



I & I News



Horace Edward Stafford Dall (1901–1986)

This issue of *I&I News* is dedicated to the accomplishments and achievements of Horace Dall. It contains Jim Hysom's obituary of Horace, personal reminiscences and memories, and an account of Horace's journey across Iceland in 1933. (I am grateful to Ben Searle – an intrepid cyclist – for permission to reproduce his article, which was first published in *Bycycle* and on his website.) Also included are several of Horace's published papers on his camera obscura, a null test for paraboloids, FP3 Series II film, atmospheric dispersion, Maksutov telescopes, visual astronomy in the ultraviolet, telescope eyepieces, finding and guiding on dark skies, photoelectric methods, a solar prominence telescope, and a Dollond–Wollaston telescope. On the last page there is a brief account of the Association's Horace Dall Medal and Gift, and the references and website links include a 52-minute video of Horace recorded by Robin Scagell in 1982.

I am privileged to have known Horace – not only because he was the doyen of British amateur telescope-making, but because such acquaintance can often provide a direct link with the distant past. Horace was born on 6 January 1901, sixteen days before the death of Queen Victoria, and during the 1920s he corresponded with George Calver, who was born in 1834, during the reign of William IV and three years before the beginning of the Victorian age. But everything and everyone passes out of personal memory eventually, and even great names and accomplishments might be known only to those who carry out research in particular specialist fields. Horace Dall was an exemplar of enthusiasm, learning, and skill, and his name and achievements should not be forgotten.

Bob Marriott, *Director*



Horace with his folding 6-inch Dall–Kirkham. In this case, 'folding' does not refer to the optical system but to the entire instrument, which he kept in his jacket pocket. The relay lens, which sets the effective focal length and ratio, can be seen mounted in the small tube at centre. In 1932 Horace produced the first instrument incorporating his new optical system – a 6-inch $f/14.3$ modified Cassegrain (Dall–Kirkham) with a distance of 15 inches between the primary and the secondary. A brief account of this instrument is included below.



A 1933 Raleigh roadster with a Sturmey Archer three-speed gear hub. Although this is not the bicycle that Horace used to traverse Iceland, it is the same make, model, and year of manufacture. Sturmey Archer began production of its first three-speed gear hub more than 100 years ago, and it is probable that Horace would have been fully cognisant of the design and workings of the system.



Headwinds

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Horace Edward Stafford Dall, 1901–1986

Jim Hysom

Horace Dall was born on 6 January 1901 (thus just missing the nineteenth century). At that time his parents were living at Chelmsford. His father was an instrument maker in the small team that Marconi had put together during his experiments with wireless.

Horace's early upbringing was anything but smooth. His mother died when he was three; his father left Marconi and went to work 'up north', putting Horace and his brother out on various relations. As a result, Horace had twelve different addresses before he was six years old. Horace and his father were reunited when Mr Dall remarried and found a job at George Kent Ltd of Luton.

At school Horace was diligent, as can be seen from some of his workbooks that survive. It is not surprising to find that he gained excellent marks in science and mathematics, but he also proved to be skilled with a pencil, both at draughtsmanship and at free-hand work. This skill was to be most useful when he started work. He commenced with Hewlett & Blondeau, aircraft manufacturers, on 27 December 1914, just before his fourteenth birthday, and he was to stay there for the next three years. Most of the time he was in the drawing office. He was clearly fast and accurate, for on one occasion when a copy of a drawing of a new Rolls Royce engine had to be made in one day the task was entrusted to him.

It was during his period at Hewlett & Blondeau that Horace got his first telescope, a spyglass of 1 inch aperture, which he soon modified to give a higher magnification. This was followed in quick succession by a spectacle-lens refractor with a cardboard tube, and a 2½-inch achromat which he used to make planetary drawings. He had other optical interests at this time. At the age of sixteen he acquired a second-hand Baker microscope, and, a year later on a cycle trip to Clacton, he had his first view of a camera obscura. It was a bright and sunny day, and the view on the table of the camera obscura was so beautiful that he promised himself that he would make one of his own. He was active in the local scientific society and chummed up with a musician: together they purchased an 8½-inch Calver reflector from William Porthouse, a Manchester amateur. Later Horace was to buy out his friend's share, and part of this telescope was eventually incorporated in the 15½-inch reflector, the telescope for which he is best known.

Horace had continued his education at night school (at the Luton Technical College). With a recommendation from one of his tutors, he moved to George Kent Ltd in January 1918. He was to stay at Kent's for the rest of his working life, until he retired in 1965. The company made a variety of meters, especially for the measurement of fluid flow. Horace worked in the research and development department, and he was soon to prove his worth: in fact he became so valuable to the company that he was allowed a say in fixing his hours of work and his holidays. His inventive mind led to a number of patents. It is no exaggeration to say that the name 'Dall' is as famous in the field of water engineering as the name 'Hoover' in vacuum-cleaning.

His flexible hours were a great help with the astronomy. On a fairly typical day, Horace would start work at 10 am; and, twelve hours later, when most men were leaving the pub or getting ready to go to bed, he would pack up at work in order to start a session of observing, or, if cloudy, some microscopy, or instrument development. His twin loves were his home workshop and being outside in the countryside. Even before his teens he would tramp 20 miles from Limehouse to Epping Forest or Greenwich Observatory. Later, a bicycle allowed him to extend the range considerably, to the seaside and, eventually, to Oxford, to pore over William Herschel's notes on mirror-making.

Horace joined the BAA in 1925 – the year he started making optics. He said that he 'took to mirror-making like a duck does to water', and he could soon claim that his mirrors were up to the same standard as Calver's. He also made eyepieces, and by 1927 he was advertising in *Scientific American*, *Popular Astronomy*, and the *BAA Journal*. Soon he was corresponding with people worldwide, and as a result made many friends. Captain M. A. Ainslie, then the Director of the BAA's Instruments and Observing Methods Section, compared the quality of Dall's eyepieces to the best obtainable anywhere. Within five years of starting his optical work, Horace had made a 6-inch f/3.3 Cassegrain telescope with a spherical (rather than hyperboloidal) secondary and a transfer lens – a design that solved many of the objections to classical Cassegrains. This prototype, worked out while he was still in his twenties, was to be the basis of his later portable models – telescopes so light that they could be carried in his pockets.

Horace disliked the English winter, so every Easter he would be off to Switzerland, to walk and scramble among the high hills. His main holiday, later in the year, would be more adventurous. He explored as far as the transport of the day would allow. There was a 19-day trip cycling across the North Cape and down into Lapland. On another occasion, ten years after Lawrence of Arabia had set them, he found some unexploded charges attached to a railway line in the Middle East; these Horace left strictly alone, knowing that the explosive was by then probably unstable. A favourite area was the High Atlas and the fringes of the Sahara.

In reply to a question about the dangers of these trips, Horace said that he had very little trouble with people. Once he had been fired at by dissenting tribesmen, but 'I wasn't over-worried as I knew their guns were very worn and of low accuracy' – and he soon scooted away. He was in more danger when caught out on a high plateau during a violent electrical storm, when he and his bicycle were the highest points. Returning from one trip in the open cockpit of an aeroplane, the pilot warned him to hold on tight because on a previous flight the aircraft had hit an air pocket and passenger and aircraft had become separated!

In 1932 Horace made his first trip to Iceland. The following year he returned, to make the first wheeled crossing of the Icelandic desert (Europe's largest) on his bicycle; the going was so rough that he could cycle only about 20% of the way. In 1934 he married his first wife, Vivien (*née* Andrews), and together they would revisit his favourite European hills and mountains. There were no children – a matter of regret to them both.

Horace, in conjunction with an architect, planned his house on a carefully chosen site overlooking Luton. The roof was built deliberately high in order to incorporate a camera obscura of exceptional quality and performance. One could use it as the equivalent of a near-perfect pair of vibration-free binoculars. In the high-power mode, a 7-foot image of the Sun could be projected; or, if the observer wished to view the Moon, an eyepiece was available that gave x135 magnification and just encompassed the whole disc. The image was flat, sharp to the edge, and seemed totally free of false colour: it was an awe-inspiring visual experience. After the completion of the camera obscura, Horace went on to build an observatory and equipped it with a 15½-inch modified Cassegrain reflector. It was with this telescope that he took his outstanding lunar and planetary photographs. It was equipped with a dispersion corrector, which allowed good definition to be obtained even when viewing objects near to the horizon.

Horace had struck up a friendship with Albert Ingalls, who edited the telescope-making column in *Scientific American*, so it was to Ingalls that he often gave descriptions of his latest developments. It was Ingalls who gave the name 'Dall-Kirkham' to the form of Cassegrain employing a prolate

ellipsoidal primary and spherical secondary – independently discovered by Alan Kirkham. By the end of the 1930s Horace was probably better known in the United States than in the UK. Other friends in the USA included Prof John Strong, the inventor of the aluminising process, and Roger Hayward, the Pasadena architect. Strong and Hayward were part of a group of friends who were constantly vying with each other to see who could develop new instruments: Horace became their 'foreign correspondent'.

Around 1939, when he had perfected his optical techniques, Horace heard of an Englishman who had written with a diamond splinter, on glass, letters so small that the contents of five bibles could be fitted on a square inch. This was a challenge! He invented a new method – elegant in its simplicity – with which he was to fit the equivalent of fifty bibles to the square inch; and with further development he reached 280 bibles per square inch. This was his first world record. Eventually Horace captured others, including the most accurate spherometer (a mechanical device capable of detecting a change in shape as small as $1/40$ the wavelength of visible light) and a barometer capable of showing a change when raised or lowered the height of a thick book. Having gained skill working with diamond, he went on to use diamond dust for polishing tiny lenses made from jewels. He mounted these as microscope objectives, achieving a numerical aperture of 1.92 – another world record. (The numerical aperture gives the resolving power of a microscope objective, and is about 1.4 for the best commercially available objectives.)

During the Second World War, when British scientists did not have access to German optical works, Horace repaired all the broken Leitz microscope objectives – a task that involved making hundreds of lenses. The camera obscura was also turned to good use. Horace spotted exploding bombs and was able to give the authorities instant impact positions. As an expert on gas flow he formed part of a team which examined a German V2 rocket engine. By measuring the jets, chamber shape, and so on, it was possible to work out the distance that the V2 had flown: the rocket had fallen in Sweden – and Peenemünde, on the Baltic coast of Germany, was at the correct distance. Ten days after the war was over, Horace was at the rocket factory in Peenemünde, helping to assemble a V2 rocket which was launched on a test flight into the North Sea.

The year 1947 saw a paper in the *BAA Journal* on the null testing of paraboloids – a real gem! This one test was so developed by Horace and others that it greatly simplifies the making of most of the conic surfaces that the amateur needs. Horace's papers and notes on optical matters are classics: they are precise, simple to understand, and brief.

After the Second World War Horace was kept very busy at work, sometimes being sent abroad, for example, to sit on some international committee. This did not stop his experiments in optics. Following the work of Gabor, Bowers, and Maksutov on catadioptric systems, he soon developed his own version of what is now known as the Maksutov design of telescope. Horace combined the Maksutov meniscus shell and his Dall–Kirkham (with transfer lens) to produce a very compact instrument. Over the years he produced dozens of these telescopes, including a 2¼-inch instrument that would fit into his jacket pocket – stand and all.

With the introduction of cheap air-fares Horace expanded his adventure holidays to include the whole world. Long-standing friendships were renewed, and new friends made. Horace did not enjoy standing up in front of a crowd: in fact, friends sitting next to him at BAA meetings would often have whispered into their ears, 'Someone really ought to tell them.' One knew one's duty – and passed on the message. In the company of a few close friends, however, he really relaxed, bubbling over with enthusiasm with the latest news, or demonstrating the current project. He never seemed to stop. Horace would remark, 'Life's too short to spend it sleeping';

and in his early days he trained himself to make do with only five hours sleep per night. In later years he supplemented this with 40 minutes' sleep in the afternoon, but used an alarm clock to make sure that he did not overdo it! There were just too many exciting projects to get on with.

Retirement from George Kent Ltd came in 1965, a year after Vivien had died, but he carried on as a consultant for a time. He was also an *ad hoc* consultant to various telescope companies around the UK: for example, in the early days of Cox, Hargreaves, and Thomson Ltd he did much ray-tracing for Hargreaves. Amateur astronomers would arrive at his home in their droves, often with objectives that needed testing or reworking. Then there was the correspondence: he must have answered not hundreds but thousands of letters every year. This inevitably led to more visitors from abroad, and more places to visit when overseas.

Horace remained tremendously fit. On a visit to Tenerife when in his mid-sixties he recalled: 'On the first day I did 6½ miles overland, and came back aching all over; but a hot bath and early to bed. Then the following day I did 25 miles and didn't feel a thing!'

The bicycle had been pensioned off when Horace was in his fifties, and was replaced by a Vespa motor scooter. On retirement from Kent's he flew to Australia, bought a Vespa, and proceeded to ride all the way round the continent, on a trip that took some months. He had with him his pocketable 6-inch Cassegrain. In 1968 he determined to travel the whole length of South America, and while he was in Patagonia he met Helena (*née* Thurley), who was to become his second wife. She was a kindred spirit, who had also lost her spouse about three years earlier. They were married later that year. Suddenly Horace gained a family: Helena had a son, two daughters, and several grandchildren.

It was a happy time. Horace had the knack of knowing instantly what level to communicate at, and it was rare for anyone to feel after a conversation with Horace as baffled as before. Maybe not all was revealed, but one felt as though one had been shown the way. Children delighted in being shown around the workshop, with its host of interesting things. Memories of a visit were likely to last for decades, as I know from my own children's recollections.

Soon Horace and Helena were off on trips that people half their age would have felt too ambitious. There was an expedition to southern Africa, where Horace pursued a rhinoceros into the bush, determined to get a photograph. There was the time when they visited a monastery in the foothills of the Himalayas and stayed overnight, after the rest of the party had left. The following morning they walked the 18 miles back to the hotel, along forest tracks. One winter, Helena attended the local college in Luton and learnt enough Russian for them to cope with a trans-Siberian trip to Mongolia. The final major expedition, undertaken when Horace was aged about 80, was too much: it involved going to South America, California, Vancouver, Toronto, and then home. He was bitten by a tropical insect – which he duly mounted up, and delighted in showing to visitors through a stereo microscope. A minor heart problem developed, but he recovered; then throat problems had to be overcome. Finally, however, in March 1986, while repairing a friend's microscope objective, Horace suffered a stroke, which proved to be fatal. He died on 9 May.

Horace always refused to be BAA President, but he did serve for many years on the Council, for several sessions being a Vice President. He was the Walter Goodacre Award recipient in 1967. Even when he had to stand down from Council he would continue to referee papers for the *Journal*.

In 1977 the Institute of Measurement and Control awarded Horace their Callender Silver Medal. As a measure of this honour, it is worth noting that by far the majority of previous recipients had been Fellows of the Royal Society. In the same year, Horace joined the Queckett Microscopical

Club, who met at the Science Museum, and it was here that he would exhibit his latest techniques for increasing contrast. After a cataract operation he found that he could see into the near ultraviolet. This allowed him to focus directly his high-power microscopes in order to photograph detail which had rarely, if ever, been recorded before with a light microscope.

The Science Museum now has much of Horace's instrumentation, notebooks, files, and correspondence: Dr Jon Darius* is preparing an archive. This obituary article can highlight only some of Horace Dall's achievements; it would require a book to do him full justice. Another obituary, by Reg Taylor, has appeared in the Queckett Microscopical Club's biannual journal *Microscopy* (summer 1986), and the *Proceedings of the Royal Microscopical Society*, 19 (1984), 98, carries an appreciation by Brian J. Ford and Peter Evennett's description of Horace's gemstone-working techniques.

To many of my generation Horace was a father figure whose great help and many kindnesses will be sorely missed.

Thanks are due to a number of persons for help in preparing this article: in particular to Mrs Helena Dall, to Reg Taylor for a draft copy of his obituary mentioned above, and to Robin Scagell. Noel Dunmow, Norman Groom, and Ron Livesey also provided material.

* Director's note

Jon Darius (1948–1993) held degrees in physics and music and a doctorate in astronomy. He worked at observatories in Chile, Brazil, and Spain, specialising in ultraviolet astronomy, was a lecturer in acoustics at the Guildhall School of Music, a Senior Curator at the Science Museum, a founder of the Scientific Instrument Society and the National Museum of Photography, Film, and Television, and a civil servant at the Treasury. He was also fluent in several languages.

The first Dall–Kirkham telescope

Bob Marriott

Report of the Ordinary Meeting of the British Astronomical Association, 29 June 1932:¹

'Mr H. E. Dall then described a 6-inch reflector of Cassegrain type, constructed chiefly for terrestrial use, which he had brought with him to the meeting. In answer to a question, he stated that the loss of light as compared with a Newtonian of the same aperture, due to the triple achromatic lens in the optical system, was not more than about 10%. Instr-Capt Ainslie said that he would like to congratulate Mr Dall both on the design of his telescope, and also on its execution. He would like also to draw the attention of members to the



fact that the aperture ratio of the large speculum was only 3.2 to 1: this meant considerable difficulty in figuring, and the fact that Mr Dall had been able to do it argued very high skill on his part; he (the speaker) knew from experience the difficulty of figuring a mirror of ratio 7 to 1, and Mr Dall had done something far more difficult. Mr Dall's telescope was certainly the most compact he had ever seen of its aperture; and the fact that the weight had been kept down to something like 5½ pounds for a 6-inch aperture was, in itself, a very remarkable feat.'

Report of the Methods of Observation Section, 1932:²

'In particular, mention may be made of the very remarkable modified Cassegrain constructed by Mr H. E. Dall, and exhibited at a recent meeting of the Association. This instrument, originally designed for nature study, gives an erect image, and although 6 inches in aperture, is only 20 inches long, and weighs only 5½ pounds. It is admirably suited for astronomical work, and avoids the more serious disadvantages of the Cassegrain very closely.'

In 1949 the Rev M. P. M. McLean bequeathed a collection of books to the Royal Astronomical Society and nineteen instruments to the Association. Of those instruments, only one remains: No. 131, the prototype Dall–Kirkham.

¹ *Journal of the British Astronomical Association*, 42 (1932), 319.

² *Journal of the British Astronomical Association*, 42 (1932), 367.

Over unknown Iceland on a Raleigh roadster

Ben Searle

In 1933 Horace Dall and his Raleigh three-speed roadster (complete with fully enclosed chain case) made the first crossing of Iceland's Sprengisandur wilderness by wheeled vehicle, preceding the first motorised vehicle by a month.

Sprengisandur is the virtually trackless volcanic and glacial wasteland of central Iceland, and probably the bleakest area of Europe. The man attracted to its challenges, Horace Dall, was an intrepid cycle-tourist. He made a first crossing of the High Atlas mountains in the 1930s, and was arrested and accused of spying. He was eventually rescued by the French Foreign Legion. No-one could believe he was holidaying in temperatures of over 48° C. He also toured Lapland, sleeping in tents with the native Sami.

It was during a strenuous tour in western Iceland in 1932 that Dall conceived the ambition to cross the fearsome Sprengisandur. He had assumed that the crossing would be comparable with his road and track journeys of the previous year, and was not well equipped. He took just 1.75 lb (0.8 kg) of glucose and impalan pemican (dried meat), a stove, and sleeping bag, but no tent. He had expected a track of some kind, but had to guide himself by cairns, compass, and a poor 1:1,000,000 map which showed little more than the direction of some of the formidable rivers. The story of this remarkable cycle crossing of the interior of Iceland is narrated on the backs of his original photographs.

The point of no return

Dall enlisted help to cross the first major river – the point separating 'civilisation' and wilderness:

The great moment has arrived! The Icelanders rowed back to their truck after having carried out their contract to dump me and the bike on the north side of the Tungnaá River. This is deep and very swift and I waved goodbye to them with mixed feelings as I realised the nature of the trackless wilderness ahead. These were to be the last human beings I saw until reaching Mýri Farm in the north.

No sooner had he left the river and headed north-east into the wilderness when a heavy rainstorm gave him a vicious send-off. He had to climb high in the hills to avoid boggy ground, was often in mist, and had to make very frequent compass checks.

The first day gave a taste of the rough stuff – rocks, gullies, sand, and swamps, and I quickly realised that my hopes of making thirty percent use of the bicycle were to be disappointed.

By the evening of the second day he was becoming distinctly worried:

This is only one of the many gorges and rivers which the compass course led me to. I had to detour five miles before I could cross both the gorge and the river – the walls are 500 ft high. It was interesting to speculate on what kind of obstruction was coming next... I had an exciting moment when I came across pony tracks. Later, after I had tried to trace them through bogs and rivers and they insisted on going at right angles to my compass course, I decided they were wild ponies, and ignored them, but not before wasting much valuable time... Soon after crossing the watershed I saw the vast crater of the volcano Askja to the east. It seems incredible to those unfamiliar with the crystal clear air of Iceland, that the nearest point of the crater is forty miles away. The diameter is fifteen miles – one of the world's largest – and situated in almost unexplored wilderness.

Kept prisoner by the river

The Skjálfandafhljót River held me prisoner for more than a day – most of the time wedged between the water and the cliffs. On the parts where the struggle was worst I did no photography, the job in hand was sufficiently worrying. The ground here was of a flour-like consistency – very hard to get through... 5th day of the wilderness. Great joy! Have just escaped from the Skjálfandafhljót by way of a side valley which enabled me to climb above it. The cycle here is 800 ft above the river – a terrific volume of glacial water from the Vatnajökull icefield, the largest in Europe.

