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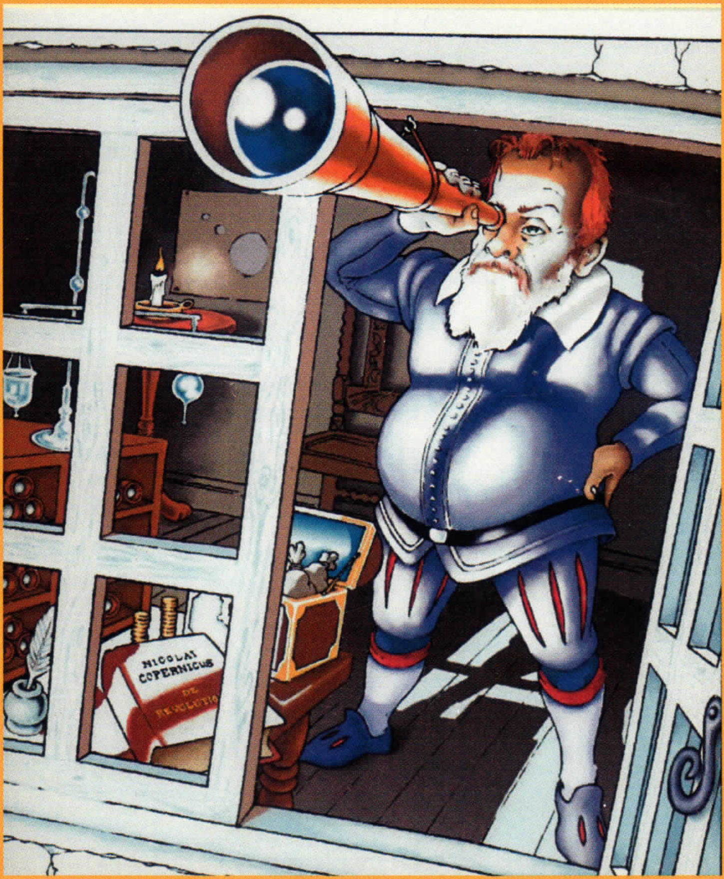
Newsletter



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Cover picture by Stuart North

Contents

Editorial

Dear Member,

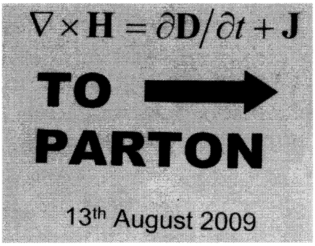
You will notice that this issue includes fewer items than usual and in consequence is very much thinner. This is because, including the special on Lord Rayleigh, it is the third issue this year. It was thought that the group would receive extra funding to produce the special but it fact this turned out not to be the case and the costs had to be borne out of our normal annual budget. I, and the committee, consider it has been a great success and was well worth all the effort put in by the authors and I should particularly like to thank Professor Ted Davis for all his help and support throughout its production.

Also, we are unfortunately unable to bring you transcripts of the lectures of the last meeting however in keeping with the celebrations of the *IYA* I am pleased to say that we have the first part of an excellent article by Dr. John Reid of the University of Aberdeen entitled '400 years of the telescope'. The second part will follow in the next issue.

Malcolm Cooper

News

IEEE Milestones in Electrical Engineering and Computing



What better way to direct a group of engineers and physicists to this event held at Glenlair, the home of James Clerk Maxwell, in Kirkcudbrightshire, Scotland?

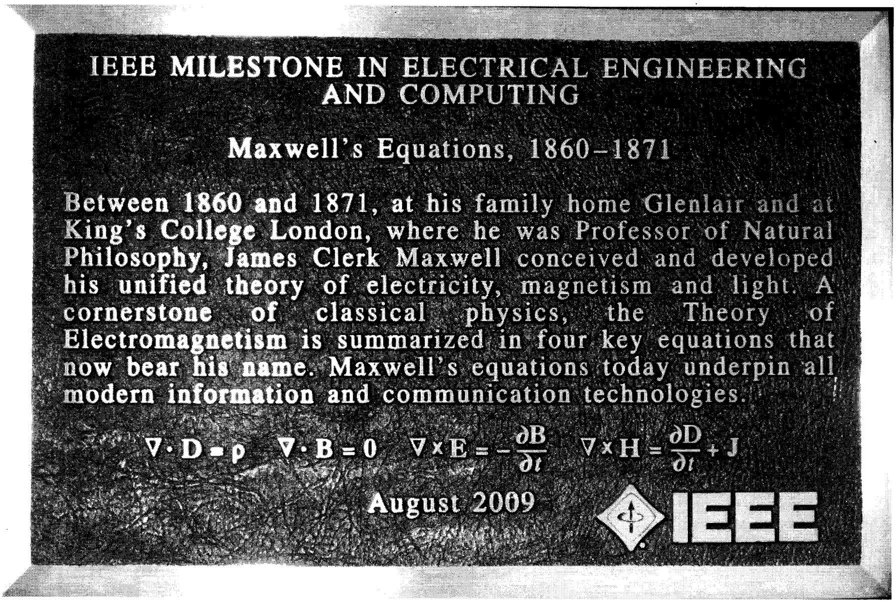
Around 50 people from all over the UK and many from the USA gathered to pay homage to James Clerk Maxwell being honoured by the unveiling of a plaque under the IEEE Milestones Scheme.

After a welcome and short introduction by Dr. Graham Turnbull of the University of St Andrews, the IEEE President, Dr. John Vig delivered a substantial speech giving the background to the milestones scheme. He pointed out that there have been a large number recognized in the UK/RI section including Nicholas Callan's work in electrical science and technology, Ambrose Fleming's diode valve and the code breaking at Bletchley Park.

The IEEE not only instigated this commemoration but has also provided, via its Microwave Theory and Techniques Society and Fellow, James Rautio, some \$250,000 towards the cost of restoring Glenlair (following its destruction by fire in 1929) and the establishing of a visitor centre and museum.

The partly restored main house

Dr. Vig expressed his thanks to Captain and Mrs Ferguson, the present owners of Glenlair, for their excellent hospitality and help in organizing the event.



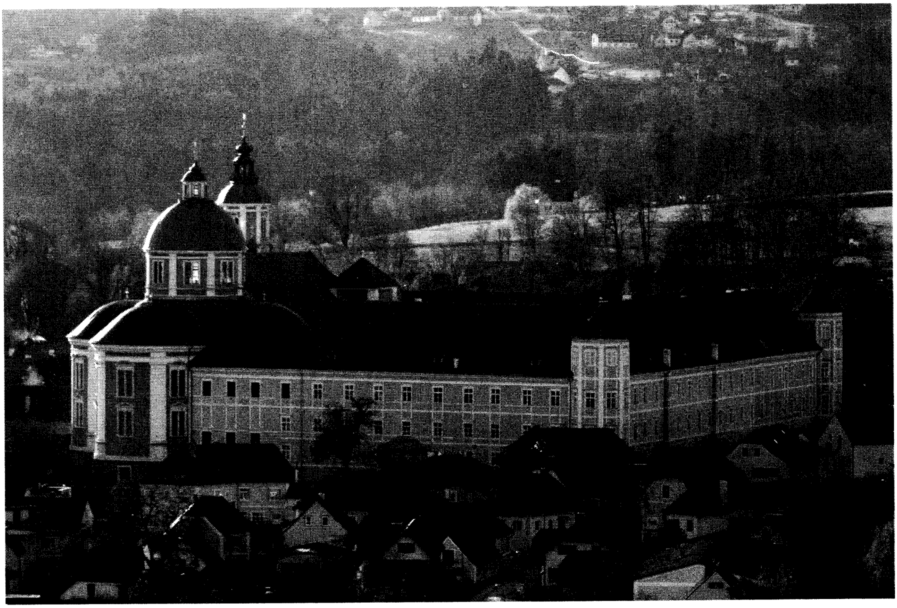
After the unveiling and a brief viewing of the house a cavalcade of cars set off for Parton village hall where, after an introduction by Prof. Ajoy Kar of Heriot-Watt University, we had three most interesting talks: the first by Capt. Duncan Ferguson on the 'Maxwell at Glenlair Trust' (see www.glenlair.org.uk), then an illuminating overview, by Prof. Malcolm Longair, University of Cambridge, of 'A Treatise on Electricity and Magnetism' (you can get your own 1873 copy for only ~£6000) and finally a talk entitled 'Some aspects of JCM's legacy in photonics' by Prof. Martin Dawson, University of Strathclyde.

