THE PRODUCTION OF ACHROMATIC OBJECTIVES IN THE FIRST HALF OF THE NINETEENTH CENTURY: THE CONTRIBUTION OF GIOVANNI BATTISTA AMICI

Edoardo Proverbio
Istituto di Fisica Superiore e Astronomia, Università di Cagliari

1. Optical Glass in the First Half of the Nineteenth Century

At the end of the 18th century, the production of glass or common optical crystal was limited to Venice, London and surrounding areas (English crown glass) and to the few glassworks in France (common French glass) and Bohemia (Bohemian glass and crystal), as had been the case fifty years before[1].

Lead glass (English flint glass), which was heavier than ordinary glass owing to the lead oxides contained in it, was produced in small quantities even in England, at least up to 1825, at which time the tax on glass was no longer calculated on the basis of weight[2]. The production of German strass glass was even more limited, and in France the first works for the production of lead glass was built only some time around 1785[3]. Besides the scarcity of raw materials, represented by common glass and lead glass, there was also the problem of obtaining homogeneous glass disks with no irregularities (veins, layers, etc.) or air bubbles that made it difficult to produce good achromatic lenses. Even at the beginning of the 19th century glassmakers considered themselves fortunate when they succeeded in getting disks above 4 inches in diameter without visible defects[4], and the renowned three-

lens objectives with a three and three-quarter inch aperture and a forty to forty-six inch focal length built by Peter Dollond starting from 1763, represented the state of the art in England, at least up to his death in 1820[5].

It is thus no wonder that in the early years of the 19th century refractory telescopes seemed incapable of competing with the large metal reflecting telescopes built by William Herschel. Apart from the large, forty-eight inch, forty foot focal length reflector, begun in 1786 and finished in 1789[6], it is known that Herschel also worked on a large number of reflecting objectives having apertures varying from six to eighteen inches[7], which were used by Herschel himself and many other observers and, following his death in 1822, many London opticians followed his example by building reflecting objectives and telescopes at fairly reasonable prices[8]. However, in the light of the difficulty of working large-sized mirrors, their apertures were rarely above twelve inches, and only the most skilled craftsmen and amateurs, like John Ramage, succeeded in producing Newtonian telescopes with thirteen and a half and fifteen inch mirrors during Herschel's lifetime[9].

Still in 1840, after the large, forty-eight inch azimuthal telescope had been taken out of service in 1839, the largest and most accurate reflector was the eighteen inch, twenty foot focal length one built by Herschel with which his son John made the important austral observations that were published in 1847[10].

But in the meantime a revolutionary change in perspective had taken place in the production of optical glass thanks to Pierre Louis Guinand, a Swiss craftsman from Brenèts who succeeded in producing al-

most perfect, large flint glass disks. Guinand began producing optical glass sometime around 1783, and by the end of the century he was able to produce excellent four to six inch glass disks. A decisive step forward was made in 1805 when Guinand, by improving a technique he himself had introduced in 1798, made use of a device for stirring the vitreous material during fusion, thus obtaining flint glass of great homogeneity and without defects[11]. Guinand's stirring technique guaranteed not only a uniform distribution of the components such as silicon dioxide, lead oxide and sodium or potassium carbonate having quite different densities, but also helped in completely eliminating the air bubbles generated during the fusion and refining of the glass.

In 1806 Guinand was invited to direct the works of a laboratory for the production of flint glass at the "Mathematical-Mechanical Institut" financed by G. Reichenbach and other partners with headquarters in Munich. In this laboratory, situated in an old Benedictine monastery at Benediktbeuern, about sixty kilometers from Munich, Joseph Fraunhofer began his work in 1806[12].

Collaboration between Guinand and Fraunhofer led to improvements in the kilns used for melting and in techniques for the grinding and cleaning of lenses, which was entrusted to Fraunhofer. The latter also introduced new methods for checking the spherical surfaces, based on Newton's rings and special micrometric spherometers[13]. This led in 1812 to the production of flint glass disks of up to approximately ten inches[14]. In 1814, due to disagreements between Fraunhofer and Guinand, the latter returned to Brenèts in May of that year, where he continued his research on the production of flint glass. Using a new method, which is still in use today for the production of glass disks, based on the slow cooling of the material in special circular moulds,

he succeeded in avoiding having to carry out the finishing operations that were necessary with the blocks of glass obtained directly from the melting pots, and managed to produce homogeneous glass disks of twelve, and in one exceptional case, eighteen inches in diameter[15].

Guinand's glass disks were at the time far larger and more homogeneous than those obtained with traditional methods by the best English and French glassmakers. The finest French producers of optical glass, such as d'Artigues and Dufougerais, were still convinced of the technical impossibility of obtaining good flint from anything but large blocks of crystal, and in 1809 the latter succeeded in producing a block of crystal weighing six hundred kilograms[16]. But the most skilled opticians and builders of optical instruments, both in France and England, fought to buy all the crystal that Guinand made[17], and Guinand himself was asked insistently, but in vain, to set up a crystal works in England just before his death in 1824[18].

It is to be presumed that during his activity at the Munich institute Fraunhofer came to know of the new methods introduced by Guinand for the production of homogeneous optical glass, and that he was therefore able, following Guinand's departure, to produce excellent flint glass[19].

Besides the good quality of the glass, the construction of an achromatic telescope also required an exact knowledge of the radius of curvature and the curvature at every point on the surface of concave and convex lenses, as well as the precise measurement of the refraction and dispersion indices of the glass used.

More than fifty years before, in 1767, R. J. Boscovich had proposed a method for measuring the radius of curvature of lenses based on observation of the image of a reticule reflected on the surface of a lens[20]. This semi-quantitative method, however, gave only the average curvature radius and could not show up defects in the sphericity of a lens. As has been said, Fraunhofer introduced much more precise measuring techniques, and it can be said that with the use of his spherometers he contributed to the birth of the modern science of spherometry[21], even though still in 1851, the general report of the Paris Exposition, in the part dedicated to astronomical instruments, underlined the fact that: "Les progrés qui ont été faits, en optic et dans l'art de tailler, de polir le verre, ont beaucoup simplifié la construction des objectifs; cependant la courbure de surfaces des lentilles est ancore assez difficile à determiner par le calcul et à executer par les moyens mécaniques connus"[22].

Still more complex at the beginning of the century was the problem of measuring the refractive and dispersive quality of glass. Also in this field the methods and instruments introduced by R. J. Boscovich, in particular his "vitrometro", were widely used and still in use for teaching purposes in the second half of the 19th century[23].

A real advance in this field was however made following Fraunhofer's discovery of the lines in the sodium spectrum. Above all, the dark absorption lines in the solar spectrum which, already hinted at by Wollaston in 1802[24], were analyzed by Fraunhofer and Soldner in 1814 and used as a source of monochromatic light in the measurement of the refraction index of various crystals[25]. Boscovich had already made use of the method of the "minimum deviation" of a luminous ray on passing through a prism, the theory of which had been previously deve-

loped[26], for calculating the refraction index $\underline{m}(\lambda)$ of glass, using the colours of the solar spectrum for the purpose. Fraunhofer applied the same method to the calculation of the refraction index, using absorption lines C (λ = 656 nm), D (λ = 589 nm) and F (λ = 473 nm) of the solar spectrum instead of its colours, which he himself had proposed, thus arriving at much more precise measurements. With the solar spectrum method, Boscovich and his contemporaries were able to determine the value of $\underline{m}$ up to the third decimal place. Fraunhofer, by measuring the prism's angle of refraction by means of the goniometer introduced by Wollaston and the angle of deviation of the monochromatic radiation beam in the minimum deviation condition with a spectrometer consisting of a collimator and a telescope on a graduated circle, was able to measure the refraction index of glass up to the fifth decimal place[27].

This progress in the techniques used in the production and working of optical glass and in the measurement of its refraction index, as is known, gave Fraunhofer the possibility of producing in the period around 1820 some of the best achromatic objectives, and of arriving at the production in 1824 of the famous equatorial telescope with the achromatic nine and a half inch objective with a fourteen foot focal length, corrected for spherical aberration, with which Wilhelm Struve carried out his fundamental observations of double stars at the Dorpat Observatory.

Fraunhofer was the first to publicize his success in the production of optical glass against the claims made for the glass produced in England[29], and, as has justly been pointed out[30], this was undoubtedly the result of the new processes of industrial production developed at the Benediktbeuern laboratory which Utzschneider, after Rei-

chenbach had set up his own workshop specialized in the construction of astronomical instruments, had transferred to Munich in 1820, sharing its management with Fraunhofer[31]. This situation, which in practice had determined the passage of hegemony in the production of optical glass from Great Britain to Germany, led to the decision by the British government in 1825 to reduce drastically the excises on the sale of flint glass based on weight and, albeit tardy, to take steps to stimulate the production of this kind of glass with the creation, in 1824, of a technical committee of which the chemist and physicist Michael Faraday, William Herschel and George Dollond, the grandson of John, were members[32].

Following the death of Fraunhofer in June of 1826, Utzschneider directed the Munich institute with the assistance of George Merz, who had worked with Fraunhofer from 1808 on. At the death of Utzschneider in 1839, Merz, with financial help, took over the entire Munich complex for the production of optical glass, producing excellent achromatic objectives[33], like the large twelve and three quarter inch, eighteen foot focal length objective of the equatorial telescope that G. B. Airy installed at the Greenwich Observatory in 1846[34].

However, there is no doubt that at least up to the first half of the century the largest and finest quality glass disks were still being produced by Henri Guinand, the eldest son of Pierre who, in 1827, having passed on the secret of working and preparing lead glass to the glassmaker Georges Bontemps and the optician J. N. Lerebours, had moved his productive activities to the Bontemps Glassworks in Choisy-le Roy, near Paris[35].

