removal of the former to Greenwich. He left Cambridge in the beginning of 1845, and became Astronomical Assistant to the Rev. J. B. Reade, of Stone, and to Dr. Lee, at Hartwell. In July 1845, he sustained a shock, from which he never recovered, in the death of his wife, three weeks after their marriage. During his employment at Cambridge, he made most of the circle observations, and was conversant with the other instruments. Mr. Challis says, "In all the instruments he was equally skilled. He computed rapidly and correctly; and in all respects was to me a most valuable assistant."

Mr. John Rowbotham was born September 5, 1793, at Elston Mill, near Newark, in Nottinghamshire. This mill, by which his father earned his livelihood, was a freehold, which had descended from father to son from the time of Charles II. After a school education, he was employed under his father, at the age of fifteen, and was soon allowed to understand the business better than any one in the neighbourhood. Two years afterwards, having saved a little money, which he earned by surveying for the farmers in the neighbourhood, he resolved to try his fortune in London. He failed, and was obliged to return; but, in one more year, having been employed as clerk and overlooker in a larger mill, he had again saved a little stock, and resolved to try once more. He was employed as assistant to George Crabb, known as the author of several works on education and on teaching German; and afterwards was his partner and successor in his school, which was at Walworth. Mr. Rowbotham had a turn for acquiring languages; his knowledge of which he first began to extend beyond his foundation of school Latin and Greek, by playing at dominos with the French emigrants in the coffeehouses which they frequented. He procured a knowledge of French, German, Italian, Spanish, Dutch, and Danish, besides a little Chinese; on some of these languages he wrote grammars or other elementary works. With an early turn for mathematics (a taste seldom combined with that for languages), he cultivated the elements of that science with success, and his name is associated with that of Mr. Peter Nicholson in the later editions of the work on algebra, published by the latter. Mr. Rowbotham's useful and laborious life terminated on the 16th of October last, at Walworth. He had long been a Fellow of this Society, and was a regular attendant at our meetings. His elementary works are numerous; they are carefully done, and have had much circulation. Perhaps no Englishman of his day has written so many helps to foreign languages.

Among the losses which the Astronomical Society have to deplore by death among its members in the year elapsed, is that of our illustrious associate, Bessel, a name for ever memorable in the history of our science as that of one who, independent of great and distinct discoveries, by which he enlarged its bounds, may be said to have impressed on it a new aspect in almost all its details, and to have contributed more than any preceding astronomer to give to all its processes of calculation, and to many of those of observation,

that refinement and systematic perfection which now so pre-eminently distinguish them. This is, perhaps, the more remarkable, as he was, in the most especial sense of the word, a self-taught astronomer; but, unlike self-taught men in general, whose characteristic is for the most part that of rude energy and native strength rushing upon its object, and satisfied with its attainment, his genius, assimilating every new acquisition to a model of ideal symmetry and completeness in his own mind, embodied it at once in its neatest and most finished form, and in that which offers the easiest handle for subsequent application.

Friedrich Wilhelm Bessel was born at Minden, July 22, 1784. His father held an office of local administration under the Prussian government (Justiz-Rath). His mother was the daughter of a clergyman, Schrader by name, at Rehme. Being one of a family of nine children, his education, though not neglected, was in no respect calculated to fit him for his future distinguished career. It is said that he shewed an early disinclination for the elements of classical literature; most probably from the repulsive form in which they are usually administered to children. Be that as it may, he manifested a decided preference for, and early expertness in, arithmetic; which his father perceiving, placed him, at the age of fifteen, as an apprenticed clerk in a considerable commercial house at Bremen (Kuhlenkamp and Sons).

A boyish story is told of his grinding a glass with emery in a saucer, and remarking, with delight, that it in some degree concentrated the rays of the sun; perhaps in rude imitation of some process he had read of, or been told. A more decidedly characteristic anecdote is recorded of his having, in his thirteenth year, remarked, while comparing the constellations in the heavens with their representation on a planisphere, that ε *Lyræ*, marked as one star in the chart, consists of two, which his eye was sharp enough to distinguish separately, though at so small an interval as $3' 32''$. This must certainly be regarded as an uncommon proof, not only of acute vision, but of close and careful attention in a boy so young, and as manifesting that capacity for becoming earnestly interested in a subject to which the natural faculties of the mind are best adapted, which is all that can be understood by an early bent of genius.