These were followed by an excellent buffet lunch and a visit to the churchyard where the Clerk Maxwell family are buried.

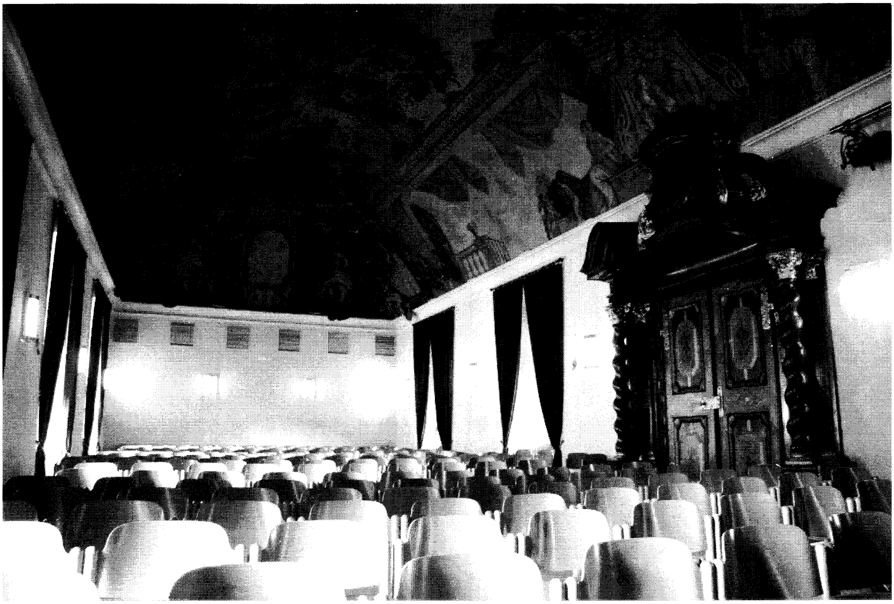
Please note that a similar plaque will be unveiled on 7th October at the Strand campus of King's College London (provisionally 2pm). The organiser for that event is Charles Turner of KCL c.turner@ieee.org

New centre for the history of physics opens next year

2010 will be a remarkable year for the history of physics – the establishment of a European Centre for the History of Physics (echophysics). This is the brainchild of Dr. Peter M Schuster - the EPS HoP Group chairman and will be set up at the magnificent Pöllau Castle in the little town of that name in the Bundesland of Steiermark, Austria.



Pöllau Castle (shown above) began life as a 15^{th} C monastery but its spectacular halls and vaulted ceilings were decorated with frescos created by Antonio Maderni in 1698. It was secularized in 1785 and has now been refurbished and equipped with all modern furnishings to provide substantial conference and educational facilities as well as 500 m^2 of space for temporary and permanent exhibitions. The castle will also be the home of the newly formed Victor Franz Hess Society and will become a focal point for a multitude of activities concerned with the history of physics – both within the scientific community and those involving the general public.



One of the magnificent halls of the castle

The acronym ECHOphysics refers to the mountain nymph 'Echo' of Greek mythology that is able only to repeat what others have said and here stands for the EPS/HoP Group's task: retracing and close re-evoking of the perception, feeling, events, observations and methods that incited our predecessors to their ideas and new notions.

The grand opening is to be on May 6th to 8th 2010, with, no doubt, many dignitaries present and will feature a symposium on the history of physics, European in scale, (details of which are still under discussion) as well as the first exhibition presented by the host nation entitled 'Radiation – the Exposed Humankind'

Other exhibitions are planned - and says Dr. Schuster: 'If you are thinking of consigning any historical equipment to a dusty basement – get it restored at Pöllau castle!'

Meeting Report

The last meeting of the Group was held in the Cavendish Laboratory, University of Cambridge on the 8th and 9th July to mark the International Year of Astronomy. It is 400 years since Galileo pioneered the use of the telescope and turned it towards the heavens and discovered mountains and craters on the moon, that the Milky Way contained a myriad of stars and that Jupiter had four satellites revolving around it; such discoveries have had a profound impact on both science and theology. Coincidentally, just as the world celebrates the 400th anniversary of Galileo's work so the University of Cambridge is celebrating the 800th anniversary of its founding in 1209.

We were fortunate to have three distinguished lecturers. We began with Professor Mike Edmunds from the University of Cardiff lecturing on "Telescopes – Past, Present and Future". It was a wide ranging lecture beginning before Galileo and continuing through to the important work of John Dollond in developing achromatic lenses, essential for practical astronomy, and the important telescopes developed by William Herschel with which he discovered the planet Uranus, the first planet to be discovered since antiquity. Equally importantly, William Herschel made a systematic study of the night sky in the Northern Hemisphere while his son, Sir John Herschel, carried out something similar in the Southern Hemisphere using a telescope which he brought out from England and erected outside of Capetown. During the nineteenth century the size and power of telescopes increased steadily and two major advances increasing their versatility were the introduction of photographic imaging around 1845 and the use of the spectrograph some fifteen years later. The twentieth century saw the development of ever larger telescopes mainly in America. These include the Mount Wilson in 1917, the Mount Palomar in 1948, both in California and the Keck telescope, with its the very complex optics, on top of mount Kea in Hawaii in 1992. A major advance was the Hubble telescope launched in 1990 and designed to operate in space so that the distorting effects of the earth's atmosphere are eliminated. Further powerful telescopes are being developed such as the James Webb due to be launched in 2013 and designed to orbit the earth at the Lagrange point.

Of course, much of our knowledge of the Universe has been derived from optical astronomy, however, for the last fifty years or so we have derived a great deal of knowledge using other regions of the electromagnetic spectrum. Radio astronomy has become particularly important and the work in this area mainly at Cambridge was the subject of the lecture by Professor Malcolm Longair of the University of Cambridge. Radio astronomy had it roots in the work of Karl Jansky of the Bell Telephone Company in 1932. Work on radar during the Second World War led several scientists in the United Kingdom to believe that Radio Astronomy might become a very powerful tool. The first radio source, discovered in 1946, was Cygnus A - identified as a very distant galaxy. Bernard Lovell was instrumental in developing the Jodrell Bank telescope outside Manchester and this acquired immediate fame as being the only instrument capable of tracing the orbit of the Russian launched Sputnik in 1957.

Radio astronomy using ingenious interferometric techniques was pioneered in Cambridge by a team led by Martin Ryle. Initially work was carried out (including the first survey of the radio sky) on the rifle range site, now the venue of the University Rugby Ground, but later it was transferred further away from the city to the present Lords bridge site and renamed the Mullard Radio Telescope in recognition of a £100, 000 grant from the company enabling research to proceed. Probably the most important discovery to come from the Cambridge Astronomy Group was that of pulsars made in 1967 by Anthony Hewish and Jocelyn Bell Burnell. Pulsars are magnetised, rotating neutron stars and the possibility of the existence of such neutron stars was made by Zwicke in 1934.