He finally reached the southernmost farm of the north:

Mýri farm and luscious green pastures. Civilisation! I was able to send a telegram via the British Vice Council to the farmer who rowed me across the Tungnaá River – telling him of my safe arrival at the north (in accordance with a promise I had made to relieve his anxiety).

It was only his stamina, pluckiness, and sheer good fortune with the weather that got Dall across. Remarkably, he made the crossing with food to spare, and was able to ride 5–10% of the way. It might be argued that his crossing was more of a walk than a bike ride, though the same could be argued about the first car crossing – for most of that journey, the driver and passengers had to walk beside the car, if not help it along by pushing it. It, too, was ferried over the Tungnaá River by the same rowing boat.

In 1996 I called in at Mýri. The farmer, Héðinn Höskuldsson, who was nine years old at the time of Dall's arrival, remembered him clearly: 'He emerged from the wilderness well dressed with polished shoes and a tie – as if going to a job interview in Reykjavik! He did not even seem that tired! The neighbourhood still spoke of him many years later.'

As Dall was a passenger over the Tungnaá River, credit for the first 'under one's own steam' coast-to-coast crossing by this route goes to the British Rough Stuff Fellowship expedition in 1958, organised by Dick Phillips. While a track had become sufficiently well established by that time to ride 75% of the way, a half mile of rope and an inflatable rubber dingy were carried to cross the rivers!

Sprengisandur today

The modern-day crossing of Sprengisandur bears no resemblance to Dall's or Phillips' experience, and in recent years its appeal has grown immensely. Each year more than a hundred cycle-tourists take up the challenge. They must carry provisions for 300 km (220 km between habitations), and make their crossing during the brief open period of late July to early September. Now the only major unbridged (glacial) river is the Fjórdungakvisi, which has two branches untouched. These require care, but are not dangerous in normal conditions. The rewards are views of the huge ice-caps, distant peaks, and volcanoes, and a grand feeling of solitude, isolation, and the splendour of the wild.

Most cyclists will want to allow at least five days for the crossing, but it is wise to carry provisions for double this, due to unpredictable strong winds and the possibility of snow-fall in any month. The track runs at over 900 m for 125 km, is unsurfaced, and consists mainly of compressed volcanic sand. It is almost all rideable by mountain bike, and the Nyidalur tourist hut half-way across and a cafe and guest-house near the southern end are the only facilities.





11 Iceland 1933

A Ton truck makes its own tracks in the wilderness!

The two Icelanders whom I persuaded to get me across the Tungnaa river are resting here a few moments on a small gravel plain under the northern slopes of Hecla, after a very rough time crossing wide mountain streams, etc. This ton truck is the only motor that has ~~not~~ ever reached the Tungnaa river - 20 miles from Hellmilla.

H.K.



16 Iceland - The Wilderness - 1933.

I felt so elated (altho it doesn't look like it!) at having managed to get across safely some very nasty swamps & wide streams, that I used the automatic shutter release when a convenient rock presented itself



19 Iceland - The Wilderness - 1933.

I had an exciting moment when I came across pony tracks in the sand. Later - after I had tried to trace them through bogs & rivers & they insisted in going at right angles to my compass course, I decided they were tracks of wild ponies, & ignored them, but not before wasting much valuable time.

The Hofs Icefield - about 1000 square miles in area, is behind - with clouds resting on the snowy skyline

H.K.



21 Iceland - The Wilderness - 1933.

Plodding through the sand - a stretch fairly free from obstructions gave me an opportunity of seeing how straight a course I was making. I could see the track here for about a mile, with foot marks complete, & it was amusing to see the little meanders from the straight

The weather was beautiful - very fortunately.

H.K.



22

Iceland - The wilderness 1933

Some time after crossing the watershed I saw the vast crater of the volcano Askja to the east. The crater ring is the dome shape ridge with end lumps.

It seems incredible to those unfamiliar with the crystal clear air of Iceland that the nearest point of this crater is 40 miles away. The diameter is 15 miles - one of the world's largest - & situated in almost unexplored wilderness.

The sky is a cloudless dark blue overhead. The very shallow cone on the right is ~~the~~ an unnamed shield volcano 26 miles away.

H.B.



23

Iceland - Wilderness. 1933 -

I spent the fourth night in the wilderness on a ledge in sight of the river with the unpronounced name (Skjaldfandalfjot) which runs into the arctic.

This is the first night in a patch of greenstuff but as it consists of stiff bushy plants, the ground near between was more comfortable.

The sleeping bag is laid out in the bright morning sunshine to dry off the heavy dew which wets it overnight.

H.B.



32

Iceland 1933 - The wilderness.

An easier (but still too loose & sandy to ride) stretch of wilderness heralds the approach to civilization.

I took this photo at the memorable moment when 2 white specks (just visible on photo) - unmistakably farm-houses - came into sight after topping a hill.

Still 8 miles away & several bad rivers & gullies to cross - but I was in great spirits, & very lucked at the success of my navigation across the wilderness.

A

H.B.



35

Iceland 1933.

On track up valley towards Akureyri. 30 miles of unrideable stuff before reaching an almost unrideable road.

These are pony tracks - narrow & deep ruts in which the pedals are most exasperatingly catching at every step when trying to walk along. Sometimes the rut is about 2 feet deep, but the hummocky grass away from the track is no better. Another annoying habit of the track was that of completely disappearing at intervals in the rougher ground & rivers.

H.B.

The camera obscura

Horace Dall

I am very bucked with my camera obscura, just finished. I told you that the object glass was unusual. Personally I have never heard of coincidence of focus for four colours of the visible spectrum with only two components – consequently I don't see any false colour even on Venus, and my old grudge against the refractor is wiped out.

The viewing table is 2 feet in diameter, and I can turn the handle and show over a hundred different views – full of life and colour of the surrounding landscape and townscape. Up to an altitude of 40° I can get any part of the sky – unobstructed; which means that the Sun is observable nearly any time I want to see it. Sitting in a comfortable chair in the dark I project a 6-foot solar disk on to a screen – full of detail – granulations, faculae, and spots. There is enough light for a projection on a scale of 22 feet to the solar disk, and a sun-spot group a foot or two long sails majestically across the screen. The flat mirror above the OG has to be unusual in accuracy (flatter than 1×10^{-6} inches) to pass on without visible error rays for such a long-focus beam. The viewing telescope is arranged at a comfortable microscope angle 45 degrees downwards – no neck aches here. The lowest-power eyepiece, x48, has a field lens 2½ inches in diameter. Rack focus on both table and viewing telescope, and rod controls from up aloft.

A little novelty tried with it recently: I projected in the dark a microscope slide of a flea (using the camera obscura like a projecting microscope), with a magnification of 500, on to a screen rigged up by a friend in a village over a mile away from here. Does this suggest possibilities to you? Anyway, it's good fun.

Any optical system is reversible in the sense that if a self-luminous object is placed in the normal image plane, an image is thrown toward the normal object plane. In the flea projection, an illuminated microscope slide becomes the self-luminous object. The light-source is an arc lamp (a car bulb, 12V, 48W, or 6V, 24W, can be used, but of course the intensity will not be so good as with an arc). The arc is placed within an enclosure having an opening, behind which is a condenser lens of short focus, to fill the OG with light. The arc lamp is placed at one focus, the OG at the other. In front of the enclosure is the micro slide with the flea or what-have-you. Next comes a flat or a prism, turning the light directly upward to the OG. If the projection distance is 1 mile, the image thrown will be as many times full size as the focus of the OG is contained in a mile (in my case, x480, and the flea shows about 4 feet long). The novelty with this method of projection lies only in the distance, and the fact that the OG has such an unobstructed outlook. The same kind of projection or signalling can, of course, be done with any telescope, especially if of long focus, but it is not generally so convenient as with the camera obscura. I have projected slides of written messages in the same way, and as the field is so confined in size, even the next-door neighbour of the collaborator two miles from the camera obscura doesn't see the light. For example, a youthful couple is known to be sitting in a cozy, dark corner on a porch. A message – for example, 'Watch your step!' – suddenly appears on the side of the house above the sofa. Variants will suggest themselves.

You ask for more data about my camera obscura; also Porter seems not to be familiar with them. Well, if you saw the view of a sunny landscape pictured by mine – full of living detail and brilliant with colours, apparently more vivid than the colours of nature itself, because the observer's eye is not flooded with sky light, I think you would vote the camera obscura a marvellous optical invention. Not a recent invention, either. I have an ancient English book of popular science, dated 1848, describing one of a sort.

At English seaside resorts they are not uncommon, and for a charge of tuppence one enters the dark interior of a tall tent-shaped hut – generally on the pier or other high spot – and gets a fascinating and highly magnified view of the seething life on the sands, and around the whole 360° of the viewpoint up aloft. The scene glides across the table in endless panorama as the control rods are operated. The seaside variety merely needs a lens and mirror housing but no tube.

In my case I have a house on top of a hill, some 200 feet above the valley level, and higher than practically any house in the vicinity. My loft is boarded and forms a useful room with a 20-odd feet-square floor. A 5' 6" x 3' three-section window is in one end, but can be covered in a few seconds by a hinged screen – lightproof. As I wanted to get a viewpoint well clear of the roof ridge, I had to poke a hole through the roof and insert a fixed tube, inside of which slides an inner tube carrying the optical items.

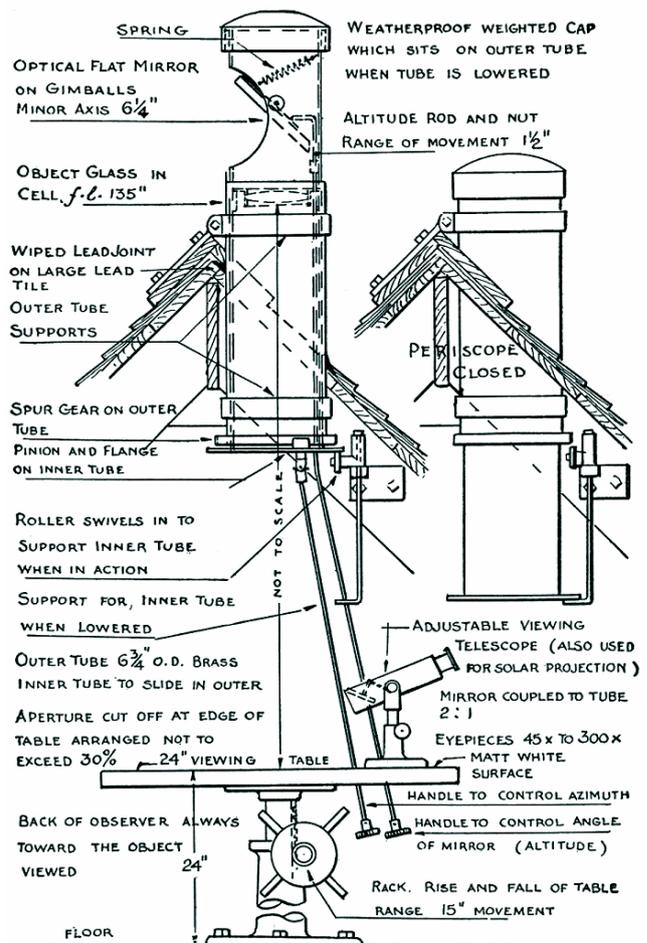
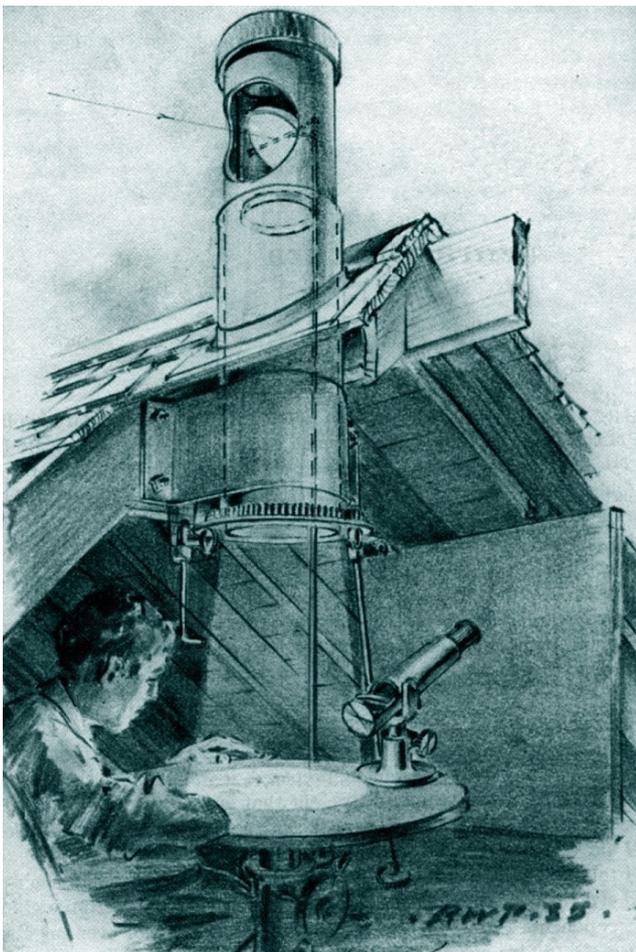
The main items of the layout are shown on the rough sketch [redrawn by Russell W. Porter] attached which, if you read the various items noted, becomes self-explanatory. The OG forms an image of external objects to which the mirror is directed, and throws it on to the viewing table. Ten degrees diameter (say nearly 80 square degrees) at any one position of the mirror is seen on the table, and if you look at the table from a distance of 10" the effective magnification of the view is $135"/10" = \times 13\frac{1}{2}$. If a short-sighted person looks from 5" distance the magnification becomes $\times 27$. Not only do you get good magnification, but the field of view is extensive. Three or four of us can get a 'tabular' view of a cricket match nearly one-half mile away and not miss a ball. Ditto tennis – quite a number of courts are in view from 150 yards away and upwards.

Now, if you want to see anything in greater detail and higher magnification, you apply the viewing telescope and observe in great comfort a very brilliant image. The viewing telescope is somewhat like a microscope without an objective, and with a body large enough to take the lowest-power eyepiece – in my case a fine Huygenian of about 3 inches focus and 2½-inch field lens (1° actual field, 45° apparent). Rack focusing and swivelling bracket add to the comfort. The image is much more brilliant than the same aperture would give with a telescope used in normal terrestrial fashion, because 'visual purple' is secreted on the retina in the dark.

Although the OG works at f/32 (¾ inches aperture in my case), anyone familiar with the ground glass screen view of a camera at f/32 might think the image would be too feeble. This is not so, because of the sensitivity of the observer's eye under such ideal conditions.

Of course, if the day is dull or the Sun on the horizon, the landscape image on the table is not so bright as one would like. Incidentally, a beautiful sunset (or sunrise) seen on the table is a thing not to be forgotten in a hurry. The solar image is 1¼ diameter and is a great sight, toned down by the horizon vapours.

The whole panorama of the horizon is 70 feet long, and as one sweeps the horizon across the table by operating the azimuth control, so must the observer move round the table to keep his back toward the object viewed, if the top is to be at the far side of the table. If looking at the Moon (usually with the view telescope), face the direction of the Moon if you want to see it astronomically inverted, and put your back toward it if not. Of course, it is only a mechanical addition to have a rotating floor operated automatically, if you feel badly in need of it! For astronomical purposes, as I have said in my last letter, solar projection is ideal. I tilt the view telescope nearly horizontal and use a four-lens achromatic eyepiece, giving me a 6-foot solar disk on a vertical white screen 7 or 8 feet away. Granulations of the surface together with spots and groups in great detail (also faculae) make a great sight for an observer who has struggled to get a decent view through a dusty cracked sun-glass (not that I am including



Russell W. Porter's drawings based on Horace Dall's sketches. (In actuality, the tube is 9 feet above the top of the table.)

myself); or who has managed a milky, flooded projection about 6 inches across on a rickety rig-up threatening to sag the eye-end earthward. Instead of a view on the horizontal table, a somewhat brighter ground glass view can be obtained using a ground glass and mirror in a frame on the table. In either case the view is companionable – several people can see at the same time, but not with the viewing telescope.

Of course, anything can be photographed with ease – the operator is inside his own camera. With an infrared filter, etc., I am hoping to get some good views of distant items, like churches in wooded surroundings 17 miles away. One is naturally dependent to some extent on atmospheric steadiness for the telescopic or photographic view. I don't seem to have been much worried by hot air off the roof, but a sunny day is never any too good for telescopic views of landscape, except in the evening or perhaps the early a.m. if you are energetic. A whitened roof would be all to the good, but I haven't whited mine.

In addition to the 70-foot horizon strip there is of course the 70-foot strip above or below – several of them, each side – glorious views of scudding cloud in blue sky – curdled thunder clouds, or 'mackerel', in addition to quite a new world of cloud colour in the refractive zone of a solar halo of cloud water particles.

I have only 3/4-inch aperture, but remember that I have aimed at getting as near to optical perfection as I can achieve. I chose a pair of Chance Bros melts – a hard crown and a special telescope flint, the crown having a N_D of 1.515 and the telescope flint only 1.530 (approx.), which enabled me to get what is, for me, an unheard-of coincidence of focus for four colours of the visible spectrum, viz., h, F, D, and C. The quaternary spectrum left over is less than a tenth of the usual secondary spectrum of a normal flint and crown doublet, and to ordinary observation, astronomical or terres-

trial, false colour is non-existent. The other night I was looking at the Moon – as hard and colourless on the edge as with a reflector – and I could just see the twin craterlets inside Plato.

A long focus enables this high colour correction to be achieved without absurdly deep curves, but naturally the surface accuracy needs to be very good and the mirror above superlatively so if the image is to be at its best possible. A silvered-back, plano-parallel mirror in optical glass is a teaser, and is probably not worth the trouble in these days of aluminising.

There is nothing in the outfit beyond the scope of the advanced amateur – but if the advanced amateur has his house tucked in a valley or between high chimney pots, there won't be so much attraction. I do not see much need to go into minute details of my construction – any advanced amateur prefers to settle details himself to suit his own available means. My sketch, plus all notes lettered on it, plus this letter and the last, ought to suffice for you to put out a new idea in optical equipment, at least, let us say, a rehash of an old idea. Ever since I got into this house (and I got it built rather tall with this in mind) I have hankered to have a periscope type of view. I started in May, and was viewing in early July – but of course it was only one of several other odd spare-time jobs. I have yet to add refinements like azimuth and altitude scales, shutters for photography, photo-projection lenses for enlarging the image, screens, and so on.

Was it in my last letter that I told you about my projection game? It was funny to project the image of a flea on the side of a house a mile away – well the camera obscura did this and I have done other signalling with it – it would not be difficult to arrange to talk via light ray to a distant friend – any advanced amateur could think out fascinating sidelines or stunts for his amusement similar to these. You get strings of friends along to see the view.

A null test for paraboloids

Horace Dall

The Foucault or Ronchi test applied at the centre of curvature is probably still the most commonly used method of testing paraboloids for astronomical mirrors. That this is so is more due to the convenience and simplicity of the set-up than to the ease of interpretation of the results. While no particular difficulty of interpretation or zonal measurement of the parabolic shadows is experienced for mirrors of aperture ratio $f/8$ upwards, the test becomes increasingly more difficult for short-focus mirrors from $f/7$ to $f/3$. Zonal errors of appreciable magnitude may remain undetected, and in particular the outer zones are frequently found to be faulty, even though the knife-edge shift r^2/R between the centre and outer zone is correct. It is just these outer zones which contribute so greatly to the formation of the final image, and if a short-focus mirror is to equal in performance its longer-focus counterpart, it is essential that the grading of curvature in these zones be correct to a close tolerance. Hence the need, felt even by the most experienced mirror-maker, for changing to a null method of testing.

Where equipment is available this need is fulfilled by the well-known null test utilising a large flat mirror and a smaller flat or prism for deflecting the beam to a convenient viewpoint. A large silvered flat of high quality is not, however, always available, and even if it is, the test rig is sensitive to careful squaring on, and cannot be compared in simplicity with a test made at the centre of curvature.

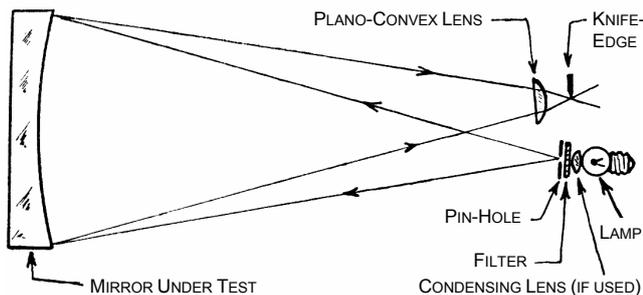


Fig. 1.

The method shown diagrammatically in Fig. 1 is carried out at or near the centre of curvature with approximately monochromatic light by interposing a simple plano-convex lens a few inches inside the normal focus of the pin-hole image. The knife-edge is applied in the ordinary way, but to the pin-hole image as modified by the lens. The aberration of the lens is opposite in sign to, and of the same character (within limits) as the aberration r^2/R of a paraboloidal mirror with the pin-hole near the centre of curvature.

The principal requirement in applying the new test is to intercept the pin-hole image cone at the correct diameter appropriate to the lens in use, and the data to enable this to be done are given with sufficient simplicity for the less mathematically minded to follow. A perfectly regular paraboloid will give a null test; that is, it will darken uniformly over the mirror disk as the knife-edge cuts across the pin-hole image at focus. Defective zones show up clearly and are identified with the same certainty and precision as in the case of a spherical mirror tested at the centre of curvature in the normal manner.

