I & I News

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The pursuit of astronomy and allied fields such as navigation and surveying has produced, in addition to telescopes, a wealth of instruments and peripheral devices, large and small. Some have been superseded by modern technology, some are still used but in modified form, and others are used very rarely and only by specialists. The articles included here present some of these instruments: the artificial horizon, the spherometer, the dipleidoscope, the Barlow lens, and fluid lenses and dialytes.

Bob Marriott, *Director*

The artificial horizon

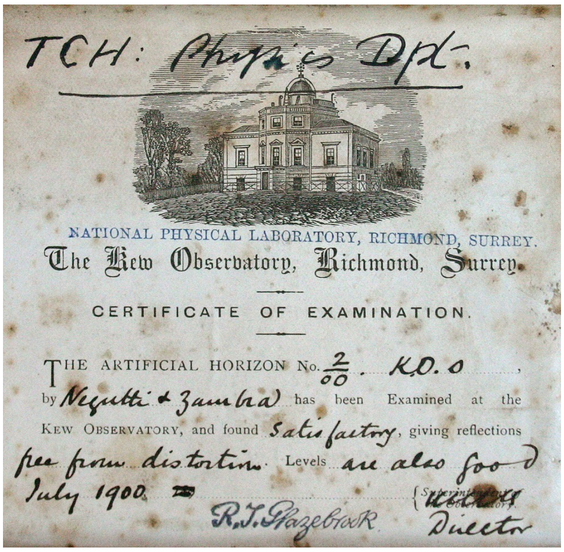
Bob Marriott

With developments in navigation the horizon became one of the bases for measurement of the altitude of the Sun or a star; and when the horizon was obscured by fog or other causes an artificial horizon served as an alternative. When properly levelled to obtain a reflection of the Sun, the angle between the Sun and its reflection is measured and then halved to derive the altitude.

At the end of the nineteenth century the Royal Society was seeking a home for its proposed National Standards Laboratory. It was originally intended that it should be housed at the Kew Observatory, but the premises were not suitable. However, an ideal home was found, and the National Physical Laboratory – the first state-funded scientific establishment – was established at Bushy House, Teddington. (Bushy Lodge – later renamed Bushy House – had been built for Edward Proger, by command of King Charles II, in 1663.) At the end of 1900 the First Commissioner of Her Majesty's Works informed the President of the Royal Society, Sir William Huggins (the amateur astronomer), that 'Her Majesty, the Queen, has granted to the Commissioner of Works, by her Grace and Favour, Bushy House and Grounds for the use of the National Physical Laboratory under the direction of the Royal Society.'

The instrument illustrated here (in the author's collection) was certified in July 1900, at the time that the NPL was established at Bushy House but before it was formally opened by the Prince of Wales (later King George V) on 19 March 1902. It consists of a slab of black glass mounted in a frame with three-point suspension, and two spirit levels. The label is that of the Kew Observatory, but also bears the rubber stamp of the NPL and the rubber-stamp signature of Richard Tetley Glazebrook, FRS, the first Director of the NPL, appointed on 1 January 1900.

The optical and mathematical instrument-making firm of Negretti and Zambra operated in London from 1850 to the 1990s. From its earliest years it also served as official photographers to various companies, and commissioned photographic expeditions to several countries, including Egypt, Ethiopia, and China.



TCH: Physics Dpt.

NATIONAL PHYSICAL LABORATORY, RICHMOND, SURREY.
The Kew Observatory, Richmond, Surrey.

CERTIFICATE OF EXAMINATION.

THE ARTIFICIAL HORIZON No. 2/00. K.D. 0
by Negretti & Zambra has been Examined at the KEW OBSERVATORY, and found Satisfactory, giving reflections free from distortion. Levels are also good
July 1900
R.T. Glazebrook Director

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The spherometer

Len Clucas

Amateur mirror-makers use a variety of methods for measuring the sagitta or the radius of curvature of a mirror. A radius gauge can be used, and a straight edge and 'feelers' or the 'meerkat' method are often employed, though probably the best method is a straight edge and the 'depth' end of a digital vernier. These devices are for a one- or two-off number of mirrors and have no repeatable accuracy; but a professional maker needs these conditions, so a spherometer is the instrument used. Spherometers have been around a long time. Various descriptions can be found on the Internet but with little detail concerning manufacturing requirements, so when John Nichol, a professional optician, asked me to make him one this was *terra incognita*. The result is presented here.

The spherometer has a body, three fixed legs, and an adjustable leg. This leg is the spindle of the micrometer drum. All the legs have 6-mm diameter hardened ball ends. A 16-mm thick aluminium plate is used for the three-lobed body. In it, four holes are drilled and reamed to take the legs. Three of these holes of 10 mm diameter, for the fixed legs, are equispaced on a 150-mm pitch circle. The fourth hole, for the micrometer drum or adjustable leg, is 1-inch diameter and at the exact centre of the 150-mm pitch circle. The accuracy of the hole positions is obtained by the 'direct readout' system on my milling machine, theoretically 1 mμ linear. The fixed legs are machined to exactly the same length. Using the best side of the body as a datum, the legs are 'loctited' in place, and the flat ends of the legs and the datum face of the body are pressed against a surface plate. Thus the ball ends are set in a level plane. The length of these legs has been calculated to give a datum reading of 15 mm on the micrometer drum when all four legs rest on a plane surface. This is to make the instrument usable for convex and concave surfaces. John Nichol (in the photograph) took a reading against a 20-inch mirror carefully measured by the Foucault test. The spherometer was within 0.03% of that figure.

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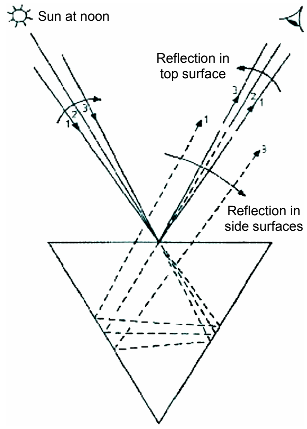
The dipleidoscope

Bill Barton

The word ‘dipleidoscope’ is derived from Greek and means ‘double image viewer’, and the instrument can be considered a solid-state transit instrument.