The final lecture was given by Professor Peter Coles also from the University of Cardiff and was entitled "The Cosmic Web". In 1915 Albert Einstein published his general theory of relativity – a theory that explains gravity as a curvature of space-time caused by the presence of mass. Einstein applied his new theory to a simplified model of the whole universe which is the largest possible gravitating system. He was troubled to find that his theory failed to supply a stable solution, one that would represent a non-changing eternal universe in which he and everyone else at the time assumed that we lived in. To this end Einstein added an extra term to his equations which has become known as the 'Cosmological Constant'. The idea was that this extra term would provide enough 'push' or 'pull' to prevent the universe from expanding or contracting. In the early 1920s the observational work of Vesto Slipher showing that the light from distant galaxies was shifted towards the red part of the spectrum and the observational work of Edwin Hubble which showed how to measure the distances to galaxies combined with the theoretical work of Alexander Friedmann showed that the universe was actually expanding. Einstein subsequently referred to his creation of the cosmological constant as 'my greatest blunder'. Prof Coles went on to explain how our current understanding of the large scale structure of the universe as an interconnected web of luminous matter held together by mysterious 'dark matter' yet pushed apart by even the even more mysterious 'dark energy' has arisen from a complex web of interrelations between theorists and observers and the reinstatement of Einstein's cosmological constant.

The following day we had a visit to the Whipple Museum of Science in Free School Lane, which is situated some 100 yards from the old Cavendish Laboratory where so many seminal discoveries in physics were made. The museum has an important and wide ranging collection, which includes quite a few telescopes a highlight being a 7 foot instrument made by William Herschel. We were treated to an excellent private guided tour of the Museum by Josh Nall. In the afternoon we had the opportunity to visit the Lords bridge radio astronomy site. Again we were treated to an excellent guided tour, which helped bring alive the lecture given by Malcolm Longair the previous day.

I believe that this was a highly successful and informative meeting and our thanks are due to our three outstanding lecturers and also our tour guides. The numbers attending the lectures were increased by our being joined by several members of the Cavendish Laboratory. However, the number of people attending from the History of Physics Group was most disappointing and we would be very interested in trying to find out why this was the case and what steps we might take e.g. increased publicity, to improve matters.

Peter Ford

History of Physics Group Silver Jubilee

The HOP Group is 25 years old! A celebration is being held on Wednesday 25th November at 76 Portland Place at 2pm - so come and join us for a trip down memory lane for a good helping of talks, eats and drinks celebrating 25 Years

We hope to have a number of speakers – all past or present committee members looking back over the years – including the group's first chairman, Jack Meadows on physics history; Stuart Leadstone will reveal 'Night thoughts of a Classical Pedagogue and Denis Weaire on the triumphs and failures of G.F. Fitzgerald

Refreshments will be available and if there is sufficient demand a dinner might be arranged but we would need to know how many are interested asap!

In any case it would be very helpful to have an idea of numbers attending so please do contact me ***as soon as possible if you hope to come.***

Further details from Dr. John Roche, email: john.roche@linacre.ox.ac.uk

Malcolm Cooper, Secretary mjcooper@physics.org

400 Years of the Telescope:

Part 1 – The first two centuries

Dr John S. Reid

Hon Curator of the Natural Philosophy Collection of Historical Scientific Instruments, Department of Physics, University of Aberdeen

In the beginning

This is one version of the story, for many could be written, of a simple device invented at the dawn of modern science. It is the story of the instrument itself more than the story of its achievements. Many simple devices have been invented that have remained simple, but not the telescope. Every contemporary reader will know that 2009 is the 'Year of Astronomy', designated by UN mandate as a year chosen to key in with the history of the astronomical telescope, an instrument that has done more than any other to change mankind's view of our place in the Universe. It is an appropriate time to look back at how the telescope has evolved.

400 years takes us back to 1609, a momentous year for the astronomical telescope but not quite to the origin of the instrument itself. Many devices invented in the past couple of centuries have a clear and well documented origin. Think of the telephone of Graham Bell, the electric light bulbs of Edison and Swan, the engine of Rudolph Diesel, and so on. Not so the telescope. I think it's true to say that there are at least three reasons why the origin of the telescope is visible only through a haze of circumstantial documentation. One is that the performance of early attempts was so poor that the real potential of the device was not seen; secondly those who first produced magnified images failed to develop the concept of the telescope as a device; thirdly, those who had glimpsed the concept realised the implicit military value of a successful instrument. The ability to see an opposing army or ships as clearly as if you were, say, even a few times closer than your actual position would have given an enormous advantage, if it could have been effected well. You will still recognise the old name of 'spyglass'.

Early telescopes were broadly speaking a tube holding two lenses. It had been known since antiquity that even a tube on its own could help one see distant objects a bit more clearly. This may be a red-herring in the history of the telescope but it's certainly true. If the only other components needed are two lenses, why wasn't the telescope invented earlier?

This may seem like a digression but it raises a point about telescopes that is relevant to their entire history. The idea of putting two lenses in a tube at such a separation that in combination they produce a magnified image probably does go back to the 1500s. It would have been an idea that was born of tinkering with lenses and not an idea of a theoretician, since there was no general theory of lens imaging in those days. However, making it work well was almost certainly beyond the materials available. Lenses were not common items. In the 1500s, more or less the only device using lenses was a pair of spectacles, and they were a rarity. It is indicative that *The Worshipful Company of Spectacle Makers*, the professional body of the trade in technologically advanced England, wasn't founded in London until 1629. Concave lenses, the lenses of the first eyepieces, were themselves a comparative rarity among spectacle lenses, for they are needed only by people who can focus well on objects close at hand but also need to see distant objects in fine detail. Moreover, there is a good optical reason why two spectacle lenses of 16th century quality would have made a very poor telescope even though they had useable focal lengths. The first illustration (Fig. 1) shows why.

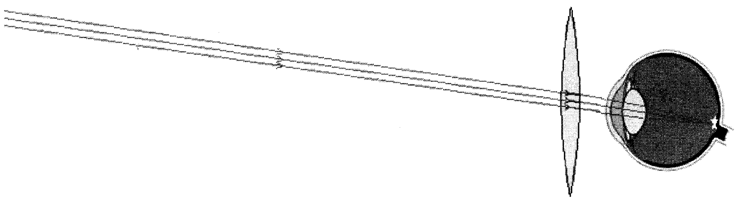
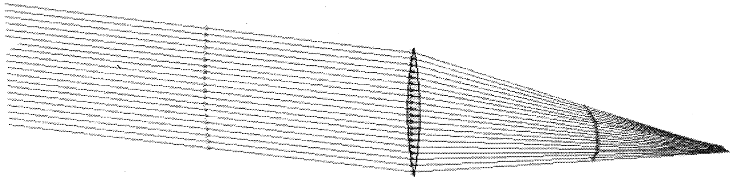


Image forming by spectacles uses only a small part of the lens at one time



Imaging by a telescope objective uses the full area of the lens

Fig. 1 Illustrating how imaging in spectacles and imaging in a telescope objective make different use of a lens.

With a spectacle lens, only a very small part of the lens is used at any one moment, a part that is about as large as the pupil of your eye, a few mm across. If each part a few mm across is working well, you will see a clear image. In fact a spectacle lens didn't need to be particularly good at all to be welcomed by someone who couldn't see clearly.

For a telescope objective lens to work well, the entire lens must image the object point, say a star, to exactly the same image point. If a spectacle lens of just 25 mm across is used as a small telescope objective, it must work satisfactorily over its entire area of 490 mm^2 and not just over 10 mm^2 at a time needed to make it a workable spectacle lens. To make matters worse, a star is the most unforgiving of all objects to image. In fact **for several centuries, astronomical telescopes were the most accurate objects made by mankind**. The main lens, or mirror in later telescopes, should ideally be shaped accurately to at least a tenth of a micron. This is some thousand times more accurate that the craftsmanship needed to manufacture most everyday objects. Such accuracy wasn't achieved for a long time but even so the history of the telescope is a history of design evolution and craftsmanship of the highest order.