The only addition to the normal Foucault testing equipment required by the new test is a red filter and a plano-convex lens and holder. The filter is required owing to the dispersion of the simple plano-convex lens. The latter, being of crown glass, has a very low dispersion at the red end of the spectrum, hence a simple red gelatine filter of the type 'tricolour red' is highly economic of visual light while being sufficiently monochromatic for the purpose. Ruby glass will also

serve, but will pass barely 10% of the visual light compared with some 30% for the tricolour red. Coloured glass, gelatine, or cellophane film of the bright red type will generally work quite well. A small piece of the filter material is placed in the lamp, preferably between the lamp and the pin-hole. The writer has used a monochromator giving 1% spectral purity, but finds no appreciable gain in sensitivity compared with the simple red filter when used with lenses up to 4-inch or 5-inch focal length. Lenses of longer focus than this would be required only for the largest sizes of mirrors outside the usual amateur's range, and these would of course need and warrant a higher degree of monochromatization. The plano-convex lens is used with its plane side towards the mirror under test. This is the direction of maximum aberration for which the data given are calculated.

The lens must be centred in relation to the cone of light proceeding from the mirror. This is easily done by adjusting the height and lateral position of the lens holder so that the central mark or intersecting cross lines put on the lens for this purpose are seen to be central with the disc of light viewed by placing the eye at the final pin-hole image focus. It is also necessary for the optical axis of the lens to be aligned within a degree or two of the centre of the mirror. Sighting along the tube of the holder will generally ensure this. Serious errors of alignment or centring will result in astigmatic effects in which the knife-edge shadow fails to advance parallel to the knife-edge movement. A similar type of error also results from too great a lateral separation between pin-hole and knife-edge. This should be arranged, if possible, not to exceed 2% of the focal length of the mirror, and the use of small-diameter housings for spotlight torch-type bulbs is strongly recommended for all mirror-testing. Alternatively, use can be made of prisms or similar devices to reduce the separation.

All types of optical testing are facilitated by the use of brilliantly illuminated pin holes, perhaps more so with the new null test, not only owing to the losses in the red filter, but also because the apparent diameter of the mirror is about doubled as seen through the lens. The use of a short-focus condensing lens inside the lamp holder which images the filament on the pin-hole is recommended although not essential; moreover, a short vertical slit may be used instead of a pin-hole, though the writer has a preference for the latter. If a slit is employed, its length should not be greater than 0.02 inch, as longer slits cause the mirror disk to have an ill-defined edge. The pin-hole diameter or slit width recommended for general testing is from 0.001 inch to 0.002 inch.

To select a suitable plano-convex compensator lens, preference should be given to one having a focal length of ten to fifteen times the r^2/R value to be compensated. For example, if testing a 12-inch diameter 60-inch focus ($f/5$) paraboloid, $r^2/R = 0.40$ inch and a 3-inch or 4-inch focus plano-convex lens is very suitable, though the limits mentioned can be treated as somewhat elastic. The field lens of a low-power Huyghenian astronomical or microscope eye-piece will generally supply the need. Supposing in the example quoted a lens is found having a measured focal length of 3.5 inches. (The precise focus f should be measured as closely as possible, remembering that this is the distance from the vertex of the curved surface to the screen when the image of a distant object is formed on that side. Allowance should be made for the considerable aberration by stopping the lens down to, say, $f/10$, or if used without a stop, by measuring the maximum distance at which a sharp image can just be recognised inside the aberrational halo.)

Next refer to the curve, Fig. 2, to find the ratio of the interception distance N to the focal length F of the lens. This is shown plotted against the ratio of the foci of mirror and lens. In the example quoted the latter ratio is $60/3.5 = 17.15$. Hence, from the curve the interception ratio is found to be 1.36. The interception distance N is thus $1.36f = 4.76$ inches.

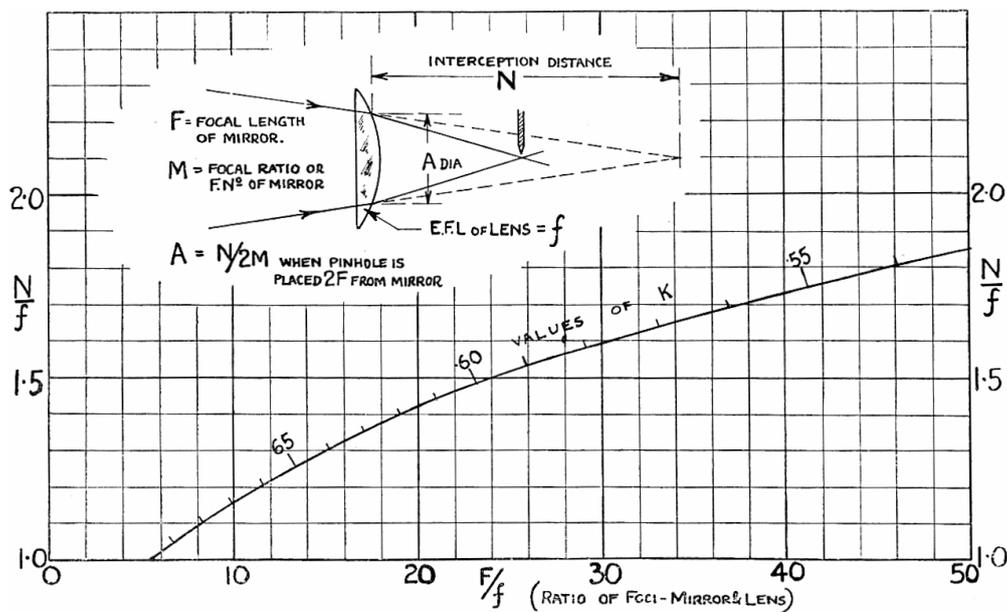


Fig. 2.

The utilised aperture A of the lens is $N/2M = 0.476$ inch; that is, it is working at an aperture ratio of $3.5/0.476 = f/7.4$. It should be noted that the curves of Fig. 2 depend to some extent on the utilised aperture of the compensating lens. The curve is calculated for $f/7$ – a value for which the higher-order aberrations are negligible. The curves were obtained by rigorous ray-tracing for a glass of refractive index 1.52 and a reasonable lens thickness. Departures of normal crown glass from this assumed value will not seriously affect the result. Having obtained the correct interception diameter A (0.476 inch in the example chosen), a pair of ink markings should be made on the lens at this separation – symmetrical about one of the centre lines which, as mentioned before, should also be marked.

The lens is then ready for use, and upon adjusting its axial and lateral position so that the illuminated mirror disk fits the diametral marks when seen with the eye just behind the final focus, a null test should be obtained with the knife-edge if the mirror is perfect. If preferred to aperture marking, a careful setting to the correct interception distance N may be made; alternatively, a thin disk drilled with the correct size hole, then bisected to assist judgement of coincidence, can be fitted centrally against the convex surface of the lens. A few further examples are given in the table, some of which may fit individual requirements and obviate the necessity for further calculation for those less practiced with slide rule or logarithms.

Mirror aperture D	f /number of mirror	Suitable focus of lens = f	Intercept distance N	Intercept diameter A
6-inch	$f/5$	2.0-inch	2.60-inch	0.260-inch
6-inch	$f/6$	1.5-inch	2.25-inch	0.187-inch
8-inch	$f/4$	2.5-inch	3.11-inch	0.389-inch
8-inch	$f/5$	2.5-inch	3.33-inch	0.333-inch
8-inch	$f/6$	2.5-inch	3.50-inch	0.292-inch
10-inch	$f/6$	3.0-inch	4.26-inch	0.355-inch
12-inch	$f/4$	4.0-inch	4.88-inch	0.610-inch
12-inch	$f/6$	3.0-inch	4.50-inch	0.375-inch
100-inch	$f/4$	35-inch	42.0-inch	5.250-inch

If the mirror is regular but over-corrected, it will be found that a null test is given when the lens is advanced somewhat nearer to the mirror, and *vice versa* for an under-corrected mirror.

If desired, the actual longitudinal aberration a can be calculated from the formula $a = KN^4/M^2f^3$, where K can be obtained from the curve and other symbols are indicated in

the diagram. High sensitivity to N is shown by this formula. For small errors the percentage departure from true parabolic correction is four times the percentage change of N . In the 12-inch x 60-inch example, if a null test is given with the lens shifted outwards by 0.11 inch, the mirror is under-corrected by approximately 9%.

Comments on the null test

Frederick J. Hargreaves

I had the privilege of seeing Mr Dall's paper a week or two ago at an opportune time, as I was then in the final stages of figuring an 18-inch parabolic mirror of 102 inches focal length. I mounted a plano-convex lens of 4.2 inches focal length in a tube of the correct length with a fixed knife-edge at the other end. I mounted the tube on three adjusting screws so that it could be accurately aligned with the aid of cross-wires on the lens, and I secured the 'cut-off' by making the pin-hole movable laterally.

The mirror looked enormous – as big, actually, as a 45½-inch mirror of the same focal length would appear under normal conditions. The diffraction bands at the edges of the mirror were also enlarged in the same ratio.

Errors showed up very clearly. As the nature and location of these errors were already known from other tests, the ease with which they could be seen inspired confidence, and I therefore continued figuring the mirror until it looked quite flat – like a spherical mirror tested at the centre of curvature. This confidence was fully justified, as the subsequent tests on stars showed no aberrations of any kind.

I consider that Mr Dall has provided opticians with a very powerful and convenient tool for workshop use. There are other null tests of parabolic mirrors, but none which is so convenient as this for use by the optician during the progress of the figuring.

I found that the centring and squaring-on of the lens are extremely critical; the slightest error introduces astigmatism or coma or both. For this reason it is probably prudent to use other tests for these errors.

It would be interesting to know at what point the accuracy of this test breaks down. My experience of the last few days shows that it is amply accurate for an 18-inch of $f/5.7$, but one wonders whether the aberrations of the lens would match accurately a 100-inch of $f/4$. Would there not be a certain amount of residual zonal aberration? If so, it could presumably be calculated and allowed for.

FP3 Series II film

Horace Dall

In September last [1959] the firm of Ilford introduced a new emulsion for their medium-speed FP3 film and called it FP3 Series II. They say it has a finer grain but is otherwise unchanged. My experience confirms their statement. The silver grains seem no smaller, but less clumping occurs; they are spread more uniformly, and the enlarged picture has slightly higher resolving power. Even a gain of 10% is very welcome.

There are many telescopes in use today that are sufficiently perfect optically to show detail and texture down to the limit imposed by the aperture. You know, for example, that a good 4½-inch telescope will resolve a double star with a separation of 1 second of arc. It will also show a lunar crater 1½ miles in diameter.

If you are familiar with microscopes, you have had a very similar experience. A good objective will resolve detail down to the so-called theoretical limit – say two luminous points separated by about half the wavelength of the light. Now, if you put a camera on the microscope you can easily photograph this fine detail. The photograph will show all that the eye can see, and perhaps a little more. It shows all the diffraction patterns and the ultimate image structure. Unfortunately, this has not yet been achieved with a telescope on any astronomical subject – not even an easy one such as a bright double star. When it comes to photographing detail on the Moon, the best achieved to date shows about half the resolution seen by the eye at the same telescope. As you all know, this is because of our turbulent atmosphere. The eye *can* discount the wobbly image; the camera cannot. We also know that once in a while we get a second or two of steady image which, if only the photographic opportunity were seized, could result in a photograph showing detail down to the aperture limit. The fact provides a real challenge to our members with telescopes and cameras, and adds zest to their endeavours. After a favourable session on the Moon or the planets it is quite exciting to examine the resulting pictures to see how near perfection has been achieved.

For amateur-sized telescopes, when photographing the Moon or planets, the prime-focus image is sufficiently bright to allow exposure as short as a fiftieth of a second with fairly fine-grain films. This is a speed that would cut out the need for a clock-drive and would be very convenient except for the troublesome fact that the negative would need enlargement by some fifty diameters to make the *potential* detail visible on the print. At this enlargement the film grain would be far too coarse to show this potential detail. A film with a resolving power of about 500 lines to the millimetre would be needed. Perhaps some day a fast grainless film will become available; meanwhile, we must be thankful for small improvements such as provided by FP3 Series II, giving about seventy lines per millimetre, and overcome the difficulty by optically enlarging the image projected on the film or plate. It is quite easy to do this with a positive projecting lens, an eyepiece, or a Barlow lens, but the exposure time increases with the square of the degree of enlargement. To decide on the best type of film to use, the obvious thing is to calculate a factor of merit, which can be shown to be the product of film speed and the square of the resolving power (SR^2). Obtaining the data from the manufacturers' literature, one obtains a list from which it would appear that the fastest film is best for our purpose. I can say that this is *not* borne out by experience. A medium-speed film gives slightly better results on the Moon and planets. The discrepancy is presumably due to the fact that the resolving-power data are for black-and-white bar test objects, which are not truly comparable with our low-contrast detail.

The new FP3 Series II is probably the best film now available for our purposes, if the primary image is enlarged optically five to ten times, or to a final f number of from f/40 to f/80, exposures are kept down to a second or less and, in the lucky event of a dead steady image, the picture *should* contain the detail of which the telescope is capable. A clock-drive is essential.

Factor of merit of films

Type of film	Relative speed BSI (Arith) = S	Resolving power Lines/mm = R	Factor of merit $SR^2/1000$
Ilford HPS	500	40	800
Ilford HP3	200	50	500
Ilford FP3	64	67	300
Ilford Pan F	20	70	100
Kodak Plus X	64	65	270
Microfile Pan	7	170	200

Atmospheric dispersion

Horace Dall

All observers with astronomical telescopes are familiar with the troublesome effects of atmospheric dispersion, giving rise to red and blue fringes at top and bottom of the images of planets or any bright object. The blue image is lifted by atmospheric refraction to a greater extent than the red image.

Visually the effect is only seriously noticeable for objects at altitudes below 30°. At this altitude the differential lift from red (C) to blue (F) is approximately 1 second of arc, which is two-thirds of the diameter of Ganymede at opposition. The whole visible colour band is almost twice this. Naturally, a large telescope will be more affected than a small instrument because, for example, 1 second of arc atmospheric dispersion can barely be detected with a 4-inch aperture, but it represents twice the resolving power of a 9-inch telescope.

Experienced observers often attempt to reduce or nullify it by using filters, or more commonly by decentering the object in the field of view of the eyepiece. Most eyepieces suffer to some extent from off-axis colour errors, and some degree of neutralisation is given by opposing this error against that due to atmospheric dispersion. However, this is so severe at low altitudes that neutralisation is difficult or impossible to achieve even with eyepieces having considerable off-axis colour, such as the Ramsden type. The best eyepiece for the purpose is the compensating type used in microscopy – more particularly the four-element type resembling the Zeiss orthoscopic eyepiece having triplet an overcorrected field lens and a plano-convex eye lens. This type is by no means uncommon, and is sometimes available second-hand in foci from 10 mm to 30 mm, often made by Zeiss. They are excellent for low- and medium-power astronomical work if the off-axis colour error is made use of for neutralising atmospheric dispersion.

The object viewed is placed on or near the vertical axis and well below the centre of the field at a point where the best colour freedom is obtained. For objects at altitudes below 20° and for fairly high powers this method is inadequate, however, and other methods become imperative. For visual purposes on the brighter planets, Ilford's 'Astra' green filter is very suitable, as it absorbs the greater part of the red and blue images without excessive reduction in the visually active regions of mid-spectrum. The saving grace of visual observation is the peaked nature of the sensitivity curve of the eye (Fig. 1) at mid-spectrum; that is, in the yellow-green for normal illumination. Owing to this fact, definition is far less degraded by atmospheric dispersion for visual observation than for photographic purposes. The sensitivity curve of panchromatic films is fairly uniform over the whole visual spectrum band, and atmospheric dispersion has a seriously

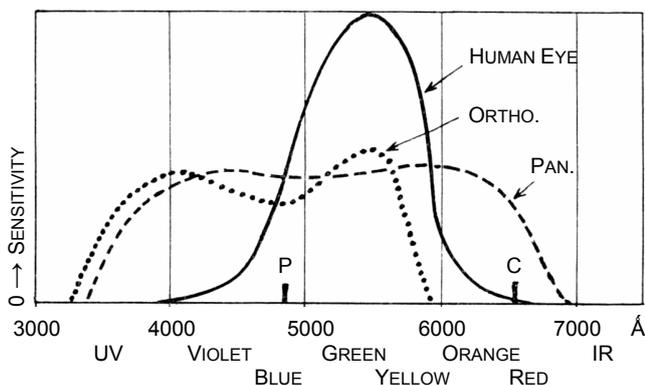


Fig. 1. Sensitivity curve of the eye.

harmful effect on high-resolution photography. For orthochromatic or ordinary emulsions the effect is less pronounced. Their sensitivity curve extends from the yellow to the violet and beyond, and for low-altitude objects the atmosphere acts as a filter in the violet and to a considerable extent in the blue. However, the fastest emulsions are desired for planetary and lunar photography, and these are primarily panchromatic. Some means must therefore be adopted to neutralise atmospheric dispersion in the optical system of the telescope used for such photography if the optimum results are to be achieved. In the case of a refractor a simple translational movement of the flint element of the object glass on a vertical axis in relation to the crown element will achieve the desired result, but the necessary alteration to the cell needs careful design to permit proper control of the movement. It is evident from Fig. 2 that a decentred flat back

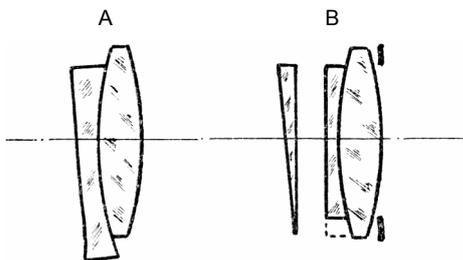


Fig. 2. Displaced flint element and its equivalent.

achromat as at A is precisely equivalent to B; that is, to a slightly smaller properly centred pair plus a wedge or prism of flint glass, the angle of which is proportional to the displacement. The Earth's atmosphere behaves optically as a prism with base down, but the effective angle of the prism varies considerably with the altitude of the object viewed and to a lesser extent with the atmospheric temperature and humidity.

For normal astronomical observation I find the reciprocal dispersive power v of the atmosphere to be close to 100, which means that the angle of atmospheric dispersion between C and F is 1% of the angle of atmospheric deviation or refraction. As an example, the normal angle of refraction at the horizon is 2,000 seconds of arc, giving a dispersion of 20 seconds of arc. To neutralise this a flint glass wedge giving a deviation C to F of about 730 seconds would be required; that is, about $\frac{1}{2}^\circ$ wedge angle. For a flat-back achromat of 4-inch aperture $f/15$, this could only be achieved with a displacement of about 0.22 inches. This amount is perhaps impractically large, hence correction right down to the horizon is not normally advisable. However, correction down to an altitude of 4° would cut the required displacement to a perfectly practicable amount of 0.08 inches. At 30° altitude only 0.01-inch displacement would be required.

This example of a decentred refractor object glass is given in quantitative detail to illustrate the principle involved, which is similar to the displacement system applicable to a

reflector. In the case of my own 15½-inch modified Cassegrain telescope the displacement is applied to the element of an erecting or transfer lens located between the secondary image and the final image. This lens is easily accessible for adjustment, or for replacement to cover a wide range of final focal lengths, because the telescope is 'tubeless'. A group of three such lenses, each fitted with displacement cells and dials to set for the required altitude, cover the needs for any final focal length from 900 inches to 3,500 inches.

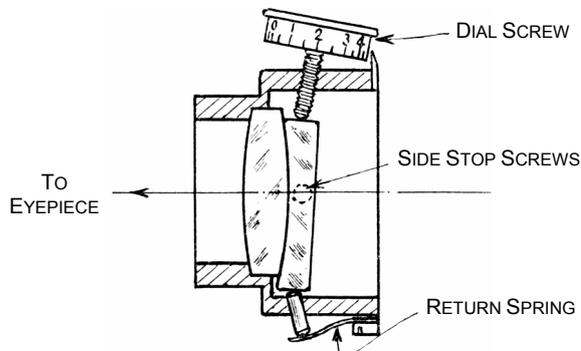


Fig. 3. Dispersion corrector unit.

Fig. 3 shows the actual cell construction adopted for these relatively small lenses. They are in my case coma-free cemented achromats with flat or nearly flat backs. Instead of Canada balsam or other hard cements, a non-drying synthetic immersion oil is used (as in microscopy). This permits the free movement of the lens elements while giving good adhesion, and in several years of use hardly any thickening occurs. The screw and spring which move the lens are inclined slightly in a direction to keep the elements together. This system of dispersion correction can be applied in identical fashion to achromatic Barlow lenses used with reflectors or refractors, particularly if the Barlow lenses are used at fixed magnification not less than $\times 2$.

The table shows the average dispersion C to F in seconds of arc at various altitudes. From these data, and from a knowledge of the pitch of the adjusting screw, and the curvature and optical constants of the lens elements, the desired rotation of the dial screw for any altitude can be calculated. In the absence of this information the finished unit can be arranged with a displacement up to 7% of the lens diameter and be calibrated visually with planets or bright stars at various altitudes. The eye can, with a little practice, easily detect the altitude at which colour freedom is attained – and it is usually repeatable within a degree or so.

