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A remarkable vision – Brewster's 1822 proposal for a 'National Burning Apparatus'

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In order to reduce the energy losses resulting from the thickness of large burning glasses, the French naturalist the Comte de Buffon proposed that such lenses should consist of a relatively small central lens surrounded by a series of stepped annular glass rings, all ground to direct light to the same focal point. In order to simplify the problems associated with manufacturing such rings, the Scottish physicist Sir David Brewster suggested in 1822 that it would be simpler if each annular ring consisted of a number of separate close-fitting segments. Convinced of the importance for scientific research in Britain of the availability of a burning glass larger than could be afforded by any single institution, he proposed the construction of a 'National Burning Apparatus,' "to the construction of which all the scientific institutions in the kingdom might contribute" – a remarkably prescient vision of the need for and value of national research facilities. He also outlined some of the important research that might be undertaken using such a device. However, his proposal elicited no response.

Keywords: Brewster; burning glass; National Burning Apparatus; Burning Sphere; national research facilities; William Parker

SIR DAVID BREWSTER

Sir David Brewster, FRS (1781–1868), a distinguished Scottish experimental physicist and exceptionally industrious editor and author, trained for the church at the University of Edinburgh (which he entered at age 12) but never practised as a minister (Morrison-Low, & Christie, 1984; Morrison-Low, 2004). He received no formal education in the sciences but, in the words of Sir Walter Scott, became a "self-taught philosopher, astronomer and mathematician" (*Encylopædia Brittanica*, 1911, 4, pp. 513–514). In 1799 his fellow-student Henry Brougham encouraged him to study refraction, marking the beginning of the study of many of the most important properties of light which occupied a central place in the rest of his life. During his long professional life, Brewster was the author of several hundred scientific papers, the great majority on properties of light such as polarisation by reflection and refraction. His work in this field is still universally remembered in the Brewster angle and Brewster's Law ("The tangent of the polarising angle for a substance is equal to its index of refraction"), the effect on polarisation of heat and pressure, the phenomenon of double refraction in materials such as Iceland Spar, reflection of light by metals and the absorption of light.

After a number of early contributions to the *Edinburgh Magazine*, in the year 1801–when aged only 26 – he assumed the editorship of the periodical. Six years later he also accepted the editorship of the planned *Edinburgh Encyclopædia*, a major publication in 18 substantial volumes, the publication of which spanned the years 1808–1830 (*Edinburgh Encylopædia*, 1808–1830). He also contributed numerous major articles – mostly on scientific subjects – both to this work and to the seventh and eighth editions (1823 and 1833) of the *Encyclopædia Brittanica*. Together with Robert Jameson he founded the *Edinburgh Philosophical Journal*, editing it together for its first 10 years, while at the same time editing the first 16 volumes of the *Edinburgh Journal of Science* (1824–1833). He is also notable as the author of the ground-breaking 1855 *Memoirs of the Life, Writings and Discoveries of Sir Isaac Newton* (Brewster, 1855), which remained the undisputed standard biography of Newton until R.S. Westfall's *Never at Rest* appeared in 1980, more than a century later (Westfall, 1980). In 1859 he was appointed principal of the University of Edinburgh, a position he held until his death in 1868.

Successful as he was as a physicist, editor and educator, in retrospect there can be little doubt however that his most enduring monument is the critically important role he played in the founding in 1831, together with Charles Babbage and Sir John Herschel, of the British Association for the Advancement of Science.

BREWSTER ON 'BURNING INSTRUMENTS'

Among the numerous papers and articles on optics published by Brewster, one of the most fascinating – and now largely forgotten – is the long entry on "burning instruments" published in 1812 in the *Edinburgh Encyclopædia* (Brewster, 1808–1830, 5, pp. 130–144). This is without question the most detailed and authoritative account of the overall history and properties of burning 'instruments', i.e. lenses and mirrors, that had yet appeared in English, showing Brewster's wide reading on the topic in English, French, German, Latin and Greek sources. Consisting largely of a comprehensive historical survey of the numerous devices, ranging from the time of the Greeks, designed to focus the rays of the sun in order to obtain the high temperatures required to carry out various dramatic processes ranging from the destruction of enemy ships to melting extremely refractory materials such as the noble metals, clays, rocks, etc., it was illustrated by two plates containing 18 diagrams.