Earnest attention and zealous occupation with the business before him, of whatever nature, seems, however, to have been a primary feature of his character. In his new situation, he speedily mastered, not merely the routine of his own subordinate position, but gained a thorough insight into the general nature of the business of his firm; and, entering into all his duties with uncommon diligence, rapidly acquired the approbation and confidence of his employers; leading him to hope that the more responsible situation of supercargo, in a voyage to the French and Spanish colonies and China, might be offered to him. To prepare himself for this great object of his ambition, he commenced the study of the French and Spanish languages, and of navigation, taking for his guide in that

branch the old work of Hamilton Moore. The rules and processes of nautical reckoning delivered in that work as precepts, without their theoretical grounds, induced him to seek the latter elsewhere, He procured a popular treatise on astronomy. This directed him in the right course; and, proceeding from book to book, and mastering their difficulties as best he might, he found at length an effectual bar to further progress in his entire unacquaintance with mathematics. He immediately entered on a course of mathematical reading, and now we hear no more of commercial projects, or of the voyage he had so ardently desired. Every leisure hour (and they were chiefly in the night) was devoted to astronomical and mathematical reading. Practice was also combined with theory. By the aid of a rude wooden sextant, which he got constructed by a carpenter, and a common clock, he began to make observations for time; and great was his joy when the occultation of a considerable star by the moon, which he was fortunate enough to observe, gave him the longitude of Bremen with considerable approximation. The rapidity of his progress from this time was truly astonishing. Trains of original research and learned inquiry opened out before him at an age when the generality of students, under the most favourable circumstances, hardly advance beyond the elements of science. Already in his twentieth year, he had executed the reduction of Harriott's and Torporley's observations of the comet of 1607, which has become so celebrated by the great discovery of its periodical return by Halley. These observations had been but recently rescued from oblivion by Baron Zach, in his search among Harriott's papers, in the possession of the Earl of Egremont; and, being the first observations of this remarkable body made with any kind of instrumental aid, their reduction was an object of undeniable importance. This task Bessel executed in so masterly a manner, as to call forth the warmest eulogies from Olbers to whom he communicated them, and to excite the strongest desire in him to secure for astronomy one whose future eminence in that science he clearly foresaw, and in no sparing or measured terms predicted. This performance, his first published work, appeared in Zach's *Monathliche Correspondenz*, and was immediately followed by a theoretical memoir, of great merit, " On the calculation of the true anomaly in orbits nearly parabolic." So expert had he become in cometic calculations, that Olbers, having placed in his hands, on the night of the 1st of November, 1805, four observations of the comet of that year, he returned them to him the next morning, with the elements, whose calculation had occupied him only four hours.

His seven years' engagement with Messrs. Kuhlenkamp was now terminated; but, instead of entering on the mercantile world on his own account, we find him placed forthwith, at the recommendation of Olbers, as assistant to Schröter, at Lilienthal, and successor to Harding. Astronomy thus became his profession; he gave himself wholly to it, with an energy and success which very speedily placed him in the first rank of its cultivators.

The instruments of Schröter were better adapted for physical examination than for precise astronomical determinations. Among the more especial objects to which his attention *as an observer* was there directed, may be mentioned a series of micrometrical measures of the distances of the sixth, or Huyghenian, satellite of *Saturn* from the ring, made with a Newtonian reflector by the aid of the projection micrometer, with a view to the better determination of the mass of *Saturn* and of its ring, by means of the perturbations caused thereby in the satellite's motions. This work, so began, was never subsequently lost sight of. It forms the subject of several elaborate memoirs, the first of which appeared in the *Königsberger Archiv fur Naturwissenschaften*, No. 2, in which all the observed conjunctions and oppositions of the satellite, and all the recorded disappearances of the ring, are subjected to a rigorous and systematic calculation; the position of the ring itself normally determined, together with elements of the orbit of the satellite in question, and even the perturbations of its motion by the attraction of the ring and by the sun are made objects of minute inquiry. The subject was resumed as observations accumulated, especially those made with the celebrated heliometer of Fraunhofer, in three admirable papers, Nos. 193–5, No. 214, and No. 242 of the *Astronomische Nachrichten*. At Lilienthal, also, were made his observations of the comet of 1807, the investigation of whose elements, taking into account its perturbations, was published in 1810, and gained him the prize founded by Lalande, from the Institute of Paris.