In 1608, Hans Lipperhey, a Dutch spectacle maker in Middleburg, travelled to the capital of the Dutch Republic in the Hague and made an application for a patent for his telescope. He demonstrated his tube, a device with a magnification of about 3, to assorted high officials and visitors who were there for a peace conference. The novelty of Lipperhey's device was that it performed quite creditably and brought home to the dignitaries that a spyglass could deliver the magnified view promised. He was offered 300 florins to make an improved version using a rock-crystal lens (indicative that his objective was significantly flawed) with another 600 florins promised on delivery. He did not, though, get his patent or the pension for life he was asking for, because at least two other artificers claimed to have made similar devices. Nonetheless, the secret was out and Dutch telescopes were made in moderate numbers and disseminated across Europe and to some of the Dutch colonies. A practical spyglass, at least, had been born, probably with a magnification of about 3, given the lenses of the day.

I'm tempted to add here a comment that various Elizabethans and 16th century contemporaries are sometimes credited as unsung inventors of the telescope but it's one thing to describe how after tinkering with lenses and mirrors you have been able to see clearly ships or other distant objects and another to have the concept of a self-contained device that can be manufactured, packaged for a target audience and sold to perform a clear function. In other words, a telescope is more than a magnified image produced by a combination of optics. For inventing the device as a marketable package, I believe the Dutch have it.

Galileo

1609 was the year Galileo first turned his own telescope to the heavens. Galileo was born in the same year as William Shakespeare. He was an academic who at different times in his life had posts in Pisa and Padua Universities and a personal retainer by the Medicis in Florence. He discovered things rather quickly once he had made his first successful telescope. After a few early trials he had a tube about a metre long with lenses at both ends. He pointed it at the heavens, looked though it and engaged his brain.

What Galileo saw was not much different from what we would see through a pair of powerful binoculars, except that we will get a wider field of view and see things more sharply than Galileo ever did. He saw: *mountains and valleys on the Moon; sunspots; thousands more stars; 4 moons of Jupiter – the Galilean moons; the complete set of phases of Venus*, a sequence of images different from that predicted by the old Ptolemaic view of planetary orbits.

Good for him, you may think; *Bravo*! Surely his contemporaries were delighted. Galileo himself probably thought so, for unlike his possible predecessors he published the results of his telescopic observations, with some flamboyancy. In fact, many of his contemporaries were not a bit delighted. The story of what happened to Galileo is one of the seminal stories in the history of science. However, it's a story that takes us away from the instrument itself. What exactly was Galileo's telescope like?

Galileo's optics was the same as that used in the early Dutch telescopes, namely a convex objective (Galileo used a plano-convex objective) and a concave eyepiece. This arrangement produces an upright image with a magnification determined by the ratio of focal lengths. For example a long focal length spectacle lens of focal length 500 mm followed by a short focus concave spectacle lens of focal length 150 mm gives a magnification of just over 3. This is about what the early Dutch telescopes had. The overall length of the telescope is the difference in their focal lengths, 350 mm in the Dutch example, or quite short. Galileo's optical contribution was to make his own lenses and give the objective a focal length nearer 1 m and the eyepiece lens a focal length nearer 50 mm. This raised the magnification to 20, and the tube was correspondingly longer.

On paper the device looks to be a perfectly viable instrument that gives a magnified image but this optical arrangement is not the best, as we shall see.

Before leaving Galileo, this is a suitable place for a brief digression on the name 'telescope'. It's derived from Greek and yet no Greek has come into the story. Up to 1610, several names were used for the new device, none of them 'telescope'. To cut a long story very short – there is an entire book on how the telescope got its name – it seems the name was suggested by John Demisiani, a Greek mathematician in the employ of one of the Cardinals, at a banquet in Galileo's honour in April 1611. Galileo had not yet become the bête noir of the Catholic establishment.

Enter Johannes Kepler

Kepler was Imperial Mathematician to Rudolph II in Prague and in 1604 had published the first book on Optics in Europe that one could call modern. In 1611 he published his *Dioptrice*, a follow-up that set out a description of the behaviour of light rays and how lenses imaged. He proposed an alternative arrangement of lenses for a telescope using two convex lenses. In Kepler's telescope, the image is inverted, the magnification is given by the same ratio of focal lengths and the whole thing is physically longer, being the sum of the focal lengths. This last one may seem a disadvantage but the arrangement has a hidden advantage over Galileo's optics.

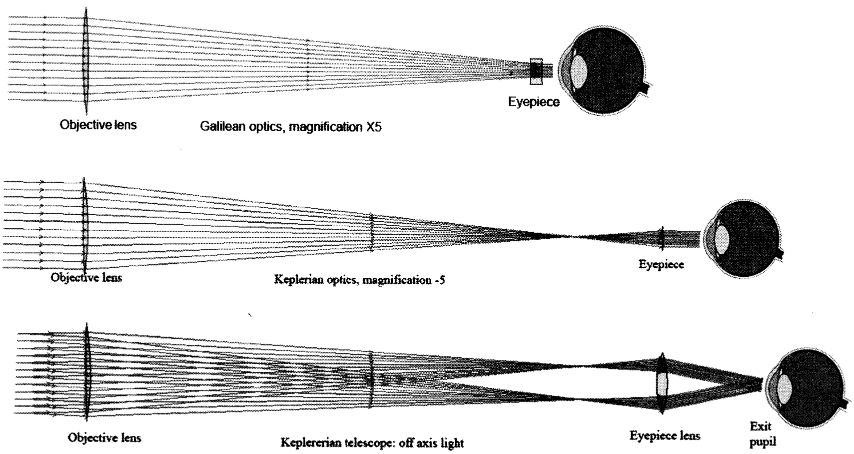


Fig. 2 Imaging in a Galilean and Keplerian telescope of the same magnification. The final diagram shows how the full pencil of light from off-axis objects in a Keplerian telescope passes through the exit pupil, which should coincide with the observer's eye pupil. Note also that the imaging of the two versions of the telescope with the same magnification, clearly show that Kepler's version has to have a longer tube for the same magnification.

The final part of Fig. 2 shows the imaging of two objects, one of which is above the centre-line and the other below. The light from all such objects ends up passing through the same area behind the eyepiece called the 'exit pupil'. This is very convenient, for if the pupil of the observer's eye is placed there then the observer will see all the light that comes through the telescope from off-axis objects. It is not hard to make sure the exit pupil is well situated so you can rest the telescope on your brow and the telescope exit pupil coincides with your eye pupil. In the Galilean or Dutch design, the exit pupil is formally inside the telescope where you can't put your eye, with the result that off-axis objects are necessarily seen less brightly and you may need to move your telescope or your eye, or both, around to catch sight of them. This is not what you want when you're trying to sell the telescope concept to a sceptical audience, as Galileo was. One resulting feature of the Keplerian design is that it has a wider field of view. In Kepler's design, you extend the tube length to project an image of the Sun onto a sheet of paper placed behind the eyepiece to observe sunspots. In Galileo's design, the tube is pushed in to achieve the same effect and the optical arrangement morphs into that of a telephoto lens. The practical advantage of Kepler's design is so great that the Galilean telescope disappeared rapidly from the scene.

Rheita's erector

Anton Rheita was a philosophy professor in Trier, now in Germany, who is remembered for his contributions to astronomy and for his collaboration with Johann Wiesel, one of the 17th century's foremost telescope makers. In a book on optics and astronomy published in 1645 he described his image inverter for the Keplerian telescope. It's quite clever, being essentially a telescope of unit magnification placed inside a telescope. For reasons that Rheita didn't know, it is the configuration of choice in all modern erecting telescopes that use lenses and not erecting prisms.

So by the mid 17th century the optical configurations of telescopes astronomical and terrestrial were in place. You might have expected the device to evolve to a high degree quite quickly. That did not happen. As has been said often in connection with technological devices – the devil is in the detail.

17th century telescopes

If you want to see far-off objects on land in more detail, you need more magnification for your telescope. If you want to see more detail on the moon or planets, then it's most natural to build telescopes with more magnification. From the formula for magnification, that means longer telescopes.