One of the topics addressed by Brewster in the article is the relationship between the diameter and thickness of burning lenses. Clearly as the diameter of a convex burning lens increases, the temperature at the focus will also increase, but at the same time the thickness of the lens, especially at the centre, will also increase. This will result not only in the absorption of an increasing proportion of the incident radiation, but also in lenses that are increasingly difficult to manufacture, ever-heavier to mount and track the movement of the sun across the sky as well as being very expensive. (In effect these factors had imposed a practical limit to the size of the biconvex lenses which had hitherto been used as burning glasses.)

This problem had been addressed by the great 18th century French naturalist the Comte de Buffon (1707–1788), author of the magisterial multi-volume *Histoire Naturelle*. Brewster was clearly impressed by Buffon's proposed solution (Figure 1) and described it at some length in his article:

> In order to avoid the great thickness of glass at the centres of large convex lenses, Buffon has proposed a very ingenious contrivance. Instead of making the burning lens of one piece of glass, he proposes to form it of three concentric circular pieces resting upon each other.* Thus if the whole diameter of the lens is to be 24 inches, which would require a central thickness of three inches if it were of solid glass, the middle part will be a lens 8 inches in diameter, with a thickness of 1 inch. This lens is inserted in the middle of a circular zone, whose diameters are 8 and 16 inches, and this circular zone is again inserted in the middle of another circular zone, whose diameters are 16 and 24 inches. The surfaces of the lens and of the two zones are all ground to the same radius; so that when they are placed together, the solar rays will be refracted to one focus, in the very same manner as if they had fallen on a lens of 24 inches in diameter. The great advantages which are gained by this construction, is the diminution of the quantity of glass, as it does not require half as much as is necessary in lenses of one piece. In consequence of this diminution of thickness, the power of the lens is remarkably increased. The rays which fall upon the central parts, instead of being absorbed by the great mass of glass through which they had to pass, will be transmitted through the lens of 8 inches, and will be twice as powerful as if they had been refracted by a similar portion of a solid and continuous lens. (Brewster, 1808–1830, V, p.140) [*i.e. fitting snugly into each other].

BREWSTER'S POLYZONAL LENS

While Brewster was clearly impressed with the proposal for what Buffon called *Lentilles en echelons* ('stepped lenses'), acknowledging that he had "very ingeniously" eliminated the important problem of the "quantity of glass at the centre of the contrivance", at the same time he correctly pointed out that one of the relatively thin, flat circular outer zones of Buffon's burning glass "must be nearly as difficult to cast and grind as if it formed a part of the whole lens" – about which critically important issue Buffon had conveniently said nothing! (There is no evidence that Buffon actually constructed such a stepped lens, although the great Scottish lighthouse constructor Alan Stevenson noted that: "This suggestion of Buffon regarding the construction of large burning glasses, was first executed with tolerable success by the Abbé Rochon; but such are the difficulties attending the process of working a solid piece of glass into the necessary form that it is believed the only other instrument constructed in this manner, is [a lighthouse lens] made by this committee" (Stevenson, 1835, p.16)). At the same time Brewster emphasised some problems associated with large lenses in general: procuring large pieces of glass of an acceptable optical quality (i.e. free of veins, striations and bubbles); the problems associated with casting, grinding and polishing such large glass discs; the high absorption of light in the thick centre portion of the lens arising not only from its thickness but also from the 'numerous veins and imperfections' in the glass, and the cost both in terms of the purchase of a single large glass disc and the labour required to grind away a substantial proportion of the mass of the disc. He therefore proposed a development of Buffon's lens that was very similar in principle but differing in structure:

> In the year 1811, the idea occurred to me of constructing large lenses of *many zones* or *rings*, and of composing each zone of separate segments, so that a lens of any magnitude might be *built* as it were, of separate pieces; and in 1812, I published in the article already quoted, the following method of construction.... (Brewster, 1822–1823, p. 161)

Thus in Brewster's proposal for what he called a polyzonal lens, a relatively modest central circular convex lens of convenient size (he suggests 18 inches) would be surrounded by a close-fitting ring, or *zone*, made up of four glass pieces ground to the same focal length as the central lens and known as *segments* (Figure 2). If a larger lens was required then this first zone would be surrounded by a second one consisting of a set of eight segments, each of which would of course only subtend an angle of 45° at the centre of the lens, instead of 90° as in the first zone. Figure 3 shows a frontal, i. e. head-on, view of the central lens and the first two circular zones. If required, further zones could be added. A cross-sectional view of such a lens, clearly showing the stepped nature of the two zones, is shown in Figure 4.