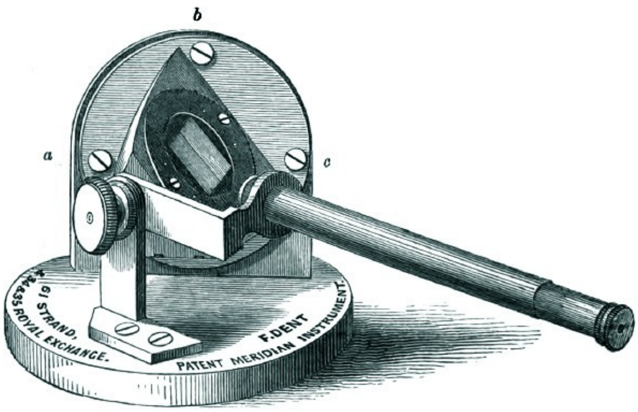
The chronometer maker Edward John Dent (1790–1853) worked for some time in the mid-nineteenth century to simplify the transit telescope originally developed by Ole Rømer (1644–1710) in Denmark. Dent wanted to make ascertaining the correct time easily available to the non-astronomical community, and was approached by James Mackenzie Bloxam, a barrister from Denbighshire (*c.*1814–1857), with an already working device. The two went into partnership, with the first dipleidoscopes going on sale in March 1843, for 2 guineas (£2 2s – £161 in 2010, adjusted by the RPI). Bloxam appears to have been afraid of compromising his professional standing as a barrister, with much of his work being published only after he died. To secure their respective rights over the device, a patent was sought by Bloxam and was granted on 20 June 1843 (United Kingdom Patent no. 9793), and a French patent was applied for on the 24 July 1844. After Dent died his stepson Frederick William Dent took over manufacture.

A dipleidoscope consists of a hollow equilateral prism with a clear glass front face and the two rear faces internally silvered. The long axis of the prism is approximately aligned with the Earth’s polar axis. The prism thus produces two images of a celestial object – one by direct reflection from the front face that moves in the opposite direction to the object, and the other reflected via the two rear faces that moves in the same direction as the object, but at double speed. At one point these two images coalesce. When the dipleidoscope’s prism is correctly orientated this conjunction of images occurs as the object transits the local meridian.



The dipleidoscope as manufactured by Dent utilises three separate pieces of glass. These had to be precisely and securely placed, and in 1928 Sir Charles Vernon Boys (1855–1944) promoted the use of a solid prism which could not move out of alignment.

The mounting, which is made of brass, is 2⅛ inches long by 3⅜ inches wide by 2⅜ inches high, and weighs around 1 lb 15 oz. The front aperture of the prism is ⅞ inch long by ½ inch wide. A tight-fitting lid is provided to protect the optics from the weather, as the instrument was designed to be mounted outdoors with a clear southern meridian aspect, though portable versions were also available. The lid bears E. (or F. for models after 1853) Dent’s name, together



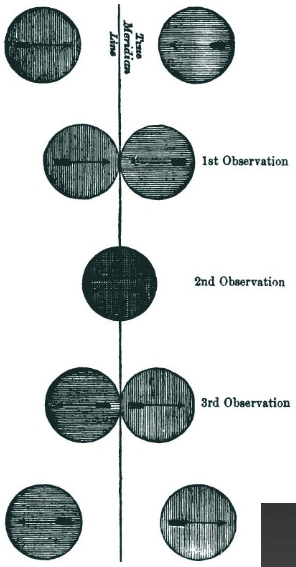
with his business address. To aid observation of the moment of transit, a viewing telescope was sometimes fitted. The brass was matt-painted, as if it were polished, solar observation would be very difficult due to the mounting also reflecting sunlight. The length and width of the prism is sufficient to allow, as a minimum, correct observation of any ecliptic object. Prospective owners in the tropics were invited to state the latitude where the instrument was intended to be installed, so that the correctly angled mounting could be supplied.

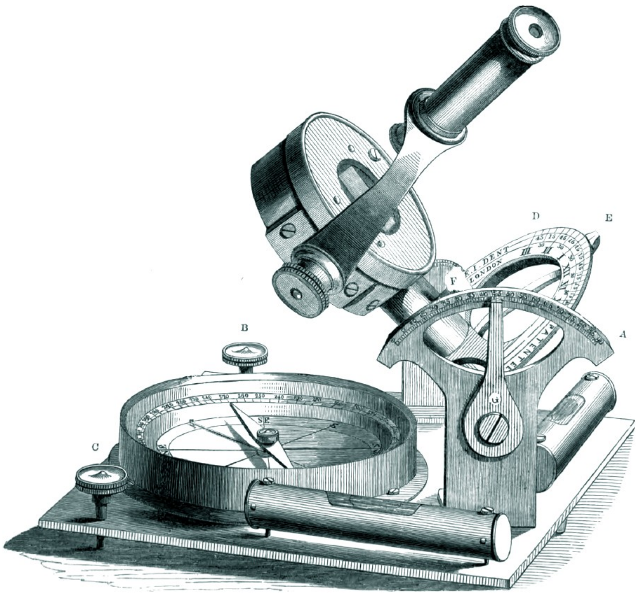
The instrument was a success, and within a year Dent was importing additional parts from France at 3s 6d (£13.40 in 2010, adjusted by the RPI) per dipleidoscope in order to keep pace with demand. In 1851 he had a stand at the Great Exhibition in the Crystal Palace in Hyde Park, where two dipleidoscopes were displayed in class X (philosophical, musical, horological, and surgical instruments), entry 55, numbers 29 (an ordinary dipleidoscope) and 30 (an equatorially mounted dipleidoscope).

To help owners align their instruments, Dent produced a 28-page instruction booklet.[1] Additionally, he offered initially to dispatch a competent person with a chronometer to carry out the adjustments. The employee’s stay was charged at the cost of travel expenses plus 10 shillings (just under £40 in 2010, adjusted by the RPI) remuneration per day. By 1862 this service was replaced by a double orthogonal spirit level and magnetic compass accessory made available at no cost. It was to be returned to the Dent Company within a specified time, as once the dipleidoscope was correctly set

the accessory was of no further use. The booklet ran through at least eight editions and was still being published in 1868, some twenty-five years after dipleidoscopes were first offered for sale. Interestingly, there is a complete section devoted to whether the dipleidoscope owner desiring to catch a train, running according to Greenwich Mean Time, should arrive at his local railway station earlier (eastern longitude) or later (western longitude) than the local time obtained from the dipleidoscope.