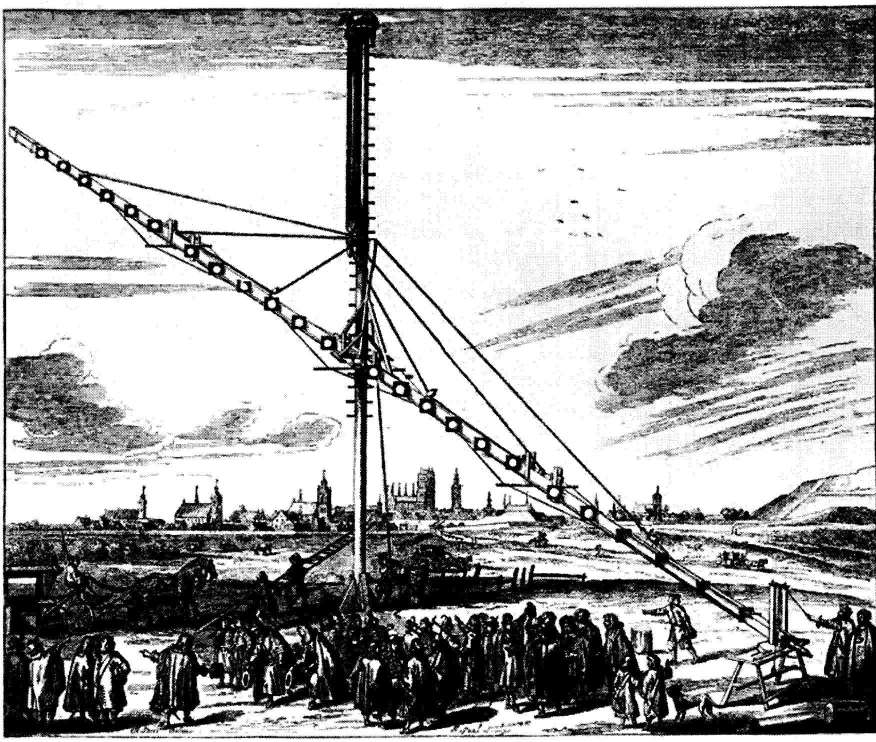


Fig. 3 Mid 17th century evolution, the age of the long, very thin telescope, epitomised by Hevelius's construction over 40 m in length depicted in his 'Machina coelestis'.

It's hard to imagine using such a device on a moving target in the sky such as the moon or a planet. Hevelius must have done so from his hometown of Gdansk in Poland, for he did produce much better charts of lunar features than Galileo. Long, thin astronomical telescopes were characteristic of the 17th century. Chromatic aberration is part of the detail that the devil puts in the way of making a good telescope. It's often repeated that these long focal length instruments showed reduced chromatic aberration. In fact a long focal length spreads out the coloured images more than a short focal length lens of the same glass does.

The Moon was a popular subject in the 17th century. It was commonly imagined then that the Moon might be inhabited. The famous Robert Hooke, a contemporary of Newton, speculated that one crater he saw through his telescope and drew in detail in his notes might contain *Grass, Shrubs, and Trees; and most of these incompassing Hills may be covered with so thin a vegetable Coat, as we may* *observe the Hills with us to be, such as the Short Sheep pasture which covers the Hills of Salisbury Plains.* This is a nice illustration of how misleading it can be to assume our predecessors interpreted telescopic images in the same way we do.

Christiaan Huygens

Christiaan Huygens was one of the greatest Dutch scientists of all time. He built his own telescopes with his brother, grinding their own lenses that were arguably the best in his era. His discovery of Titan was made with a telescope of about 50 mm objective diameter. Huygens introducing into telescope design an element that is essential for a decent image, namely an eyepiece made with more than one lens. The Huygens eyepiece, which is still common in microscopes, divides the imaging task of the eyepiece between two lenses in such a way as to reduce image aberrations and even provides reduced chromaticity. Over the first two century's of telescope development, the emphasis was largely placed on the telescope objective and Huygens' attention to development of the eyepiece wasn't followed until the late 18th century and well into the nineteenth century.

Reflecting telescopes

The mid 1600s saw the invention of the reflecting telescope. The first clearly described design was by James Gregory, an Aberdonian, near enough, who became professor at St Andrews and then at Edinburgh. Gregory's reflexive design (Fig. 4) folded the light path to shorten the length of the instrument and used a reflector instead of an objective lens to circumvent the problem of prismatic dispersion of different colours by the glass objective. His pattern consisted of a concave mirror as objective, specified by Gregory as parabolic, followed by a second concave mirror, specified as ellipsoidal, that re-imaged the light back through a hole in the centre of the primary mirror to an eyepiece in the rear. He got a prototype of his design made in London, a centre of instrument making, but the maker was not able to figure the surfaces with mathematical precision. Gregorian telescopes were to become very fashionable only in the following century.

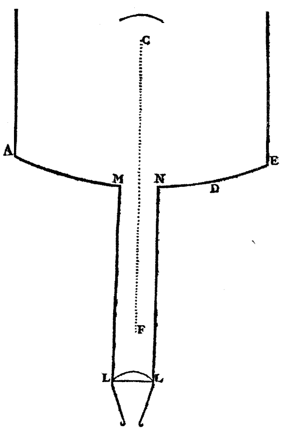


Fig. 4 James Gregory's sketch from his book 'Optima Promota', 1663, the first well-known published design for a reflecting telescope. AMNE is the objective mirror. (University of Aberdeen Library).

Newton had been led to the value of a reflecting telescope by a faulty analysis of the cause of chromatic aberration. His design, some 5 years after Gregory's, with its well known flat 'secondary' mirror to deviate the path of the primary image out to the side was simpler. He made the first two examples himself, experimenting on the composition of 'speculum metal', the alloy of copper, tin and a little arsenic that became the common material for the primary mirror. Reflecting telescopes are today the instrument of choice for the majority of professionals and amateurs but they didn't catch on when the designs were first published. In fact it was over half a century before the first reflecting telescopes that challenged the refractors were made. It didn't help the cause that the prototypes looked a bit like toys.

The first telescopic observatories

The last few decades of the 16th century saw the first national astronomical observatories built for telescopes. First was the Royal Observatory of Paris, seen in Fig. 5, under the patronage of Louis XIV.

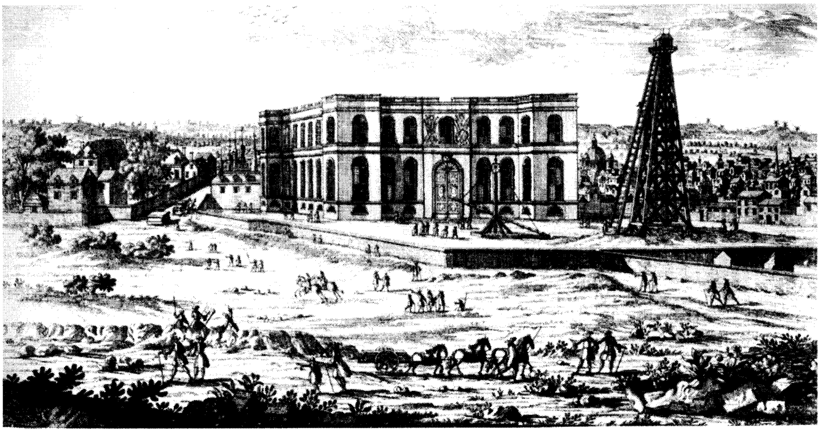


Fig. 5 The Paris Royal Observatory, opened in 1672.

The long telescope of the age, focal length 34 French feet (~11 m), is in the foreground. The building is large because it was built as a science centre, not simply as an astronomical observatory but being out of town it turned out that only astronomers were prepared to use it. The first director was Jean-Dominique Cassini, famous for identifying the now prominent gap in the rings of Saturn and making a fine map of lunar features.

The bizarre wooden structure 40 m high, Paris's pre-cursor to the Eiffel tower, was used to hold even longer focal length objectives.