In the context of this work by Brewster, it is interesting to note that in 1822 the eminent French physicist and engineer, Augustin-Jean Fresnel (1788–1827) constructed an annular lens in which the centres of curvature of the different rings receded from the axis according to their distances from the centre of the lens, thereby practically eliminating spherical aberration. Fresnel's extremely important work in this area, however, was driven by the requirements of the precision lenses required for lighthouses, a field to which he contributed substantially, rather than burning glasses.

In order to construct a burning device even more powerful than a large polyzonal lens – indeed 'unlimited in its power'– Brewster further proposed a more complex device which he named a 'Burning Sphere'. This consisted of a medium-sized central circular lens around which would be arranged a set of five, or more, relatively modest, circular, plano-convex lenses arranged such as to all have a common focus and onto which sunlight was directed by a number of plane mirrors set at appropriate angles (Brewster, 1808–1830,

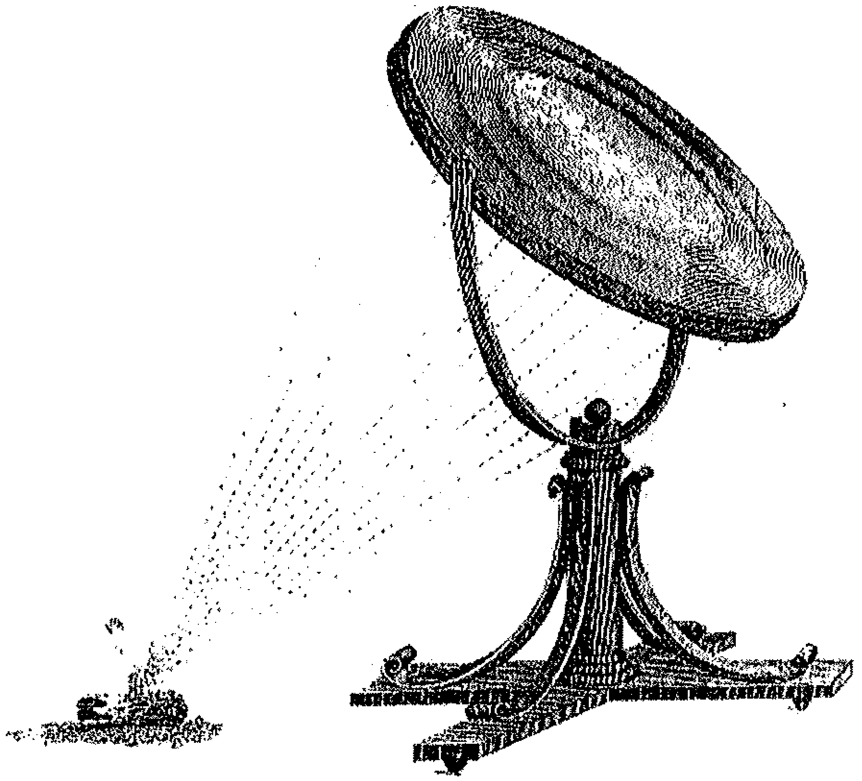

Figure 1. Buffon's *Lentille en echelon.*

V, pp. 143–144). A cross-sectional view of the device is shown in Figure 5. (Although not discussed by Brewster, clearly some form of rigid, weight-bearing, steerable support structure or frame would be required in order to maintain the optical components at the correct distances and angles relative to each other as well as to both point the whole system in the right direction and then track the sun as it moved across the sky.)