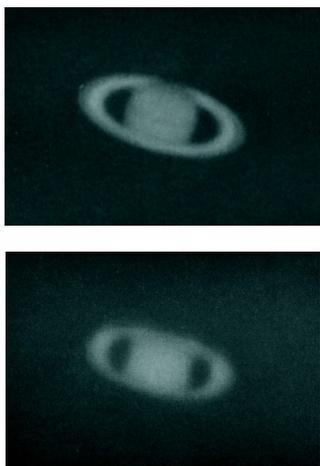
Altitude (degrees)	Atmospheric dispersion (seconds)
10	3.1
15	2.1
20	1.5
25	1.2
30	1.0
35	0.8
40	0.7
50	0.5
60	0.3
70	0.2

Other methods of dispersion correction, such as supplementary geared contra-rotating wedge prisms, have been used, but the methods described have the merit of simplicity of application by the amateur, and involve no losses of precious light in astronomical photography. Even for visual purposes the gain is surprisingly worthwhile both in definition and colour discrimination.

The method of use is the same in both cases; the altitude is estimated, or measured with a clinometer. Reference to a table gives the required dial setting. The setting is made and the orientation adjusted to the vertical. Automatic means could obviously be designed to eliminate hand setting at a considerable loss of simplicity.

The photograph of Saturn was made at the exceptionally low altitude of 12° in June 1957 when seeing was unusually steady for this altitude. The blurred picture, taken imm-

ediately after, was without dispersion correction and represents the best that could be achieved with fast panchromatic film with the colourful spectrum-like image of Saturn at this low altitude, and without using filters.



[Discussion following the presentation of Dall's paper at the Ordinary Meeting of 29 June 1960]

THE PRESIDENT [DR H. C. KING] Is this the first time that an attempt has been made to put a corrector in the optical system? Has anything of the kind been tried at the large observatories?

MR DALL When I first developed the system I imagined it to be the first of its kind; but in the *Scientific American* I have found a reference for one large observatory instrument which was equipped with a contra-rotating wedge system. However, I doubt whether anything of the sort is now in use generally.

THE PRESIDENT The system is not used, for instance, for lunar and planetary photographs taken at the Yerkes and other observatories?

MR DALL Not so far as I am aware.

THE PRESIDENT Does not the system produce an increase in chromatic difference of aberration?

MR DALL In the transfer lens, the colour injection is negligible and normally cannot be seen at all.

THE PRESIDENT In the case of the flint field-lens, there must be a red ring produced round the edge.

MR DALL Yes, that is so. There is a yellowish fringe round the field. This sort of eyepiece is used extensively in microscopy.

THE PRESIDENT For visual observers, it would seem to be important not to get one's eye trained for this sort of thing.

MR DALL For a planet only twelve or so degrees above the horizon, you are bound to get somewhat worried about it.

DR J. G. GIBBS I should like to ask Mr Dall if he has observed variation in atmospheric dispersion from one occasion to another. He has said that atmospheric dispersion depends on the conditions; the conditions show measurable variation, and so, presumably, does the dispersion – probably in a seasonal manner.

MR DALL I agree that variation must occur with changing atmospheric temperature and pressure, but we have to deal with the mean temperature of the whole atmospheric mantle, and this mean temperature does not vary much. Above 10,000 feet or so, the temperature is practically unaffected by the seasons. Little variation in atmospheric dispersion from this cause is seen.

DR GIBBS I believe that Laplace once commented on a fixed relation between extinction and differential refraction. In this connexion, are Bessel's tables of temperature, pressure, and so on, applicable?

MR DALL Temperature and pressure corrections are applic-

able, but are a second-order effect amounting to only a few per cent.

MR W. H. NEWMAN I have experimented with a prism and a spectacle flint glass, and have found that the image is sharpened up.

THE PRESIDENT The prism would be a five-degree one of crown glass, presumably.

MR D. G. HINDS Does Mr Dall find that his system introduces astigmatism?

MR DALL No, it is merely a question of displacing the image prismatically.

DR R. D'E. ATKINSON Does not the decentring introduce coma?

MR DALL None is observable with such a shallow wave-front.

MR J. R. SMITH Normally, atmospheric dispersion seems to vary in depth. With Mr Dall's system it would seem that one should get differential effects – red at one side, blue at the other.

MR DALL No, we do not get effects of that kind across the relatively small fields.

THE PRESIDENT What about the differential effect of producing 'blue and blue'. I feel a little worried about this!

MR SMITH You should get blue on one side, varying in depth. If the qualities of the major components tend to cancel out, you will get blue on one side and red on the other.

MR G. A. HOLE Airy devised a system on this principle by means of decentring the eye-lens. There is a reference to it in Chambers' *Astronomy*.

MR DALL That is most interesting. In any case, I am sure the system has been used in the past. It is usually true to say that there is nothing new under the Sun.

THE PRESIDENT Herschel said that he used to put a prism between his eye and the eyepiece, thereby enlarging the spectrum of the star. That was about 1780 or 1790.

MR D. A. CAMPBELL I have used Mr Dall's device. It produces astounding results. It is rather like tuning a wireless set, when you pass over a station and come back to it. The sharpening of definition is remarkable.

MR E. J. HYSOM Yes, I confirm that. I saw Saturn when about 8° above the horizon. I have never had so good a view of the planet when so low in the sky.

THE PRESIDENT Mr Dall had better be prepared for a spate of orders! Thank you very much, Mr Dall, for this interesting and valuable paper.

Maksutov telescopes

Horace Dall

Even those of us who are more interested in the observational than in the instrumental side of astronomy are seeing more and more references to Maksutov telescopes, and would probably like some clarification on the special features of the type. There is no doubt that as a class of telescope they have come to stay, simply because they offer advantages in manufacture and in use which cannot be obtained with earlier types.

The basic idea of using a meniscus lens of almost zero power as a corrector plate to convert a spherical mirror into the equivalent of a paraboloidal mirror occurred to several optical designers at about the same time; that is, early in the last war. They were Bouwers¹ of Holland and Gabor² in this country, as well as the Russian Maksutov.³ It is to the great credit of the latter that the technical details and specifications were revealed to the world freely through a paper presented to the Optical Society of America in 1944, following a Russian patent of December 1941. It is of interest to note that Dennis Gabor's British patent was applied for in January 1941.

Just as in the case of the Schmidt telescope, it was many years after the original publication before their merits were appreciated sufficiently to encourage moderate-scale

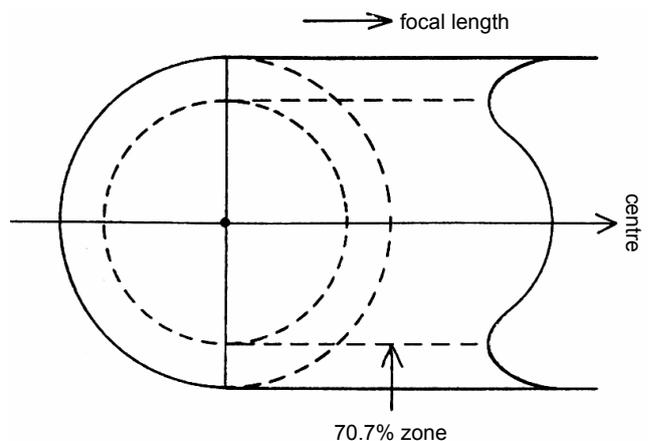
production. Ingalls, of *Scientific American*, aroused some interest in late 1944, even to the extent of forming a small group of amateurs into a Maksutov Club. There seems to have been a long pause after this until 1953 with the publication of Ingalls' *Amateur Telescope Making Book 3*, with F. B. Wright's summary of Maksutov's specifications. Within three years of this, Allen Mackintosh, through the medium of the 'Gleanings' feature in *Sky and Telescope* conducted by Robert E. Cox, founded a sizeable 'Maksutov Club'. Mackintosh and John Gregory were able to organise the supply to club members of the deep meniscus lenses with the curves already 'diamond generated' ready for fine grinding and polishing. Also in America the Questar Corporation expanded the sales of the beautifully designed 3½-inch aperture Questar which originated in 1954. One of these was described and discussed by our member Mr Arthur C. Clarke at a BAA meeting in October 1958. In the same year at least three Maksutovs were built by amateurs and BAA members in this country, some being shown or described at our Exhibition Meetings in 1959 and 1960, including a 6-inch Gregory Maksutov made by Mr J. Youdale. Since then, a dozen or more have been made by amateurs in this country, samples being shown at our Exhibition Meeting each year.

Having briefly outlined the developing use of the Maksutov telescope, its special characteristics should be explained in more detail. Its prime and most appealing feature is that it enables high performance to be obtained with an overall length only two or three times the aperture, and this without excessively difficult figuring work. It hardly needs to be explained that compactness and light weight are very desirable qualities. The greatly increased portability is an asset if only for the purpose of transport between house and garden. If an amateur or a professional astronomer goes abroad or to eclipse sites for holiday or duty, it adds greatly to the pleasure to take a fair-sized telescope to explore unfamiliar skies. A 3-inch refractor or a 5-inch reflector of the ordinary type would mean a major demand in baggage space and in cost if air travel is involved. A 6-inch Maksutov less than 2 feet overall would be easier to contemplate, and can be quite a lightweight instrument capable of reasonable rigidity or a correspondingly lightweight stand.

The Schmidt and Maksutov instruments are classified by the rather clumsy name 'catadioptric', meaning that the primary image is formed by both reflection and refraction. Comparing these with normal Newtonian or Cassegrain reflectors, only the Maksutov has all elements with spherical curves. The Schmidt type is essentially a photographic instrument, and the prime reason for the spherical mirror is to achieve freedom from coma over a wide field of say 10° with a resolution of 40 or 50 lines per millimetre all over the field. This resolution in an f/2 instrument, while being ample for photographic purposes, is greatly inferior to that of an f/2 Maksutov, which, with far less difficult figuring of the mirror, will achieve resolution to the Dawes limit over a more limited field. The Dawes limit is in this case some twenty times better than the photographic needs of the Schmidt. Whilst it is not impossible to figure a Schmidt corrector plate to give the Dawes-limit resolution near the axis, it is extremely doubtful if it has been done, even at f/3, and optical enlargement of the image would be necessary to take advantage of this resolution. It is also quite possible to figure a Newtonian or Cassegrain to give Dawes-limit resolution with a primary working at f/2, but the difficulty is so great and the coma-free field so small that it is not a practical proposition. The great post-war American reflectors working at about f/3, and in the recent case of the Kitt Peak 84-inch, working at f/2.6, have a tolerance on the figure set much lower than that of amateur-type instruments of the quality that regularly achieves the Dawes limit. The larger instruments have a main duty photographic, photometric, or spectroscopic, and considering the extreme difficulty of parabolising these deep curves a rem-

arkably fine job has been done. The demand for short foci in the big instruments is mostly for compactness and weight reduction, which in turn permits relatively small mounts and observatories.

Reverting to the Maksutov telescope, several other advantages accrue in addition to compactness. Firstly, the meniscus lens closes the tube, greatly reducing tube currents and protecting the aluminised surfaces. Secondly, it permits the secondary mirror to be supported on the meniscus, thus cutting out spider supports and their diffraction effects. Both these advantages can be achieved with Newtonians and Cassegrains by fitting a plane optical window at the mouth of the tube. A few amateur-sized telescopes of this kind have been so fitted, and with the increasing availability of optical-quality plate glass the practice is certain to grow. Tube closure with plane or curved white glass for all types of telescope results in a loss of light of 10%. This is reducible to about 7% if the inner surface is coated. With greenish glass some 3% or 4% is added to the loss. These losses are not serious and are easily offset against the gain in reflection over the lifetime of protected surfaces.

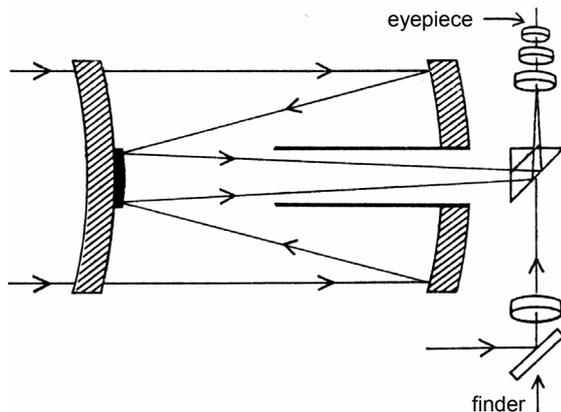


If then we compare a closed-tube Cassegrain with a Maksutov-Cassegrain there would be nothing to choose in performance in midfield if both are figured perfectly. However, to achieve perfection of the near-spherical curves of the Maksutov is much easier than the deep figuring of the Cassegrain for equal tube lengths. By 'near-spherical curves' I refer to Maksutovs of shorter focus than f/4 where residual errors are quite appreciable if the curves are made strictly spherical. For f/4 or longer foci the curves may be left spherical without errors exceeding the Rayleigh tolerance. These residual errors are completely analogous to the corresponding errors of achromatic object glasses of short foci. f/3 object glasses are common enough for binoculars. They suffer from zonal aberrations of the same kind as for Maksutovs due to the imperfect matching of the opposing errors in the two components. These errors can be figured out for both types, but in the case of the f/3 object glass the residual colour errors are too great for high-power astronomical use.

The simplest high-performance telescope is the f/15-20 Herschelian, for which a spherical mirror suffices. If simplicity were the main criterion, this would be the choice of most amateurs. In fact, exceedingly few are in use—a clear indication that large size is a great disincentive. Maksutovs come at the other end of the scale, where the effort in man-hours, as well as the materials' cost, is considerably greater to produce the optics than for normal reflectors or even refractors. This difference is worthwhile if only for the benefit of size reduction and the simpler mounting and housing as well as portability. There is no denying that a rigidly mounted large instrument of the observatory type weighing several tons is very comfortable to use. One can actually support one's head or body weight against the instrument without shifting

the image much. Unfortunately, the average amateur cannot expect to own such a massive outfit. His choice may be either a lightweight and relatively portable instrument or nothing at all, and it is in such cases that the Maksutov can be expected to increase the sum total of amateur observers in the future. The demand has hardly started in this country yet, but the combined efforts of the amateur and professional telescope-maker will surely be capable of meeting it.

The Maksutov design is variable over a wide range to suit the needs or preferences of the user. It can be of Newtonian type, but is nearly always made in the Cassegrain form because it best suits short-focus primaries. A design which permits a short focus inevitably gets applied to short foci, and $f/2$ to $f/3$ is the commonest range, which can only be dealt with comfortably by the Cassegrain type, giving a final image of anything from $f/10$ to $f/30$.



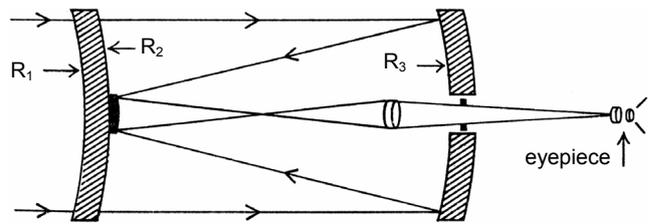
All forms of Cassegrain telescope suffer from sky flooding – a disadvantage from which the Newtonian is free. The trouble arises from the fact that when looking from the eyepiece end, the secondary is seen surrounded by an expanse of sky. If the sky is very dark there is no trouble. Unfortunately, the sky is rarely dark. It may even be a daylight sky, and the flooding trouble must be tackled properly. Most books on telescopes steer clear of the problem, and the Cassegrain has probably acquired a bad name for this reason.

The method adopted in the Questar is to use a shrouding cone projecting from the mirror towards the secondary. This method results in a large central obstruction at least one third of the mirror diameter, giving diffraction effects somewhat harmful to contrast in fine planetary detail. The only other satisfactory method – one which I have adopted since 1930 – is to place a sky-flooding stop between the eyepiece and an erecting lens which is introduced for this purpose between the secondary and the final image.

This method allows a central obstruction one fifth or less of the mirror diameter, at which ratio the loss of image contrast from diffraction is negligible. The performance of an accurately made Maksutov-Cassegrain of this type should at least equal a similar-aperture refractor because of the much more perfect colour correction of the former. Even if it costs as much or more than a refractor it has the great asset of compactness and portability.

The meniscus lens of the Maksutov is made of a hard and durable glass – usually borosilicate crown. It is not especially sensitive to squaring-on to the mirror axis, but that of the mirror and secondary are, just as in the case of a short-focus Cassegrainian. The eyepieces of both types are only required to deal with fairly long-focus final images; thus they can be of simple Huygenian form. Cameras can be affixed to them in just the same way as for other telescopes.

Coma in the secondary image of the Maksutov is less than for the normal Cassegrain, and if the coma-free design is used, fields up to two degrees of critical quality are obtainable here, but not necessarily at the tertiary image if an erector or Barlow lens is used, because the field would then



depend on the character of these lenses and the magnification adopted.

As mentioned already, the deep meniscus lens, known as the 'shell', can be produced by diamond generation from solid or moulded blanks, or alternatively from parallel discs little thicker than the final lens, sagged over a former in a temperature-controlled oven, followed by annealing. The action of the meniscus is highly dependant on the precise difference between the radii R_1 and R_2 , which for a particular glass index has to be made proportional to the central thickness.

The usual procedure for an amateur is to finish one of the curves against a suitable glass or metal tool, then measure the radius and estimate the final thickness from which the desired difference is calculated. As the second curve approaches the desired value it is corrected to a more accurate value of the final thickness, meanwhile keeping the edge thickness uniform. The mirror curve R_3 is also dependent on the meniscus thickness. Its production follows ordinary mirror-making technique. It can be made spherical in the first place, and the final figuring carried out in combination with the meniscus and secondary, using a separate collimating telescope or by autocollimation with a full-sized optical flat. The aperture of the mirror should be about 4% more than that of the meniscus lens.

References

- 1 Bouwers, *Achievements in Optics*, Elsevier, 1946.
- 2 Gabor, British Patent No. 544694, 1942.
- 3 Maksutov, *Journal of the Optical Society of America*, 34 (1944), 270.

Visual astronomy in the ultraviolet

Horace Dall

The title appears to be a contradiction in terms. How can one carry out visual observation by means of light from the invisible part of the spectrum? The answer to this question depends on whose vision we are dealing with, also with the intensity of the light.

Authors of textbooks on light are in the habit of copying one another, and it is usual to find a statement that the sensitivity curve of the eye in good light extends from 4000\AA in the far violet to 7000\AA in the deep red. However, it is generally recognised that the curve has a longer asymptote at the red end, and if a high-intensity source is examined spectroscopically the eye can see light up to and even beyond 8000\AA .

At the other end of the spectrum the fade-off of the sensitivity curve (Fig. 1) is more abrupt, but with considerable dependence on the individual and his age. Some young people I have tested can see (very faintly) the ultraviolet line at about 3655\AA in the spectrum of mercury vapour either in fluorescent lamps or in street lamps. However, most prism-type direct vision or non-direct vision spectroscopes of high dispersion do not show this ultraviolet line because the dense lead glass in them cuts out this part of the spectrum.

Even if the spectroscope is capable of showing the ultraviolet, very few adults can see appreciably beyond the mercury violet line at 4047\AA . I happen to be one of those adults, and can now see right into the ultraviolet to a wavelength of about 3300\AA , or one third of a micron, because the

so-called crystalline lenses of my eyes have been removed in normal cataract operations.

In consequence, I can see relatively well through a Wood's glass filter which substantially cuts out the usual visual spectrum while being fairly transparent in the ultraviolet down to about 3000Å. Not only so, but I can see with good clarity and in extra-high resolution through a microscope illuminated only by a 'black' lamp of the type used for fluorescence effects. This type of lamp has a Wood's glass envelope. The characteristic transmission curve of Wood's glass, such as Ilford filter no. 828, shows two regions of transparency: the greater one with a peak of about 73% (in 2 mm thickness) centred at 3600Å and extended from 2900Å to 4200Å, and the lesser one with a peak of about 25% centred at 7500Å and extended from 6800Å to 7600Å. Fig. 2 shows these two peaks in relation to the sensitivity curve of the normal eye (dotted).

The two widely separated peaks provide an excellent means of testing one's eyes for sensitivity in the ultraviolet. If, for instance, a naked filament lamp or one with a 'pearl' envelope is viewed through such a filter, it will appear quite red to a person having no ultraviolet sensitivity, because only red light gets through to the retina, and red sensitivity is high in young and old alike over a wide range of intensities. I see the lamp as blue, and young adults see it as a purple mixture. Very young people will see it as a bluer purple. Incidentally, although the violet line at 4047Å appears to me as a vivid violet, the ultraviolet line of Mercury vapour at 3655Å appears as blue rather than as violet, indicating an unsuspected kind of fold in colour-vision sequence.

Following the cataract operations I quickly noticed that blues were much more vivid than before the operation. For instance, a bunsen burner flame became a rich blue colour instead of the greyish blue to which I had been accustomed. Further tests with spectroscopes revealed that I could see abnormally far into the ultraviolet, making possible new fields of visual observation. The new field on the astronomical side developed when I made a pair of Wood's glass spectacles to see what changes of view occurred with stars and

planets both visually and through the telescope. We have in this Association heard a great deal about the use of filters in planetary observation, and the subject arouses considerable interest and discussion; thus an extension into the ultraviolet field is a useful gain of experience, and one in which there must be a number of members, both young and old, capable of partaking.

The eye is a non-achromatic organ, and I find that the focal power is 1½ dioptries greater in the ultraviolet – hence I ground and polished the Wood's glass spectacles as negative lenses of this strength. When the crystalline lens of the eye is removed in a cataract operation, rather high-strength spectacle lenses (such as positive lenses of 3-inch to 4-inch focus) are necessary to replace the focusing power removed, and to supplement the power of the transparent cornea, and so on.

The first trials were plain visual views of stars and planets through the spectacles. Mars was so weak in ultraviolet that it was only just visible, equivalent to about sixth magnitude. Jupiter was much brighter – probably 4.2 magnitudes, a difference of 1.8 magnitudes when the *Handbook* gave only 0.8 magnitudes difference in white light. This was not an unexpected result; neither was the observed weakness of the redder stars. For example, Betelgeuse, Aldebaran, and even Arcturus were invisible, or practically so, whereas the much fainter three stars of Orion's belt were all plainly visible. Familiar constellations change their character. Only two stars (η and ε) are visible in Ursa Major.