In 1837, Lucas Change of the Change Brothers Glassworks in Birmingham, then bought the secret of working lead glass from G. Bontemps and patented it in the following year. However, only in 1848, since Bontemps had had to flee to England for policital reasons, a new plant was set up for the production of optical glass, based on Change's patented process, and from that time on English production reached the level of the best European products[36].

2. Giovanni Battista Amici's Practical Experiments in the Field of Optics

In Italy, during the first decades of the 19th century, after Giovanni Stefano Conti's experiments in the production of flint glass carried out in Lucca with the cooperation of Roger J. Boscovich,[37] approximately from 1763 to 1773, and those carried out in Venice by Lorenzo Selva, he too with Boscovich's help[38], there does not appear to have been any production of lead glass of a quality even remotely comparable to what was being produced in the specialized glassworks of France, England and Germany, and even in the production of common optical glass the activity of the venerable glassworks of Venice and Murano was in rapid decline in both quality and quantity. In the field of the production of optical instruments, and more precisely in the production of astronomical instruments, it appears that the situation was no better. To the names of the German mechanics and builders of the Munich school Georg Reichenbach (1772-1826) and his apprentice Trangott L. Ertel (1778-1858), or Johann Georg Repsold (1771-1830), who worked in Hanover, to the fame of the English builders Edward Troughton (1753-1835) and George Dollond (1774-1852) or, finally, to the ability of the Parisian mechanic Henri Gambey (1767-1847), at the beginning of the 19th century Italy could boast of no craftsmen capa-

ble of competing with them in the production of astronomical instruments. This is not to say that the mechanical and technical opticians working in, or in connection with, the astronomical observatories and university laboratories were less skilled than their foreign counterparts, but they certainly had less experience in the construction of large reflecting and refracting telescopes, and it was above all the fragmentation and limited size of the Italian domestic market and the lack of capital and incentives in the research field that were among the obstacles hindering the development of productive activities in this field in the Italian States, except on a very small scale at the workshop level.

In actual fact, theoretical studies on optics were not in the least neglected in Italy. Following the great example of Boscovich[39], Giovanni Santini (1787-1877), who had been educated at the school of the Milanese astronomers Oriani and De Cesaris, and who had been appointed Director of the Observatory of Padua in 1817, published, in the wake of Euler, a treatise in 1828 on the "Teoria degli stromenti ottici", which still at the beginning of our century constituted a most useful aid for builders of optical instruments.

And it is just at the beginning of the 19th century that we can place the beginnings of the activity of Giovanni Battista Amici (1786-1863), who deserves credit for having brought practical and instrumental optics in Italy back to a level competitive with English and German production.

On the exceptional activity and merits of Amici, an optician and the inventor of the most varied optical instruments, from reflecting telescopes down to microscopes and other special optical instruments,

there is a long bibliography, and numerous contributions were published to celebrate the two-hundredth anniversary of his birth[40]. There are still, however, certain aspects of Amici's activity that deserve further exploration in depth. The long road that led the great optician from the assembling of reflecting telescopes to the production of achromatic telescopes, at first without lenses, and then to very large achromatic objectives, is in fact still disseminated with as yet undiscovered particulars which may lead, among other things, to the shedding of new light on some aspects of Amici's activities that have not been fully assessed, such as his contribution to the development of the optics of prisms[41] and the extending and connection of the purely technical aspects of his production of instruments to problems just as essential, but of a more strictly technological nature. I refer, in particular, to the question of finding and using special metals for mirrors and optical glass, and of Amici's contribution to the production of these materials.

There is little first-hand information on the formation of Amici's theoretical knowledge in the fields of physics and optics. We know that he enrolled in the course for engineer-architects in scholastic year 1802-03 at the Scuole Maggiori at the Scuole (later "Licei") Dipartimentali of Modena, and followed the first three courses. During school year 1805-06 he also attended, still at the Lycée of Modena, a course in Natural History as well as that of Mechanics and Hydromechanics taught by the famous mathematician Paolo Ruffini.

After his period of military service, he concluded his university studies at the University of Bologna in June 1808, with an Honours degree in Engineering and Architecture[42]. Most precious is the information given in the manuscript "Appunti di G. B. Amici sugli inizi della

sua attività tecnica", to be found in the Biblioteca Estense[43], from which it can be deduced that already in 1809 Amici had a good knowledge of the classic treatise on practical and theoretical optics by Robert Smith[44]. It must also be thought that Amici's interest in the problems of theoretical optics was closely connected with the applications of achromatic objectives that he later made, at different times, to the microscope and to the telescope. This hypothesis is confirmed, in particular, by the correspondence that Amici carried on with Giovanni Santini and Fabrizio Mossotti (1791-1863), without doubt the most illustrious Italian scholar in the field of optics in the 19th century[45]. It is no mere coincidence, in fact, that Amici, upon his return from a journey to France and England in 1827, where he had presented his new achromatic microscope, wrote to Santini to thank him for having sent the second volume of the "Teoria degli stromenti ottici"[46], and also added: "Avrei amato di trovare nella sua opera qualche cosa di più, intorno agli obiettivi acromatici da microscopio. Le teorie di Eulero e di Krugel sono imperfette; e questo ramo difficilissimo meriterebbe d'essere portato avanti. Io ho fatto qualche passo, oserei dire considerevole; ma una completa teoria potrebbe forse prometterci un miglior successo"[47].

Thus, Amici's discoveries and contributions to instrumental and practical optics are first and foremost based on a solid knowledge of theoretical optics together with the capacity to apply and improve methods for calculating optical instruments contained in Smith's classic work, and in the more recent works by Santini and then Mossotti.

But to arrive at a better evaluation of his contribution to the development of techniques for the building of achromatic objectives and telescopes, a more detailed investigation into his degree of com-

petence and activities in the field of the production and working of optical glass is indispensible.

In the Giornale Italiano mentioned in the biography of Amici written by his son-in-law Francesco Palermo[48], we find: "L'Amici da sé solo, senza l'opera d'alcuno artista, tentò la maggior parte degli esperimenti, alcuni dei quali di sua invenzione, e vi riuscì, prima dell'autunno 1809", and Palermo added that Amici had commented in his own handwriting on this information with these exact words: "I suoi metodi per costruire specchi da telescopio, gli ha potuto immaginare in virtù delle sue cognizioni teoriche. Cose agevoli e di poca spesa; il che ha fatto che si siano formati diversi allievi"[49]. This addition by Amici, probably written some time after the article in question, brings us forward, however, to a later period , since Amici had already demonstrated his great talent as a practical optician and had presumably already begun his activity of producing optical instruments of the highest quality.

It is known that towards the end of the 18th century and in the first years of the century that followed, there were several good craftsmen in Modena capable of working lenses and prisms[50]; and it is in the same period that the treatise "Macchine per formare nel medesimo tempo lenti convesse e lenti concave" by Giambattista Vandelli, a professor at the University of Modena, was published[51].

It also appears certain that Giuseppe Amici, Giovanni Battista'a father and head of the General Accounting Office[52], that is to say the Land Office of Modena, had already set up a workshop in his home in Contrada de' Servi no. 1830, in which he presumably repaired or even built regular optical instruments for use in mapping and land survey-

ing[53], and it is also to be presumed that his young son gained his first experience in the field of practical optics in this very workshop, with the help and encouragement of his father. And it seems that the father not only gave Giovanni Battista Amici his start in this activity, also with financial assistance, but "poiché si recava spesso a Milano per ragioni d'ufficio, si fermava anche nella Biblioteca di Brera a copiare intere memorie di ottica, per agevolare al figlio l'acquisizione di notizie teoriche e pratiche di ottica"[54]. If we are to believe G. B. Amici's "Appunti", mentioned above, it was in June of 1808 that Amici himself, "frequentando la bottega di certo Mattioli armajolo di professione", found himself witnessing "certi esperimenti di composizione di metallo che il S.r. Giuseppe Zoboli modenese famoso fabbricatore di telescopi acromatici, faceva eseguire al detto armajolo. Portatomi subito a casa mia", Amici declared, "ove abitava ancora un fonditore di metalli e lavoratore di tornio S.r. Giuseppe Sgarbi gli feci fondere le due leghe che si trovano nel Montucla cioè la prima due parti di rame, una di stagno ed una di ottone, e l'altra 32 di rame, 15 di stagno, d'argento, di ottone ed una d'arsenico e mi parve che risultassero assai buone e specialmente l'ultima"[55].

Amici went on to describe the method he applied, taken from the "Ottica" by Smith, for working and polishing the sheets of metal, based on the use of a marble or bronze piatto or padella covered "con un taffetà in cui vi si applica una dissoluzione di pece nello spirito di vino, e vi si usa sopra il pezzo che vi si vuol pulire con della poté ossia stagno calcinato"[56]. The cleaning operation was a success, and at that point Amici must have been highly motivated to improve his knowledge, above all on techniques for working mirrors so as to give them the proper curvature[57].

