

Optical part specification	Supplier, part number, price, comment
Slit, 1.0 mm width	Philip Harris, B6G98647, £2.29 for 5, B6A44222, £2.74 for mixed set
Prism, high refractive index	SF-18 glass, n=1.722, Edmund, T43-498, £63.07 Flint glass, n=1.620, Leybold, 465 32, £28.74
Lens, focal length about 100 mm	This should be a cylindrical lens if working on the benchtop, but can be a spherical lens (50 mm diameter) if using a prism table.
Light source: white 1 W Lumiled	Lumiled Luxeon 1W Star with Optic (Low Dome Batwing) Enhanced-White LXH-NWE8, RS, 467-7519, £10.49. See Bulletin 212 for circuit diagram.
Light source alternative: Compact Light Source	Griffin, XGH-600-M, £207.50, Philip Harris, B6H76839, £112

Table 2 *List of optical parts*

The *Experimentum crucis*

An *experimentum crucis* is the crucial experiment or telling demonstration that makes a critical point. It gives irrefutable evidence of how things are.

We know quite a lot about how Newton worked. 1665 and 1666 were plague years. Newton, then a young Cambridge scholar, was forced to return to his mother's house in Lincolnshire, where he pursued his scientific studies in solitary confinement. He learnt much about optics from playing around with prisms and lenses. There is a lesson for us from that. We should allow children to play with apparatus. From play, we get a tacit understanding of how things are. It is an aid to sensory perception and the formulation of concepts. And it is from play that great thoughts sometimes emerge.

Some years later (1972) Newton wrote a discourse on light and colours which he sent to the Royal Society. The Society published it. It was his first scientific publication. This letter is regarded by historians of science as the prototype of the scientific paper. It contained practical details of his experiments, letting others see and copy what he had done, and gave his findings, letting them be argued over and confirmed or disagreed with. In presenting science in an open, non-dogmatic way and looking for, and getting, a disputatious response, it set the way that science has been conducted ever since.

In playing around with prisms, Newton had come to realize that what he had found out on light and colour could be shown with one telling experiment. At that time, prisms were thought to colour light by staining, as if, indeed, by magic. Indeed the word 'spectrum' was invented by Newton as a testimony of old beliefs; it comes from 'spectre', a ghostly apparition. In the *experimentum crucis*, light was refracted a second time, showing that refraction sifts rather than stains light and, in Newton's words, that "light does not change colour when it is refracted". Therefore it was evident that sunlight, or white light, had been decomposed into rays of different colours.

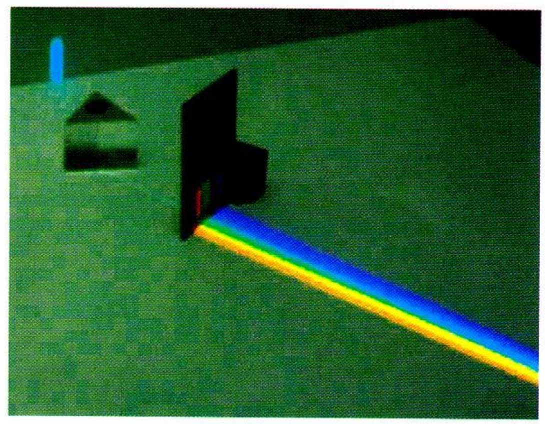

Figure 5 *Experimentum crucis.*
Photograph of a second refraction.

Further reading

Crease, R.P., *The prism and the pendulum: The ten most beautiful experiments in science*, Random House, 2003, ISBN 1-4000-6131-8.