Using the same ultraviolet filter spectacles in views through the 15½-inch reflecting telescope, Mars was still remarkably faint, and no features were visible on the disk at the same sky conditions that permitted two belts of Jupiter to be just seen. Again there is nothing surprising about these observations, but as opportunities occur I hope to examine other objects in ultraviolet, particularly the brilliant surface of Venus. It will be remembered that various photographs of Venus taken through a similar ultraviolet filter have been published showing slabs of shading near the terminator, though never near the limb.

In my own efforts at photography of Venus in ultraviolet, none of this shading has appeared, probably because I aimed at negatives of the same density as those taken in white or orange light. My theory, which I would like to see proven or disproved, is that the slab shading is spurious and due to underexposure of the emulsion near the terminator, which means working at the foot of the characteristic curve of the emulsion. The limb is so much brighter that the exposure point is well up the curve. The foot of the curve is notoriously unstable and unsuitable for useful work, but can be avoided only by rather lengthy exposure through the dense ultraviolet filter. With ultraviolet-sensitive eyes I hope to be able to see the surface of Venus sufficiently brightly through the filter spectacles to detect the presence or absence of the shading by the simple visual process using the telescope.

Ultraviolet light is somewhat harmful to the retina in heavy doses – for example, from the direct or indirect solar rays – and the adult's eye protects itself at this end of the spectrum by developing a yellowish colour in the lens. This protection is absent in ultraviolet-sensitive eyes, and suitable precautions should be taken. There will be a number of amateur or professional astronomers in a similar situation, and this short note may serve to encourage similar experiments. Wood's glass filters are obtainable from several manufacturers and, as already mentioned, the Ilford product is filter no. 828, while in America suitable filters are available from well-known surplus suppliers specialising in scientific and optical items. For filters used with the telescope, there is of course no need to work a curve on the surface to correct for chromatism of the eye, though some change of focus of the eyepiece will be necessary. Youthful eyes have sufficient accommodation not to need correction in many cases.

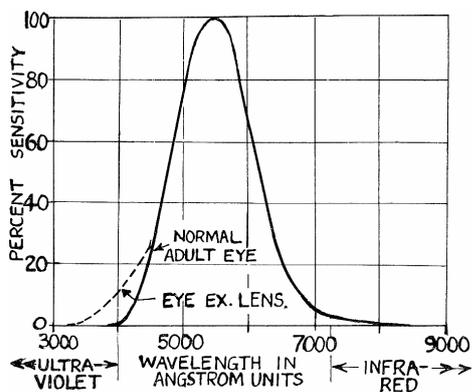


Fig. 1.

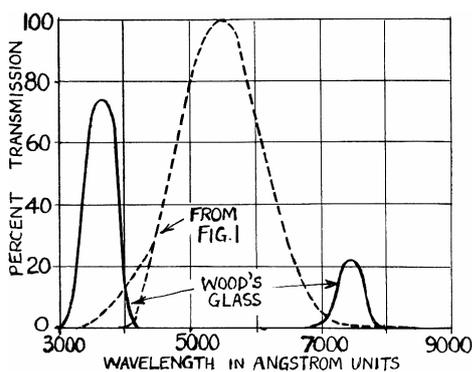


Fig. 2.

Telescope eyepieces

Horace Dall

The function of an eyepiece is to magnify the image formed by the other optical elements of the telescope, and to present to the eye a bundle of rays covering a fair viewing angle and in a condition to be refocused by the eye easily and clearly on the retina. It is axiomatic that no optical system is perfect; imperfections of one kind or another may vitiate the retinal image, and the aim should be to reduce those from the telescope until they are smaller than the imperfections of the human eye itself. When choosing an eyepiece a compromise is involved, and the factors involved can be itemised:

- 1 Cost.
- 2 Correction of optical errors which affect performance; for example, spherical and chromatic aberration, coma, astigmatism, distortion, ghosts, and flare.
- 3 Efficiency of light transmission.
- 4 Angle of field of acceptable definition.
- 5 Eye clearance.
- 6 Suitability for projection purposes.
- 7 Hardness and durability of external surfaces and accessibility for cleaning.

Before considering each item it is desirable to stress that simple and cheap eyepieces may be quite satisfactory for long focal ratio (focal length/aperture) telescopes ($f/10$ upwards), yet quite unsuitable for those of short focal ratio ($f/4$ to $f/7$). The vast majority of reflecting telescopes in use by amateurs have medium focal ratios $f/7$ to $f/10$. The ratio referred to is the final focal ratio in the case of compound telescopes or those fitted with Barlow or transfer lenses.

1. Cost. The fewer the elements, the lower the cost, and if the elements are identical and of low-cost glass, so much the better from this one point of view. The most expensive types have five or six elements with several different types of glass of varying degrees of hardness and stability. These complex types are usually designed for wide fields and low focal ratio, usually for use after prisms, and are often bulky and heavy. If used with high-focal-ratio instruments, such as the normal astronomical refractor, they may be much inferior to the simple two-element Huyghenian type.

2. Correction of optical errors. As already mentioned, simple eyepieces of the one- or two-element type can give quite good definition when used with telescopes of focal ratio greater than $f/9$. For $f/4$ to $f/7$ more complex types are essential. They can be of three- or four-element type for medium field angles (see 4 below for a definition of this), but for wide and extra-wide fields, five- or six-element types are necessary. At or near the centre of the field, the only errors of significance are spherical and chromatic aberration. To illustrate the effect of these errors and their great dependence on focal ratio, an example will be useful. If a Huyghenian eyepiece is applied to a good $f/5$ telescope, a halo of aberration will be seen surrounding the image of a bright star or planet. If the aperture of the telescope is then halved by fitting a stop making the focal ratio $f/10$, the aberration halo will be invisible because it is reduced in diameter by a factor of 8 and by a factor of 64 in area. Thus the visibility of the error can be considered to vary inversely as the fifth power of the f number – an enormously important variation. Replacing the Huyghenian with an orthoscopic eyepiece of good type, the aberration halo at the full aperture $f/5$ will be no more than that of the Huyghenian at $f/10$.

3. Loss of light in transmission through the eyepiece is inevitably greatest with complex types, but lens coating (blossoming) can offset much of this loss, as shown in Figs. 1–10. Every air/glass surface contributes to this loss. Other small

losses occur at cemented surfaces and by absorption in the glass. It is not advisable to coat the lens surface nearest to the eye, as this is usually subject to frequent cleaning, and the coated surface is more vulnerable to scratches during cleaning. The reflection loss per air/glass surface is slightly over 4% for crown glass and about 6% for dense flint and dense barium crown. Glasses of the two latter types acquire a natural bloom with age, due to leaching out of the lead and barium in the surface layers in humid atmospheres. This natural state is sometimes beneficial, but eventually the outer surface weathers to a scattering layer of an undesirable kind. Loss of light by absorption does not usually exceed 1% per element except when cheap green glass is used. Typical figures for overall loss of light are:

Single-element type	Loss
	9% uncoated
	6½% coated 1 surface
2-element type	17% uncoated
	10% coated 3 surfaces
3-element (4-glass/air)	19% uncoated
	11% coated 3 surfaces
4-element (4-glass/air)	21% uncoated
	12% coated 3 surfaces
5-element (6-glass/air)	28% uncoated
	15% coated 5 surfaces
6-element (6-glass/air)	30% uncoated
	16% coated 5 surfaces

The gain from coating in the last item is between a transmission of 70% and 84%: this is a 20% gain in light.

4. Angle of field. The angle through which the eye moves between an examination of two opposite sides of the field of view is called the 'apparent' angle of view. This must not be confused with the actual field when the eyepiece is used with a particular telescope. Apparent fields less than 35° are considered narrow, 35° to 50° are medium, 50° to 60° are wide field, and 60° to 80° are extra-wide fields. In no type of eyepiece is definition at the edge of the field as good as in the centre. The edge deterioration is not particularly serious, because an object under close scrutiny should be brought near to the centre. A wide field is useful for searching purposes or for spectacular views of star clusters or wide spreading objects. Vignetting, or partial obstruction by the mounting of the outer ray bundles is very common in wide and extra-wide field eyepieces. This may affect the use in variable-star work, but not for general viewing. The majority of telescopes are fitted with medium field eyepieces.

5. Eye clearance is the distance between the outer lens surface and the exit pupil; that is, the image of the primary formed by the eyepiece. It is here that the various parallel bundles of rays from all points of the field converge, and the iris of the eye should be located here if the whole field is to be visible at once. If the clearance is less than 8 mm the iris cannot be placed at the exit pupil, and only part of the field of view can be seen without moving the eye about. A clearance of 16 mm or more is necessary to see the whole field at once by a spectacle wearer. The clearance is rarely more than 80% of the eyepiece focal length, hence a wide field cannot be seen in toto without eye movement with eyepieces less than 20 mm focus for spectacle wearers, or 10 mm focus for others. Thus there is no great virtue in wide fields for short-focus eyepieces; even a 30° field is acceptable for really high powers, especially with a clock-driven telescope. For low powers, on the other hand, it is possible (but not common) to have too great an eye clearance. This results in unpleasant shadowing of the field until the eye is withdrawn to the exit pupil.

6. Suitability for photography. In general the three- to six-element achromatised types are most suitable for photogr-

aphy by projection through the eyepiece. The simple Huyghenian, if correctly made, does not show colour fringes when used visually, because the red and blue virtual images are seen of equal size. When used for projection, colour fringes may be troublesome, but not seriously so for large focal ratios.

7. Accessibility of the elements for cleaning is quite an important point. In particular, the surface next to the eye should not be shrouded with an eyecap which would prevent easy cleaning. The outside field surface is also liable to collect dust, and should be easily accessible for cleaning yet protected from contact when laid down. The inner surfaces may need attention at, say, yearly intervals, and again should be accessible. Permanent burnishing in of elements preventing dismounting should be condemned. Durability of the glass, particularly of the outer surfaces, is worth consideration. This point is dealt with for specific types in the next section.

Descriptions of eyepiece types

Figs. 1–10 illustrate the form and relationship of all the eyepiece types in common use, given in order of increasing complexity. The small cross shows the position of the exit pupil or eyepoint for each type.

Fig. 1 shows the single-element Tolles form – sometimes called solid Huyghenian. It has high light transmission and no ghosts. Spherical aberration is less than one fifth that of an equal-focus Huyghenian, and it gives crisp and colour-free images even for f/6 telescopes. The disadvantages are fairly severe: considerable field curvature and no eye clearance, also a small field of 28° – 30° of which little more than 20° can be seen without eye movement. The focal plane is internal, and a groove in this plane forms the field stop. If this is omitted (indeed from any eyepiece) a blurred edge to the field of view results – psychologically less satisfying than a sharp boundary.

Hard crown or barium crown glass is used, and the best ratio and separation of the curves vary with the glass type. If the small field is not objected to, it is an excellent eyepiece for planetary and double-star observation. An achromatic version with a cemented eyecap of dense flint glass has been used, which places it in the class of Fig. 4 with corresponding advantages but higher cost.

Fig. 2 is the common Huyghenian – one of the oldest and cheapest types, and well suited to long focal ratios. It is probably more used for refracting telescopes and microscopes than any other kind, both having long focal ratios. Its merits for these duties are considerable. Fields of 40° – 45° are usual, flat and colour free, and the lenses are of inexpensive crown glass, durable, and not easily scratched. Poor design and manufacture, such as the use of poor non-optical glass, bad centring, and wrong separation has often vitiated the performance, but this is not a defect of the type. A real disadvantage is the large amount of spherical aberration, amounting to 3%–4% of the focal length for f/10 telescopes and four times this for f/5. The effect of this is described in the example under item 2 above.

If a telescope is found to be overcorrected (not uncommon in falling temperature gradients), use of this type of eyepiece may well be found to neutralise the error for medium to high powers, even for f/6 to f/8 telescopes.

The textbook 3:1 ratio of foci of the elements results in a small eye clearance. A better and much used compromise is a ratio of 2:1 with a separation half the sum of the foci (element foci 0.75 and 1.5 times the eyepiece focus); plano-convex is the standard form of the lenses, but variants giving slightly improved results have been used. Another variant with a cemented achromatic eye lens has been used for projection purposes.

Fig. 3 is the common Ramsden eyepiece. The textbook

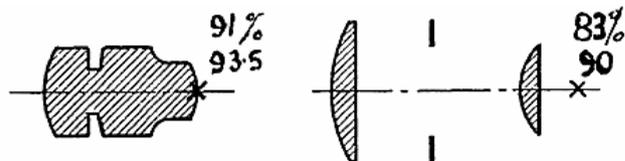


Fig. 1
Solid Tolles

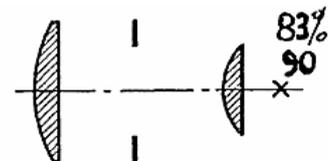


Fig. 2
Huyghenian

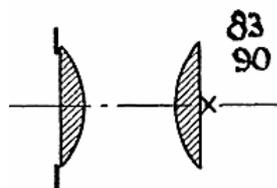


Fig. 3
Ramsden

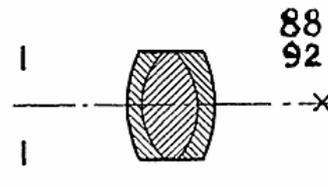


Fig. 4
Loups monocentric

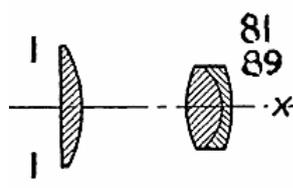


Fig. 5
Achromatic Ramsden

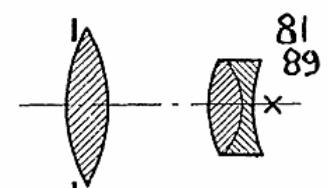


Fig. 6
Kellner

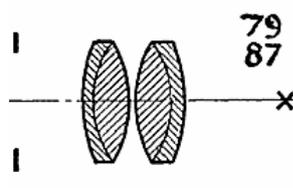


Fig. 7
Dialsight

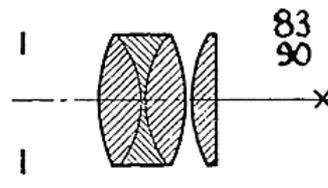


Fig. 8
Orthoscopic

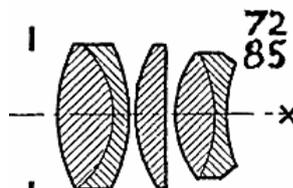


Fig. 9
Five-element tank binocular

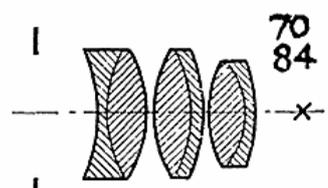


Fig. 10
Erfle

Figs. 1–10. Ten basic forms of eyepiece, with positions of field stop and eyepoint, and giving percentage of light transmission, uncoated and coated.

form, consisting of two identical plano-convex lenses of crown glass separated by a distance equal to their focus, suffers from zero eye clearance and in having the field lens in focus together with any dust on its surface. In addition, there is a great deal of outfield false colour. The first two defects are reduced by making the separation about 70% of the focal length, which is fairly common practice. This gives an eye clearance of about 20% – not sufficient to enable the field of 40° – 50° to be seen without some eye movement. The spherical aberration of the Ramsden is much less than that of the Huyghenian, and it can be used down to about f/6 in short foci.

The field stop is just outside the lens, and the type has been much used for micrometers and surveying instruments which have cross-wires coincident with the primary image. For non-spectacle wearers the close eyepoint is less inconvenient, and the outfield colour can be made use of to counter-

act atmospheric dispersion to some extent for low-altitude astronomical objects. Observers with short sight (myopia) find they still focus dust on the field lens too easily, and get more satisfaction from the Huyghenian, with which this does not occur. The Ramsden is the cheapest two-element type to produce, and is used in America to a much greater extent than in England.

Fig. 4. A cemented triplet, which has been considerably favoured for its crisp images and economy of light, is the monocentric or its equally satisfactory variant, the Loups triplet. In the former, all the six curves are struck from the same point, the centre lens being of crown glass which is nearly spherical, and the two outer lenses are of dense flint – relatively soft. With the concentric design, centring of the components becomes of minor importance, but little if any other advantages accrue, and it is noteworthy that many pre-war Zeiss monocentrics did not follow this design, but were of the Loups type, as shown in the figure. With only two air–glass surfaces and a good eye clearance of 80% or more, they make an efficient type of eyepiece very free from errors, and there is less curvature of field than the solid Tolles of Fig. 1. However, the field of view is small: only 30°. They can be used down to $f/5$ or even $f/4$, but are relatively expensive, although the cost of production should obviously be less than the four-element orthoscopic of Fig. 8.

Figure 5. The achromatic Ramsden is a great improvement on the simple two-element type of Fig. 3. A common design has a plano-convex field lens of crown glass and a cemented doublet eye lens, with a plane or slightly convex surface to the dense flint element facing the eye. However, many variations are made with the plane surfaces replaced by convex surfaces. The crown component of the eye doublet is usually of barium crown. This achromatic Ramsden is probably the most common three-element type extant, and is fitted to many military instruments and to probably 80% of all prismatic binoculars. It has a field from 40° to 50° and an eye clearance of 30% to 45%; the performance is good and the field flat, and it is usable even down to $f/4$. The outfield colour of the two-element Ramsden is eliminated by the corrected eye lens, but the dense flint eye surface is vulnerable to scratches. Although made in such large numbers in the focal range 15 mm to 27 mm they are not invariably well made or well designed, although those by well-known makers can usually be relied on. The proper description of this type is achromatic Ramsden, but it is often referred to as Kellner type. The eyepiece properly described as of Kellner type is that shown in Fig. 6, which has a double convex field lens with a cemented doublet eye lens having a concave surface facing the eye. The type is not common, but had a vogue in microscopy at one time. It has a very wide and flat field (for example, 60°), but such a small eye clearance that much eye movement is required to see the whole field. A further defect is that dust on the field lens is in focus.

Fig. 7. Dialsight orthoscopic, Plössl, and so on. This type was used in large numbers in military instruments, and gives a large eye clearance of 80% combined with a good flat field of 40°. The design is also used for rifle sights where a large eye clearance is a vital requirement, and for erecting purposes in gun-sighting and other telescopes. It consists of two fully corrected achromats placed crown sides together and nearly touching. Usually the two cemented achromats are of crossed convex form and are identical, but a number of variations in design exist in which the eye doublet is of shorter focus than the other. By this means, fields of up to 50° are achieved. Other variants have plane outer surfaces. They are excellent for astronomical use for foci down to 15.24 mm, and the only disadvantage is the vulnerability of the relatively soft eye lens to scratches. The old Browning achromats can be considered as variants of this form, but the separation of the doublets is much greater than for the dialsight type.

Fig. 8. True orthoscopic. This type, to which the name was originally given, is distinguished by the plano-convex eye lens with the plane side next to the eye, and a triplet field lens. This cemented triplet is overcorrected to balance the errors of the simple eye lens, and consists of a double concave dense flint lens between two hard crowns – symmetrical in some designs, but not in the best ones, in which a field of 50° is achieved. The field is usually 35°–40°. The eye clearance is as large as the dialsight type; namely, 80% of the focus. It has all the other merits of the dialsight type, and is unique in four-element eyepieces in having all the exposed surfaces of hard and durable glass. There are numerous variations in the pattern, but maintaining the characteristic of a plano-convex eye lens. One variation by Goerz, with a plane outer surface to the triplet and a dense barium crown eye lens, achieves a field of 60° at the expense of soft and relatively unstable glass at both ends. A further variant used in some German military instruments has a cemented quadruplet field lens, and a field of 75°–80° is attained with long eye relief. Large fields have also been obtained by using an aspheric eye lens with a triplet field lens.

Fig. 9 is a five-element eyepiece used in tank binoculars and giving an extra wide field of 75°. This is selected as one example of the numerous designs of five-element eyepieces that have been used in military instruments. Most of these designs have six air–glass surfaces, and all suffer to some extent in giving ghosts, which detract from astronomical use. The eye clearance of most designs is 40%–50%, and their chief merits from an astronomical point of view arise from their wide fields and their availability at reasonable prices in the form of war-surplus lenses.

Fig. 10 is typical of the Erfle six-element eyepieces made for military use. They consist of three separated cemented pairs. The eye lens is undercorrected and the field lens overcorrected. Normally, fields of 65°–70° are given, but some rather uncommon ones achieve 80°. The most common of this type in England was made for predictor sights, and has a focal length of 19 mm. For astronomical use it is advisable to beware of scratched eye lenses (made of soft glass), and also of deteriorated cement in the three doublets, while they are also prone to giving one or more ghosts of bright objects. If in good order, they are excellent for wide-field spectacular views and their suitability for projection. The eye clearance is about 50%, and for planetary observation they are not very suitable.

Zoom eyepieces have become available recently from Japanese sources. They have a large number of separated elements, and although coated there is a strong danger in humid climates of light scattering developing from condensation and filming between the elements, which are not readily accessible for cleaning. For this reason and for the relatively high losses it is doubtful whether they are advisable for astronomical use, especially as the power range covered is only 2.5:1, and refocusing is desirable after a power change. The alternative of combining a short-focus achromatic Barlow lens with a normal eyepiece of moderately low power can, with equal overall length, give a power ratio of about 4:1, and the fewer elements are all accessible for cleaning. An equally rapid power change to the zoom is given by a turret of three or more parfocal eyepieces.