For a transit to be taken using either the Sun or the Moon, Dent recommended making three observations to increase accuracy – the first as the two limbs initially touch, the second as the two images overlap exactly, and the third as the two images separate. Averaging the time of the three events gives the time of the true transit. A table in the booklet gives solar semidiameter values throughout the year, allowing for possible missing triple timings to be reconstructed. For solar timing Dent recommended using either the viewing telescope fitted with a dark filter (of the type fitted to sextants) or capturing a projected image using a sheet of paper, held about 2 feet away from the dipleidoscope. The time taken for the two solar images to pass over each other varies through the course of a year, with a maximum of 2 min 22 sec in mid-December and a minimum of 2 min 7.6 sec in mid-September. A well-adjusted dipleidoscope had a claimed accuracy of less than 1 second.





A ‘universal’ model was also produced with the prism placed on an adjustable miniature equatorial mounting, enabling the user to time observations at any latitude and at up to 45° (three hours of time on the celestial equator) either side of the object’s meridian passage. This had the great facility of enabling the observer to capture an observation at his convenience rather than wait for the chosen object to transit, which would depend on the vagaries of the weather.

The advent of telegraphic, telephone, and radio time signals made amateur dipleidoscopes (and transit telescopes, for that matter) redundant. However, dipleidoscopes can still be found occasionally in antique shops and on-line auction sites. As these instruments are solid state, with no moving parts to wear, unless the optical system has been interfered with they can still operate as well as when they left Dent’s workshop more than a century ago. A clue to the date of manufacture of an instrument is whether E. (Edward) or F. (Frederick) Dent’s name is on the lid and what addresses are given, as

the Dents opened several shops over the years. In addition, each dipleidoscope is stamped with a serial number.

Notes

1 The illustrations for this article are taken from this booklet, which is available at: http://books.google.co.uk/books?id=9QlbAAAAQAAJ&pg=PA5&source=gbs_toc_r&cad=4#v=onepage&q&f=false

The photographs presented here are of dipleidoscopes in the author's collection. Dipleidoscopes are also mentioned in an article by Carole Stott and David Hughes, 'The amateur's small transit instrument of the nineteenth century', *Quarterly Journal of the Royal Astronomical Society*, 28, 1 (1987), 30–42.

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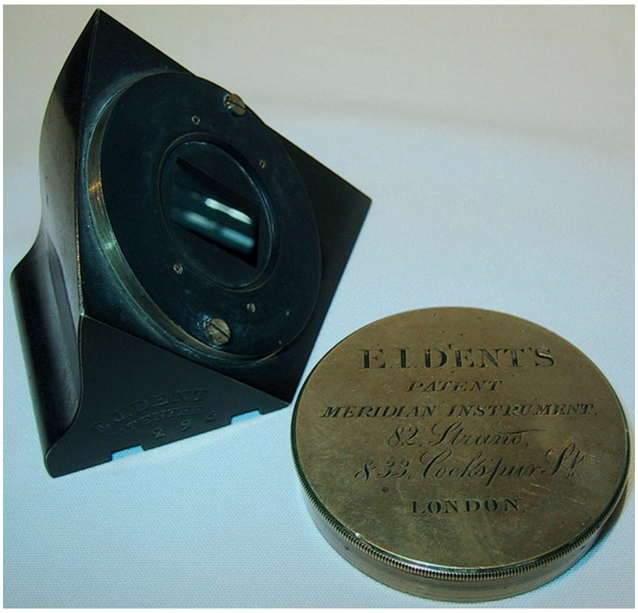


The Barlow lens

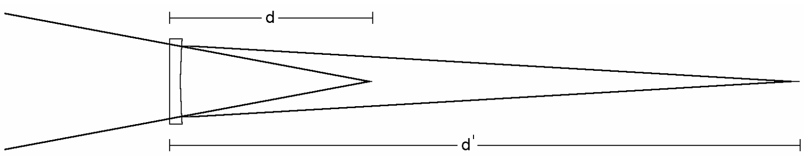
Bob Marriott

The Barlow lens is commonly considered as simply an additional optical device for increasing magnification. However, when it was invented, around 180 years ago, it was intended for a more specific purpose.

During the 1780s and 1790s William Herschel measured and remeasured many double and multiple stars, the results of which, when published in 1801–03, demonstrated the physical connection between associated and mutually orbiting stars and proving the extension of Newton's gravitational theory to stellar systems.

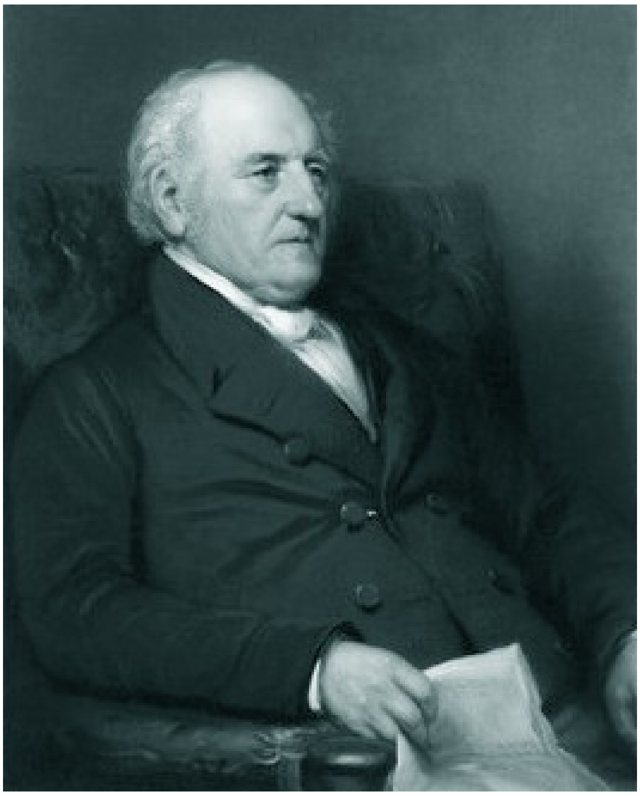
During the 1820s Herschel's double stars, plus many new double and multiple stars, were measured and remeasured – notably by F. G. Wilhelm Struve, James South, and John Herschel. Compared with the long tradition of measuring the positions of stars for the compilation of catalogues — known as 'grinding the meridian' – this was a new type of positional astronomy connecting to the study of physical and gravitational systems, pervading observational astronomy until the advent, around 1860, of physical astronomy and the new science of astronomical spectroscopy and astrophysics.