In 1810, he removed from Lilienthal to Königsberg, being appointed to the direction of the observatory about to be established there by the King of Prussia, and whose construction and provision with instruments he was called on to superintend. This observatory will ever remain a monument to his glory, no less than to the munificence of the sovereign who, amidst the alarms of war and the desolation of his country, still mindful of science, ordained its institution. The building was completed and the observations commenced in 1813, from which time to the conclusion of his life an uninterrupted series of the most valuable and important observations continued to emanate from it. Soon after his appointment to this situation (in which, besides the duties of an observer, he had also those of a professor in the Königsberg University to fulfil, by giving a course of lectures on astronomy and mathematics) he married the daughter of Professor Hagen, by whom he had one son and two daughters. The death of the former, however, in 1841, a fine and talented young man, who already, at an early age, gave the promise of eminent distinction in astronomy, proved to him a most severe trial; which, however, he bore with resignation, taking refuge from his grief in increased exertions. These brought on, or at least exasperated, an internal complaint, arising, in the opinion of his physicians, afterwards verified on actual examination, from the abnormal and fungous growth of some intestinal organ, under which, after much protracted suffering, he at

length succumbed, and expired on the 7th of March, 1846, in the 62d year of his age.

An extensive and minute account of the labours of this illustrious astronomer cannot be expected in a notice of this nature: all that can be done is to touch, and that briefly, on some of the principal among them.

Of his early and successful devotion to the improvement of our knowledge of comets something has been already said. This ever continued a favourite subject with him; and, in 1835, he had the great satisfaction to observe, with all the means which modern instruments afford, the wonderful phenomena of Halley's comet, the reduction of whose early observations (in preparation for this return of it to its perihelion) had signalized his first entry into his astronomical career. His observations of its physical appearance previous to its perihelion passage, and especially of the apparent oscillations to and fro of those singular jets of light from its head, which created so much astonishment among European observers, from day to day, and even from hour to hour, led him to conclude the inherence in the cometary matter of a polar or magnetic energy, and even to make (*Astronomische Nachrichten*, No. 310) the effect produced on a comet's orbit by the reaction of the matter of these jets, so projected forth from the nucleus into space, a subject of mathematical calculation. And it may not be irrelevant here to notice that other phenomena, of a totally different nature, exhibited by the same comet subsequent to its perihelion passage, as observed in the southern hemisphere, appear to authorize conclusions which, though not precisely identical with those of Bessel, have yet so much in common with them, that the assumption of repulsive forces as a means of accounting for cometary phenomena must henceforward take its place among hypotheses which cannot be lightly rejected, but must come to be tested by the combined aid of rigorous mathematical deduction and increased refinement of observation.

In a note appended to one of the numbers of the *Astronomische Nachrichten* (No. 175), the following remarkable expression of Schumacher occurs:—"One may almost assert that one exact and able calculator is capable of doing better service to astronomical science than two new observatories." It was in the capacity of such a calculator (taking the word in that enlarged and eminent sense in which the writer doubtless understood it,—a calculator thoroughly master of every resource of theory, and capable of bringing them all to bear on the subject of discussion) that Bessel undertook and completed, while yet young as an astronomer, his great work, the *Fundamenta Astronomiæ*, a work which it is difficult for any astronomer, and least of all an English one, to speak of in measured terms. It affords the first example of the complete and thorough reduction of a great series of observations, grounded, in the first instance, on a rigorous investigation, from the observations themselves, of all the instrumental errors, and carried out on a uniform plan, neglecting no minutiæ which a refined analysis and a

perfect system of computation could afford, and resulting in a model catalogue, such as (without disparagement to the far more extensive catalogue of Piazzi, published four years antecedently) the world had not before imagined. As Englishmen, we cannot but be proud to have furnished from our national observatory, in the twelve years' work of a single British astronomer, that "one entire and perfect" mass of precious material, from which has been sculptured forth in so masterly a manner, and in all its classical proportions, the fair form of modern sidereal astronomy. Independent of the deduction of the places of the stars, of the instrumental reductions, and of the local data, the disquisitions which this work contains on the several uranographical corrections are, and ever must remain, models of delicate and powerful research, monographs of their respective subjects, embodying in a succinct and perspicuous point of view, so far as their complexity will admit, the totality of our knowledge of their theory brought into the most practical forms for application. In the reduction of these observations, however, his final improvement, which does away altogether with the necessity of using special tables for the several uranographical corrections, and for individual stars, and renders it practicable, by the calculation of a system of constants for each star, and an annual table common to all the stars, to provide for the reduction of all meridional observations, was not yet adopted. That capital step, which has so infinitely facilitated all subsequent reductions, was not made till somewhat later, and had nearly been anticipated by Mr. Baily, who, on his part, and independently, had been occupied about the same time on a similar simplification.* In furtherance of the important object of facilitating the reduction of observations of the planets, as well as of the fixed stars, on a uniform system, he prepared and published, in 1830, his *Tabulæ Regiomontanæ*, a work of the greatest utility and influence on the practice of astronomers in this respect.