In reality, the problem of the form to give mirrors and telescope lenses still presented serious practical problems. After Descartes had shown that only lenses of elliptical or hyperbolic form were corrected for axial geometric aberrations, a certain number of attempts were made during the 17th and 18th centuries to produce this kind of lens, but with no success[58]. And the parabolic form to give to long focal length mirrors still seemed a mirage in the first decades of the 19th century if we are to believe Amici who, in a letter to Michele Araldi dated 3rd September 1820, stated on the subject of the working of mirrors: "Rispetto alla curvatura io non sono capace finora di dargli altro che la sferica, e con grande difficoltà anche a dargliela perfettissima, imperocché bastano quattro o cinque colpi irregolari quando si è vicino al termine del lavoro per guastarla sensibilmente". And on the same subject Amici confirmed having "eseguiti con diligenza tutti i processi descritti nell'Ottica di Smith, nella memoria del Dr. Mudge stampata nelle transazioni filosofiche[59], ed in altri autori, per dargli la figura parabolica, e non mi è stato possibile ottenere l'intento". And he concluded the question by saying: "Mi sovviene però di avere letto nel Tomo terzo della Storia delle matematiche di Montucla continuata da Lalande, che il Signor Herschell ha trovato che sono tutte chimere i processi par dare la figura parabolica, ad uno specchio che supera i sei piedi di fuoco, perché in tal caso la vera figura differisce così poco dalla sferica che si potrebbe scomettere cento contro uno, che il più abile e sperimentato artefice non è capace di dargliela. Ma gli specchi che ho costruito non arrivano ai sei piedi di fuoco, ma vi approssimano, e quantunque in questi non sia esclusa la possibilità di dargli la figura parabolica, bisogna che io convenga che questa è la parte più difficile, e stimo non potersi pervenire, che con l'abitudine e destrezza nel lavoro"[60]. On the other hand, the controversy that saw him opposed to the turner Giovanni

Gualtieri appears to have been centred around the problems of the cleaning and the parabolic shaping of mirrors[61], at the perfect working of which it can be supposed that Amici arrived only many years later[62].

In any case, it can be said that the period from 1809 to 1811 was that of Amici's first experiences as a practical optician. In those years his ability and competence in the working of metal mirrors surpassed those of other illustrious craftsmen and opticians, as for example those of the craftsmen of the famous Isimbardi workshop in Milan[63]. It is in this period that he came into contact with Count Pietro Moscati, Minister of Education of the Kingdom of Italy[64], and made the acquaintance of the astronomers at the Brera Observatory, Oriani and De Cesaris[65].

With the knowledge and experience he had accumulated, in 1811 Amici was able to build the two famous six and a half inch aperture telescopes that he presented both to Moscati and the Brera astronomers, which led to his recognition by the Committee of the Istituto Lombardo, and, the following year, the reflecting microscope that he demonstrated at the national Concorso delle Arti e dell'Industria.

Despite some unpleasant controversies[66], and the problems inherent in the difficulty of finding highly qualified personnel[67], in 1811, in the workshop in Via dé Servi, Amici succeeded in setting up the production of telescopes, microscopes and other optical instruments, such as the "camere lucide" based on the use of mirrors and prisms, and managed to meet the growing demand for these products from Italy as well as from abroad[68].

Thus, Amici's main activity developed at the level of high-quality craftsmanship in his own laboratory[69], and proves to have been mostly centred round the production of instruments with mirrors. The basic material, that is to say the metal alloys for the making of mirrors, was produced in his workshop or at the "fonderia de' cannoni di Pavia" for large-size objectives such as those having a four foot diameter, designed but never built[70]. Still in 1818, in one of his few works that were published on catadioptric microscopes, he stated that he had "avuto occasione di riconoscere in pratica la superiorità che hanno i riflettori astronomici sopra i rifrattori"[71].

In 1824, Amici was visited by John Herschell, and in 1825 and 1826, in two letters to the latter[72] and to Baron de Zac[73], the renowned observer of double stars, he went to great lengths to demonstrate the superiority, both in luminosity and separating power, of his eleven inch reflector with respect to the large, nine and a half inch refracting telescope built by Fraunhofer.

In reality, as has been seen, the production of excellent optical glass, both common and lead, had led to the realization, starting from about 1820 on, of excellent achromatic objectives which, compared to reflectors, had the advantage of requiring less precision in the working of spherical surfaces[74], a higher factor of incidental light transmission[75] and far fewer problems with the deterioration of the reflecting and transparent surfaces caused by air and atmospheric dust. The very high quality of Amici's mirrors, ever in comparison with those of William Herschel[76], was substantially due to the use of metal alloys having high reflecting power, which were the result of numerous and painstaking experiments as well as to the techniques for working and cleaning the reflecting surfaces that he used. A refe-

rence to Amici's important activity in the field of technical optics and the problems connected with the realization of reflecting surfaces is made in the letter he wrote to Michele Aroldi in Bologna dated 5th September 1820, in which he stated that: "riguardo alla composizione degli specchi metallici, ho trovato una lega poco dispendiosa, e che gode della proprietà di essere più bianca, più compatta, e più dura di qualunque altra a me cognita, ed in conseguenza di questa più atta a riflettere maggiore luce, ad acquistare un più fino pulimento e meno soggetta ad offuscarsi per l'azione dell'aria, ed infine a mostrare gli oggetti, quasi del loro colore naturale e non tinti di un colore giallognolo, o rossiccio". The "pulimento", Amici went on to say, "glielo dò con somma facilità, ed il metallo acquista un lustro non inferiore agli specchi lavorati in Inghilterra, non esclusi, per quanto mi si fà credere, quelli del S.r. Herschell e certamente più lucidi di quelli d'altri autori, che ho veduto"[77].

Concerning the difficulties involved in the parabolic shaping of the reflecting surfaces, these have been mentioned before, and the many large spherical mirrors built by Amici bear witness to this fact[78].

On the other hand, it was Fraunhofer himself who was quick to draw attention to the defects presented by reflecting telescopes of the time in his famous Memoria of 1824, presented to the Bavarian Academy of Sciences[79], and the arguments raised by John Herschell to contest his affirmations do not appear to be entirely convincing[80].

3. Giovanni Battista Amici's Achromatic Objectives

Amici's interest in the construction of achromatic lenses and objectives can be placed in the period 1820-1821, which can thus be considered a period of transition. In fact, it was in 1821 that Amici, perhaps doubting the possibility of improving the performance of reflecting objectives, but still convinced of the difficulty of obtaining lenses made of common and lead glass of the necessary purity, turned his attention to observational techniques, which at first sight appeared unusual, and even arrived at the point of designing and building a prismatic telescope, that is to say, an achromatic telescope using prisms of the same material instead of lenses having different refraction indices[81]. This telescope, based on the use of three or four prisms of crown or flint glass, with which Amici said he had worked from 1815 onwards, although bearing witness to the ingenuity of this great optician, cannot be said to constitute a credible alternative to reflecting or refracting achromatic telescopes, since the magnification that could be obtained with this instrument was quite modest. Amici's prismatic telescope leads us to discuss one aspect of Amici's practical and theoretical activity that has still not been dealt with in great detail, and which concerns his studies and observations on the properties of prisms[82]. This activity, which presumably is to be placed in the period from 1815 to 1820, is connected with his first experiences in the working, and perhaps in the production, of optical glass, which in turn led him to the construction of the first "opera glasses", the production of which surely goes back before 1820[83]. His activity in the production and use of prisms put him, in fact, face to face with the problem of finding optical glass, which must have been, to judge from a letter to Giovanni Santini written in February of 1824, one of the new, not easily solved problems to which Amici dedicated great interest from that time on[84]. The making

of small prisms and objectives for opera glasses and, starting from 1826-27, following the construction of the first dioptric microscopes, the production of objectives for the latter instruments, presented no difficulties that could not be overcome easily, since it was a fairly simple matter to find small pieces of crown and flint glass of good quality on the English and French markets. But if the idea was to produce astronomical telescopes with objectives of even modest size the problem became far more complex.

If we are to judge from the "Libro de' Conti del Laboratorio", in Amici's own handwriting, it can be seen that among the "macchine esitate", which is to say sold, we find, on 6th April 1821, "un cannocchiale acromatico con piede e camera lucida, con cassetta di noce per l'Arciduca di Modena"[85]. This was perhaps the first achromatic telescope that Amici had produced. Its aperture and focal length are unknown.

The fact that Amici gave this telescope to Archduke Francesco IV d'Austria-Este[86] cannot but confirm this hypothesis, since on many other occasions, such as that of the making of the first reflector and mirror microscope or, later on, the first achromatic microscope, Amici had always considered it a good idea to present these instruments to important personages in the fields of government and science, perhaps with the idea not only of showing off their good quality but also of promoting his discoveries commercially. The fact remains that starting from 1821, as we see from the "Libro de' Conti del Laboratorio", not only in the list of the "macchine esitate"[87], but also from the "spese di materiale", in which we find for the first time the items "cristallo" and "dischi di cristallo"[88], Amici showed an ever-growing interest in the production of achromatic objectives and telescopes.

It was in this period that he was involved, among other things, in the building of a transit instrument for the new Astronomical Observatory of Modena[89].

As has been said, one of the greatest difficulties that Amici was faced with was that of obtaining the purest optical glass for the production of prisms and objectives. And it was this difficulty that for a certain number of years led Amici to believe, with alternating phases, that reflecting astronomical instruments were a valid alternative to the use of achromatic objectives. Still in October of 1824, in a letter to Giovanni Santini, in the face of the unfruitful search for optical glass in England, France and Bohemia, which he needed for the construction of a micrometer with divided lenses[90], he proposed overcoming this obstacle with the construction of a reflecting circle with mirrors[91].

The strong point of Amici's reflecting telescopes was in their high reflecting power as the result of the special alloys he used and his great ability in the grinding and polishing operations. Amici was, however, aware of the fact that his alloys were too friable to be used in the making of large-size ojectives[92]. Furthermore, although at the beginning of 1825 he was still a partisan of reflecting telescopes, he openly recognized that the latter were inferior to refracting ones "se si riguarda alla minor apertura che gli ultimi abbisognano, al comodo di applicarli ad istrumenti diversi, all'inalterabilità della sostanza del vetro, che rende comparabili le osservazioni, in epoche lontanissime, ed in fine al facile uso che se ne può fare, rimanendo il vitreo obiettivo costantemente centrato, in quel miglior modo, che l'artista lo ha disposto". This was a condition "di tale importanza presso una certa veste di osservatori che per essa sola"

the latter "non esitano preferire un mediocre cannocchiale acromatico ad un buon telescopio di forma newtoniana"[93].