When measuring the position angle and separation of a double star with a filar micrometer it is necessary that the



A = d'/d
m' = mA

Distance of Barlow lens from original focus	d
Distance of Barlow lens from new focus	d'
Amplification	A
Magnification without Barlow lens	m
Magnification with Barlow lens	m'


Peter Barlow (1776–1862)

webs be as fine as possible, so that the stars are bisected and not obscured. But when the magnification is increased, the webs also increase in apparent thickness. An amplification lens placed behind the micrometer, however, will increase the field magnification without increasing the apparent thickness of the webs – and it was for this purpose that the Barlow lens was designed. It should therefore be considered as a device which amplifies the focal length and focal ratio of a system rather than simply increasing the magnification, though the result is the same.

The Barlow lens is a diverging negative lens which increases the effective focal length of an optical system as perceived by all components which follow it, the practical result being that it magnifies the image. It is not a single glass element (though it is shown in simple form in the diagram above), as this would generate chromatic aberration, and spherical aberration if the lens is not aspherical. More common configurations incorporate three or more elements for achromatic correction, apochromatic correction, higher image quality, and a flat field.

In modern usage, Barlow lenses are usually fixed at 2x and occasionally 3x, but if adjustable can be set to any amplification required. When the length of a 2x Barlow lens tube is doubled it becomes a 3x Barlow; when the length of the tube is tripled it becomes a 4x Barlow ... and so on – and comparatively few increases in tube length are required to produce an amplification of several thousand and eventually infinity! An additional advantage of the Barlow lens is that it multiplies the number of eyepiece magnifications available. Therefore, when purchasing eyepieces for the first time it is worthwhile obtaining, for example, 25-mm and 18-mm eyepieces and a 2x Barlow, which will effectively also produce 12.5-mm and 9-mm eyepieces.

The following are the original papers of George Dollond and Peter Barlow, demonstrating that Barlow's original suggestion was put into practice by Dollond, trialled by William Rutter Dawes, and explained mathematically by Barlow, who, quite correctly, was assigned the credit for the invention.

George Dollond

An account of a concave achromatic glass lens as adapted to the wired micrometer when applied to a telescope, which has the property of increasing the diameter of the micrometer wires

Philosophical Transactions of the Royal Society
124 (1834), 199–203

When the application of any optical or other arrangement is found to be useful, a correct statement of the manner in which it became so is essentially requisite, in order that each person who may have had a share in bringing it forward may have his due proportion of the merit.

The achromatic lens which I have applied to the wired micrometer, and which has been found to produce such very considerable advantages to that instrument, arose out of a trial that was made at the suggestion of Professor Barlow, for the purpose of improving the chromatic aberrations which affected the field of the eye-glasses applied to the telescope invented by that gentleman with a fluid correcting lens, and made by myself for the Royal Society.

The lens in question not being found so effective for his purpose as he expected, was laid aside. It has now been introduced for my purpose, and is made, with some trifling variations, in accordance with his calculations.

The interposition of a concave lens between the object-glass and the eye-glass of a telescope has been generally known by opticians to produce an increase of the magnifying power, in proportion to its focal length and distance from the object-glass: also that a convex lens, if so applied, would diminish the power.

Except in the Huygenian eye-tube, I am not aware that either of these lenses have been so applied generally, it having been considered that their introduction would materially diminish the light proceeding from the object-glass of the telescope, and also, by deranging the aberrations, disturb the image.

In the lens I am now describing, these errors are very materially obviated, owing to its being constructed upon achromatic principles, by which the magnifying power of the telescope is increased in a two-fold ratio, without so much diminution of light as is produced by the introduction of a simple lens.

For example, if the eye-glasses in the original arrangement of the telescope gave 100 of magnifying power, the same eye-glasses with the new lens, if I may so term it, will give 200, and the light will be fully equal to that power if obtained by the usual means. The field of view will also be considerably flattened.

Thus it will be seen that we have the advantage of using longer eye-glasses with an extension of power, whereby the wires or spider-webs of the micrometer are not increased in diameter, a very essential advantage when observing minute double stars; nor is the eye of the observer so much distressed as when the magnifying power is obtained by shortening the focal lengths of the eye-glasses.

The advantages of this improvement having been shown by the foregoing introduction, I will now proceed to give an account of the causes which led to its being applied to the micrometer, and the result of its application. The Rev W. R. Dawes, a gentleman pursuing practical astronomy with great zeal and perseverance, and to whom the public are already much indebted for several valuable communications, being desirous of carrying his measurements of the double and revolving stars, to a greater extent than the powers of his micrometer then allowed, applied to me to construct for him an arrangement of eye-glasses that would increase the magnifying power of his telescope without increasing the apparent diameter of the spiderwebs in his micrometer, or interfering with the mode of illumination. Several combinations were tried without success, when it occurred to me that the achromatic concave lens, which had been decided by Mr Barlow to be of no use for his purpose, might accomplish what was required.

The result I will now state from a letter I soon after received from Mr Dawes, to whose micrometer this improvement had been applied.

March 14, 1833

My Dear Sir, You will doubtless be surprised at not receiving from me any account of the performance of your scheme for the improvement of the achromatic telescope. My general opinion of your improvement is, that it is, for the purpose it is designed to answer, as useful as it is elegant.

By a careful determination of the value of the micrometer divisions, I find the magnifying power of any eye-tube is increased in the proportion of 2.1068 to 1: each part originally = 0″.55922 is now = 0″.263867. To obtain the magnifying powers of the eye-tubes, I content myself with multiplying the original powers by 2.1. But I will detail a few particulars noted in my journal on the subject. I have thus set down the advantages of the additional lens.