Binocular eyepieces for astronomical duties

The beam-splitter principle as used with high-power binocular microscopes is quite applicable for astronomy, but some loss of light compared with the monocular view is inevitable. This is minimised by using dielectric beam splitters instead of metal films. Matched pairs of eyepieces are, of course, necessary, and add to the cost. However, the view of astronomical objects, particularly the Moon and planets, is enhanced and made comfortable by the use of the two eyes.

Finding and guiding on dark skies

Horace Dall

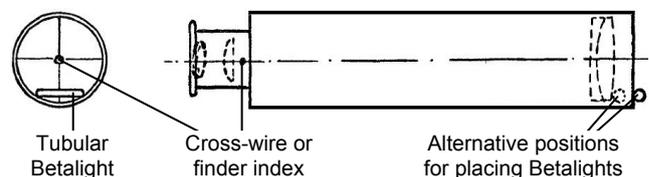
Objects seen in a finder against a bright sky background (such as Venus before sunset) present no difficulty in being located in the main telescope if the finder is accurately set. For most amateur observers, matters are quite different when the sky is dark, and especially so if the finder cross-wires (or other form of index) are thin and there is a fairly high power on the main telescope. The cross-wires may, in fact, be completely invisible, and the need of some illuminating device is felt strongly. In professional observatories (also in military instruments) the need is often met by the provision of a small low-voltage lamp, generally arranged to shine through the polished edge of a glass graticule disk. The engraved or etched lines on the graticule intercept some of the light and so enable cross-lines to be seen easily on a dark sky background.

Few amateurs go to this trouble for finders, but more do so in the case of guide telescopes used for comet or star-field photography where the need is much greater. Guide telescopes are used at relatively high magnification, with exit pupils only 1 or 2 mm diameter. More often than not they are permanent installations in observatories, and the provision of graticule illumination is less onerous. If the installation includes micrometer eyepieces, for example for double-star measurement, illumination of the very fine spider web, fused quartz, or glass fibres, which are usually less than 10 μm diameter (a human hair has a diameter of 50 μm), lighting becomes quite essential, and the methods about to be proposed are not intended for such cases.

Reverting to finders, cross-wires made from metal wire 50 μm or more in diameter are commonly used, while glass graticules are not often found. They would tend to collect dust particles or condensation more than for hermetically sealed military instruments. Metal cross-wires are usually arranged either as a two-wire cross or a three-wire system leaving a small central triangle, or a four-wire system leaving a small central square. The three- and four-wire systems are intended to obviate the loss of the object (particularly a faint object) behind the simple cross. The late Captain Ainslie and other famous observers have used the point of a pin as an index instead of cross-wires, since the relatively thick pin is more visible than the wires. For many years I have used a central circular loop or ring on a single support wire. More recently the ring has been replaced by a tiny disk (1.5 mm diameter) punched from gelatine filter material of light orange colour. This obviates much of the obstructive effect, and an object is seen to change colour when it enters the disk whether the sky is dark or not. My finder, nearly one fifth the aperture of the main telescope, has a power of $\times 10$ with an aperture of 76 mm, thus giving an exit pupil 7.5 mm diameter. The actual field is 6° , fairly near the ideal specification for finding purposes. However, there is still the need to illuminate on a dark sky, and I have met this need in a very simple way without interfering with the finder eyepiece, merely by providing a small amount of background illumination from a tiny low-voltage bulb or pea lamp interposed at the edge of the 76-mm entry beam in front of the finder object glass. Distance from the finder is unimportant. The bulb is capped with a red filter, and can be either battery or transformer operated to a feeble illumination half to one third of the nominal operating voltage. This method provides a background illumination equivalent to the sky on a night of full Moon. More recently I learned from our member Mr Jipson of Abbots Langley that small self-luminous glow tubes are now available, and it seemed that these might be used to provide the background illumination required. The glow tubes are known as Betalights. The glow arises from the bombardment by energetic β particles (electrons) of a phosphor-coat-

ed inner wall of the sealed glass tube containing tritium, a radioactive isotope of hydrogen. The light output is greenish in colour and eventually decays, but remains adequate for this duty for 20–30 years. The type of tube (TO3/G/190) seems most suitable; it has a diameter of 3.5 mm and a length of about 25 mm, and is very reasonably priced. The luminosity is some twenty times greater than luminous paints, and unlike radium paints presents no radiation hazard.

The Betalight proved excellent for providing the finder background illumination, and was soon in the position previously occupied by the pea bulb. The figure shows a typical finder and suitable locations for the Betalight. It can be held in position in any suitable way; for example, with a strip of Scotch tape or a pea-sized piece of plasticine. Alternatively, it can be mounted in a holder capable of being hinged in or out of the optical path. There are no connections of any sort to be made. When the finder is used quite normally with the eye located close to the eyepiece exit pupil, the cross-wire or index is seen silhouetted against a faintly luminous background. As the edge of the exit pupil contains an image of the Betalight, the background luminosity can be cut out by a slight movement of the eye without losing the stellar or planetary contents of the field of view. This would be an automatic procedure when locating a faint comet or nebula which needs a dark background. Mr E. G. Moore in a recent paper (*Journal*, 82, 42) described the fitting of glass filament cross-wires in a guide telescope eyepiece and pointed out the self-illuminating feature when the image of a star is precisely located on the cross-wire. However, Commander Hatfield has subsequently noted the extreme difficulty of locating the stellar image on the cross-wire when a dark sky makes the latter completely invisible. Yet a Betalight fixed on the edge of the graticule (assuming it has a polished edge) with the engraved or etched lines not too thin or shallow, could give sufficient illumination to render them visible against a dark sky.



Photoelectric methods in amateur astronomy

Horace Dall

[With reference to] S. W. Dunham's very interesting and relevant letter on high-speed photoelectric methods (*Journal*, 83 (1973), 143). It has seemed to me for a long time that these methods, though difficult, are well within the scope of our electronically experienced members ... Fifty years ago, photoelectric cells and high-speed galvanometers were available which would permit the recording of bright stars with large telescopes, but recent electronic methods greatly extend the potentialities.

In a letter to Professor Eddington in February 1926 I suggested the lunar occultation method. He replied that an analogous photographic method had been tried some years previously. Ten years later I repeated the suggestion in a letter to the *Scientific American*, published in December 1935. Since then, several attempts were made by amateurs and professionals, even before space-age electronics and light amplifiers were available.

Advanced amateurs would surely find a new thrill in analysing occultation light curves, making appropriate allowances for diffraction bands from the Moon's edge and for the telescope aperture. About 10% of the whole sky is covered in the occultation band – quite a sizeable sample.

Filter-type solar prominence telescope for amateurs

Horace Dall and Michael R. Whippey

This paper presents a practical design for a filter-type telescope for viewing solar prominences, making use of narrow-band filters. It also includes a note on the filters themselves, and on viewing surface phenomena.

George Ellery Hale, the famous American astronomer who, while still a youthful amateur, invented the spectrohelioscope in 1889, has written:

From whatever angle you look at it, the Sun offers interesting and remarkable subjects for investigation. Unlike most celestial objects the brilliant and spectacular phenomena of its atmosphere are never twice alike, and the most violent outbursts of terrestrial volcanoes are tame affairs in comparison with solar explosions. In order to gain any conception of the fantastic beauty of solar prominences it is necessary to see them in action.

The spectrohelioscope is a comparatively complex instrument needing many man-hours of highly skilled work to produce, hence only a few amateurs have made and used them.

The filter-type instrument for viewing solar prominences is a recent development enabling many amateurs to participate in this field at reasonable cost. Continued development in the very specialised technique of making these filters (which is the vital part of the instrument) now enables even solar surface phenomena to be seen by amateurs prepared to pay the considerably higher price of this 'extra-narrow-band' type of filter. This paper is intended to present a practical design and guidance for making a prominence telescope, together with the experience gained in fifteen years of its use. One of us (Whippey) has added his experience in the use of the extra-narrow-band filters used for both surface phenomena and prominences.

The term 'filter-type' refers to the use of the multilayer vacuum-coated glass disk which allows only a very narrow band of the whole spectrum to pass – typically only 4\AA out of the total visible range of about 3000\AA . (The alternative metric unit the nanometre, nm, should not be confused with the Ångström unit, Å. The former is ten times greater. $1\text{ nm} = 10^{-9}\text{ m} = 10\text{\AA}$.)

Solar prominences are 'flames' of incandescent hydrogen seen projected beyond the Sun's disk against a dark background. It is the function of the filter to provide this dark background without seriously reducing the light from the prominences, in spite of the glare from the Earth's atmosphere illuminated by the Sun. This glare is many hundreds of times brighter than the incandescent hydrogen, thus preventing any possibility of naked-eye or normal telescopic views of the prominences in our atmosphere. This is so whether or not the eye is shielded from the light from the solar disk. The filter selectivity allows the chosen wavelength to pass without much loss of light while being relatively opaque to the whole spectrum band from the atmospheric glare. The wavelength chosen is normally that of the red H α radiation at 6563\AA , hence such filters are described as H α filters.

Early methods of prominence viewing

Before the first half of the nineteenth century, prominences had been seen only during total eclipses of the Sun. Ancient accounts of these noted red clouds or protuberances which occasionally projected beyond the solar disk by one tenth of its diameter or more. The invention of the spectroscope permitted the first views of prominences without waiting for a total eclipse. If the slit of the spectroscope is placed tangentially with the edge of the solar disk in a telescope, the dark absorption line seen at 6563\AA in the spectroscope becomes bright if and where a prominence occurs. By opening

the slit the shape of the prominence can be seen or inferred. Unfortunately a very clear sky is necessary to permit much widening of the slit, and generally the observer must be content with rasher-like piecemeal views.

The spectrohelioscope came in 1889. This allowed views of the solar disk with any prominences to be seen for the first time by virtue of persistence of vision through an oscillating slit traversing the solar image. Apart from the difficulty of building these instruments, prominences appear relatively feeble because the narrow slit exposes them only for about 1% of the time or less, depending on the slit width and travel. The solar disk appears much brighter, and the ability to study any part of the spectrum at any chosen bandwidth is the outstanding feature of the spectrohelioscope.

The next method of prominence viewing to appear was the Lyot quartz-polaroid type – again a highly complex instrument demanding skills given to very few amateurs. It consists of a long stack of seven or more quartz and other birefringent members, together with many polaroid separators. The disadvantages include a restricted field of view and poor luminosity, estimated to be ten times less than for the filter which is the main subject of this paper.

Metal-dielectric and all-dielectric filters

In 1962 Mr G. Klaus reported from the clear skies of Switzerland that he had seen and photographed prominences using a cheap and simple metal-dielectric H α filter of bandwidth 120\AA supplied by Messrs Schott & Gen. This filter of Fabry-Perot type consists of only three vacuum-coated layers. The two outer coats are of silver, each controlled in thickness to transmit about 6% of the light. The inner film – a single dielectric coat, usually of magnesium fluoride, zinc sulphide, or cryolite – is deposited to a specific controlled thickness related to the chosen wavelength for which peak transmission occurs. Mr Klaus' report was the first intimation that the late W. M. Baxter (then Director of the Solar Section) and the writer had heard that so broad-band a filter as 120\AA was capable of showing prominences. We promptly acquired a filter each, and the writer designed and built the appropriate telescopes in 1962. In 1963, after some months of use in which we had seen only the faintest trace of prominences on rare occasions, we decided that British skies demanded much narrower bandwidths. This meant the all-dielectric type, and our first experience was with 30\AA filters obtained from Messrs Barr & Stroud later that year. With these we saw and photographed many prominences when the skies were fairly clear.

In 1964 came news from America of the availability of 4\AA filters, and we soon had this type in service, but obtained satisfactory results only after fitting heaters round the filters. These all-dielectric narrow-band filters are more expensive than the Fabry-Perot type by a factor of five or so. They consist of a stack of non-metallic coatings each spectroscopically controlled in thickness. The stack may consist of thirty or more layers of alternatively high and low refractive index dielectric materials such as cryolite and zinc sulphide. The narrower the spectral bandwidth the more layers that are required, hence the cost is relatively high, though within the reach of many amateurs. Light passing through these filters suffers multiple destructive reflection from the two boundary surfaces of the low-index films, resulting in enhanced peak transmission at the chosen wavelength. Other unwanted peaks or side-bands also occur which must be cut out with wide-band or colour filters. The term 'bandwidth' is often used loosely, but ordinarily means the spectral interval where transmission is half that at the peak.

To recapitulate: in order to see solar prominences well it is essential to use a filter of narrow-band type giving maximum transmission in the light of incandescent hydrogen, choosing by preference the prominent red spectral line H α

wavelength of 6563Å. If the extra cost of a filter with a bandwidth of 4Å is not a deterrent, it is well worth while. This bandwidth is near the optimum for prominence viewing for good contrast and luminosity, though it is naturally much more sensitive to temperature than broader bandwidths such as 30Å.

Control of the filter

The wavelength of peak transmission of these filters is dependent both on their temperature and on the angle of the rays to the normal. Both factors should be under the control of the observer. Tilting the filter so that the rays pass through at an angle to the normal causes the peak to move to shorter wavelengths; that is, towards the blue end. Raising the temperature has the opposite effect. The use of a heater is generally inconvenient and could shorten the life of the filter; hence if there is any choice when buying a H α filter for prominence viewing, preference should be given to a peak at 6568Å (at mean temperature) rather than 6563Å. This could eliminate the need of a heater.

Tilting the filter broadens the bandwidth, but for a tilt confined to 2° or 3° the broadening effect is negligible. There is a further need to control the filter angle to allow for Doppler shift, since the hydrogen 'flames' may be advancing towards or receding from the observer by up to 0.1 % of the velocity of light, giving rise to a corresponding change of wavelength.

Finally, the filter tilt can be adjusted to meet the passing rays squarely at any part of the field of view. The maximum obliquity of the rays from the axial image is determined by the f number, and the reason for choosing an f/30 cone at the filter location – as in the recommended design which follows – is to limit the obliquity to less than 1°.

Principle of the telescope

This is of the Lyot coronascope type, designed for viewing the solar corona near the Sun without an eclipse by eliminating as much scattered light as possible. For coronal observation, sky clarity such as occurs only at times in high-altitude observatories is necessary, and even then, scatter in the telescope must be reduced to near zero.

For solar prominence observation such perfection is not essential, particularly with narrow-band filters, but it is a worthwhile target to aim at, especially for filters of 30Å or more. Using 4Å filters, ordinary high-quality achromatic refractors

axis. About 0.8 inch beyond the cone stop is the field lens, which forms an image of the object glass on a blackened diaphragm with an aperture barely large enough to pass its image (see figure below). By this means, light reflected or scattered from the tube walls or cell edges is eliminated. The second (projecting) lens is located after the diaphragm (scatter stop) at a position throwing a sharp double-size image of the edge of the cone stop in the focal plane of the eyepiece. The final cone is thus f/30, minimising ray obliquity. Any prominences will be seen projected outside the cone stop which itself blocks the solar disk image.

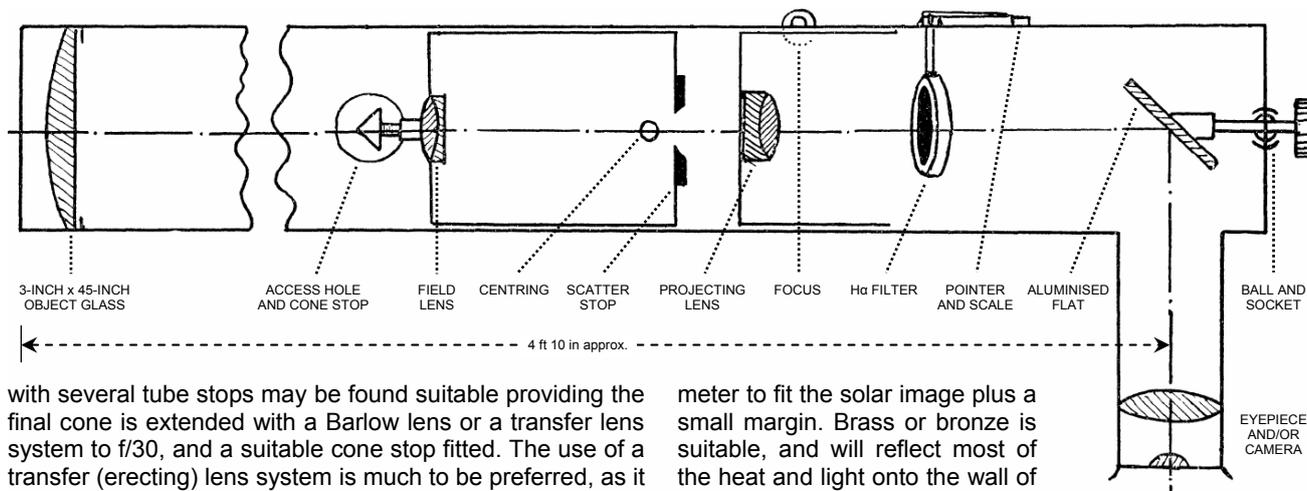
The H α filter in its cell is mounted on a stalk which can be rotated and, for preference, tilted as well. Finally, a prism or flat turns the beam through 90° to give a comfortable viewing position. A good scratch-free and dust-free aluminised flat mounted on a stem projecting through a ball-and-socket joint in the end cover of the tube enables the solar image to be placed concentrically or eccentrically in the eyepiece. Eccentric placing enables any interesting prominence to be viewed or photographed in the centre of the field.

The object glass

The accompanying figure is based on the use of a 3-inch f/15 well-polished plano-convex lens, preferably made of boro-silicate or hard crown glass of optical quality, free from striae. Although an unfigured spherical plano-convex lens of 45 inches focal length with a front surface radius of 23.2 inches has a longitudinal aberration of 0.05 inch, this is inside the Rayleigh tolerance, but a careful worker would want to figure it out by normal techniques and using a deep red filter. A telescope of this aperture will show a great amount of detail and result in a relatively compact instrument readily carried on the same equatorial mounting as larger instruments used for other astronomical observations. Needless to say, a clock drive is highly desirable when viewing, and particularly for photography, because the solar image must be held on the cone stop. A good, smooth hand-operated slow-motion drive can also achieve satisfactory results in skilful hands.

The cone stop

This is made in the form of a smoothly machined metal 90-degree cone with a sharp and clean-edged base, with a dia-



with several tube stops may be found suitable providing the final cone is extended with a Barlow lens or a transfer lens system to f/30, and a suitable cone stop fitted. The use of a transfer (erecting) lens system is much to be preferred, as it enables the filter to be placed where the beam is small and away from the eyepiece. These major alterations emphasise the advantage of making a special prominence telescope.

General design features of the prominence telescope

A single-element f/15 object glass forms a solar image on a cone stop which deflects light and heat away from the optical

meter to fit the solar image plus a small margin. Brass or bronze is suitable, and will reflect most of the heat and light onto the wall of the surrounding tube, where a lining of black velvet will absorb it harmlessly. A cone base diameter of 0.92% of the object glass focal length will suit the British aphelion summer Sun. Another at 0.95% will suit the winter Sun. Say, 0.42 inch and 0.43 inch for the object glass described. If a single cone is used all the year round, the larger size is preferable. From the base of the cone a 0.16-inch stalk is machined in the same operation as making the

cone. A socket 0.5 inch long, sprung for easy focusing and removal, is stuck with Araldite centrally on the convex forward side of the field lens. To provide access to the cone stop, a hole about 1.5 inches diameter is cut in the wall of the telescope tube and fitted with a sliding cover to keep out dust and dirt, which can be annoying when occupying the position of potential prominences at the cone edge.

The field lens, projecting lens, and scatter stop

Achromats of 4 inches focus and 1 inch diameter are very suitable for each of these lenses. The main function of the field lens is to collect and condense the rays from the object glass to form an aberration-free image of the object glass for placement of the scatter stop, and a corrected lens is best for this duty. It also becomes a suitable support for the cone stop. The projecting lens works at smaller aperture, and at $f/30$ it could, if desired, be a single plano-convex lens. The scatter stop should have a thin-edged bore of 0.288 inch and be located 4.2 inches from the rear surface of the field lens. These figures apply only if this lens is precisely of 4 inches focus. If not, new figures can be calculated from the known focal length, or an external rig and screen can be used to get the correct dimensions by trial.

Accurate centring of the scatter stop with the image of the object glass is also necessary, and centring screws accessible from outside are advisable. An iris diaphragm giving a good circular aperture can be used if preferred – again adjustable from outside. The projecting lens is located about 1 inch following the scatter stop, in order to throw the final image of the cone stop and prominences into the eyepiece field at a distance of 12 inches from the projecting lens. The final cone at $f/30$ will give a solar image of about 0.85 inch diameter. Focusing can be arranged by moving the projecting lens along the axis by a lever operated through the wall of the tube; alternatively by a movement of the eyepiece over a four times greater range. The smaller movement of the projecting lens is preferable – housed in a sliding sleeve or by other means.

The filter, and precautions in its use

The filter should be located about 2 inches after the projecting lens where the beam has not expanded to more than 0.5 inch or so in diameter. The reason for this is indicated below (deterioration of filters). The adjustments for tilt and rotation of the filter have already been discussed. The provision of a small heating element round it is an inconvenient necessity if the peak wavelength of the filter is too low to permit obtaining the prominence wavelength by tilting or rotation. This point is discussed above (control of the filter). The filter, which need not be larger than 1 inch in diameter, has a side-band eliminator of red glass on one side. The other side is a highly reflective mirror which is prone to give ghost images in the eyepiece. These are minimised by preventing overspill of the Sun's image beyond the cone stop. Overspill is also inadvisable because injurious solar heat can get through to the eye. To prevent this when locating and centring the solar image on the cone stop, a temporary object glass stop about a quarter of the full aperture of the object glass should be used; alternatively, use a safe dark glass temporarily over the eyepiece, or, if the scatter stop is an iris diaphragm, close this down temporarily. There is no danger once the Sun's image is safely behind the cone stop, and full aperture can then be used.