The Royal Greenwich Observatory

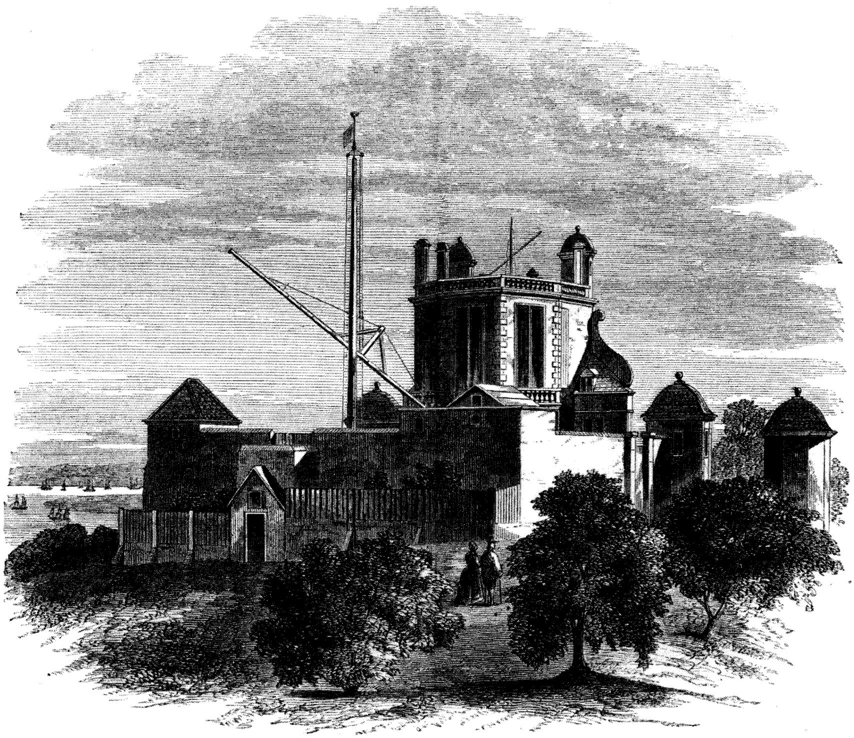


Fig. 6 The Royal Greenwich Observatory, 1675.

The RGO soon followed, in 1675. The building (Fig. 6) was mainly functional, including serving as a residence for the Astronomer Royal but also, according to its architect Christopher Wren, 'a little for pomp'. Wren had been Savilian Professor of Astronomy at Oxford so was fully aware of the astronomical requirements. In the illustration you can see the long telescope of the day, this one of 60 foot focal length on an 80 foot mast. The telescope was not a great success. It is recorded that on a calm day in 1690 '*the mast began to sway spontaneously, threatening to fall on the Sextant House*' and soon after it was taken down.

John Flamsteed was the first Astronomer Royal and one of the first to get down to doing what the 17th century had conspicuously failed to do in-spite of having the tools: make a telescopic catalogue of the stars. Flamsteed's catalogue was published in the 18th century after his death. He had to invent a new naming scheme for stars and this he did, numbering stars in a given constellation from west to east. Thus stars like *51 Peg*, *26 And* etc. are stars known by their Flamsteed designation.

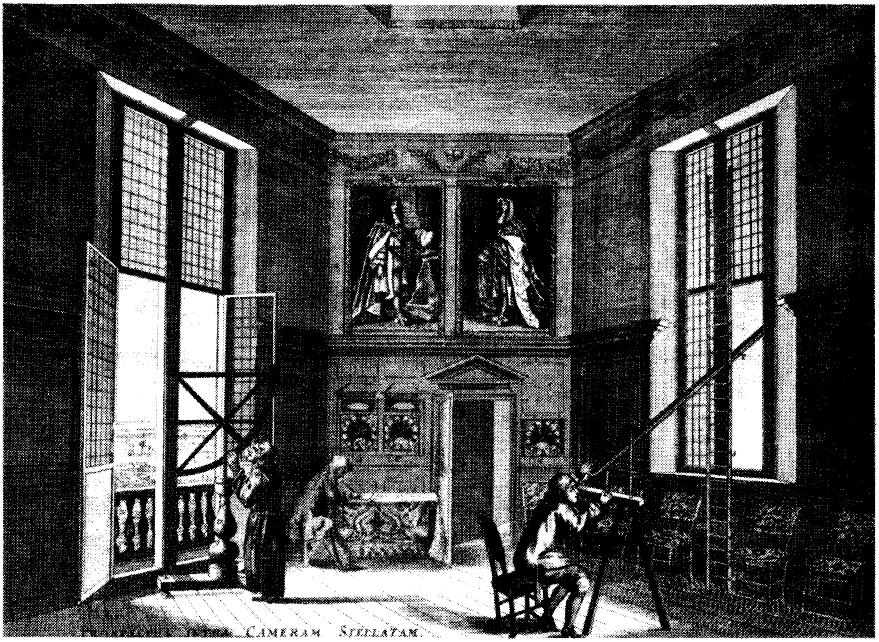


Fig. 7 The stellar observing room of the Greenwich observatory in Flamsteed's day.

The illustration of the observation room (Fig. 7) shows the 3-foot quadrant in use; clocks in the wall, one of which survives, portraits of the patron Charles II and the future James II and the 8.5 foot telescope supported by a ladder. The point I want to make is that a successful astronomical telescope is a synthesis of superb optical design and construction, and well thought out, rigid, secure, ergonomic, high-quality, mechanical design. A century after the invention of the telescope the concept that the mechanics were pretty well as important as the optics is nowhere to be seen. It was much the same with the evolution of the microscope too.

Moving on

Looking back over the 17th century, telescope design matured; telescope practice didn't keep up. Telescope performance wasn't good after a hundred years. Small telescopes did develop into a recognisable product and some military use was made of them but they couldn't deliver the wonders of seeing-at-a-distance that the imagination of people at the beginning of the century had credited them with. As so often happens, imagination had been given a reality check.

Commander-in-chief of the British fleets, Sir Cloudesley Shovell, whose portrait in the National Maritime Museum shows him holding a telescope, had a significant impact on 18th century astronomy, though that was not his intention. His arrogance and navigational misjudgement at the beginning of that century resulted in several men-of-war being wrecked on the Scilly Isles, with the loss not only of the vessels but at least 1300 men, himself included. The Admiralty, under whose jurisdiction Greenwich Observatory came, needed improved navigational tools. A great deal of work by astronomers and observatories in the 18th century was motivated by the need to be able to determine latitude and longitude accurately at sea. The need for improved charts also meant correctly determining latitude and longitude of features on land and hence both the disciplines of navigating and surveying were involved. The problem of understanding how stars were distributed in space, what stars were and how they worked was well below the horizon.

The 18th century

Some 18th century highlights that drove the development of telescopes were *the rise of the reflector*; *the spread of the gentleman astronomer and peripatetic lecturer*, *the founding of many more observatories*; *the invention of achromatic objective lenses*; *the importance of positional astronomy*; *the realisation by William Herschel that diameter was the key issue to seeing more deeply into the sky*. Incidentally, the problem of finding latitude and longitude accurately was solved over this century.

Gregory and Newton's reflectors had languished for half a century after their appearance on paper and attempts at proof of concept prototypes by their inventors. The person who rescued both types was John Hadley who, assisted by his brothers, made workable telescopes that were tested against the best refractors and found as good. His first Newtonian telescope had a 6 inch (~150 mm) diameter mirror and 5 foot (~ 1.6 m) focal length and was mounted on a thoughtfully designed wooden frame (Fig. 8). The diameter of the objective was considerably greater than glass objectives of the day.