A NATIONAL BURNING APPARATUS

There is no evidence that Brewster's proposal in the *Edinburgh Encyclopædia* article that polyzonal lenses and burning spheres should be used for the attainment of high

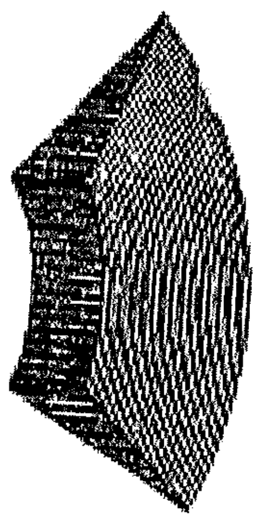

Figure 2. A segment of Brewster's Polyzonal Lens.

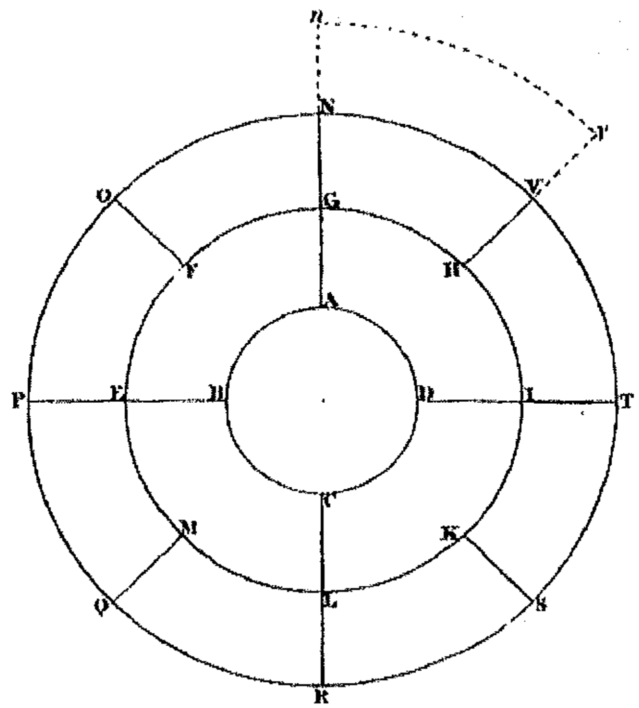

Figure 3. Head-on view of Brewster's Polyzonal Lens.

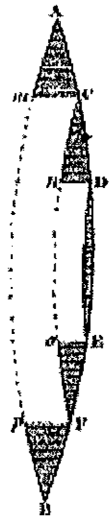

Figure 4. Cross-sectional view of Brewster's Polyzonal Lens.

temperatures evoked any interest at all amongst fellow scientists and one can only assume that his proposal had fallen on stony ground. He nevertheless persevered with the idea and some 10 years later, in an 1822 paper in the *Edinburgh Philosophical Journal*, the proposal was repeated almost word-for-word, but once again failed to bring any response.

Nevertheless Brewster's paper of 1822–1823 is of particular interest for a very different reason in that the paper contains an even more radical proposal for the use of the Sun in attaining high temperatures. This related to the construction of what he termed a "National Burning Apparatus" (or "national lens"), a somewhat grandly named device which would result in a burning lens "*five* or *six* feet in diameter", making it amongst the very largest yet constructed in either Britain or on the Continent. His proposal reads as follows:

The munificence of Sovereigns and of public Societies, has been so frequently displayed during the last century that, in the construction of instruments, beyond the reach of individual zeal, we cannot omit the present opportunity of suggesting the formation of a National Burning Apparatus, to the construction of which all the scientific institutions in the kingdom might contribute. Each society, for example, might undertake the formation of a single zone of the national lens, which zone would of itself be a useful burning glass, and might be afterwards completed when the society's funds enable it to do so. These numerous zones might then be combined for the purpose of occasional experiments, under the direction of our most distinguished philosophers, and we cannot doubt but that discoveries would thus be made which would form an epoch in the history of the arts and sciences. The fusion and combination of refractory materials could not fail to produce the most interesting compounds, and create processes in the useful arts of which at present we can form no conception. The reduction to fluidity of simple and compound materials, and the phenomena exhibited by their union, and by their slow cooling, would throw the clearest light on many of the most perplexing questions in geology, while every branch of general physics would derive new resources from the energy of such an irresistible agent. The expense of a polyzonal apparatus *five* or *six* feet in diameter, even in the more compound form of the *Burning Sphere*, could not much exceed L.[£] 300*, and we are confident that the public spirited individual who should advance such a sum for the interests of science, would do more for its progress, and acquire more reputation, than if he were the author of the most splendid discovery. (Brewster, 1822–1823, pp. 168–169)

*Parker's solid lens of 32 inches, now in the possession of the Emperor of China, cost L.[£] 700.