All these considerations could not but lead Amici to a progressive modification of his already uncertain point of view concerning refracting telescopes.

In the summer of 1827 he made a journey first to London and then to Paris, where he presented his new achromatic microscope, and it is more than probable that at this time he made the acquaintance of the best-known London opticians, such as George Dollond and Peter Barlow[94], but above all of the craftsmen in the workshops producing crown and flint optical glass. We cannot even exclude that at that time George Bontemps' glassworks at Choisy-le-Roi, near Paris, had already begun the production of flint glass, and that Amici had had the occasion to get in touch with Henri Guinand for the first time in order to assure himself a supply of optical glass[95]. In effect, it is known that Amici bought, presumably already in 1826, flint and crown glass produced by Pierre Guinand's son in a glassworks that the latter must have set up in Neufchatel, in France, even before going to work in Bontemps' works at Choisy-le-Roi[96]. What is certain is that in 1829 Amici was already certainly a buyer of optical glass from the Bontemps glassworks, as can be seen from one of his letters to the Parisian astronomer Arago, dated 1st July of the same year[97].

We can therefore say that in his Modena laboratory Amici had some time before begun producing achromatic objectives for astronomical telescopes, and later for microscopes, buying quality optical glass in England, France and Germany and, perhaps starting from 1826, directly from the factory where Henri Guinand, the depositary, at least for a-

nother ten years' time, of his father's secrets and techniques for the production of optical glass the latter had introduced, was working.

In October of 1831, Amici was called to Florence to take over the chair of astronomy that had been left vacant on the death of Giovanni Pons (1761-1831), and was also appointed astronomer of the Museo di Fisica e Storia Naturale, the director of which was at the time Vincenzo Antinori[98]. And it was in several rooms on the ground floor of the "case de' Bini" that housed the Museum, that Amici organized a workshop that immediately became a small enterprise to which he transferred the optical material and utensils from his old Modena laboratory[99].

As concerns the workers employed in the new workshop, we know little or nothing, except that they must have been two or possibly three in number[100].

In his new position as director of the Florence Observatory, Amici must have immediately planned an increase in the number of instruments[101], proposing in 1832 the construction of an equatorial telescope[102] that was built at a later, but not precisely known time, with an objective having an aperture of 48 lines (10.8 cm)[103]. It must be this telescope that Amici spoke of in a letter to Bianchini, dated 28th July 1834, when he stated: "Riguardo poi al telescopio acromatico di larga apertura e brevissima distanza focale, io non potrei dirle nulla presentemente. Io ho tutto il fondamento che si possa fare un buon istrumento per esempio di 4 pollici di apertura e lungo solamente 30 pollici, ma la quantità di altre incombenze non mi permette ora di applicarmi a questo perfezionamento"[104].

It is interesting to observe that in the same letter Amici referred to the so-called dialytic telescopes, "che si fabbricano a Vienna e che sono tanto lodati"[105]. They are telescopes with three lenses of different indices, built for the purpose of correcting the well-known "secondary spectrum", and which at the time were being built in Vienna by the optician G. S. Ploss under the supervision of S. Stampfer[106]. In the letter to Bianchini, Amici in fact went on to say: "Essi consistono di tre lenti, due di Crown-glass e una di flintglass separate. Io trovo che è migliore costruzione la mia di due lenti di flint-glass, e due di crown-glass", with which he asserted that he had "eseguito provvisoriamente un ottimo cannocchiale acromatico di 33 linee di apertura e 24 pollici di lunghezza focale"[107].

The experiment with dialytic objectives does not appear to have been followed up, at least at that time. It does however represent further proof of the fact that Amici not only considered the "cannocchiali acromatici preferibili ai telescopi metallici" as he stated in a letter to the Roman astronomer Ignazio Calandrelli dated 14th December 1834, if for no other reason because of their optical force, that is, their superior transmitting power "e per la loro inalterabilità"[108], but that he also considered it possible to make objectives of such dimensions as to outshine the fame of the great Fraunhofer.

To the latter he in fact made respectful reference in a letter to Bianchini in 1835, acknowledging that the degree of perfection he had reached was to be attributed both to the quality of the optical glass used and to the kind of objective, made up of a biconvex lens of crown and a slightly divergent meniscus of flint placed in contact, and that he considered an objective of this kind preferable to those in which the two lenses were placed at a distance[109].

There is no doubt of the fact that Amici's theoretical preparation in the field of optics, together with his acknowledged ability in the working of optical surfaces, made him one of the most prestigious constructors of achromatic objectives in the first half of the 19th century. Unfortunately, as Pagnini complained, "niente noi sappiamo dei suoi metodi di lavorazione del vetro per le parti ottiche". He was of the opinion that the great success of Amici's objectives was the fruit of "sua straordinaria perizia ed abilità manuale"[110] rather than due to mechanical means and devices. Although we can agree with this judgment concerning the working of lenses, we must however point out that side-by-side with manual ability, there is no doubt that Amici had to resort to special processes for the working and cleaning of the lenses as well as for checking their curvature and sphericity, and we still have no knowledge of these.

These techniques are just barely mentioned in the Proceedings of the III Meeting of Italian Scientists, at which time Amici illustrated his achromatic telescope of about eleven inches in aperture and sixteen feet in focal length, built in the workshop at the Museum, and which came to be known as Amici I[111]. The disks of crown and flint glass, which had arrived in Florence on 30th July 1840, had been produced by Henri Guinand at the glassworks of Georges Bontemps and J. N. Lerebours at Choisy-le-Roi[112]. Since the crown glass disk of this objective presented "alcune imperfezioni"[113], Amici had another disk of crown glass sent[114], and the new, large achromatic telescope was presumably completed during 1844[115].

The Amici I telescope with a 28.3 cm aperture, at that time one of the largest, following that of 32 cm realized by the Frenchman Cauchoix (1775-1845) in 1835 for the Cambridge Observatory, and the

large, 38 cm equatorial instrument built by Fraunhofer's successors Merz (1793-1867) and Mahler (1795-1845) in 1839[116], did not receive the attention it deserved in its time. What is worse is the fact that the valuable experience and ability that had accumulated at Amici's workshop later found neither sufficient economic support from the Tuscan government nor the necessary stimulus for taking on new, more ambitious projects in the field of the production of telescope objectives.

In the summer of 1844, Amici made his second trip to London and Paris, where he purchased from Guinand two more disks of crown and flint glass having a diameter of eleven inches[117], from which he made his second achromatic objective with a 23.8 cm aperture, which later came to be known as Amici II.

The planned purchase of two more fifteen inch disks of crown and flint glass from Guinand[118] seems not to have taken place, and Amici's activity in the field of technical and instrumental optics, starting from 1844, seems to be concentrated on a constantly expanding production of composite achromatic microscopes, those with an immersion objective, introduced in 1847, and of his line of the most common astronomical and geodetic instruments. Amici's final interesting contribution to technical optics was the building in 1852 of the achromatic triplet having a six inch aperture and a fifty-two inch focal length, made up of a biconvex lens and a converging meniscus of crown glass in contact with a diverging meniscus of flint glass having different refraction indices. This objective was built on the basis of the new theory proposed by Fabrizio Mossotti[119], and is a confirmation of Amici's exceptional ability in the working of lenses having special curvatures. The excellent workmanship of this objective, whose six inch

aperture and fifty-two inch focal length were determined by Amici himself, and the "buon successo degli esperimenti conseguiti" convinced Mossotti to publish his theory on optical systems after hesitating for some time[120].

This final contribution of Amici's, which goes back to his previous experiences in the building of astronomical triplets of almost twenty years before, is to be considered more as an occasional exercise for the purpose of checking on the good quality of Mossotti's objective, and confirming his own exceptional theoretical and practical abilities, than as an element of continuity in the great optician's involvement in the building of astronomical objectives and telescopes[121].

This conclusion receives even more support if we consider that Amici, as was rightly pointed out by Cesare Morais, must have guessed at the importance of Mossotti's new theory and its applications in the construction of astronomical objectives[122].

But, as has been seen, Amici's activity in this field came to a close around 1844, and this can only partly be explained by Amici's ever-growing involvement in the production of instruments for use in physics, geophysics and astronomy and in the running of his laboratory.

4. Final Considerations

If the facts that have emerged in the course of this work have not given satisfactory answers to a series of questions concerning basically the methods and techniques that Amici resorted to in preparing achromatic lenses and objectives, and the reasons why he desisted from building large astronomical objectives, they have in any case allowed us to arrive at a better knowledge of his activities and merits in this specific field. Although Amici had the possibility of producing the basic material for the building of his first metallic mirrors, it does not appear that he was ever seriously interested or involved in the production of optical glass, especially lead glass.

One of his most significant contributions to practical optics was his devising of procedures for the working of plane and curved surfaces of optical material and the production of prisms and lenses for microscopes and telescopes with the use of traditional methods, in which he demonstrated extraordinary skill and manual ability.

One is justified in thinking that with such capabilities he would have arrived at the same level as the great lens makers of the 17th century: the Fontanas, the Divinis and the Campanis, had he been in possession of raw materials of the right quality and quantity. The serious problem of the lack of optical glass led him to propose to the Accademia di Belle Arti of Florence the production of disks of "flint-glass, del diametro non minore di quattro pollici, esente da strisce e vene, etc."[123] as the subject of the ten-year prize in the field of industrial arts.

It does not appear that this prize was ever offered; it must be pointed out, however, that prizes of this kind had been announced as far back as seventy years before by the Academy of Sciences of Paris and other scientific academies in Petersburg and Germany, but it is certainly more important to point out that in these same countries, as well as in England, a certain number of measures were taken to favour the birth and development of manufacturing activities in the field of optical glass.