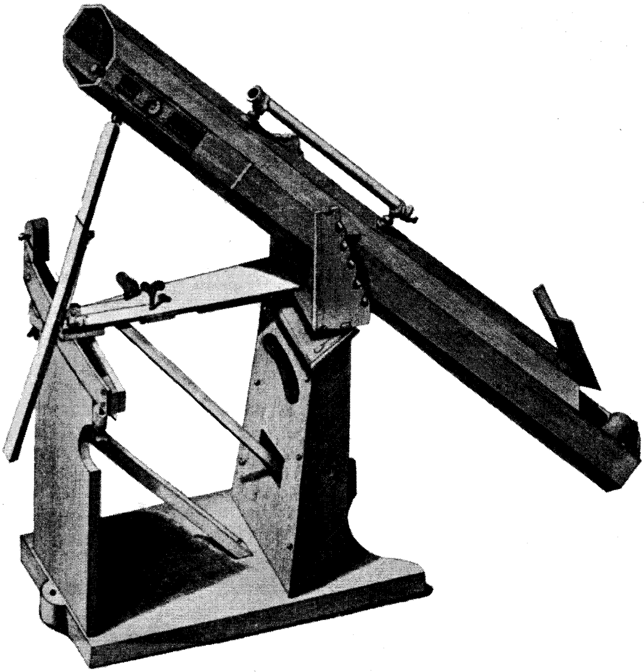


Fig. 8 John Hadley's 5 foot reflector, circa 1720.

Hadley ruled out mercury on glass as a reflecting surface because of the rapidity with which it tarnished and used speculum metal. Speculum metal is harder than glass and at least as brittle, making it quite difficult to work with. Hadley also claimed to produce parabolic primary mirrors and introduced an imaging test for the quality of his specula, an important step to quality control in grinding and polishing. Hadley style telescopes were made by many others throughout the century.

John Hadley invented the octant, the key instrument for measuring angles at sea on the moving platform of a swaying ship. The octant evolved into the sextant and small telescopes were added to many sextants. A line of telescopes developed as components of other instruments rather than as stand-alone instruments. They are found for example on repeating circles, another instrument for measuring angles, on surveyors' levels and theodolites, on astronomical quadrants and later on spectrometers and elsewhere. None of these developments extended the basic concept of the device.

The mid 18th century saw the rise of commercial instrument makers capable of producing good telescopes. This initiated a rapid spread of interest in astronomy to gentleman astronomers, from the highest echelons of the aristocracy, who could afford to buy top-of-the-range instruments, and did so, to squires, learned clergy and University professors. The spread of telescopes in this way was fuelled by the availability of convenient and effective Gregorian telescopes. Of particular note were those made by the Scotsman James Short, who started in Edinburgh but moved to London. Short operated between the late 1730s and 1768 during which time he and his workshop turned out a few thousand of telescopes. Short telescopes are now one of the prize possession of museums around the world. Many other makers produced similar looking products, spreading the astronomical telescope to a new range of clientele.

Achromatic objectives

John Dollond may not have invented the concept of the achromatic objective, a combination of glasses that reduces spurious colouring of the images typically by a factor of about 10, but he was certainly the one who carried out extensive experiments with different glasses, devised a commercial product and sold it to the commendation of an international base of customers. When he died in 1761, the business which he enjoyed with his son Peter continued in partnership with other family members and prospered into the twentieth century. A successor to the business still exists in the firm of Dollond & Aitchison, ironically purveyors of spectacles not telescopes. The wheel has turned full circle from the spectacle makers of Middelburg.

The 18th century Dollonds hadn't solved the problem of making large objectives. A 3-inch diameter objective would have been exceptionally large for an 18th century telescope. Refracting telescopes had not been swept away by reflectors because speculum metal, or even the cheaper bronze, did tarnish. Lenses didn't. The importance of pushing the frontiers of instrument making was recognized at that time as of equal value in science to that of moving theory forward. For example Hadley, Short and John Dollond were all elected Fellows of the Royal Society of London.

There is another valuable historical lesson from this time, too. For most of the 18^{th} century, English makers of astronomical instruments, telescopes included, pretty well led the world, to the great financial advantage of London instrument makers in particular and indeed the economy of the country as a whole. They lost this position because of a 'crushing excise duty imposed on glass by the unwisdom of the Government'. This limited production and rendered experiments on making larger lenses too costly. As a result, the expertise, skill and commercial initiative of producing new, larger refracting telescopes moved to Germany and France.

In our story we're coming up for 200 years after the invention of the first telescopes but interestingly enough, there was still no proper and accurate theory of lens imaging. The reason that telescope design was progressing so slowly over the decades was partly material inadequacies – glass and mirrors – partly manufacturing inadequacies – no tooling to the exquisite tolerances that are really required – and partly theoretical inadequacies – no proper target for designers to aim for.

There's an old argument in astronomy over which is best, refractors or reflectors? As we now know, no shape of imaging surface will give perfect imaging over a wide field of view, one object point creating precisely one image point. All images are necessarily blurred to some extent and the image field distorted in one way or another but with refracting lenses there is more scope to minimize these imperfections. Why? Because there are more parameters under the designer's control. A reflector with a single objective surface of a specified shape has essentially no free parameters after the image distance has been set. An achromatic objective has 4 surfaces, each of whose radius can be varied, 2 refractive indices of the two glasses and the separation between the lenses can be varied a little. That's at least 7 parameters. Having determined the image distance and the achromatic condition, there are free parameters left over to reduce the image blurring and other imperfections for a range of off-axis objects. There is, though, a good reason why most serious astronomical telescopes today are reflectors and that is part of the later story.

Optics and mechanics merge

The end of the 18^{th} century saw the appreciation of the importance of the integrated design of mechanics and optics, for short-term and long-term stability, for the precision measurement of angles. Jesse Ramsden, another FRS, was the foremost developer in this direction and his international order books were filled up years in advance. Waiting 5 years for a precision Ramsden telescope was not unusual.

William Herschel was the mid-life amateur turned consummate professional who is in this story because he transformed the world of serious astronomical telescopes. He started off in his mid-thirties making 7 foot telescopes not all that much different from John Hadley's designs. They performed very well. Even King George III had one. One of our local Aberdeen University professors had one. Herschel himself discovered the planet Uranus with one. If it were just for these achievements, Herschel wouldn't get a mention here.

In daily life if you want to see distant objects more clearly then you get binoculars of higher power. Herschel realized that this didn't apply in astronomy. The stars are so far away that no higher power is going to make any details of their surface visible and, besides, atmospheric disturbance limits useful magnification to a few hundred. To see further you need a wider telescope, not a longer telescope. To some extent width and length are interconnected, for image quality deteriorates if width is increased without increasing length. Scaling up a 6 inch objective with a 6 foot focal length by a factor of 7, gives a 42 inch objective with a focal length of 42 feet. That's pretty well what Herschel did in the late 1780s. His contemporaries were amazed.

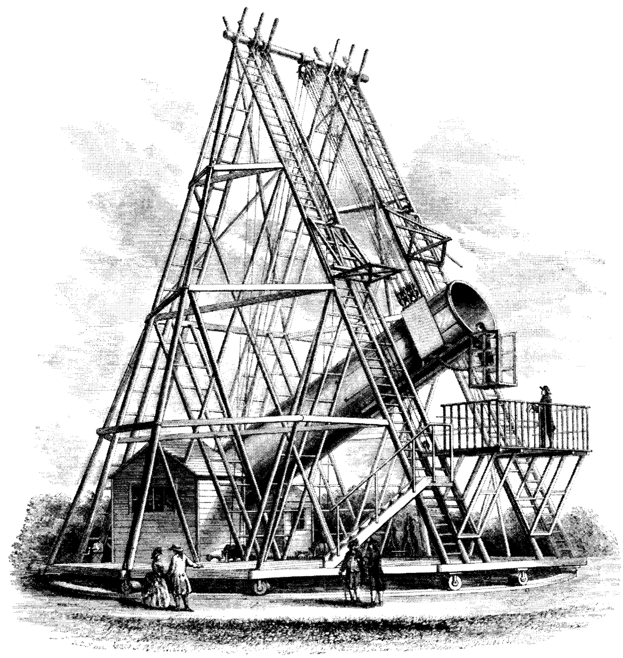
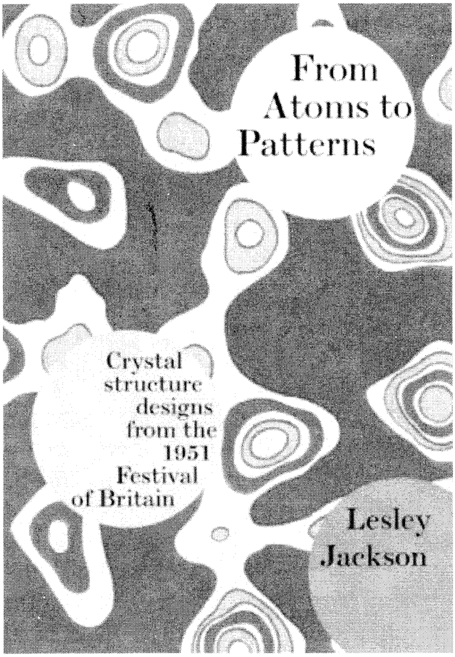


Fig. 9 Herschel's forty foot telescope, finished in 1789.