The principal instruments at first supplied to the Königsberg Observatory were two, a transit by Dollond, and a meridian circle by Cary. This last instrument, though not itself of a very high order of excellence, may be considered as having been rendered so by the masterly and elaborate investigation of its errors of division which Bessel bestowed upon it. The complete investigation of instrumental error was a subject on which he was at every period remarkably scrupulous, and not without reason, as the dreadful consequences which have followed its neglect in more than one instance clearly demonstrate. In *his* opinion, the reputation of no artist, however distinguished, could be held to dispense with the most careful and searching scrutiny into the errors of his workmanship; or, with the most refined application, both of experience and theory, into the amount and laws of its flexure, whether of the telescope or limb, by its own weight in different

* See the Memoir of Mr. Baily, *Mem. Ast. Soc.* vol. xv. p. 324, where, in line 7, for "*precession*" read *nutation*.

positions. In fact, no astronomer has ever gone deeper into the theory of instruments, or exemplified that theory by more elaborate experimental inquiries. The finishing hand was put to a most remarkable memoir on the effects of flexure, but a very short time previous to his death, which has only just seen the light (see *Astronomische Nachrichten*, No. 577, *et seq.*), its publication having been directed in his will.

The improvement of Carlini's tables of the sun was the object and result of the first five years' observations with Cary's circle and Dollond's transit; though other objects of interest were not neglected, especially that of an exact determination of the places of those stars in which large proper motions had been remarked. But when, in the year 1820, the circle of Cary was replaced by the larger and more accurate meridian circle of Reichenbach, a wider field of inquiry was opened out, and a task undertaken and completed of which astronomy is only now beginning to reap the fruits. This was no less than a determination of the places of all the stars, down to the ninth magnitude, in a zone of the heavens extending from 15° south to 45° north declination. Previous to entering upon this great work, however, the new instrument was subjected to the same, or a more severe and rigid scrutiny into the divisions of its circle, and the accurate adaptation of its parts (by the aid of a microscopical apparatus contrived and executed by Pistor), which its predecessor had undergone. It sustained the ordeal to admiration. The zone observations were commenced on the 19th of August, 1821, and completed on the 21st of January, 1833, in 536 zones, comprehending upwards of 75,000 observations. The arrangement of the work, as printed in the Königsberg observations, is in the highest degree convenient for reference. Every zone is accompanied by a small table, by means of which the reduction of any one of the observed objects to a fixed epoch may be performed at once, and in the shortest possible time; so that the observations themselves, by the aid of an index to the zones, have nearly all the advantage of a catalogue, and that of a very high degree of precision. Their actual reduction and arrangement as a catalogue was commenced in 1830 by Professor Weisse; but the promised work has not, we believe, yet appeared. Bessel was assisted in the observation of these zones by M. Argelander, who, since his removal to the direction of the observatory at Bonn, has continued them from the 45th to the 80th degree of north declination, the observations being very recently published in the first volume of the transactions of the Bonn Observatory, in 204 zones. It will be a matter of no small interest, when the elements of the new planets which have so recently been added to our list shall have become sufficiently known to admit of a retrospective ephemeris being calculated, to search the Königsberg zones for missing stars lying in their paths, and corresponding to former places of them. The detection of such will be of inestimable value in the correction of their elements and the theory of their perturbations.

Future astronomers will reap the rewards of this laborious work; but there was one subject of astronomical research, of a practical nature, which Bessel was destined to commence and carry out to its completion, terminating in a discovery of first-rate importance, in the determination, beyond the reach of reasonable doubt or cavil, of the parallax of a fixed star. The star, 61 *Cygni*, pitched upon for his attack upon this difficult question, which had so long bid defiance to the attempts of astronomers, and which seemed destined constantly to afford fresh proofs of the imperfections of our instruments and the inadequacy of our methods, was one which combined, with distinct grounds of *à priori* probability in favour of its proximity to our system, peculiar advantages for the application of the mode of observation contemplated. The proper motion is remarkably large,—the greatest, with one exception, yet observed. This of itself affords some presumption of proximity. Another, less equivocal, is found in the fact, that it is demonstrably a binary double star, whose orbitual motion is remarkably rapid when compared with the apparent angular distance of its individuals, indicating a large angular dimension of the orbit mutually described about each other as seen from the earth. As regards its adaptation for micrometric observation, two minute stars, at the respective distances of 8′ and 12′ from the middle point of the pair, situated with respect to that point in positions differing by very nearly a right angle, permit no parallactic movement to take place without effecting a change of apparent distance from one or other of them; so that the maximum rapidity of change with respect to one shall correspond to the minimum, and near evanescence of such change with respect to the other, a very important circumstantial character of the *reality* of any observed movement supposed to arise from parallax.