The fact has been mentioned that in the second half of the 18th century Italy was the site of several initiatives at the artisan level that could have led to quite interesting developments had they received the financial support necessary to overcome difficulties in the finding of raw materials. However, even as late as 1879, Enrico Bordoni was forced to comment: "La fabbricazione di vetri e cristalli in Italia trovasi presentemente in condizioni tali da non lasciare buone speranze di più lieto avvenire, se il Governo formulando i nuovi trattati commerciali, non prenda in considerazione lo stato precario di questa industria, e voglia, per poco abbandonando l'assoluta teoria dei liberi scambisti, procurare quei mezzi, onde anche per questo articolo l'Italia possa rendersi indipendente dall'Estero"[124].

On the other hand, we know that the fate of Amici's intense activity in the field of the production of optical instruments used in topography, geodetics and astronomy was quite different. This aspect of his production, which is certainly the most representative, multifarious and original part of it, which was born and developed at the "Laboratorio" in Modena and the "Officina" in Florence, also thanks to the contribution of modest but skillful craftsmen, and to which he dedicated his utmost attention and energies, in my opinion deserves pro-

per recognition in the light of the enorous amount of unexplored documents stored mostly in the State libraries and archives in Modena and Florence. It must also be borne in mind that as a consequence of this activity the "Società Tecnomatica Italiana" was set up in Florence by Giovanni Battista Donati and other deserving members of the scientific and technical communities and, later on, also led to the founding of the Officina Galileo.

Bibliographical Notes

1. Cf. E. Proverbio, "The Manufacture and Working of Optical Glass in the XVII and XVIII Centuries", Atti Fond. G. Ronchi, (in press).

2. L. M. Angus-Butterworth, "Glass", in A History of Technology, Ch. Singer et al., (eds), Oxford, Vol. 4, 1958, (Trad. it., Storia della Tecnologia, Torino, Vol. 4, 1976, 232).

3. M. Daumas, Les instruments scientifiques aux XVII et XVIII siècles, Paris, 1953, 207.

4. Henry C. King, The History of the Telescope, New York, 1979, 159 and 176.

5. According to the testimony of W. Kitchener, who had bought a Dollond three and three-quarter inch telescope in 1806, this instrument was to be considered "one of those perfect Instruments which are rarely producted and only attainable, by a happy concurrence of the various circumstances which combine to form these compound Object-glasses" (cf., ibid, 158-60).

6. Cf., H. King, cit. in Note 4, 128-29.

7. On the production of objectives and reflecting telescopes by W. Herschel see: J. L. E. Dreyer, Scientific Papers of Sir William Herschel, 1912.

8. Cf., H. King, cit; in Note 4, 198.

9. Ibid, 199.

10. J. F. N. Herschel, Cape Observations, 1847.

11. Cf., H. King, cit. in Note 4, 177-78.

12. Ibid, 178.

13. Ibid, 180.

14. Ibid, 180.

15. Ibid, 179.

16. Cf., M. Daumas, cit. in Note 3, 210.

17. Cf., H. King, cit. in Note 4, 179-80.
18. Ibid, 188.

19. We still have no direct evidence of the fact that Guinand communicated the secrets of the production of flint glass to Fraunhofer, but there is indirect proof based on the fact that G. Utzscheider, one of Reichenbach's partners at the Institute of Munich, had promised Guinand a pension of 800 florins on his return to Switzerland if he ceased making optical glass (cf., W. H. S. Change, Proc. Phys. Soc., 1937, 49, 437, cit. in King, 79).

20. R. G. Boscovich, "De recentibus compertis pertinentibus ad perfeciendam dioptrican", De Bonomiensi Sc. et Art. Inst. atque Acad., Commentarii, Tomi Quinti, Pars Prima, Bonomiae, 1767, 202-215.

21. Cf., M. Rohr, Trans Opt. Soc., 1926, 27, 283.

22. Cf., Daumas, cit. in Note 3, 211 (nota 1).

23. The famous "Vitrometro" introduced by Boscovich for measuring the refraction index and dispersive power of prisms was still in use in the first decades of the 19th century. On the "Vitrometro" and the other instruments Boscovich used, see: E. Proverbio, "R. J. Boscovich and the Measurement of the Refractive Quality of Lenses", Mem. Soc. Astron. It., (in press). The "Vitrometro" was still being used in laboratories for physical experiments in the second half of the century (cf., M. J. Jamin, Cours de Physique de l'Ecole Politechnique, Paris, 1879, III, 61-62 and Fig. 48). A. M. Rochon had proposed a more complex and less reliable instrument for measuring dispersive power called the "diasporamètre" (cf., ibid., 174-76).

24. Cf., Wollaston, W. H., Phil. Trans. 92, 1802, 378.

25. J. Fraunhofer, Denkschriftn die K. Akad. der Wissenschaften zu Munchen, 1815, 5, 193-226.

26. The theory for the measurement of the refraction index with the "minimum deviation" method is given by Boscovich in the work cit. in Note 20, 215-229 (§ VI, de iisdem inveniendis ope prismatum).

27. Cf., V. Ronchi, Storia della tecnica ottica, Firenze, 1970, 199-200.

28. Cf., H. King, op. cit. in Note 4, 180-84.

29. In the article "Ueber die construction des so eben vollendeten grossen Refractors" (cf., Astron. Nachrichten, 1826, 74, 18), edited in 1814, in which Fraunhofer presented the 9.5 inch equatorial telescope, the great German optician himself pointed out the defects not only in the English glass, but also of the empirical methods used by English opticians in the production of achromatic objectives.

30. Cf., G. Righini, "Storia e vicende degli obiettivi acromatici di G. B. Amici", Physis, 1969, 469-92.

31. Cf., H. King, op. cit. in Note 4, 186.

32. Ibid., 188-89. See also L. M. Angus-Butterworth, cit. in Note 2, 370.

33. Ibid, 188.

34. Ibid, 250.

35. Cf., L. M. Angus-Butterworth, cit. in Note 2, 369.

36. Ibid, 369.

37. Cf., E. Proverbio, "La collaborazione di Giovan Stefano Conti e Ruggiero Giuseppe Boscovich per la produzione di vetro flint", Atti del X Congresso Naz. di Storia della Fisica, a cura di F. Bevilacqua, Milano, (in press).

38. The experiments in the production of flint glass carried out by Lorenzo Selva in Venice are described by himself in the work: L. Selva, Sei dialoghi ottici teorico-pratici, etc., Venezia, 1787, 88-106. Pietro Pagnini, one of the very few authors who has rightly indicated the importance of the activities of Lorenzo and Domenico Selva in the production of optical instruments, maintains that the Selvas "Sono stati i primi che in Italia, e subito dopo il Dollond, abbiano fabbricato il Flint per le lenti" (cf., P. Pagnini, L'ottica geometrica in Italia nella prima metà del XIX secolo, etc., Firenze, 1918, 12), forgetting the contribution made by Giovanni S. Conti, described by E. Proverbio in the op. cit. in the previous Note.

39. Boscovich's practical activities and theoretical production in the field of optics are included in the five-volume work: R. G. Boscovich, Opera pertinentia ad opticam et astronomiam, Bassani, 1787, (especially Volume II).

40. Cf., Giorn. di Fisica, 2-3, 1988.

41. One of the few contributions to an examination of Amici's activities in the field of prism optics is that of Vasco Ronchi: "Giovanni Battista Amici, ottico", La Ric. Scient., Anno 33, Serie 2, 1963, 269-292.

42. Following the law passed on 4th September 1802 by the Legislative Body of the Italian Republic, all universities, with the exception of Bologna and Pavia, were declassified to the status of departmental liceums where, however, university-level studies were carried on. Academic titles were awarded only by universities. On Amici's academic record at Modena and Bologna, see: P. Di Pietro, "Gli anni modenesi di G.B. Amici", Giorn. di Fisica, 1988, 201-13.

43. Cf., Biblioteca Estense, Modena, Fondo Amici 1182/14548. The "Appunti di G. B. Amici", are given in Di Pietro's work, cit. in the previous Note, 211-13.

44. Cf., A compleat system of opticks, etc., by Robert Smith, Cambridge, 2 Vol., 1738. Of this important treatise on practical and theoretical optics two translations were made, both in 1767, one by Duval-Leroy (Traité d'optique, Brest), the other, perhaps the better known, by P. Esprit Pezenas (Cours complet d'optique, Avignon).

45. Ottaviano Fabrizio Mossotti must be given credit for the elaboration of an optical theory that led to the building of achromatic objectives corrected for the geometric aberrations of rays passing through planes inclined in any way with respect to the optical axis (cf., O. F. Mossotti, Nuova teoria degli strumenti ottici, Pisa, Nistri, 1859). Mossotti's "nuova teoria" occupies Tome II of the "Scritti" of this great optician, published by the Domus Galilaeana, Pisa, 1955.

46. Cf., G. Santini, Teoria degli stromenti ottici, Padova, Seminario, 1828.

47. The excerpt from Amici's letter to Giovanni Santini is contained in: F. Palermo, "Sulla vita e le opere di Giovanni Battista Amici", Boll. di Bibliogr. e St. delle Sc. Matem. e Fisiche, Vol. II, 1870, 196.

> "I should have liked to find something more in his work about achromatic objectives for microscopes. Euler's and Krugel's theories are imperfect; and this very difficult branch deserves being worked at. I have taken some steps, I dare say of considerable importance; but a complete theory would perhaps lead to greater success."

48. Francesco Palermo (1800-1874), the husband of Elena Amici (1808-1845) the great optician's second child, has left us an ample biography of his father-in-law, cit. in the previous Note.