1st. The micrometer threads are only half the thickness, with the same magnifying power on the object; small stars are therefore neither obliterated nor distorted.

2nd. The parallel threads are both very nearly in focus with any power up to 600; before, only up to 285 (the same eye-piece).

3rd. The value of the micrometer divisions is less than one half its former amount, permitting a proportionally fine motion in measuring the distances of delicate objects.

4th. A much greater extent of the field being flat, and the threads distinct further from the centre; of great importance in accurately determining the zero of position by the passage of a star along the thread.

5th. The definition of the stars seems quite as good; and the false light does not appear to be increased, or the regularity of its distribution affected. The discs of the stars seem in fact to be, if anything, rather smaller and cleaner with the concave. Perhaps their brightness might be perceived to be a trifle less; but even this is doubtful.

6th. The shallower eye-glasses are much more easily cleaned; of great importance in high powers.

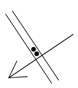
7th. The prism can be conveniently applied to all powers as high as 600; before, only to 285. This prism is of essential utility in other respects besides facilitating zenith observations; and it is no small improvement that its use is thus extended.

From the performance of this additional lens, it is evidently a perfect production. Against all the advantages detailed above, the trifling addition to the length of the telescope is not to be mentioned; indeed it is to me surprising that so great an effect should be produced with so minute an increase of focus.

As a severe trial of the difference in illuminating power, I have examined Saturn's satellites, and κ Geminorum. I could discover no decided difference in the apparent brightness of the satellites, allowance being made for the difference of power employed. It happens awkwardly, that among moderate powers, fit for planets, none coincide sufficiently with and without the concave lens. The nearest I can get are a negative 195 with the new lens, and a double convex 208 without it: with these, little difference in brightness; but the planet might be a trifle sharper with the latter. Have you ever seen the minute companion of κ Geminorum? It is the finest test of a 5-feet achromatic I have yet seen: distance about 6". I saw it steadily with negative 140 without the concave, and quite as well with negative 116 with it; but these powers are not near enough to each other.

For tolerably bright stars, I have on the micrometer 475 with the concave lens, and without it 480; also 600 with, and 625 without. These afford an excellent comparison. Vision appears to me equally good with both; and the fineness of the micrometer threads leads me always to prefer the new arrangement, as I can then use the same eye-piece generally for the distances, as I use for the positions.

In clear weather, I always use 600 for stars of the fifth magnitude and upwards, and sometimes even of the sixth; and last night I got a very good set of positions of Castor with a power of 1010, with which the discs were occasionally perfectly well formed, though of course not so sharply defined. I also obtained last night very satisfactory measures of ζ Cancri, certainly one of the most difficult stars for a telescope of 5 feet. That you may judge for yourself of the way in which it was seen, I will detail here my measures, exactly transcribed from my observation paper.

Power	Position	
600	336° 56'	Mean = 335° 28'
Stars placed between	335° 50'	z = –271° 26'
the parallel wires thus	336° 22'	———
	335° 8'	64° 02' nf
	335° 7'	———
	334° 1'	25° 58' from N
	334° 49'	

Though 600 did well for the angles, the stars were not sharp enough with that high power for accurate bisection. The parallel threads are sweetly fine and sharp with 295 (formerly 140). Indeed, this is a very efficient and generally useful power.

Thus you will see, my dear Sir, that a long-lamented desideratum has been efficiently supplied by your elegant invention. I have thus nearly all the advantages, and none of the disadvantages, of a 10-feet telescope of the same aperture.

I remain, my dear Sir
Yours faithfully
W. R. Dawes

I shall now introduce some extracts from a letter I have since received from Professor Barlow, in which his formulae for constructing the lens are given.

February 1st, 1834

Dear Sir, In answer to your letter of January 30th, 1834, I will endeavour to state the views which led to my requesting you to make the achromatic concave lens you allude to, and explain the formulae and principles on which I computed the curves.

First, with regard to my views. Everyone is aware of the ease and comfort of observing objects in a long telescope in comparison with viewing the same in a short one, supposing the powers equal in both instruments; and my object was to produce this effect by taking up the rays before they arrived at their focus, extending them to a greater distance, and thereby increasing the size of the image, which is of course the same as increasing the length of the telescope in a like proportion.

In order to render this lens achromatic, it is only necessary to make the foci of the lenses proportional to their dispersive powers, as in the object-glass itself; except that here the crown lens must be made concave and the flint lens convex.

Suppose, for example, the compound lens is to be placed at a distance, d, from the focus, and that the image is to be doubled, then the focal length of the compound lens must be $2d$; for $1/d - 1/(2d) = 1/(2d)$. Again, δ being the dispersive ratio, we have

$$f = 2d(1 - \delta) \quad = \text{focal length of the crown lens}$$
$$f' = 2d(1 - \delta)/\delta = \text{focal length of the flint lens}$$

To correct the spherical aberration requires more labour. Let us suppose the crown lens placed towards the object-glass. Assume its radii r, r', or rather their ratio $r/r' = q$, at pleasure, and compute its aberration for rays converging to the distance d, which may be done by the following formulae, a being the index. Find

$$\begin{aligned} d' &= ((a + 1)/(ad - r))dr \\ b &= a/(a + 1) \\ d/r' &= c \\ d'/r' &= c' \\ r/r' &= q \end{aligned}$$

Then the aberration will be

$$(((c + q)^2/(ac - q)^2) \times ((c + (a + 2)q)/(c(ac' + a + 1)^2)) + ((c' + 1)^2/(bc' + 1)^2) \times (((c' + 2 - b)q)/c')) \times a/2r$$

Let the quantity when found be called m, then for the flint lens proceed as below, the radii being r'', r''', the latter towards the eye, and the index a'. Find

$$\begin{aligned} d' &= ((a' + 1)2dr''')/(2a'd - r''') \\ b &= a'/(a' + 1) \\ 2d/r''' &= c \\ d'/r''' &= c' \\ r''/r''' &= q \end{aligned}$$

Then find r''', r'', and q, such that

$$(((c + q)^2/(a'c - q)^2) \times ((c + (a + 2)q)/(c(a'c' + a' + 1)^2)) + ((c' + 1)^2/(bc' + 1)^2) \times (((c' + 2 - b)q)/c')) \times a'/2r''' = m$$

and the resulting curves will be those required.