The only obstacle in the way of the detection of any minute parallactic motion, by means of these stars, consisted in the difficulty of measuring distances so large as 8′ or 12′ to the precision of a very small fraction of a second. Thanks to the perfect workmanship of the Munich opticians, this precision was rendered attainable by the heliometer constructed for the Königsberg Observatory, and there erected in 1829. The observations in question were made in the years 1837–1840; and their result, as is well known, has satisfied every astronomer of the reality of the parallax attributed by Bessel to this star, and of the near approximation to its true amount.

The discussion of these observations involved considerations of very great delicacy, chiefly turning on the effect of temperature on the focal distances and metallic mounting of the lenses, as well as on an infinity of minute considerations as to the effects of refraction, &c., and of instrumental errors on the measures of angles of such magnitude in various positions with respect to the vertical. Every thing of this nature has been made the subject of minute and careful inquiry in four very elaborate papers forming part of the first volume of a series of Essays (*Astronomische Untersuch-*

ungen), of which we shall have further occasion to speak. The first of these enters in its fullest extent into the general theory and formulæ of an equatorially mounted heliometer. The second is devoted to a special application of this theory to the Königsberg instrument. Among the remarkable features of this second memoir, deserves to be noticed a happy application of the general resolution, by continued fractions, of an equation of finite differences of the second order, to the expression of the course of a ray refracted through any combination of spherical surfaces. The third of these memoirs relates to the elimination of the influence of refraction; and the fourth to that of the several effects of precession, nutation, and aberration, from measures so taken, and from micrometic measures generally.

The exceeding precision of micrometic measurement of which the heliometer proved capable was also brought to bear upon other objects, such as the measurement of distances of the Huyghenian satellite of *Saturn* from the ring, and those of *Jupiter* from the limb of the planet, with a view to the more perfect determination of the masses of these planets. The results of the latter observations, as compared with their theory, and the improved tables of the motions of the satellites themselves, concluded from the whole inquiry, are to be found in the Ninth Essay, Vol. II. of the *Astronomische Untersuchungen*, already referred to.

In the year 1824, in a paper communicated to Schumacher's *Astronomische Nachrichten*, No. 49, Bessel recalled the attention of astronomers to the great and peculiar advantages in the determination of latitudes, and of the declinations of such stars as pass near the zenith, offered by a mode of observation whose first idea seems to have been due to the celebrated Römer, viz. by the use of a transit instrument at right angles to the meridian, and therefore describing the prime-vertical. By the use of this method, the differences of declination of two stars passing near the zenith of any given place, or the change of declination of one and the same star at different times, comes to be measured upon a vastly increased scale by the interval of its two transits over the vertical, expressed in time. It is therefore independent of the errors of division of any circle, and, as Bessel has also shewn, of a variety of other influential causes of error, and is especially adapted for those inquiries in which the zenith sector has been usually employed. A large instrument constructed upon this principle has been since erected in the Imperial Observatory at Pulkowa, with the express object of affording normal results as to the constants of aberration, nutation, &c., and the investigation of parallax; and from the terms in which the illustrious astronomer at the head of that establishment speaks of its performance, the views of M. Bessel in recommending it for general adoption appear to be fully borne out.

Intent on fully providing the observatory under his direction with the most perfect instruments which art can execute, Bessel obtained permission to order for that institution a new and improved meridian circle from the Brothers Repsold, of Hamburgh,