49. Cf., F. Palermo, op. cit. in Note 47, 190.

50. In a letter to Giambattista Venturi, director of the Teatro di Fisica in Modena, dated 15th December 1787 and addressed to the Deputazioni agli Studi, we find among other things: "Le macchine che conterei per ora di far costruire sono una cassetta d'ottone colle facce di cristallo per misurare la rifrazione della luce. Un prisma acromatico composto. Un altro di lamine di cristallo. Diverse lenti di cristallo di varie grandezze per le quali abbiamo in Modena un bravo ottico (artefice per lavorarle). Cf., G. Venturi, Carte relative alla Società Italiana di Modena e ad accademie, Università, Istituti di cultura, Biblioteca Estense, MS Regg A 77, cit. in: G. Cadoppi, "Gabinetti scientifici e strumentaria nel Ducato di Modena", Giorn. di Fisica, 1988, 97-114. And it is in the "Appunti" of Amici, cit. in Note 43, 212, that the same mentions "S.r. Giuseppe Zoboli modenese, famoso fabbricatore di telescopi acromatici".

51. Cf., G. Cadoppi, cit. in the previous Note, 104.

52. Cf., P. Di Pietro, cit. in Note 42, 202.

53. Cf., Dissertation by Cristina Valente (presented by G. Pancaldi), cit. in: G. Tabarroni, "Scienza e Tecnologia a Modena fra il Settecento e l'Ottocento", Giorn. di Fisica, 1988, 83-88. Amici, in completing and checking the instruments he produced, also used the so-called Villa Amici, in a place known as "Madonnina", near Modena where he usually spent the summer months and where he made many of his astronomical observations; cf., C. Bonacina, "La fondazione

dell'Osservatorio di Modena, etc.", in: Nel primo centenario della fondazione dell'Osservatorio, 1827-1927, Modena, 1927, 15.

54. This information is taken from MS 1182/14515 of the Biblioteca Estense of Modena, Fondo Amici, cit. by Di Pietro, 203 (see Note 42).

55. Cf., P. Di Pietro, cit. in Note 42, 211-12.

> "...on visiting the workshop of a certain Mattioli, gunsmith by profession... [Amici found himself witnessing]... certain experiments in the composition of metal that Mr Giuseppe Zoboli of Modena, a renowned maker of achromatic telescopes, had commissioned the above gunsmith to carry out. Returning home immediately, where Mr Giuseppe Sgarbi, a smelter of metals and a turner, still lived, I had him melt down the two alloys to be found in Montucla, that is, the first of two parts copper, one part tin and one of brass, and the other of 32 parts of copper, 15 of tin, silver, brass and one of arsenic, and it appeared to me that they turned out to be quite good, especially the latter."

56. Ibid., 212. The method used by Amici for the working and polishing of the sheets of metal is taken from the work by Smith cit. in Note 44 (the Avignon edition), 796, 192-93.

57. In the "Appunti", cit. in Note 43, presumably written in 1809, Amici explicitly recognized that "il passo più difficile che doveva fare era la curvatura onde a questa sola m'abbandonai".

58. On the problem of the working of non-spherical lenses in the 17th and 18th centuries, see: M. Daumas, op. cit. in Note 3, 52, 55, 94, 99.

59. Mudge's memorial concerning the working of mirrors, mentioned by Amici, appeared in Philos. Trans. for the year 1777, Vol. LXVII.

> "With respect to the curvature, I have not yet been able to give it any but the spherical one, and even this is very difficult to do perfectly since four or five irregular blows towards the end of the job are enough to damage it greatly."
>
> "...carried out diligently all the processes indicated in Smith's Opticks, in the memorial by Dr

Mudge printed in the Philosophical Transactions and in other authors, to give it the parabolic figure, and I have not succeeded in my intention."

60. Amici's letter to Michele Araldi in Bologna was published by Clelia Pighetti in: "Di alcune lettere di Giambattista Amici", Atti della Fond. G. Ronchi, 1970, XXV, 41-75.

"It comes to my mind, however, that I have read in the Third Tome of Montucla's History of Mathematics continued by Lalande, that Mr Herschell has found that they are all nothing but illusions the processes for imparting the parabolic form to a mirror with a focal length above six feet, because in a case of this kind the true figure differs so little from the spherical that one could wager a hundred to one that even the most skillful and experienced craftsman would be incapable of realizing it. But the mirrors I have built are close to six feet, and although I cannot exclude the possibility of giving them the parabolic form, I must confess that this is the most difficult part, and I estimate that I shall not succeed in it except through constant application and dexterity in my work."

61. Of the Amici-Gualtieri controversy (see Note 66), mention is also made in the diary of the naturalist Giambattista Brocchi, to whom it was referred that the turner Giovanni Gualtieri, who had worked with Amici in his workshop in Via de' Servi, "riuscì nel dare agli specchi del telescopio newtoniano il pulimento squisito, e la figura parabolica, che si richiede", which Amici, in the opinion of Brocchi's informer, was apparently not yet able to carry out. (Cf., Giambattista Brocchi, Giornale nel viaggio mineralogico per vari paesi d'Italia (1811-1812), Biblioteca di Bassano del Grappa, MS 31 A 20, cit. in Cadoppi, Note 50, 107-08.)

62. John Herschel, to whom Amici had presented a twelve inch, twelve foot focal length reflecting telescope during his journey to London in 1827, on writing to the great optician stated: "essersi perduta in Inghilterra, dopo la morte del padre, l'arte di costruire dei riflettori metallici, dando allo specchio obiettivo una perfetta curva parabolica". This seems to confirm the fact that Amici was then capable of making large parabolic mirrors.

63. Amici visited the laboratory of "Cavaliere Isimbardi" during a

trip to Milan in November of 1811. At that time he had the opportunity to observe the mirrors produced by the Milanese optician and to gain a knowledge of the processes he used in working and polishing them (cf., C. Pighetti, op. cit. in Note 61, 51-53).

64. Pietro Moscati (1738-1824), former senator of the Cisalpine Republic, professor at the University of Pavia and director of the Ospedale Maggiore in Milan, assumed the office of Minister of Education when Napoleon transformed the Italian Republic into the Kingdom of Italy (18th March 1805), under the administration of Viceroy Eugenio of Beauharnais.

65. Barnaba Oriani and Angelo De Cesaris, astronomers at the Brera Observatory, were the receivers of the first two telescopes Amici sent to Milan in April of 1811, one of which was destined for Pietro Moscati (cf., A. Mandrino, G. Tagliaferri and P. Tucci, "Gli strumenti astronomici di Amici a Milano", Giorn. di Fisica, 1988, 169-76). Amici met the Brera astronomers at the time of his visit to Milan in November of 1811 (cf., C. Pighetti, op. cit. in Note 60, 51).

66. The most unpleasant of these controversies was the one that placed Giambattista Amici against Giovanni Gualtieri who, having worked on the mirrors produced in the workshop in Via de' Servi in 1810-1811, claimed a certain superiority in their working and polishing (see Note 61). For information on this controversy see F. Palermo's biography (op. cit. in Note 47, 190) and the letters Amici wrote to his father (cf., C. Righetti, op. cit. in Note 60, 50 and 54). In 1820 Giovanni Grisostomo Gualtieri, together with other well-known machinist-craftsmen such as Antonio Sgarbi, and mechanics, watchmakers and instrument makers, was a member of the Arts Department of the Accademia delle Scienze which, following the restoration, had taken the place of the Società d'Arti Meccaniche, which had been set up by Napoleon (cf., G. Cadoppi, op. cit. in Note 50, 106 and Note 17).

67. After beginning production in the workshop in Via de' Servi, one of the problems Amici had to face was that of finding personnel highly skilled in the production and working of metal mirrors and, later on, of prisms and lenses for microscopes and telescopes. In the years 1810 and 1811 it appears that Giovanni Gualtieri and Antonio Sgarbi worked there (cf., Amici's "Appunti", op. cit. in Note 42, 212, and C. Pighetti, op. cit. in Note 60, 54). It seems that subsequently the latter found work as an assistant machinist at the Liceo of Modena, where he was employed in the construction of reflecting telescopes at the Departmental Lycées following Ami-

ci's signing of a contract with the government of the Kingdom of Italy, which was later confirmed by the government of the Duchy following the restoration in 1814 (for information on this, see C. Bonacina, op. cit. in Note 53, 21, 22 and 24). In this period Sgarbi thus worked only part-time in the workshop of Amici, who later availed himself of the work of other "artists", such as a certain young Cresti, who in 1818 worked at the "camere lucide" (cf., G. Arrighi, "Lettera di G. B. Amici nelle biblioteche di Forlì e di Lugo", Physis, 1965, VII, 57). In January of 1827 Amici allowed his valued and faithful collaborator Giuseppe Sgarbi to be hired by the new Modena Observatory as a machinist-custodian, "a condizione però che debba prestarsi ai lavori che richiedesse l'Amici" (cf., C. Bonacina, op. cit. in Note 53, 33).
His growing committments for the production of optical and astronomical instruments were a perennial problem for Amici, who found himself in the position of having to increase the number of workers in his workshop. To do so, he was willing to pay "fino a tre lire e mezzo per dieci ore di lavoro", as he himself stated in a letter to Giambattista Venturi on 1st February 1818 (ibid., 161). Even in 1853, Amici complained in a letter to Jean Louis Brachet in Paris of having "soltanto due artefici i quali appena bastano a seguire i miei piccoli lavori" (cf., Clelia Pighetti Bonati, "Di alcune lettere di Giambattista Amici - II, Atti della Fond. G. Ronchi, 1973, XXVIII, 922).

68. For records on Amici's production of optical instruments see, besides F. Palermo's biography (op. cit in Note 47) and the published letters (cf., op. cit. in Notes 60 and 67), the Libro de' Conti del Laboratorio, kept by Amici himself from the beginning of 1817 up to June of 1863, in which we find income from the "macchine esitate" as well as "spese in materiali, ect." (cf., P. Buffa and E. Filippini-Lera Buffa, "Il Libro de' Conti del Laboratorio di GiovanBattista Amici", Giorn. di Fisica, 1988, 115-40). The manuscript of the Libro has recently been acquired by the Biblioteca Estense of Modena.