By measurement, some 40–50% of the total heat received by 4\AA filters passes through them via the side-bands in the infrared. In the case of filters used for solar disk phenomena no cone stop is used, and it becomes essential to reduce the total heat to a very small percentage by heat absorption filters or by other energy-rejection methods. Locating a

small heat-absorbing filter where the beam has been concentrated is unsatisfactory, because when hot it will emit infrared radiation and may crack or even shatter. The use of an aluminised filter reflecting say 95% of the heat may be safe, but at the expense of most of the light – a scarce enough commodity after $H\alpha$ filters. In the writer's opinion the ideal solution for both prominence and solar disk $H\alpha$ telescopes is to use heat-absorbing glass of optical quality for the object glass itself. Chance–Pilkington made a series of H.A. and L.P. glasses which reduced the total heat to less than 1% with a light loss of only 20% or so, but these were of filter rather than optical quality, though careful selection could produce pieces sufficient for a 3-inch object glass of usable optical quality. Unfortunately, production of these glasses ceased because of small demand, but a growing interest notably in America in disk phenomena filters has stimulated a developing demand for suitable glasses, some of which are mentioned below in the section contributed by Mr Whippey.

Deterioration of filters

Long experience in the use of the 4\AA filters has shown that deterioration with age is by no means uncommon whether they are used with a heater or not, although it is reasonable to assume that deterioration would be accelerated by high temperature. Deterioration develops from the edge radially towards the centre, and generally increases the peak wavelength in the affected outer zone. An increase of as much as 30\AA has been measured after four years of use, due presumably to infiltration of air or moisture at the 'sealed' edge as well as to high temperature, while the central zone of about 0.5 inch or so has remained usable far longer. Additional sealing when new could be advantageous, and Mr Whippey already does this by using an epoxy adhesive.

The eyepiece

As out-field chromatic aberrations are of no consequence, it is preferable to use an extra-wide-field eyepiece of 70° apparent field such as a non-achromatic of Kellner form, consisting of a double convex field lens and a plano-convex eye lens having its flat surface towards the eye. A focal length of 0.9 inch will provide a power of $\times 100$. The cone stop will then subtend an angle of about 50° . A field lens of 1.6 inches focus and 1.2 inches diameter used with an eye lens of 1 inch focus separated by about 0.7 inch should be very suitable.

An alternative design of prominence telescope

The simplest possible optical compromise that would show prominences and use not more than two-thirds the aperture of a 1-inch 4\AA $H\alpha$ filter (this being by far the most expensive item) is to use a well-polished and aluminised $f/20$ spherical mirror of 2.5–3 inches aperture tilted in Herschelian fashion, with the type of eyepiece described. On the field-lens side of the eyepiece would be a cone stop or occulting disk with the edge sharply in focus in the eyepiece and the filter placed between. Prominences would be well seen if scattered light is suppressed suitably and the filter peak wavelength is within 1\AA or 2\AA of 6563\AA at the ambient temperature. Precautions in use would be as described previously.

Biological observations

A by-product of the action of a prominence telescope is to render conspicuously visible small objects carried in the upper atmosphere and seen in the immediate vicinity of the Sun on some fine days in full and late summer. These consist of myriads of seed spores and flying insects carried thousands of metres up by thermals, and seen by the process of dark background illumination round the cone stop. They drift acr-

oss the field of view interestingly, occasionally so dense as to resemble a snowstorm. Being sharply in focus indicates distances upwards of a kilometre, and the wing beats of insects are visible sometimes flying against the general drift. Prominence photography could be interfered with under such conditions, but no undue trouble has yet been experienced.

Prominence photography

This is quite easy with the instrument described. A single-lens reflex camera is best, and 35-mm film will accept nearly the same field as the eyepiece. A Barlow lens can be used to show details of individual prominences. Reasonably sharp pictures on a scale 2–3 feet to the Sun's diameter are obtainable under good conditions. Many common films (such as the Ilford FP and HP series) have poor sensitivity at the H α wavelength. Kodak Plus-X film was until recently fairly sensitive, and enabled good pictures to be taken with exposures under 1 second. It is no longer sensitive at H α . However, Kodak S0-115 film readily available in America can be obtained in this country, and should be excellent for this duty with exposures of a fraction of a second.

Two typical photographs are reproduced here. One shows a fairly common tree-like formation, and the other a most unusual 'chamaeleon' shape with a periodic structure.

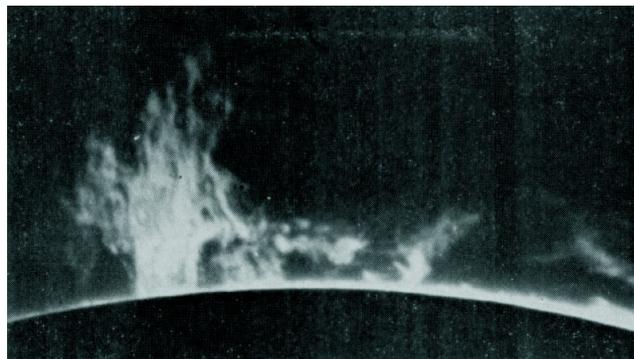
Extra-narrow-band filters for viewing surface phenomena

It is indeed fortunate for the amateur solar observer that development of the all-dielectric filter as used in the design of the prominence telescope described above led to further research and the introduction of narrower-bandwidth filters capable of revealing the Sun's chromospheric phenomena. The production of these 0.5–1Å filters is a technical achievement of very high order, and the source of supply is very limited. The multilayer stack is combined with a Fabry–Perot etalon to achieve the very narrow bandwidth. They are generally supplied in a temperature-controlled housing, and are expensive, costing perhaps ten times as much as the 4Å filter.

Such filters became available for amateur needs from 1970, when the American firm Carson Astronomical Instruments introduced their range of SkySpear filters. It is not known for certain why this firm later ceased production but, happily, filters of similar type were soon to appear from DayStar Filter Corporation under the continuing guidance of Mr Del N. Woods, formerly of Carson. These filters, known as Daystar, come in two qualities: ATM and University. The former are entirely suitable for most amateur requirements, and are currently fabricated from a bandwidth of 1.2Å, which is excellent for viewing prominences, low-contrast disk phenomena, and solar flares, down to a bandwidth just under 0.6Å for viewing high-contrast disk phenomena. A good compromise is a filter having a bandwidth of 0.75Å, which provides a fine general view of prominences and many disk features, and which has sufficient transmission at peak to accommodate the smaller object glass of 2 inches or so aperture.

Each filter is provided with an electronic control unit for maintaining precise on-band temperature, and also has a variable cermet ten-position knobpot which enables the user to raise or lower the temperature of the filter either side of the design wavelength and carry out off-band observations. These filters can be fabricated to almost any line of interest in the visible spectrum, though the most popular wavelength is that of H α centred on 6562.8Å.

We have already referred to the ideal solution of using a heat-absorbing glass of optical quality for the object glass. Glasses claimed to be suitable and safe to use are available in America and are used for producing a variety of object glasses, and also for over-the-aperture energy-rejection filters which can be supplied with off-axis aperture covers to suit Questars, Celestrons and similar telescopes. These com-



binations are made up by DayStar Filter Corporation to provide the desired f/30 beam and level of heat reduction claimed to be safe.

In experimenting with a 2-inch f/30 object glass from Schott BK-7, the writer has been able to confirm that overheating of the DayStar does indeed occur after some 20 minutes or so, but is easily remedied by use of an over-the-aperture heat-absorbing filter or by placing a piece of KG-3 immediately in front of the DayStar. This emphasizes the need for adequate heat reduction even at small apertures, and for extended observing periods KG-3 on its own is not recommended. In the writer's opinion this is too near the margin of what is not safe practice, and the recommended object glass from Schott RG-610 is to be preferred for apertures not exceeding 2 inches, or the over-the-aperture heat-absorbing filter as mentioned.

A very good lens system for solar refractors up to a clear aperture of 4.5 inches at f/30, and also claimed to be safe to use, consists of an object glass from Schott OG-590 of 0.63-inch central thickness backed by a 0.39-inch thick optically flat heat-absorbing filter from KG-2 glass, but the cost of this combination ready-made is very expensive and would inhibit many amateurs.

A most useful accessory is the negative amplifier designed to convert smaller f/15 refractors to f/30 solar telescopes by placing it inside the focus. This lens can be supplied with a multilayer energy-rejection coating to reflect away unwanted heat and, like the over-the-aperture heat-absorbing filter, its purpose is to ensure that the DayStar filter intercepts a 'cool' beam having a temperature well below on-band.

Choice of aperture

An inescapable fact of these extra-narrow-band filters is that transmission at peak for the design wavelength varies from 10% down to 2% according to the bandwidth chosen, and this should be taken into account when deciding on the aperture and type of telescope to be used. For purely photographic purposes the simplest type of solar refractor employing a heat-absorbing object glass of say 2.06 inches aperture at about f/30 is capable of providing excellent whole-disk filtergrams of the Sun, as can be seen from the accompanying photograph obtained by Arch B. Tripler, of Columbus,

Ohio; but for visual work at a bandwidth of 0.7Å and narrower where powers of x70 or so upwards are required, one should aim for an aperture not less than 3 inches at f/30, and for convenience of handling use either the negative amplifier mentioned earlier, or a design similar to that of the prominence telescope but using a red, heat-absorbing object glass.

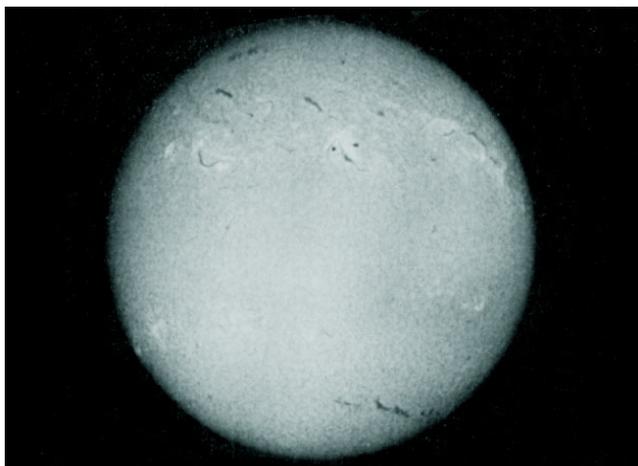
Because of its versatility the latter has become the writer's choice. From experience it has been found that image contrast is improved by use of the bevelled scatter stop and, conveniently, orientation of the Sun's disk is the same as seen when projecting it onto a white screen with a Newtonian reflector or a refractor. Moreover, the overall length of the solar telescope in use will be increased by only 9.6 inches when a larger object glass of similar f-ratio is ready to be fitted. This simple conversion will involve no alteration to the after-optics, and the very small theoretical adjustment to the axial position of the scatter stop may be ignored.

At present a full-aperture heat absorbing filter is used, and being made from red glass this also serves to eliminate the ultraviolet which is known to be destructive to any narrow-band filter having all-dielectric construction. This would be of less concern to users of the 4Å filter, which for much of its working life is protected by the cone stop. In addition to the full-aperture heat-absorbing filter, another type is also used and is placed immediately before the DayStar filter. This is a precautionary measure thought to be advisable when patrol observing is carried out. For this purpose, however, the type of heat-absorbing filter to be found in many slide projectors has, with two exceptions, proved to be unsatisfactory due to poor optical quality and the introduction of astigmatism. Moreover, this type of heat filter does not provide adequate protection when used on its own and placed where the beam is concentrated and hot.

A by-product from more recent techniques used in producing these extra-narrow-band filters has been the emergence of special multilayer coatings for reducing heat to a level claimed to be safe, and with very little loss of light at the design wavelength required. A red dichroic coating added to the flat surface of a 3-inch f/30 BK-7 object glass is claimed to reduce heat to a very safe level, and perhaps before long we can expect these filters to be available with a multilayer all-dielectric coating integral to the first blocking filter. However, these new techniques, although in use for the professional, have yet to be as readily available for the amateur solar observer.

Whole-disk photography

As has been mentioned for the prominence telescope, a single-lens reflex camera taking 35-mm film will accept nearly the same field as the eyepiece described. In order to photograph the Sun's disk with some margin to spare it becomes necessary to converge the f/30 beam emerging from the DayStar filter to a diameter that is more suitable, and one



method would be to place a positive achromat of 6 inches focus just behind the filter and at a distance of 3 inches from the focal plane of the camera—a short extension tube making an ideal coupling. It would be an advantage to have a quick-release coupling device made up so that the camera attachment and the after-optics section containing the flat and eyepiece are easily interchangeable. For the camera attachment described it will be found that focusing of the Sun's disk remains within the range of focusing provided by movement of the projecting lens for visual observation. The need for such an attachment is unnecessary in the case of solar telescopes employing the single f/30 object glass.

In conclusion, for optimum filter performance the beam should be f/30 and preferably slower. Damage is inevitable if the beam is not cooled adequately, and may result in having the guarantee invalidated. Of much greater importance, however, is the advice to be guided by whatever the filter maker should recommend is necessary to avoid injury to the eye. This will ensure adequate protection for the filter.

A Dollond–Wollaston telescope

Horace Dall, Jim Hysom, and Colin Ronan

In 1771 the Rev Francis Wollaston, a Fellow of the Royal Society, purchased from Peter Dollond a triplet refractor of 45-inch focal length and 3¹¹/₂₀-inch aperture. It was of the intermediate form between paper tubes and all-metal tubes; that is, brass-bound mahogany. There is no doubt that Wollaston 'valued it very highly', and in due course it passed to his son William Hyde Wollaston, the famous chemist, physicist, and physiologist, who 'held it in great estimation'.

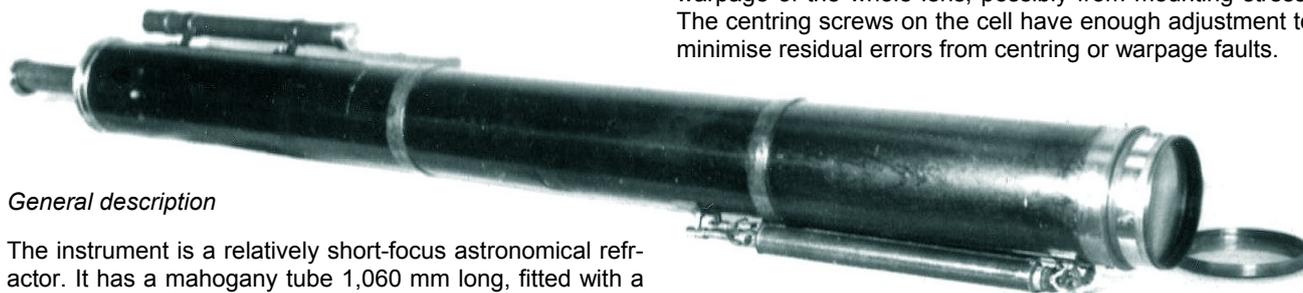
In December 1821 W. H. Wollaston read a paper to the Royal Society entitled 'On the concentric adjustment of a triple object glass', beginning 'When we venture to take to pieces an instrument which that had stood the test of fifty years trial ... those who knew the telescope, and who know the difficulty of centring, seemed to consider it an act of rashness which I was likely to regret.' Regret it he did not, for by examining the fifteen images formed by the six surfaces of the triplet when he placed a bright object at the eyepiece end and viewed from the objective end, by means of the screws he had fixed into the object-glass cell he was able to align perfectly the three elements of the triplet such that 'the telescope was capable of either separating very small



and nearly equal stars as those of 44 Boö and σ Cor or of exhibiting the minute secondaries of β Ori and 24 Aql.'

Towards the end of 1828 Wollaston self-diagnosed a brain tumour, and in a letter dated 8 December 1828 to John Herschel, then President of the Astronomical Society of London (later the Royal Astronomical Society), bequeathed the triplet to the Society 'in hopes that they will not keep it useless, but lend it, or give it if they think proper, to any industrious and useful member of the Society.' Wollaston died on 22 December.

The telescope (without stand) is listed as no. 16 in the RAS Instruments File. Council was concerned that instruments should be properly marked, and on 6 February 1829 drew up a memorandum 'that on both surfaces of an object glass there be written with a diamond the words "Astronomical Society of London" ... Dr Wollaston's [object glass] was at once sent to Mr Dollond to be marked accordingly.'



General description

The instrument is a relatively short-focus astronomical refractor. It has a mahogany tube 1,060 mm long, fitted with a finder 22 x 10 mm, and has steady-rods with Hooke's joints. There is, however, no stand. The brass outer eyepiece sleeve is 37 mm in diameter and moves up to 75 mm by rack-and-pinion focusing. The inner sleeve is 31 mm in diameter and can take a range of twelve or more eyepieces.

The most interesting feature is the triple object glass fitted in a brass cell with centring screws operating against a narrow brass ring surrounding each of the three lenses. Engraved on the brass end-plate facing the eyepiece tube is the following: '-DOLLOND-LONDON-Presented to the Astronomical Society of London by W. H. WOLLASTON, M.D., V.P.R.S. No. 2 Al.'

The triple object glass

The centre component is a light flint glass of crossed concave form, specified in modern terms as 586409 type – slightly yellowish in colour. It is free from bubbles but has curved streaks of striae easily seen by autocollimation tests of the complete object glass, but having relatively little effect on the final image. The two outer lenses are of almost identical crown glass of 531589 type, both free from striae and, as usual for crown glass of the period, quite greenish in colour. The outer crown is of crossed convex form, and the inner one has equal curves; that is, it is double convex. The three elements are in contact at the periphery, leaving central air gaps of 0.32 and 0.54 mm. The optical specification of the triplet is shown in the figure. The optical polish of all six surfaces is fair, but pits left from the grinding are very evident in the outer zones with strong illumination.

Comparison of doublet and triplet

The six surfaces of the triplet involve practically the same glass removal as the four surfaces of the doublet of equal focus. However, polishing six surfaces will take correspondingly longer than four. Thus the advantage of the triplet lies in other directions – principally in better correction of spherical aberration with the gentler curves.

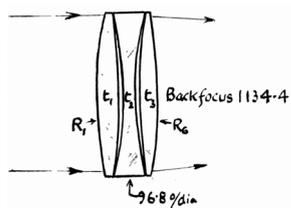
Image quality

Under autocollimation with Foucault testing, the colour correction is very good, with minimum focus in the apple green about 5600Å. The secondary spectrum is much less than for

the modern doublet of light crown and dense flint. This is to be expected for a heavy crown and a light flint having about half the difference of refractive index of the light crown/dense flint combination. In addition, the green tint of the older glass absorbs an appreciable fraction of the secondary spectrum, mainly from the blue-violet end.

Spherical aberration

Overall spherical correction is good and sufficient to give resolving power to the Dawes limit for stars; for example, double stars of 1–3 arcseconds separation. The Foucault test shows several zones with small errors – for example, a short-focus edge zone (turned-down edge) and three other faint zones – all less than 1 mm in focal error. Foucault tests on the concave surfaces of the flint lens show a moderate amount of astigmatism, believed due to slight bending or warpage of the whole lens, possibly from mounting stress. The centring screws on the cell have enough adjustment to minimise residual errors from centring or warpage faults.



$R_1 = +719.2$	$M_1 = 1.5303 \quad v = 58.9$
$t_1 = 6.2$	
$R_2 = -911.8$	$M_2 = 1.5860 \quad v = 40.95$
$g_1 = 0.32$	
$R_3 = -714.5$	$M_3 = 1.5318 \quad v = 58.9$
$t_2 = 2.55$	
$R_4 = +535.4$	
$g_2 = 0.54$	
$R_5 = +720.8$	
$t_3 = 5.41$	
$R_6 = -721.2$	

Eyepieces

In general, the low powers are of Huygenian form, and the high powers are singlet lenses, piano or double convex.

- 1 There is one angle eyepiece of 15.4 mm focal length: a single piano convex lens followed at 45° by an oval speculum-metal flat of 12 mm aperture. This gives a magnification of x74.2. Marked on the cap is 'B-67 A.S.2.L'.
- 2 The only high power of Huygenian form is 6.1 mm focus, giving x186. The cap of this eyepiece is unmarked, and the sleeve is missing.
- 3 A singlet double convex lens of 4 mm focus giving x288. Cap marked '313'.
- 4 A singlet double convex lens of 2.5 mm focus giving x450. Cap marked 'A.S.2.J. 490'.
- 5 A novel five-lens turret in cap marked 'A.S.2.K'. An aperture in the cap shows the lens number in use, and a spring click locates each.
 - Lens 1 $f = 0.83$ mm giving x1380 (lens double convex, loose in mount).
 - Lens 2 Lens missing from mount.
 - Lens 3 $f = 1.65$ mm giving x690.
 - Lens 4 $f = 2.8$ mm giving x408.
 - Lens 5 $f = 5.1$ mm giving x224.

Following William Herschel it was probably fashionable to have excessively high-power eyepieces included in the equipment, though x200 would show all detail which the object glass is capable of revealing.

The first half of this paper consists of a short history of the Dollonds which is available elsewhere, and is therefore omitted here – R.A.M.