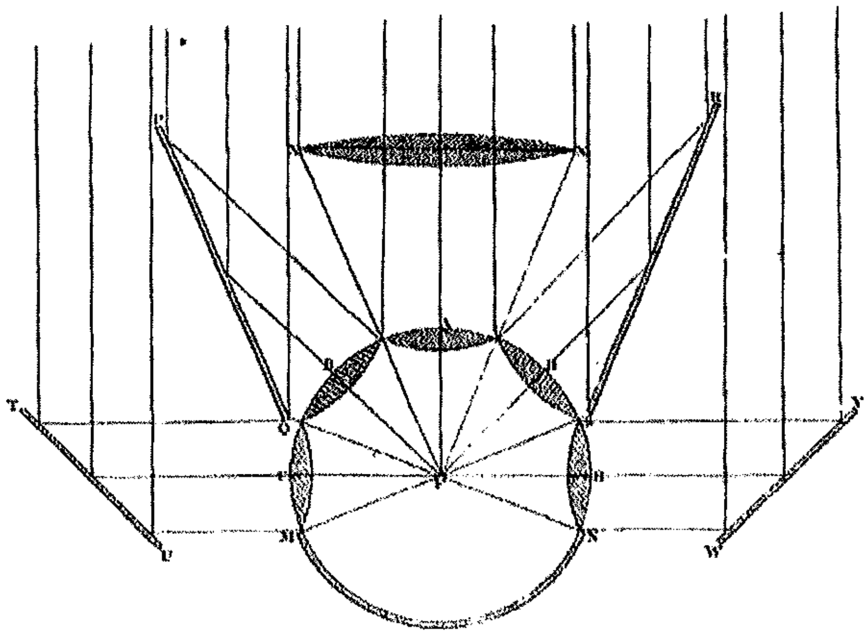

Figure 5. Brewster's 'Burning Sphere.'

[For details of Parker's lens see Appendix.]

Interestingly, Brewster provides no details as to which 'public societies' had been so munificent in the past, and could therefore be counted on as potential supporters in the future. He also provided no clue as to how he had arrived at the relatively modest estimated price of £300 for what was a relatively complex object, the construction of which would have made a heavy demand on both material and skilled labour. (He was nevertheless still anxious to promote his polyzonal lens and burning sphere, for in 1831 he again described the two devices, this time in a major paper in the *Transactions of the Royal Society of Edinburgh* (Brewster, 1831, pp. 33–72). While the article makes no mention of the proposed National Burning Apparatus, it is interesting to note that he had not completely abandoned the principle of shared components, for in discussing the Burning Sphere Brewster now makes the much less radical suggestion that "the lenses belonging to different individuals may be combined for any occasional experiments in which a great intensity of heat is required.")

As far as can be ascertained, Brewster's proposal for the construction of a National Burning Apparatus only subsequently surfaced in the literature twice, on both occasions in virtually identical form to his original proposal but with neither critical comment or response. These were in Samuel Gray's *The Operative Chemist* (Gray, 1828, p. 155) and in Smith Holman's *A Cyclopedia of Commerce and Commercial Navigation* (Holman & Holman, 1858, 2, p. 1858). But there, in 1858, the trail ended and, sadly, Brewster's dramatically original proposal had dropped out of the literature and had sunk without trace.

DISCUSSION

Brewster's 1822 proposal for the construction of a National Burning Apparatus – a potentially invaluable item of research equipment that would be available for use by any British scientist in conducting experimental work in which the very highest temperatures were required – was notable both for its boldness and its originality. It was unique not only as evidence of his realisation of the requirement in the field of high-temperature research for an exceptionally powerful national facility but also remarkable in its originality in realising that such a facility was beyond the means of any single institution and thus could only be attained by the sharing of components which could be assembled as and when required.