with peculiar adaptations devised by himself for facilitating the handling, setting, and reading of the circle. On the reception of this instrument, which was erected in the observatory about the end of 1841, a mode of determining the nadir point proposed by Bohnenberger, by reflexion of the wires of the instrument itself in mercury, by which the instrument is made its own vertical collimator, was adapted and brought into constant use; a full account of which, and of the extreme precision so attained, will be found in Nos. 480 and 481 of the *Astronomische Nachrichten*. The possession of this admirable instrument enabled him to resume, with every advantage he could desire, an inquiry of the greatest importance, but at the same time of the utmost delicacy, which had long engaged his attention. The first suspicion of a want of perfect uniformity in the proper motions of certain fixed stars, among which *Sirius* and *Procyon* may be especially particularized, occurred to Bessel in 1834. Pond appears also, at an earlier period, to have become impressed with the same idea. The observations of declination made at Königsberg, previous to the erection of the Repsold circle (see *Astron. Nachr.* 422), had tended greatly to confirm this suspicion; but it was not until a series of observations of considerable extent had been made with the new circle, that Bessel thought himself authorized to announce it as a positive astronomical fact, no longer to be confounded with possible error of observation and reduction, but as a thing to be accounted for by some distinct physical cause. On the nature of this cause he even hazarded a speculation, doubtless a very bold one, viz. that *Sirius* and *Procyon*, in which the observed deviation from uniformity is regarded by him as fully established, are really double stars, one of the individuals only, however, being luminous; and that the variability in question arises from their relative orbitual motion about their common centre of gravity. Time only, and assiduous observation, can elucidate this curious subject.

Though very far from having exhausted the catalogue of Bessel's purely astronomical discoveries and researches, the limits of this notice require us now to pass to the mention of his highly important investigations on subjects connected more immediately with our own globe, viz. geodesical measurements, the determination of standards of weight and length, the length of the pendulum, and the train of subjects therewith connected; all which afforded him opportunities of displaying a skill not less consummate as a physical experimenter, than he had already shewn as a mathematician and astronomer.

His first step in this career was the determination of the length of the simple pendulum at his own observatory. The principle of this determination is the observation of the times of vibration of two pendulums whose difference is precisely equal to a given standard of length; for which purpose a fac-simile of the toise of Peru was chosen, being a measure *aux bouts* which the principle of construction of the apparatus rendered a necessary condition. The actual vibrating pendulum was a ball suspended by a wire, the suspending

apparatus being made to rest alternately on the upper end of the toise and on the flat support of its lower end, the tangent plane of the lower surface of the ball being brought to a constant level by the use of the lever of contact. The series of experiments made with this apparatus was published in the volume of *Memoirs of the Berlin Academy* for 1826, though the date of their communication and reading was two years later, the publication of the Memoirs being so much in arrear. This investigation will always be considered as forming an epoch in the history of pendulum experiments, on account of the peculiar mode in which the subject of the resistance of the air to the motion of the suspended body is taken into consideration; this renders it necessary to estimate as part of the mass set in motion the weight of the air dragged along with it. The researches of Mr. Baily and Colonel Sabine have fully confirmed the necessity of taking into account this essential though small correction.

The determination of the same important element for the then newly erected observatory at Berlin followed in 1835. The method employed, with some slight improvements, was the same as that practised at Königsberg, and the whole process will be found in the *Memoirs of the Berlin Academy* for 1835.

The interim between these two determinations was occupied with a series of pendulum experiments of very especial physical interest and importance—a rigorous inquiry, namely, into the fundamental question whether gravity be really, in all kinds of bodies, proportional to their inertia *solely?* or, in other words, whether or not there be any thing specific or dependent on the intimate nature or chemical constitution of a body which determines the energy of its gravitating power,* the *inertia* being given? The experiments of Newton, though they preclude all idea of any considerable or palpable amount of such specific difference among bodies, could by no means be regarded as sufficiently exact to settle a point of such vast importance with that decision which modern science requires. All idea of such specific attraction is, however, completely done away with by the result of the elaborate series of experiments set on foot by M. Bessel for this purpose, which form the subject of a Memoir presented to the Berlin Academy in 1832, and printed in their Memoirs for 1830; every substance examined, including meteoric iron and stony masses, having given exactly the same coefficient of gravitating intensity as compared with its inertia.

Immediately connected with the length of the seconds' pendulum is the determination of standards of weight and measure. The fixation of the Prussian standard of length, ordered by law in 1816, after remaining nineteen years in abeyance, was committed to

* It is so easy to misunderstand the true gist of this inquiry, that it may be not amiss to state it otherwise. Suppose *a pound* of gold, *a pound* of lead, and *a pound* of ice to be formed into three spheres, and placed with their centres at the three angles of an equilateral triangle,—will they or will they not, taken two by two, attract *each other* with equal forces? The *earth* is here considered as an impartial mixture of all elementary substances.