Memories of Horace Dall

Robin Scagell

During the 1970s Luton was a hotbed of astronomical instrument-making, perhaps helped because of the presence of Horace in the town. Astronomical Equipment, run by Jim and Rob Hysom, was based there, employing optical workers such as John Mathers, who eventually went on to Optical Surfaces, and Jim Muirden. Somewhat later, Rob Miller's Astro Systems was based in Luton.

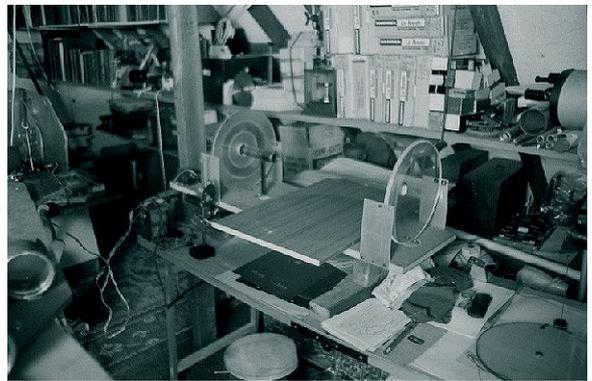
For a while I lived just down the hill from Horace, and a visit to his house was always a treat as he was always happy to show off his various gadgets. There was the world's most sensitive barometer – an aneroid model made by Horace – which could measure the difference in atmospheric pressure over the thickness of a book (as long as a fairly thick book was chosen). There was the world's smallest writing – now, of course, superseded by atomic devices, but maybe the smallest that has actually been written using a pantograph device. And, of course, his famous portable 6-inch telescope, which could be carried in a coat pocket.

During his working life Horace was at Kent Instruments in Luton, and astronomers may not know that he invented a device for fluid measurement, known as a Dall Tube, which is still a standard method of measuring fluid flow.

In 1982 I borrowed a video camera and lugged a heavy VHS recorder over to Horace's house, and recorded a video of him [see URL below]. The technical quality leaves a lot to be desired, but it is a unique record of the man and his workshop.

What happened to Horace's instruments? After his death, some of them were donated to the Science Museum. Some of his microscopical friends helped to clear his belongings, but not everything was kept. I asked his wife Lena what they had thrown away, and she said that she did not know, but they took ten black bags-full to the dump. I cannot help thinking that Horace could not have accumulated that much actual rubbish. I for one would have been happy to have had, say, a developing dish used by him – and perhaps some of his genius would have rubbed off on me.

The accompanying photographs were taken in 1978. The 6-inch Dall–Kirkham portable reflector had a secondary mirror held on an arm that folded flat across the main mirror, which was also hinged to fold down. The eyepiece was in a short tube that was carefully baffled to exclude a view of the sky beyond the secondary, so it could be used by day. Horace travelled the world with this instrument in his pocket – and in the days before metal detectors he was not once stopped by customs!



The genius of Horace Dall

Martin Mobberley

Horace Dall was an innovative optician, mirror-maker, and lens-maker, and a designer of scientific instruments. He was also a practical astronomer, and from the 1940s to the 1970s was the king of UK planetary photography, dominating in both lunar and planetary work during an era when visual observers and sketchers ruled the amateur world.

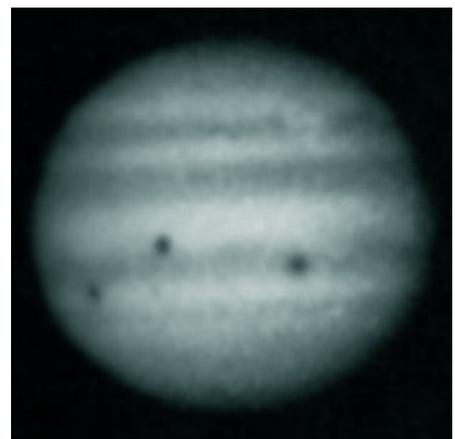
In 1934 Horace had a two-storey house custom-built on the highest hill in Luton, at 166 Stockingstone Road. It was built especially tall, and with its high ceilings it was as high as a three-storey house. Built into the attic wall was a high-quality double-glazed window, presenting fine views over the town, and accommodated in the roof above his attic workshop was his camera obscura.

In 1937 Horace completed a 15½-inch Dall–Kirkham Cassegrain, which he used primarily for lunar and planetary photography. For an amateur astronomer at that time this was a very large aperture – equal to using a 60-cm Cassegrain today. The telescope was completely tubeless, and featured a thin mirror and transfer lens which could project planetary images to $f/200$ to overcome film grain. It was mounted on the equatorial head of a telescope that he had acquired several years earlier: an 8½-inch Newtonian made by the East Anglian telescope-maker George Calver. Where the German equatorial mount's declination axis had been, Horace fitted a fork, but as the tines were not wide enough to fit a 15½-inch tube in between he mounted a tripod-like 'truss' structure to support the weight of the primary mirror and the secondary. As he wanted to observe only the Moon and planets near the meridian (he had no interest in deep-sky objects), such a flimsy-looking structure was perfectly adequate. The mirror was very light and very thin, though it was held in a cell that he designed specially to prevent any flexure and preserve a good mirror shape. Because he did not like trying to determine where the edge of the eyepiece field was, he ground a tertiary mirror surface at the dead centre of the secondary mirror. This tertiary mirror reflected and focused the light from a bulb near the primary mirror cell, such that by the flick of a switch the eyepiece field was comfortably illuminated.

For more than forty years, no-one in the UK could obtain better lunar and planetary photographs than Horace, and he even experimented with stacking film negatives and unsharp masking, decades before anyone else attempted it. In addition, he was one of the first amateurs to monitor the Sun in $H\alpha$, long before Coronado PSTs appeared on the market. He did not like inverted images, despite 'south is up' being the norm amongst amateurs, and hence his Dall–Kirkham transfer lens system produced an erect image, with north at the top. The accompanying photograph of Jupiter, taken by him on 21 April 1956, shows a very rare triple shadow transit of Io, Ganymede, and Callisto.

I first met Horace at a BAA meeting in Norwich in 1973, when as a teenager I was grinding and polishing my own 8½-inch mirror. He gave me some sage advice, and I exchanged many letters with him from that time until his death in 1986. In 1981 I won a BAA prize for the best lunar photograph at the Exhibition Meeting, and in 1983 I became the BAA Lunar Section photographic coordinator. So, I was starting to make a name for myself. Horace spotted me, and in February 1984 I received an offer I could not refuse: an invitation to visit him at his home.

Horace's study was on the top floor, overlooking his observatory dome. However, when asked where his optical workshop was, a twinkle appeared in his eye, and from a seated position he grabbed a long pole with a hook on the end, and pulled on a small ring in the ceiling. Magically, a spring-loaded set of stairs descended from the ceiling, and the sprightly octogenarian glided up them, beckoning me to follow. Then wonderland was presented, with telescopes, lenses, eyepieces, and tubes everywhere. In the roof timbers could be seen his camera obscura lens where a chimney would normally be positioned.



The instrument was adjusted with long poles to move the lens/mirror arrangement in the false chimney in azimuth or altitude, and within seconds it could project an image of the Sun or a distant landmark onto the large, white circular table in the attic. During my visit, however, we also used it for another purpose: to watch a cricket match half a mile away.

It was certainly an honour to be invited to Horace's home. There are only two other amateurs' homes from where memories of a visit have remained with me so vividly for such a long period: George Alcock's home at Farcet, which I visited in 1991, and Patrick Moore's home at Selsey, which I have visited many times. While George knew the sky better than anyone else and Patrick knew how to write books better than anyone else, Horace knew more about optics than anyone else. I also recall a story told to me by George, of an occasion in the 1970s when he and the comet and supernova discoverer Jack Bennet were in Horace's attic, enthusing over a 7-inch aperture wide-field refractor that Horace had made for comet sweeping. What a picture that would have made: Dall, Alcock, and Bennett in Dall's workshop.

Horace had little interest in verbal theoretical debate. He built telescopes and cleaned, restored, ground, and polished numerous mirrors and lenses, and as well as designing optics he made folding pocket-telescopes, microscopes, ultrasensitive barometers able to measure the variation in atmospheric pressure over a distance of 4 inches in altitude, and devices with which he could engrave letters only a few wavelengths of light in height. Using his home-made microscopes he resolved features smaller than a wavelength of light, and when he used them for ultraviolet photography he achieved a resolution that began to encroach into scanning electron microscope territory. Horace was a practical man of science and engineering – a man of action, not words.

Horace Dall's observatory

Mark Stuckey

I first had the pleasure of meeting Horace Dall in 1970, when I was 14 years old, and over the years I came to know him, his wife Helena, and his observatory very well. He had built the observatory in 1937, and after he died in 1986 it had passed to Jim Hysom. Last year the opportunity arose to acquire it from Jim, and I responded immediately (and being brave, I did not even ask the wife).

I had often used the telescope with Horace, and on some occasions on my own. On one occasion, when we were observing Jupiter, Horace remembered a television programme that he wanted to watch. There were only two types of programme that would have taken him away from observing: the news, and *Horizon* – which in those days were much more authoritative in their reporting of astronomical matters. Horace closed the observatory door, and wandered into the house. After an hour or so I noticed that he had not reappeared, and it was then that I discovered my problem: he had locked me in, and had forgotten about me. Throughout the next three hours or so I could see him quite clearly at his workbench in the back bedroom, overlooking the observatory. I was frantically turning the light on and off, lighting up the sky, but he did not even notice. Eventually, however, he realised his mistake, and (laughing) came down the garden to let me out. But at least the sky was clear.

I have always been interested in the work and products of the Luton-based telescope manufacturer Astronomical Equipment (run by Jim Hysom and his brother), and a few years ago Martin Mobberley generously presented me with his 14-inch AE Cassegrain, which he had purchased in 1980. Such an instrument requires a much larger turning circle and substantial pier height for a comfortable observing position (unlike the modern compact instruments that are very popular nowadays), and with the opportunity to acquire an obs-



-ervatory of significance in astronomical history I felt it important to ensure their continued existence and use.

I therefore assembled two large vans and four willing and completely naive volunteers, and in late August 2012 we left Cromer, in Norfolk, and headed towards Caldecote, near Cambridge. We duly arrived, and on first inspection one of the merry men asked to be dropped off at the nearest bus stop, while the others wanted to know where to build the fire. I calmed them, explained that the project was no different from restoring a classic car – and 'Ah' was the cry. Beginning to understand my philosophy, they all nodded in agreement, and a plan of action was put in place. We had to work quickly, as clouds were beginning to form, and August had so far been a washout.

The first job was to climb onto the flat part of the 12-foot square roof to disassemble the dome, which, after removal of the shutters, unbolted into three sections. At the time it seemed straightforward – until we tried to load the sections onto the vehicles. The dome is approximately 10 feet in diameter and 6 feet high, and though the sections are quite large, two of us could handle them comfortably and place them safely on the ground.

While this was being accomplished, two of the helpers (who by then had become enthusiasts) were working inside the observatory. Every few minutes could be heard laughter following a crunching noise – unfortunately caused by boots going through weak points in the floor. It was obvious that major work was required.

The walls of the observatory came apart very easily, but as they were double skinned they were extremely heavy, so dragging them down the garden was quite a task. It did not help that Jim's garden is very long, and seemed to become longer with every step. The result, however, was that within just three hours we had a kit of observatory parts. The consensus of my friends was that when I arrived home my wife Linda would telephone the doctor for an immediate counselling session.



First, however, I had to take the observatory home. One of Jim's neighbours allowed us to drive the vehicles around the back of his garden, meeting with Jim's garden, where the observatory was situated – because by then it had been moved half-way to the top of the garden. Therefore, while two large vans were being driven to the back of the garden, the remaining group was carrying the panels and other parts back to where we had started.

Due to the size of the observatory walls – around 12½ feet long and 7 feet in height – we had to cut them into sections in order to fit them into the vehicle. Even the floor and joists, good or bad, were taken – after all, this was to be a task of restoration, so it was important to retain as much as possible. I had hired the largest van obtainable, so that in the interests of safety we could fit in the dome sections like the layers of an onion, one inside another.

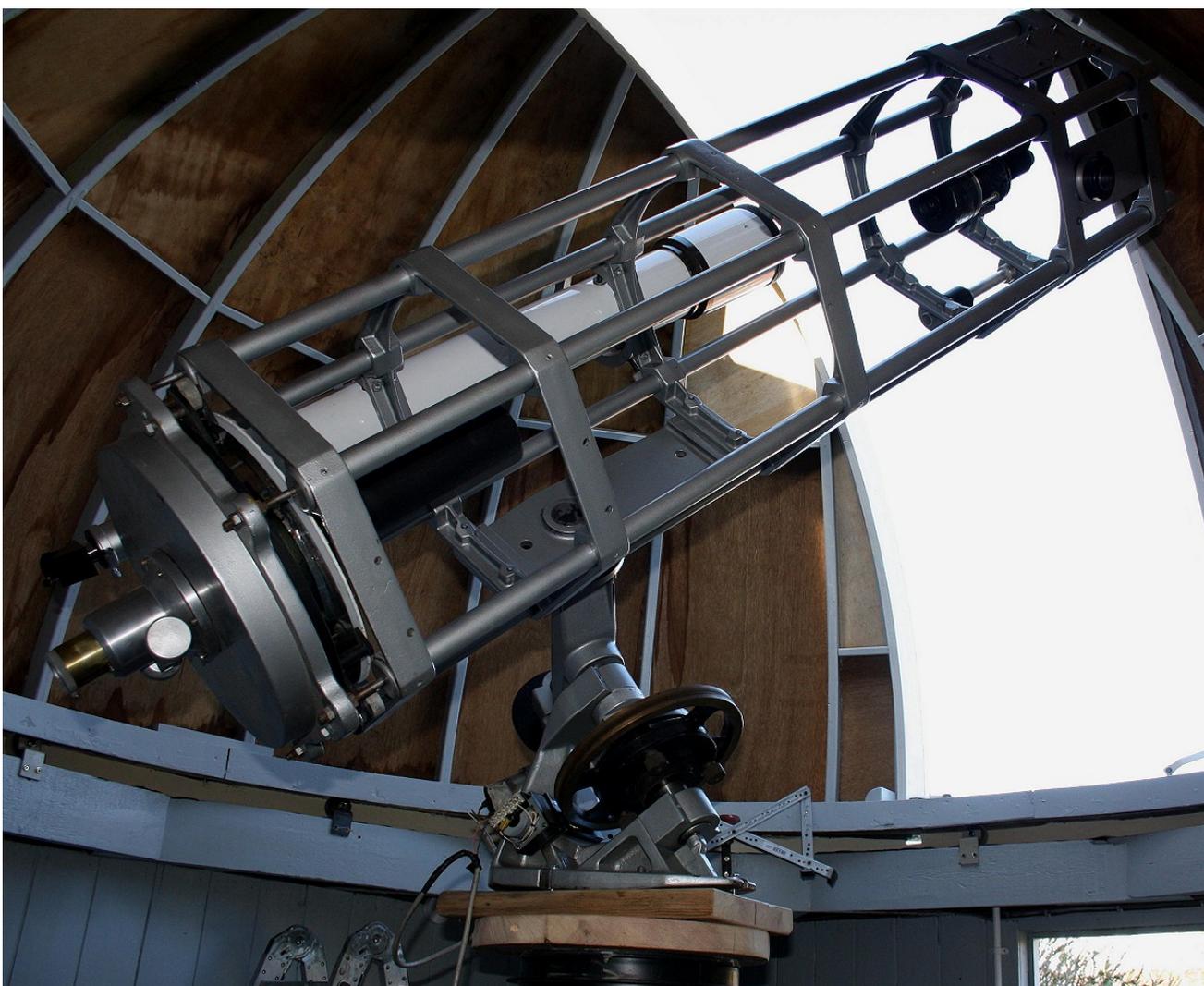
The vehicle was by then on the opposite side of Jim's garden, and with all present the dome section was lifted over the 6-foot high wired fence. However, when seeing the van against the size of the dome section as it lay by the back doors, it seemed that it would not fit; but as luck had it, it did fit, though there could not have been a fraction of an inch remaining on either side. The difficulty came when trying to stack the remaining two sections, as they were just too large. Two options were available: we return the next day and take each section one by one, thus requiring 200-mile round-trip for each journey, or we apply a saw, by now not wanting to exhaust the enthusiasm or patience of the party. The saw was presented as the solution, and the division of two sections into four sections was undertaken with considerable skill. The sections and the shutters were duly packed into the vehicle, and we then started out on the return journey to Cromer, where restoration could begin.

The accompanying photographs (a small selection of many) show the various stages of reconstruction. The main building is now complete, the dome has been recanvassed, and everything has been painted.





Since restoring the observatory I have installed Martin Mobberley's 14-inch AE Cassegrain telescope, refurbished a few years ago. Now, with the kind cooperation of Luton Astronomical Society, Horace's original 15½-inch Dall-Kirkham will, after restoration, be reinstated after some twenty-seven years of separation. I intend to provide updates of progress, and hope that, after work is completed, Members of the Association will take the opportunity to visit and, weather permitting, make use of this historic instrument.



The Horace Dall Medal and Gift

By 1976 the Association had instituted four awards – the Walter Goodacre Award (1929), the Merlin Medal and Gift (1960), the Lydia Brown Award (1972), and the Steavenson Award (1976) – but there was still no award which related specifically to optics or instruments (though Horace Dall received the Walter Goodacre Award in 1967). It was therefore decided to inaugurate such an award, and at the Ordinary Meeting of 25 May 1988 the President, Cdr Henry Hatfield, announced that Council had decided to honour the memory of Horace Dall and his contribution to optics and the construction of instruments.

Regulations

'A sum of money has been presented to the Association, and it will be invested, together with any further sums of money which any other member wishes to donate, to form a special fund to be known as the Horace Dall Memorial Fund. The first charge of the Fund shall be the award of a medal suitably designed and inscribed and a gift of thirty pounds or more, as decided by the Council from time to time. The award shall be made at the discretion of Council but not more than once in any calendar year. It shall be made to a person, whether or not a member of the Association, who has shown marked ability in the making of astronomical instruments. If two or more people have been jointly concerned in a particular work then each person may receive a medal and gift.'

Recipients

- 1990 B. G. Manning: exceptional skill and originality in the construction of telescopes, diffraction gratings, a measuring engine, a spectrohelioscope, and other instruments.
- 1993 J. R. Nichol: outstanding ability in the making of mirrors and the construction of instruments (joint award with J. Wall).
- 1993 J. Wall: outstanding ability in the making of mirrors and the construction of instruments (joint award with J. R. Nichol).
- 1995 J. Youdale: construction of instruments, including Maksutovs, Dall–Kirkhams, an 8-inch refractor, and meteor cameras.
- 1996 D. Sinden: design and construction of countless optical systems, including the optics for some of the world's largest telescopes.
- 1997 T. C. Platt: construction of instruments and the development of electronic imaging.
- 1999 E. J. Hysom: production of hundreds of mirrors and object glasses for amateur astronomers and professional observatories.
- 2001 B. Knight: high-precision innovative mechanical design and manufacture, and the production of mirrors and Maksutov telescopes.
- 2007 P. Wise: production of Newtonians, Schiefspiegler, and Schmidt–Cassegrains, and the invention of new optical systems.
- 2009 L. Newell: production and development of *Starbase* software for radio astronomy.
- 2011 C. Berrevoets: production and development of *Registax* software for image processing.

I will be pleased to include other personal memories or reminiscences of Horace Dall in future issues of *I&I News* – R.A.M.



References and website links

- Dall, H. E. S. 'The camera obscura'. Compiled by Albert Ingalls from Horace Dall's letters, and published in *Amateur Telescope Making* (various editions after 1935).
- 'A null test for paraboloids', *Jnl. Brit. Astron. Assoc.*, 57 (1947), 201–5.
 - 'FP3 Series II film', *Jnl. Brit. Astron. Assoc.*, 70 (1960), 157–9.
 - 'Atmospheric dispersion', *Jnl. Brit. Astron. Assoc.*, 70 (1960), 346–8; 71 (1961), 75–8.
 - 'Maksutov telescopes', *Jnl. Brit. Astron. Assoc.*, 73 (1963), 256.
 - 'Visual astronomy in the ultraviolet', 75 (1965), *Jnl. Brit. Astron. Assoc.*, 317–20.
 - 'Telescope eyepieces', *Jnl. Brit. Astron. Assoc.*, 79 (1969), 349–56.
 - 'Finding and guiding on dark skies', *Jnl. Brit. Astron. Assoc.*, 82 (1972), 202–3.
 - 'Photoelectric methods in amateur astronomy', *Jnl. Brit. Astron. Assoc.*, 83 (1973), 304.
 - 'Filter-type solar prominence telescope for amateurs', *Jnl. Brit. Astron. Assoc.*, 89 (1979), 122–35. Co-authored with M. R. Whippley.
 - 'A Dollond–Wollaston telescope', *Jnl. Brit. Astron. Assoc.*, 90 (1980), 422–8. Co-authored with E. J. Hysom and C. A. Ronan.
- Hargreaves, F. J. 'Comments on the null test', *Jnl. Brit. Astron. Assoc.*, 57 (1947), 195.
- Hysom, E. J. 'Horace Edward Stafford Dall, 1901–1986', *Jnl. Brit. Astron. Assoc.*, 97 (1987), 76–80.



Horace Dall in Iceland, 1932 and 1933
Sixty photographs with notes – Ben Searle

<http://www.s272714720.websitehome.co.uk/page17/page15/page15.html>



Cycling the Kjolur and Sprengisandur, 2010

Video by Gee Hurkmans (6 min)

<http://vimeo.com/user3163508>



Horace Dall, 1982

Video by Robin Scagell (52 min)

<https://vimeo.com/28160854>