Brewster's proposal was also noteworthy from another point of view. Up to this time powerful burning devices had been very largely employed in dramatic, frequently public, demonstrations of their extraordinary ability to fuse or vaporise high melting point metals such as iron or platinum or various highly-refractory non-metallic materials such as magnesia or lime. In reality virtually none of these demonstrations produced anything of scientific value other than confirming that all substances are capable of being fused. In contrast to this a key aspect of Brewster's proposal is his vision of the value of the National Burning Apparatus as a serious research tool. This meant going beyond the investigation of the fusibility of 'simple and compound materials' in order to examine the properties of compounds formed at extremely high temperatures, the consequence for a material of rate of cooling, i.e. the study of the process of crystallisation of high melting point materials, and for its time, the remarkably prescient suggestion concerning the laboratory investigation of geological processes. "Every branch of general physics" would also benefit. It was a clear vision not only of a uniquely important device for attaining high temperatures but also how it might be used in numerous ways as an important national research tool.

Brewster's proposal is even more remarkable when viewed in the light of the British scientific scene of the time – a scene dramatically different from what it was later to become. Apart from the Royal Greenwich Observatory, founded by Charles II in 1675 and paid for out of the royal purse, and to some extent the privately-funded Royal Institution in London, founded in 1799 "for facilitating the general introduction of useful mechanical inventions and improvements", there were no research institutions devoted to serving British science as a whole, i.e. what were later to be known as national facilities. In the 1820s scientific research in Britain was still very much a matter of individual endeavour carried out in private at the universities, as for example Newton did in Cambridge in the 17th century or, more frequently, in private homes as was the case with highly creative, and frequently wealthy, scientists such as Boyle, Priestley, Cavendish or Benjamin Franklin during his stay in London. There were few formal university research facilities in the universities, although in Oxford chemistry laboratories existed in some of the colleges, such as Dr Lee's laboratory in Christ Church, Oxford, which had been founded in 1767.

The concept of what would later be known as national laboratories, funded by the state and devoted to the solution of problems either deemed to be of major national importance, or requiring equipment and facilities too large and expensive to be afforded by any single university, came much later in the form of such important national institutions as the Physikalisch-Technische Reichsanstalt in Germany (1887), the National Physical Laboratory in Britain (1900), the National Bureau of Standards in the United States (1901) and the National Research Council of Canada (1916). By any standards Brewster's proposal was remarkably far-seeing.

THE ORIGIN AND FATE OF BREWSTER'S PROPOSAL

Brewster gave no indication as to what had led him to propose the creation of a National Burning Apparatus. However, as we have seen, in compiling his major 1812 review of the history of burning instruments for the *Edinburgh Encyclopædia* he had with his characteristic thoroughness read widely on the subject and from this he could hardly have remained unaware of how far Britain lagged behind France, Germany and Italy in what he clearly viewed as an important research field. In support of this view is the fact that, as Morrison-Low has pointed out, during his period as editor of the *Edinburgh Journal of Science* (1824–1833) the journal was notable for its expression of strong views on what Brewster saw as the decline of British science (Morrison-Low, 2004: 525).

To Brewster it was unquestionably important that this national gap in the availability in Britain of a high temperature research facility be closed. However, given the financial requirements inherent in such an enterprise he had clearly come to the conclusion that the resources required for the construction of such a device were too large for any single institution and the only solution was a cooperative effort involving a number of institutions.

Why did Brewster's proposal for the creation of a National Burning Apparatus not evoke any meaningful response? Perhaps the fact that it only appeared in the *Edinburgh Philosophical Journal*, which doubtless had a relatively modest circulation, especially in England, compared to the more widely read journals such as the *Philosophical Transactions of the Royal Society*, the *Transactions of the Royal Society of Edinburgh* or the

Philosophical Magazine, may well have been a factor. There was also the fact that in the early 19th century cooperative ventures between scientific institutions were simply not required as, apart from astronomy, scientific research was almost invariably carried out on a scale requiring modest laboratory facilities. On a more practical level there would have been major problems relating to the assembly of a device, the relatively fragile components of which would have to be transported to one location from all over the British Isles – and this well before the advent of a national railway network.