69. Amici was in reality one of the most illustrious practical opticians and inventor of optical instruments, who had his own personal philosophy, magnificently illustrated in a document given by F. Palermo in the biography of his father-in-law (cit. in Note 47, 191).
In this document Amici wrote: "Non accetto commissioni che mi tolgono la libertà di modificare a mio piacere la forma degli strumenti, in tutte quelle parti, che, a mio giudizio, possono essere migliorate. Se un istrumento deve portare il mio nome, io amo che sia fatto secondo que' principii che mi sembrano più perfetti".

He constantly defended this concept of the activity of the producer of scientific instruments as a free, creative activity at a high technical and technological level. He claimed this prerogative above all at the time he was negotiating with the government of the Duchy, starting from 1818, for the production of the astronomical instruments for the Observatoy of Modena, which was being built at the time, and especially in the long letter to Paolo Ruffini, the Rector of the University of Modena, dated 10th January 1821 (cf., C. Bonacina, op. cit. in Note 53, 17-32).

70. Cf., F. Palermo, cit. in Note 47, 191.

71. Cf., "De microscopi catadiottrici/memoria/ del Sig. Ingegnere Giambattista Amici, etc.", Modena, 1818, 110.

72. In the letter to John Herschel dated 16th March 1826, Amici stated: "Certamente il cannocchiale di Dorpat è un capo d'opra nel suo genere; ma lo Struve, esaltato troppo lo ha innalzato al di là della sfera di attività che gli compete. Egli indirizzando alla stella ὁ Orionis, ha veduto 16 stelle in que' contorni: ma del pari 16 stelle le ho scoperte io con un telescopio di otto piedi di distanza focale, e undici pollici di apertura, non ancora perfezionato" (cf., F. Palermo, op. cit. in Note 47, 209). See Note 75. Amici's letter to Herschel is part of the controversy between the supporters of the superiority of refracting telescopes and those who thought that at that time the best telescopes were of the reflecting kind. The controversy was set off by the memorial presented to the Bavarian Academy on 10th July 1824 by Fraunhofer and John Herschel's reply to this published in August of 1825 (see Notes 79 and 80).

73. On 30th May 1825, in a letter from Amici to Baron de Zac, we find: "Si potrebbe con ragione sospettare, che il gran cannocchiale acromatico dello Struve non abbia tanta luce distinta quanto un mio telescopio di undici pollici di diametro, etc." (cf., ibid., 209.

74. As is known, tolerance in the working of mirror surfaces is several times what is required of transparent surfaces.

75. The coefficient of reflection of a reflecting surface in bronze or steel is on the order of 60-70%, while the transmission factor of an achromatic objective with an aperture of ten to twelve inches is on the average around 80% (cf., A. Danjon and A. Couder, Lunettes et telescopes, Paris, 1935, 565-67). Thus the transmission factor of a nine inch achromatic objective, like the one built by Fraunhofer, is in theory equivalent to a metallic mirror having a

reflection of about 11 inches, as was the one used by Amici in his observations (see Note 72). Amici seems to have arrived at the same conclusions in the letter he wrote to Baron de Zac on 30th May 1825, in which, on the basis of experiments he had carried out on the "chiarezza" of refracting and reflecting telescopes, he found that a reflector having twenty-four lines of aperture is of the same "chiarezza" as a reflector (with two reflections) having 36 lines, and concluded by voicing the opinion that "questo rapporto di 3:4 fra i diametri de loro obiettivi si conservi ancora negli istrumenti di maggiori dimensioni" (cf., "Correspondence Astronomique", du Baron de Zac, Vol. XII, No. VI, 544-46).

76. At the time of the construction of the first reflecting objectives, and even following this, Amici was the subject of much praise, and his work was compared to that of the great Herschell. Pietro Moscati, at the time the first reflecting telescopes were sent to the Brera Observatory, wrote to Amici on 29th April 1811: "I signori astronomi di Brera mi hanno informato del dono che avete fatto al loro osservatorio di un telescopio da Lei fabbricato, significandomi che esso gareggia alla perfezione con quello di Herschel". And Oriani personally, in a letter to Alessandro Sanseverino dated 24th April 1811 affirmed: "L'Amici gareggia coll'Herschell nella costruzione di telescopi" (cf., F. Palermo, op. cit. in Note 47, 191).

77. Cf., C. Pighetti, op. cit. in Note 60, 57.

> "Concerning the composition of metallic mirrors, I have found a cheap alloy that has the advantage of being whiter, more compact and harder than any other I know, and consequently it is better at reflecting a greater amount of light, it can be polished to a finer degree, is less subject to dulling due to the action of the air, and finally shows objects almost in their natural colours, and not tinted with a yellowish or reddish colour. The polishing I carry out with great ease, and the metal acquires a lustre not inferior to mirrors worked in England, not excluding, as I have been led to believe, those of Mr Herschell, and certainly brighter than those of other authors that I have seen."

78. Cf., V. Ronchi, op. cit. in Note 41, 280.

79. Cf., J. Fraunhofer, op. cit. in Note 29, 17-24. Fraunhofer's article was followed, in January 1875, by a memorial written by W. Struve, in which he accurately described the nine and a half inch equatorial telescope ("le plus parfait que l'on connaisse, tant pour sa solidité et ses propriétés, que pour la perfection des cercles horaires et de declination"). In this memorial Struve maintained that the characteristics of Fraunhofer's objective were superior to the thirteen and fifteen foot reflecting telescopes, stating "que l'on peut sans difficulté mettre en parallèle notre lunette, avec le plus grand colosse d'optique qui existe, c'est à dire celui de 40 pieds de Herscell, et même le défier" (cf., "Correspondence Astronomique", du Baron de Zach, Vol. XII, Lettre XIII, 289-90).

80. Herschell's reply to Fraunhofer is contained in the letter dated 15th August 1825 which appeared in Astron. Nachrichten (No. 85, 1826, 231-36) and is preceded by a note by J. South (ibid., 228-30).

81. Cf., G. B. Amici, "Memoria sulla costruzione di un cannocchiale acromatico senza lenti eseguito con un sol mezzo rifrangente", Mem. di Matem. e Fisica della Soc. Ital. delle Scienze, Tome XIX, 1821, 121-137.

82. Mention has already been made of Amici's important contribution to prism optics from the technical and applied technical viewpoints. We consider it interesting to point out Amici's discovery of the law of variability in the dispersion of light passing through different prisms of the same substance, which he described in the "Memoria" cit. in the previous Note, 132-37.

83. "L'occhiolino da teatro del S.r Conte di S. Loen fu fatto che è molto tempo, ma io non l'ho mandato e non lo manderò perché non ne sono contento. Siccome egli desiderava una grande apertura nell'obiettivo ho dovuto eseguirlo con tre lenti una di flint-glass e due di crown-glass per non averne di questo abbastanza grosso". With these words Amici informs us, at least on the basis of the letters published up to now, that he had begun the production of small dioptrical instruments some time around 1820. This letter of Amici's, dated 18th May 1820, was addressed to Agostino Bassi in Lodi (cf., C. Pighetti, op. cit. in Note 60, 56).

84. Cf., Amici's letter to Giovanni Santini dated 21st February 1824; a summary of this letter is given by: Cecilia Ghetti, "Registro degli Archivi Antichi dell'Osservatorio Astronomico di Padova", in: G. Bozzolato, P. Del Negro, C. Ghetti, La Specola dell'Uni-

versità di Padova, Brugine (Padova), 1986, 298.

85. Cf., "Libro de' Conti di Laboratorio", cit. in Note 68.

86. On page 7 of the "Libro" cit. in the previous Note, the price indicated by Amici for the achromatic telescope is: "zero".

87. In the "Libro de' Conti di Laboratorio", starting from 1820, several other achromatic telescopes and opera glasses were registered as "esitati". But no indication of the apertures or focal lengths of these instruments is given.

88. In June of 1821, for the first time Amici registered among the "Spese in materiale, etc." in his "Libro de' Conti di Laboratorio", the item "cristallo" and, in November of the same year, we find the purchase of "due dischi di cristallo". Purchases of "cristallo", together with other expenses for "vetraio", appear almost regularly in the following years (cf., "Libro de' Conti", MS cit. in Note 68).

89. On the vicissitudes concerning Amici's projects for the construction of certain observational instruments for the Astronomical Observatory under construction in the years between 1818 and 1822, see the work by Carlo Bonacina, cit. in Note 53.

90. This is his new micrometer with a two-part lens placed between the objective and the eyepiece, about which he spoke in a letter to Carlini dated 5th August 1814, and the description of which is given in the Memorie of the Società Italiana delle Scienze, Verona, Tome XVII, 1816, 344-359.

91. See Amici's letter to Giovanni Santini dated 26th October 1824, now in the archives of the Observatory of Padua (cf., C. Ghetti, cit. in Note 84, 298).

92. "La lega metallica della quale sono fabbricati i miei specchi, forse non resisterebbe nelle grandissime costruzioni per essere troppo friabile. Egli è perciò, che il Sig. W. Herschel ha preferito una composizione più tenace, e meno atta a riflettere la luce". Thus Amici wrote to Baron de Zac in a letter from Modena dated 30th May 1825 and published in: "Correspondance Astronomique", Vol. XII, N. VI, 546.

93. Cf., ibid., 547.

> "...if we consider the smaller aperture needed by the latter, the ease with which they can be applied to different instruments, the inalterability of the substance of the glass, which makes it possible to compare observations made in faraway epochs, and finally the ease with which they can be used since the vitreous objective remains constantly centred, in the best way that the artist had set it... [a condition] of such importance for certain kinds of observers that for this reason alone... [the latter] do not hesitate to prefer a mediocre achromatic telescope to a good one of Newtonian form."