M. Bessel in 1835, who completed the task assigned to him in 1837. The account of this operation, and of the comparison of the new standard with the Peru toise, which had served for the measure of the pendulum, forms the subject of a Memoir printed in 1839 by order of the Prussian Government.

Eminent as were his mathematical resources, and his aptitude for bringing them to bear in the most advantageous and effective manner upon every point of practical application, there is, perhaps, no subject among the multitude of those which at different times engaged his attention in which these qualities were more singularly called into action, in combination with his skill as an astronomer, and his perfect knowledge of instruments, than in the geodesical operations which he was about this period called upon to conduct, in conjunction with General Baeyer, for the triangulation of Eastern Prussia. Though the actual extent of this triangulation was not considerable, the extreme points connected being only about 120 English miles distant, still few trigonometrical operations have been executed of greater circumstantial importance, inasmuch as it had for its especial object to connect the operations of Struve in the north of Russia and Finland, and those of Von Tenner in the south of that empire, with those of Western and Southern Europe, from which they previously stood altogether disjoined. The triangulation of Hessia, Thuringia, Brandenburg, and Silesia, under the direction of General Müffling, had connected the Hanoverian and Danish measurements on the one hand, and those of France (and consequently also of Britain) on the other, with the Bavarian and Austrian surveys. The chain of connexion had, moreover, been carried on by the triangulation of Western Prussia and the Grand Duchy of Posen, as far as the borders of the Frische Haff, on the Baltic; and one link only was wanting between Trunz, the furthest point of this last-mentioned operation, and Memel, to bring together these detached masses, and bind them into one vast European combination. Bessel's conduct of this operation was marked, like every thing which he undertook, by the adoption of new and refined processes, both of observation and computation. The astronomical latitudes of his stations, for instance, were ascertained by the application of that peculiar mode of using the transit instrument to which allusion has already been made, to the exclusion of the zenith sector and repeating circle, which had hitherto been used for that purpose. As respects the calculation of the triangles, also, a general mode of treatment was now, for the first time, adopted, combining the whole system of observations in all the triangles, so as to lead to a single conclusion as to the final results of the total work, and not (as had been the practice in all previous cases) to derive by several distinct combinations several distinct conclusions, either as to the whole or to subordinate parts. In the method pursued, each triangle is supposed affected with unknown or rather indeterminate errors in all its angles. The observations of the angles in each, with the application of the spheroidical excess, gives a sum to which all the errors must conform *as nearly as possible*. In the

language of modern computation, it affords an *equation of condition* which takes its place and acquires its due influence as an element of a final system of similar equations, whose joint solution is then accomplished by the application of that powerful process, the method of least squares, to which our knowledge of physical truth is so much indebted. In the measurement of the base, also, much ingenious contrivance and many peculiar features occur; and the operation, taken all together, will ever be regarded, apart from its adventitious circumstances of interest, as one of the most instructive geodesical measurements which has ever been performed.

These occupations unavoidably drew the attention of Bessel to the general subject of the figure of the earth, as resulting from geodesical measurements, and more especially to the best and most effectual means of availing ourselves of the vast accumulation of data obtained at such enormous cost and labour, in India, in France, in Britain, and elsewhere. To grasp the whole of this mass under one general and systematic process of reduction and calculation appeared to him an object worthy of his powers, and this design was carried out in that powerful, regular, and at the same time highly artificial mode which had now become habitual to him, in a series of Memoirs communicated to the *Astron. Nachr.* 333–6, 338. The first of these contains the general exhibition of the most advantageous mode of combining the several independent measures of meridian arcs, so as to obtain by the method of least squares the most probable result as to the dimensions of the terrestrial spheroid, and applies that method to the received values of the arcs, as given by their several measurers, taking for granted the correctness of their computation of their own triangles, and the latitudes of their extreme points. But he did not stop here. On the contrary, engaging deeper in the inquiry, he was led to enter upon a recomputation of the latitudes of all the principal stations in the British and Indian arcs, and finally to recompute entirely, according to the same principle of combination used in his own East Prussian triangulation, the whole system of French triangles between Montjouy and Formentera. There is, perhaps, hardly one of his numerous and laborious works calculated to give a better idea of the extreme scrupulousness of all his proceedings, and his contempt of labour where the object is to elicit truth in its most absolute form from a mass of observations of undoubted excellence, than this last calculation. A mistake, as is well known, had been committed in one part of the computation of the French triangles, by which the total distance between the parallels of these two points had been rendered erroneous to the extent of nearly seventy toises. The mistake, however, had been rectified by the independent calculations of four eminent French geodesists, and their conclusions agreed within three or four toises of each other. This, however, did not satisfy Bessel, and he actually recalculated the whole of the work by his own method, producing a result agreeing with the mean of the four determinations alluded to within a fraction of a toise.