To produce this latter equality is the only difficulty in the operation, and to treat it as a common equation would lead to immense labour. I have therefore always contented myself with pursuing the more simple method of trial and error, its facility fully compensating, in my mind, for its want of scientific elegance.

It may be proper to observe, that I proposed the lens to double the magnifying power, and the curves were computed accordingly, but the formulae will of course apply to magnifying in any ratio.

I hope this explanation will be found intelligible, and I am pleased to find my proposition has been found useful.

I remain, dear Sir
Yours very truly
Peter Barlow

I have only to add to the foregoing relation of facts, that I do hope they will prove satisfactory to those friends who have felt so much interested upon the subject as to induce me to write this paper, it not being my wish to take credit to myself for anything like an invention, but merely for the application of the lens to the micrometer, as I am fully convinced that a concave lens, either simple or achromatic, was never so applied before.

Peter Barlow

On the principle of construction and general application of the negative achromatic lens to telescopes and eyepieces of every description

Philosophical Transactions of the Royal Society
124 (1834), 205–7

The great advantage which has attended Mr Dollond's ingenious application of the negative achromatic lens to the micrometer eyepiece, seems to make it desirable that the principles on which that lens is constructed, and its general application, should be more fully illustrated than is done in the short extract made from my letter to Mr Dollond, and given by him in his recent paper in the *Philosophical Transactions*.

In my original fluid telescope, the negative lens was employed for the double purpose of lengthening out the focus and correcting the colour of the front lens; and the great advantage of the lengthening principle was manifested by the high penetrating power of the instrument in the centre of the field. Unfortunately, however, the perfect part of this was very limited, so that when Mr Dollond constructed the second telescope for the Royal Society, I gave up this advantage for the sake of enlarging the field; but I found that by this means much of the penetrating power of the former telescope was lost; for although I had the same aperture, many small stars which were before very perspicuous were in this instrument seen only with difficulty and under advantageous circumstances of weather, absence of moonlight, &c.

This led me to consider whether it would not be possible to retain the advantages I had obtained in the new instrument, and to restore the power of the other principle (that of penetration) by an artificial lengthening of the focus; but as the rays were now as nearly achromatic as I could make them, it was necessary in this case to have the lengthening lens also achromatic. I had no authority from the Royal Society to make any collateral experiment, but having mentioned my idea to Mr Dollond, he very readily undertook to construct the small lens, and it was accordingly made and tried; but owing, as I now imagine, to the imperfect means I had of fixing it, its advantages were not perceived. It was laid aside, was not referred to in my paper, and would most likely have been altogether lost sight of, had it not occurred again to Mr Dollond to try its effect on the micrometer eyepiece for the Rev Mr Dawes. It is therefore to Mr Dollond we are indebted for snatching this lens from the oblivion into which I had allowed it to fall.

It must not, however, be understood that it is only applicable to this eyepiece, for it may be applied to any eyepiece, positive or negative, or to the erecting eyepiece, or indeed to any telescope of fluid or glass, or to refractors; for it is, in fact, not a part of the eyepiece, but of the telescope itself: and it is for this reason its advantages are so conspicuous in the application Mr Dollond has so ingeniously made of it; for by lengthening the focus before the rays arrive at the eyepiece, the image is magnified, while the wires retain only their original size.

Having thus shown the origin of the negative achromatic lens, I may be allowed to state the motives and reasonings which guided me in the computation of the curves, and what appears to me to constitute the advantages it is found to possess. Notwithstanding the extreme difficulty there is in constructing an achromatic object-glass, yet with perfect materials the difficulty is only in the manipulation; and this being overcome, there is not so great a natural impediment to perfection in this part as in the eyepiece, for we know that it is impossible to make a perfect positive power; and if the same absolute impediment does not occur in the negative eyepiece, yet the thicknesses of the lenses render the task very difficult, not only to execute, but to compute the proper curvatures to ensure perfection. If this view of the case be correct, we see at once the advantage of magnifying the object as much as possible before we apply the eyepiece; and this, in fact, is the whole theory of the negative achromatic lens: that is, supposing the rays to be rendered achromatic by the object-glass, they are intercepted by the negative lens before they cross, which, being itself also achromatic, extends them to any length, and thereby produces the effect of lengthening the whole focus in the same proportion, and consequently the power of the telescope, the eyepiece remaining unaltered.

In the conclusion of my letter to Mr Dollond, I have offered a suggestion, whether it would not be possible to retain the same eyepiece for all powers by changing only the negative lens. This must of course, as he has observed, change the scale of the micrometer; but this being changed, by so adapting the lens as to render the powers simple multiples of each other, would not, I conceive, be attended with any disadvantage. In other cases, where a micrometer is not employed, and where the utmost perfection is not looked for, every variety of power may be produced by simply moving the negative lens nearer to or further from the eyepiece; for both the object-glass and lengthening lens being achromatic, the image, wherever the focus is formed, will be achromatic also; and the spherical aberration of the lens is so inconsiderable, as only to be discovered by the most perfect eye, when removed from that point in which it is computed to be perfectly corrected. The negative lens is therefore admirably suited for day telescopes with correcting eyepieces, as also for astronomical telescopes where the micrometer is not applied; for by giving an adjustment to the lengthening lens, the power may be changed in any proportion, even without removing the eye or losing sight of the object. I have no doubt that these and other applications of the lengthening lens will be made, and amongst others, I am willing to hope that it is not impossible the negative secondary spectrum of this lens may, by careful experiment, be so proportioned as in part to counteract the positive secondary spectrum of the object-glass so as to render the image more nearly aplanatic; some experiments, at all events, directed to this inquiry are very desirable.