94. That Amici actually met Barlow in London is confirmed by the latter in a letter to Giovanni Santini dated 25th October 1828 (cf., C. Ghetti, op. cit. in Note 84, 299).

95. See Note 35.

96. This information is contained in the report that von Biela drew up in March of 1827 following his journey to Italy, during which he met Amici in Modena. After a brief description of Amici's activities and the instruments produced in his workshop, von Biela added: "Inoltre nòtai anche diversi grandi telescopi riflettori, sestanti con prisma di cristallo e parecchi telescopi acromatici, gli obiettivi dei quali sono parimenti molati per mano dello stesso Sig. Amici. Fra i telescopi acromatici spicca il telescopio di un nuovo strumento dei passaggi dotato di una distanza focale di 5 piedi e di una apertura dell'obiettivo di 4 pollici. Il flint utilizzato da Amici è quello di Guinand di Neufchatel". It is not clear whether von Biela meant the town of Neufchatel-en-Bray near Rouen or Neufchatel-sur-Aisne near Reims (cf., Astron. Nachrichten, 1827, N. 120, 427).

97. Cf., C. Pighetti, cit. in Note 60, 67.

98. Cf., F. Palermo, op. cit. in Note 67, 238. See also the letter to Arago that Amici wrote on 29th November 1831 from Modena, in which he announced: "Il Granduca di Toscana mi ha chiamato al suo servizio nominandomi Professore di Astronomia dell'Università di Pisa colla residenza in Firenze" (cf., C. Pighetti, cit. in note 60, 70).

99. In a document conserved in the archives of the Istituto e Museo della Storia della Scienza of Florence (reported by G. Righini in the op. cit. in Note 30, 479) which carries the date of 11th December 1831 we find: "Richiesta di esenzione doganale per il materiale ottico e utensili della Officina di G. B. Amici, Astronomo del Museo chiamato dal Granduca. Che il Professore e la sua famiglia venga lasciato passar liberamente dalla porta di San Gallo".

100. See Note 67. In the rough draft of a letter attributed to Amici we find that he, "partendo da Modena ha portato seco i suoi artisti, e ha stabilito in Firenze la sua officina ottica" (cf., F. Palermo, cit. in Note 47, 239).

101. Among the duties outlined in Amici's call to Florence was still that of building "quegli strumenti che nella nuova montatura della specola potrebbero occorrere", (see Vincenzo Antinori's letter to Amici dated 17th October 1831, reported by F. Palermo, ibid., 238).

102. This can be deduced from Antinori's request to the Grand Duke for Amici's account dated 27th November 1832, for the sum of one thousand scudi for the purchase of a machine for dividing the graduated circles necessary in the production of astronomical instruments, among which "l'Equatoriale di cui l'Osservatorio è pure mancante" (cf., Archivio Ist. e Museo di Firenze, Fondo antico, 1832, 99).

103. In the first draft of a report in Amici's writing, undated but presumably written prior to 1840, we find: "Le principali macchine astronomiche che possiede il Museo sono quattro: Un circolo ripetitore di tre piedi di diametro, con obiettivo di 36 linee d'apertura, un cannocchiale meridiano, ossia istrumento di passaggi di Sisson, con 42 linee di apertura; un settore zenitale del medesimo autore, con obiettivo di 42 linee di apertura; un equatoriale con cannocchiale Amici, di 48 linee di apertura" cf., F. Palermo, cit. in Note 47, 239.

104. Cf., C. Pighetti, cit. in note 60, 912.

> "Then concerning the achromatic telescope of wide aperture and very shrt focal length, at present I can tell you nothing. I have every confidence that a good instrument, for example one having 4 inches of aperture and a length of only 30 inches, can be made, but the amount of other things I am

engaged in leaves me no time for the moment to apply myself to this improvement."

105. Ibid., 912.

106. In order to correct for the residual colours in the images produced by achromatic doublets, in the second half of the 18th century experiments were carried out in England with achromatic triplets with different indices of refraction, one of which a fluid lens, known as dialytic objectives. Subsequently, the fluid lens was replaced by a compound of crown and flint. On this question see: H. King, cit. in Note 4, 189-91.

107. Cf., C. Pighetti, cit. in Note 60, 912.

108. Ibid., 913-14.

109. Ibid., 915.

110. Cf., P. Pagnini, op. cit. in Note 38, 48.

111. In the Proceedings of the III Meeting of Italian Scientists we find: "Il cav. Prof. G. B. Amici prende a leggere un suo scritto intorno ad un telescopio acromatico di 16 piedi di distanza focale costruito nelle officine dell'I. e R. Museo Fisico di Firenze. Egli ne espose l'obiettivo (la cui apertura è di 11 pollici), composto da crown e flint-glass della fabbrica Guinand di Parigi, ed eseguito dall'artista Toussain, il quale si è valso dei metodi immaginati dal Prof. Amici medesimo, per curvare i vetri e pulirli" (cf., Atti della III Riunione degli scienziati italiani tenuta a Firenze nel novembre 1841, 1841, 250).

112. The date of arrival of the two disks of crown and flint glass at Customs in Florence, "Fabbricati da Guinand in Parigi", is indicated in a note by the Minister of Finance of the Grand Duchy to be found in the archives of the Istituto e Museo delle Scienze of Florence, cit. by G. Righini (see Note 30, 482-83).

113. From the Proceedings of the III Meeting of Italian Scientists, we find that "quanto alla qualità del vetro", in his paper Amici had pointed out "alcune imperfezioni che esso presenta verso la circonferenza, cioè sette sensibili gruppi di vene che si trovano nel crown, che rifrangendo irregolarmente la luce rendono meno distinte le immagini" (cf., "Atti della III riunione", cit. in Note 109, 250).

114. A document in the archives dated 25th June 1842 mentions: "acquisto di una lente di crown in parte difettosa per franchi 100. Quando il Sig. Le Reboul (Lerebours) inviò la prima lente del crown pel grande cannocchiale che sta costruendo il Prof. Amici, fu trovata con qualche imperfezione, quindi fu scritto per averne un'altra più perfetta che fosse possibile, questa seconda lente è venuta e si sta lavorando", etc. (cf., Lettere di G. B. Amici, Archivio Antinori, 25 giugno 1842).

115. Still in July of 1844, on writing to Vincenzo Antinori from London, Amici solicited the realization of the tube of the instrument ("si sollecita dunque il legnaiuolo onde al mio ritorno l'istrumento sia servibile"). Cf., ibid., 7th July 1844.

116. Cf., Danjon and Couder, op. cit. in Note 75, 674.

117. In the letter to Antinori cit. in Note 115, Amici stated: "A Parigi comprai per me due dischi di Crown-glass e Flint-glass di undici pollici di diametro per fare un obiettivo simile a quello che è stato costruito in codesto Museo".

118. In the same letter from London dated 7th July 1844, cit. in Note 113, Amici reported: "col Guinand concertai pure l'acquisto di altri due dischi di quindici pollici di apertura che mi manderebbe a Firenze verso la fine di ottobre. Egli aveva all'Esposizione un disco di venti pollici, ed un altro ne aveva il Bontemps de' quali si è molto parlato all'Istituto per fare un telescopio gigantesco; ma io credo che in Parigi sarà difficile l'eseguirlo".

119. Cf., Cesare Morais, "Su di un obiettivo costruito dall'Amici secondo la teoria del Mossotti", Physis, 1965, 2, 202-10.

120. Mossotti, in the "Preliminare" to his "Nuova teoria degli strumenti ottici, cit. in Note 45, observed: "Animato dal buon successo degli esperimenti eseguiti mi sono determinato a rendere pubblica la teoria che somministra le formule impiegate pel calcolo di quelle lenti, ed ho creduto opportuno di non dover sopprimere parte alcuna del testo delle mie lezioni, etc.".

121. In the preface to his "Nuova Teoria degli Stromenti Ottici" Mossotti summarized the events that contributed to the building of the three-lens objective corrected for the spherical and chromatic aberrations and reported that following calculations carried out by Dr. Forti for the determination of the curvature radii of the surfaces of the three lenses, in applying his new theory "i

valori ottenuti dei raggi di curvatura avendo attratto l'attenzione di un ottimo giudice, l'esimio ottico Cav. Amici, il medesimo si mostrò propenso a costruire un obiettivo sulla norma di essi". It was Mossotti himself who considered Amici's triplet a "test" that the great optician carried out for the sole purpose of verifying the effective optical qualities of this objective.

122. Cf., C. Morais, cit. in Note 119, 209.

123. In Amici's proposal to the Accademia di Belle Arti of Florence we read: "Manca in Italia un genere di manifattura, che i progressi dell'ottica hanno introdotto presso le altre nazioni: la fabbricazione del flint-glass, per uso degli obiettivi acromatici. La qual si eseguisce ora, con più o meno successo, nelle officine di Monaco, di Parigi, di Londra; e sarebbe utili e decoroso portare questo ramo di industria nella patria di Galileo. Io proporrei dunque: esibire uno o più dischi di flint-glass, del diametro non minore di quattro pollici, esente di strie o vene, d'una qualità molto dispersiva e capace di servire alla costruzione di obiettivi acromatici; accompagnando i saggi con una memoria sul processo della fusione, e il metodo di avere pura questa sostanza". (Cf., P. F. Palermo, op. cit. in Note 47, 207.)

124. Enrico Bordoni, Cenni sull'industria vetraria italiana, etc., Savona, 1879, 5-7.

> "The fabrication of glass and crystal in Italy is at present in conditions such as not to leave much hope for a better future, unless the Government in drawing up the new commercial treaties takes into consideration the precarious state of this industry and decides to abandon for a short time the absolute theory of the free traders and acquire the means necessary so that Italy can become independent of Foreign Countries even for this article."