The device looked to many of them more like a piece of diabolical ordnance, as can be seen in Fig. 9. Nonetheless, Herschel proved his point by making the most detailed stellar catalogue of his day (the basis of the future NGC catalogue and numbering system), drew the most detailed pictures of many nebulae in the sky, whose faint details were not discernable in smaller telescopes and was really the first person to appreciate the 3-dimensional, disk-like distribution of stars making up the Milky Way.

Up until Herschel's time, telescopes were described by the focal length of their objectives (e.g. 7-foot, 5 m, etc.). After Herschel's time, they were described by the diameter of the objective (e.g. the 200 inch Mount Palomar telescope or the 2.4m Hubble Space Telescope). It is amazing to reflect that in spite of the value of the astronomical telescope and all it showed, in spite of the number of telescopes that were made and used world-wide, in spite of continuous competition between manufacturers to produce better products than their competitors, it took some two centuries from the invention of the device before we reach what can reasonably be described as the dawn of the modern instrument. Galileo and other pioneers would have marveled at the clarity and stability of the images seen through Dollond and Ramsden's productions but not as much as Dollond and Ramsden would marvel could they see the images from a modern telescope. Over the next 200 years the telescope developed almost out of recognition, as will be covered in the second article.



From Atoms to Patterns

X-ray diffraction and 1951 Furnishing Design

Lesley Jackson

Richard Dennis *2008*
ISBN *9780 955 374 111*
124pp *Flexiback* *£20*

Reviewed by Emeritus Professor Derry W Jones
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Despite the continuation of wartime shortages and restrictions, Britain embarked in 1951 on a relatively austere but very successful Festival of Britain (FoB), a century after Prince Albert's 1851 Exhibition held in more prosperous times (profits from 1851 finance exhibitions - in another sense - supporting younger scientists). Temporary structures were specifically designed and constructed on a bomb-damaged site on the South Bank in London, where the Festival Hall stands. Within the Dome of Discovery (much smaller than the O_2 Millenium Dome) and at the Science Museum were on display both the science of X-ray diffraction and a diverse array of furnishing materials and everyday products, all with specially commissioned designs based on crystal-structure patterns: screens, room dividers, wallpaper, vynide upholstery, floor coverings, curtains, dress materials, tableware - even an ashtray modelled on the pentaerithritol structure. Wedgwood and others produced china decorated with patterns utilising Perutz's haemoglobin and W.L Bragg's beryl structures.

The physicist who, five years earlier, initiated this wide-ranging application across 28 industries of the patterns derived in X-ray crystal-structure analysis was Helen Megaw, then in Bernal's department at Birkbeck. Her approach was reinforced by Kathleen Lonsdale's lectures to industrial artists. In 1949, Harland Thomas (originally an architect) of the Council of Industrial Design contacted Megaw and enthused about the potential 'transcription of crystallographic diagrams' for decorative patterns on pottery or printed fabrics. Thomas and Megaw soon formed what became the Festival Pattern Group (FPG) into which they induced representatives of 28 entrepreneurial companies, deliberately only one for each kind of product, manufacturing wrapping paper, work tops, dress, tie and furnishing fabrics, floor covering, glassware, pottery, etc, even cutlery. Megaw gave the designers' representatives surprisingly detailed summaries of how the process of X-ray crystal analysis could yield usable patterns: diffraction photographs, electron-density and Patterson projection contour maps, and circle-and-line structure representations. Almost all such crystallography was photographic, while both contour maps and structure diagrams were drawn by hand at this time.

Later in 1946, Megaw, now back at the Cavendish (headed by Bragg), was in touch with some rather distinguished X-ray colleagues including future Nobelists Dorothy Hodgkin (at Oxford), J.C Kendrew and M Perutz, as well as crystallographers J.D Bernal at Birkbeck, E.G Cox and G.W Brindley at Leeds, and the chemical crystallographer J.M Robertson at Glasgow. All these scientists provided authentic pictorial crystallographic data (maps or diagrams of structures); authors were not publicly identified initially (except, of course, to those who read the crystallographic literature) so as to protect scientific reputations from such informal commercial versions of their structure determinations. To overcome copyright matters - Hodgkin said that one can hardly copyright 'a pattern perpetrated by nature' - a small licence fee was offered. Each manufacturer had to transpose black-and-white dyeline drawings of the structures to a different medium: print, weave, embroidery or mould; colours were up to the designer.

In the summer of 2008, Emily Jo Sargent (Wellcome Trust) and the design historian Lesley Jackson mounted a considerable exhibition *From atoms to patterns* at the Wellcome Collection, London. This displayed representative examples of all the fabrics, ties, wall and floor coverings, upholstery materials, etc that had been in use (eg, in the Regatta Restaurant on the South Bank) or on display at the 1951 FoB exhibition sites; since then most examples seem to have been stored out of public view in the Victoria and Albert and Science Museums. I was fortunate enough to visit both the 1951 FoB and the 2008 retrospective exhibition. I have also walked on a red machine-woven carpet patterned with the pentaerithritol crystal structure in the office of E.G Cox (a physicist then heading a chemistry department); a sample was displayed at the Wellcome Exhibition.

As a complement to this exhibition, Lesley Jackson has produced a well-researched volume essentially about the FPG, its achievements and its participants, both individual scientists and manufacturing companies. It recounts the origins and mode of operation of the FPG in the context of the preparations for the 1951 FoB and is illustrated by many archive photographs (their black and white contrast with the lavish colours of the rest of the book). Hartland Thomas's souvenir illustrated booklet on the FPG (on sale, price 2s 6d, at the 1951 sites), containing many crystal designs, is reproduced as chapter 2 in Jackson's book; its first picture is of Megaw handling a Unicam S25 X-ray photogoniometer. Megaw's 1946 essay 'Pattern in crystallography', addressed to designers, is also reproduced. The biggest chapter is a catalogue of participating manufacturers: the background of each company is sketched and its contribution to the FPG. For each, comments are quoted on the perceived success or otherwise of the venture and attributions given to the designers and scientific authors of the designs utilised. A separate catalogue gives illustrative diagrams and the literature reference for each crystal structure, ranging from June Broomhead's adenine hydrochloride and Megaw's much-used afwillite (both featured in Thomas's booklet) to W.L Bragg's spinel and Megaw's zinc hydroxide (inspiration for a striking large-scale wall tile.) Finally, there are *curriculum vitae* for the 14 eminent scientists whose structures were the design sources, followed by a bibliography.

Jackson has compiled an enjoyable and unusual book, visually attractive and well documented, with appeal to scientists, designers and teachers. Readers will gain some insight into the enthusiastic state of UK X-ray crystallography in 1951 (when the senior figures were predominantly physicists) and into the attitude to collaboration under difficult financial and material constraints. One hopes that *From atoms to patterns* may motivate some contemporary designers to consider patterns from a few of the immense number of structures now available and, indeed, from other scientific sources. One of the current IoP official ties, actually of optical vortices, has something of the look of an FPG electron-density map.

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