I have already, in my letter to Mr Dollond, given the formulae for computing the proper curves according to any distance between the focus and the lengthening lens, and for magnifying the image in any required proportion; but unfortunately the calculation is very laborious, and difficult to be rendered general, or tabulated for general practice. I would therefore recommend opticians to use the same curves as are commonly adopted for short telescopes of six, eight, or ten inches, making those of the plate or crown concave instead of convex, and those of the flint convex instead of concave, turning the plate towards the object-glass and the flint towards the eyepiece, which will in general bring out a close approximation for spherical aberration, and the colour will be sure to be corrected. Starting from this point, practical skill will readily supply the means of making corrections, if any such should be found necessary after all has been done that can be done by changing the position of the lens as regards its distance from the eyepiece. I hope these additional directions for constructing and applying the lengthening lens will not be thought superfluous, nor undeserving the attention of practical opticians.

Fluid lenses and dialytes

Bob Marriott

During the seventeenth century, Isaac Newton attempted to correct optical aberrations by using water between lenses of the same type of glass, and David Gregory suggested that materials of different refractive index might be effective. During the 1730s, Chester Moor Hall commissioned opticians to make him a two-element object-glass. John Dollond repeated and improved these experiments, and afterwards designed two-element objectives with crown and flint glass components, as devised independently by Hall. In 1758 Dollond patented this invention: the achromatic lens. For many decades, however, refractors remained comparatively small (except for a very few notable exceptions), as lenses were expensive due to the difficulty of producing large pieces of homogeneous glass with a paucity of bubbles and without striae or other defects.

In 1787 Dr Robert Blair (*d*.1828), Professor of Practical Astronomy in the University of Edinburgh, began investigations into finding a substitute for flint glass (which was difficult to produce, and more expensive than crown glass) by using various oils and metal salts – in some cases enclosed in separate cells, and in others mixed in one cell between two convex crown glasses. After several years he succeeded in eradicating the secondary spectrum – the very small residue of colour produced by an otherwise 'achromatic' lens – and was also successful in removing spherical aberration. (A lens or mirror subject to spherical aberration is incapable of bringing rays to focus in the same plane normal to the optical axis if the distances of these rays from the axis are different.) Blair consequently applied the term 'aplanatic' ('free from aberration') to his lenses.[1] Several prominent opticians maintained that lenses of this type were not reliable, due to loss of transparency of the fluid by evaporation or crystallisation, or the corrosive action of acids on glass; but Blair disagreed. However, he discontinued this work, and his later attempts to manufacture fluid lenses on a commercial basis proved unsuccessful.

During the 1820s, Peter Barlow (1776–1862), Professor of Mathematics at the Royal Military Academy, Woolwich, also began research and experiments on the use of fluid lenses.[2] In Barlow's design the fluid lens replaced the flint-glass component of a doublet, but was placed well away from the single-lens object-glass along the optical axis. It cost far less than flint glass (which was still difficult to produce in large pieces), and because of its position in the optical train it could also be much smaller. Between its two components it had a gap, into which was introduced a fluid with a refractive index appropriate for correcting the aberrations produced by the object-glass. Barlow determined that the best fluid for this purpose was carbon disulphide, due to its perfect transparency, its absence of colour, and its high refractive index – twice that of flint glass. In 1827 Barlow made a 6-inch system of this type, and in 1829 another of 7.8 inches, with satisfactory results. However, in 1833 his attempt, in cooperation with George Dollond, to produce an 8-inch (at a cost of £157) for the Royal Society proved unsuccessful, and he soon afterwards discontinued his work on fluid lenses.

To form the fluid into a concave lens it was enclosed between two discs of glass, each with the requisite curve but with parallel faces so as to have no refractive or dispersive action. These were applied to the two opposite faces of a third disc, with corresponding curves and with its centre bored out to produce a ring. The three discs and the fluid were then all gently warmed to a temperature higher than any likely to be reached under normal conditions, the ring was placed upon one of the discs, and the other disc was slipped on to one side so as to leave open a small portion of the interior of the ring. The fluid was then poured in, and the upper disc slipped into place. Tin-foil or paper was then cemented around the edges to complete the process. When the fluid cooled, its contraction produced a vacuum-bubble, which was kept out of sight by allowing the ring an extra amount of aperture.

Details of experiments with fluid lenses can be found in the notebooks of Thomas William Webb (1806–1885). By 1826 Webb had begun experiments with various fluids in an attempt to make his own lenses. In April of that year he had learned about the refractive properties of turpentine, and was soon experimenting with its use in an object-glass: 'Focal distance very short, but apparently achromatic.' He may have continued these experiments at the time, but the next notes appear three years later, when on 31 July 1829 he 'tried to make a chromatic [*sic*] lens w. spt. turpentine between two eyeglasses – it had not refractive power enough, yet certainly had a good effect. Calculating for Achromatics in which Crown glasses sh'd make the Concave, Water or Alcohol the Convex. C'd not succeed ... Various plans of telescopes.'

Throughout this time he continued with his mirror-making, and over the ensuing eighteen months occasionally returned to his fluid-lens experiments. The fluids he tried included aniseed oil, which 'ran at full speed' and 'made the house stink prodigously'; Canada balsam, 'found its refractive power very high'; and turpentine, 'colour well corrected ... Very nearly broke the glasses out of the laundry window.' The only cement referred to was a mixture of gum and pipe-clay. During December 1829 he 'tried Bates's [*sic*] lens with Canada balsam ... [and] again w. turpentine';[3] that is, he used the balsam and then the turpentine in a fluid lens to correct the aberrations produced by the single-element lens.

Eventually, in August 1830, he used the chemical which Barlow had determined was best for the purpose:

> Meant to fill the glasses before dinner, but could not have the fire. Looking to the Sulph. C. [sulphuret of carbon – carbon disulphide], perceived it was stopped down w. some queer cement. Took it to Fouracres [a Gloucester chemist]. He said it was a scandalous stopper & had wasted so that only 6 dr[ammes] remained. He gave me another bottle.'

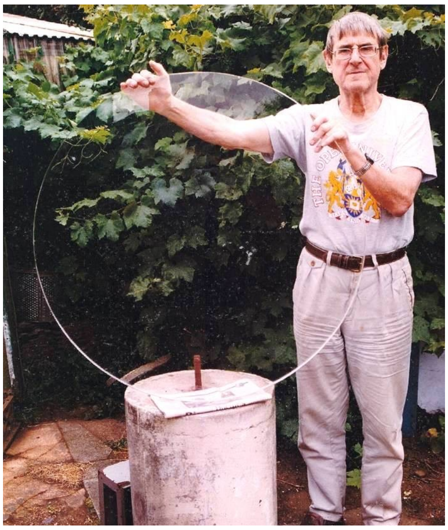
As well as its transparency, absence of colour, and high refractive index, carbon disulphide has other characteristics which clarify some of Webb's cryptic notes. It boils at 35º C (lower than body temperature), the vapour can settle for some time or can 'roll' across a surface as if adhering to it, and it smells of rotten cabbage.