In spite of – or perhaps also because of – its boldness and originality, Brewster's proposal for a national high-temperature research facility was simply both too far ahead of its time in concept and too difficult to implement in practice. In retrospect it was thus inevitably doomed to failure and, sadly, simply disappeared without trace.

Although Brewster's proposed National Burning Apparatus was never constructed in the form in which he visualised it, the concept of a national high-temperature research facility exists today in a number of large national solar furnaces, the largest at Odeillo in the French Pyrénées. This major installation, which has been operating since 1970, consists of 10 000 plane mirrors with a total collecting area of 2000 m^2 and produces temperatures up to 3000 °C. Its rich programme of high-temperature scientific research would undoubtedly have gladdened Brewster's heart.

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APPENDIX. WILLIAM PARKER'S BURNING LENS

It is particularly interesting that in his proposal for the creation of a National Burning Apparatus the only other burning glass mentioned by Brewster is that of William Parker, a glass and instrument maker based in Fleet Street, London, who had supplied Priestley with "a capital burning lens sixteen inches in diameter" for use in his researches (Rutt, 1831, p. 147). The lens by Parker referred to by Brewster was almost three feet in diameter and had been constructed at Parker's own expense in the hope that it might be bought by the Royal Society (McDonald & Hunt, 1982, p. 114). This celebrated lens (see Figure A1), reputed to have cost the very substantial sum of £700, was of flint glass, three inches thick at the centre and weighed 212 lb. – dramatic support for Brewster's concerns about the weight and thickness of large burning lenses! It had a secondary convex lens a foot in diameter and was supported on an impressive stand. As was the case with so many other large lenses it seems to have been principally used in fusing or vaporising a wide variety of refractory materials, all of which it melted or vaporised in periods ranging from 3 to 88 seconds.

Its subsequent history is particularly interesting, for it was amongst the numerous gifts that Lord Macartney bore to the Emperor of China when he visited Peking (as it then was) in 1792–1793 (Staunton, 1797). Thereafter Parker's great lens disappeared without trace and its subsequent history and present whereabouts are unknown, even eluding Joseph Needham's ever-assiduous searches.

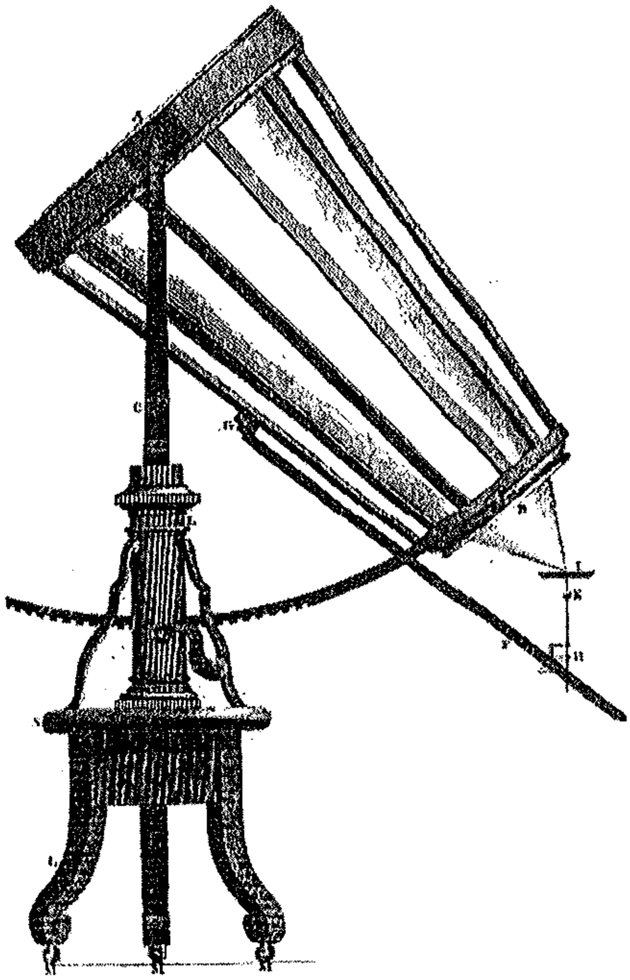

Figure A1. Parker's great Burning Lens.