Webb's diary entry for 14 August indicates that it was on that day that he finally succeeded in producing an acceptable and useable fluid lens:

> After dinner got all things ready. Heated down glue to strengthen it – warmed glasses & Sulph. Carbon, the latter to about 99[º F], & filled them – lost a good deal of stuff, but succeeded admirably – a good while glueing round edges. The thing answered beautifully – the only thing to amend was that there seemed a slight film of air left in some places between the upper glass & the ring ... I fancied minute bubbles of air escaped into the vacuum bubble ... No good c'd be done in filling the glasses till they were held horizontally. Had this been done at first there need have been no waste.'

One other problem remained, however. With this type of optical system, spherical aberration increases with increased distance between the primary lens and the corrector. At the end of the previous March, while in Oxford, Webb had visited Stephen Rigaud (Professor of Astronomy, and Director of the Radcliffe Observatory) and 'asked him about spherical aberrations, and he most kindly promised to look into it.' Rigaud subsequently provided him with information, but though Webb spent much time in investigating this problem, he did not succeed in removing spherical aberration from this telescope.

It is possible, therefore, that this instrument consisted of a 4-inch single-lens object-glass made by Bate and a carbon disulphide lens made by Webb, who also made the tube, finder, and mount, no doubt in consultation with his associates in Gloucester. Writing thirty-five years later, Webb considered its performance to be acceptable, though he equated it with Barlow's attempted 8-inch, which 'proved a failure; and such might be considered my own humble imitation ... It served me, however, for four years, with tolerable achromaticity, but much uncorrected spherical error.'[4]



Only a few fluid-lens refractors were made, and with the production of higher-quality optical glass they effectively became redundant. More than three decades later, however, in 1865, Webb wrote that 'several limpid fluids have since been discovered whose properties might merit investigation, especially chloroform, which from its density seems to promise well'[5] – an indication that even at that time the fluid lens was still considered a viable option.

In the late 1820s, at about the time that Barlow began his experiments, A. Rogers[6] proposed a new design for a dialytic[7] telescope. As with a fluid-lens refractor, a dialyte is one in which achromatism is affected by the positioning of a flint or crown/flint (instead of fluid) correcting lens along the optical axis, at some distance from the crown or plate object-glass. The object-glass is also thinner, and has shallower curves than the crown component of a doublet of equal aperture; and as the more expensive flint component is small there is a large saving in cost, especially with larger instruments. The distance between the object-glass and the corrector is arbitrary, and a smaller lens placed nearer the focus serves the same purpose; but the disadvantage (as with a fluid lens) is that spherical aberration increases with greater distance. Rogers' design enabled a 3-inch flint/crown lens to correct the colour produced by a 9-inch crown glass of 14 feet focus.

This design appealed to Webb, and in 1832 he asked his father to consult with George Dollond about the possibility of making such an instrument. Dollond replied 'very sensibly and to the point', Webb later told his father, 'but we shall never "make a deal" of it. He will not come to my terms nor I to his, to the tune, I daresay, of £50 or £60.'[8] Dollond did not consider that such an optical system would have any superiority over the usual achromatic object glasses, nor would it lessen the cost, and the planned instrument was not produced. Webb also considered making 'an attempt with Gilbert or Bate', but then decided against it, as 'they know no more of the requisite curves than myself, and we should all be in the wood together ... The wisest course is to discount such schemes and expectations altogether.'

In Great Britain the dialyte never attained popularity, and only a few were produced – even though John Herschel considered it 'a beautiful invention, highly deserving further trial'. The best of them were produced by G. S. Plössl in Vienna during the 1840s and 1850s; and of these, the largest was an 11-inch with a focus of 11¾ feet. Dialytes are consequently very rare, though there now exists a notable example. In 1865 Webb wrote that 'in theory, an object-lens of plate glass, however large, may have its colour corrected by a disc of flint glass, however small';[9] and 135 years later, John Wall completed the construction of a folded dialyte of 30 inches aperture – the fourth largest refractor in the world.[10]

References and notes

1 The results were detailed in a paper read before the Royal Society of Edinburgh, 3 and 4 April 1791.

2 *Philosophical Transactions of the Royal Society*, 118 (1828), 105; 119 (1829), 33–46; 121 (1831), 9–15; 123 (1833), 1–13.

3 Robert Brettell Bate (1782–1847) was mathematical instrument-maker to HM Excise, Optician in Ordinary to George IV, William IV, and Queen Victoria, and Master of the Spectaclemakers' Company. His output included mathematical, scientific, and optical instruments, hydrometers, standard weights and measures, bullion balances, and books on navigation, but the telescopes he produced are now seldom encountered.

4 T. W. Webb, 'The achromatic telescope, dialytes, and fluid lenses', *Intellectual Observer*, 7 (1865), 179–90.

5 *Ibid*.

6 A. Rogers, 'On the Construction of Large Achromatic Telescopes', *Monthly Notices of the Royal Astronomical Society*, 1 (1827), 71.

7 In chemistry, dialysis is the process of separating the soluble crystalloid substances in a mixture from the colloid by means of a dialyser – a vessel formed of parchment or animal membrane floated on water, through which the crystalloids pass, leaving the colloids behind.

8 Letter to John Webb, April 1832.

9 Note 4.

10 J. Wall, 'Building a 30-inch refractor', *Journal of the British Astronomical Association*, 112 (2002), 260. The plate glass for the 30-inch lens cost £100. This instrument is now at the Hanwell Observatory, near Banbury.

This article is extracted from part of my chapter on 'Webb's telescopes', in *The Stargazer of Hardwicke: The Life and Work of Thomas William Webb*, ed. Janet and Mark Robinson. Leominster: Gracewing, 2006.