We are still very far from having exhausted the long catalogue of Bessel's astronomical labours. His memoir on the precession of the equinoxes, honoured with a prize by the Berlin Academy, and his researches on the planetary perturbations, might well demand some especial notice, did not our necessary limits forbid it, and oblige us also to pass unmentioned, otherwise than generally, the astonishing host of contributions with which, from time to time, he enriched the periodical literature of astronomy. The greater proportion of these are contained in the *Astronomische Nachrichten*— so great a number indeed, and many of them of such extent, that perhaps it is not exaggerating to say that at least a fifth part of that collection (now consisting of twenty-four volumes) has emanated from his pen. The *Zeitschrift für Astronomie*, the *Königsberger Archiv für Naturwissenschaften*, the *Monathliche Correspondenz*, and the Supplements to the *Berlin Ephemeris*, contain also many and valuable communications from him.* And when it is recollected that many of these papers are essays of great length and deep interest, abounding in profound research and new conceptions on almost every subject with which astronomers are conversant, we shall see cause to admire no less the indefatigable industry of the man than the extent and versatility of those powers which produced such a profusion of valuable matter. Some of these essays, retouched and enlarged, form part of a work entitled *Astronomische Untersuchungen*, or Astronomical Researches, two volumes of which have appeared, and a third was understood to be in preparation when his labours were arrested by illness.

In the year 1842 Bessel, for the first and last time, visited England, and was received in a manner befitting the high estimation in which his merits were held. His unaffected and pleasing deportment, the charm of his conversation, and the rich fund of information and instruction it afforded, will be remembered with pleasure and regret by all who had the good fortune to be in his company.

There can be little doubt that he was preparing, on his return to Germany, and perhaps even before his visit to England, for an attack upon that great problem whose solution has done so much honour to Le Verrier and Adams. He had, in fact, with a view to this undertaking, engaged a young and promising astronomer, Mr. Flemming, to reduce anew, with the utmost rigour, all known observations of *Uranus*, including the Königsberg observations of that planet, and to compare them with the tables. This was the groundwork of his intended researches. Mr. Flemming completed the reductions, which are in the possession of Mr. Schumacher, and died soon afterwards, and the fatal malady of which, after two years of continually increasing suffering, Bessel himself died, made its appearance and interdicted every serious labour.

* In Poggendorff's *Annalen der Physik* occur occasional communications by Bessel: among others, a long and interesting one in vol. lxxxii. (vi. N. S.) on the adjustment of thermometers.

The scientific character of Bessel will have been easily collected from what has been said of particular branches of his extensive labours. One leading feature of it was the concentration of all known data on each particular subject of inquiry, with the view of expressing from them, by the highest and most refined application of mathematical and computistic power, the utmost they are capable of affording in the direction of numerical precision; and, as a means to this end, to satisfy this earnest longing after precise results, an equally earnest and successful endeavour to improve to the utmost all formulæ and systems of computations *as such*; that is to say, to put them before the computist in a state ready for immediate use, and to give the last precision which the state of science admits to every fundamental and every derivative coefficient. In the preface to his *Untersuchungen*, he says of himself, that he at no time felt any especial predilection for one rather than another particular branch of astronomical occupation, but that one idea was continually present to his mind—that of always working up to an *immediate* and *definite* object; either that of arriving at some positive result, more perfect than what had before been obtained, or that of removing some acknowledged obstacle which opposed at once the improvement of more than one subject. And in this remarkable passage he goes on to declare, that the desire of merely accumulating data by observation, without the intention of using them to such ends, was altogether alien to his tastes; and that the deduction of actual results from observations, by the observer himself, with a distinct view to the improvement of knowledge, appeared to him, at all times, an essential condition of success in all astronomical research.

As a mathematician, Bessel takes, undoubtedly, a high rank; not, indeed, as an original inventor in the abstract walks of the pure analysis, but always with a view to applications, in which, whatever occasion required its exertion, his skill was never found unequal to the task on hand, no matter what its difficulty. As a practical astronomer, his knowledge of what may be called the theory of instruments—the mode of detecting, compensating, and eliminating their errors; the influence of flexures of their limbs, tubes, and other parts; and his acquaintance with, and constant practice of, every delicacy in their use, were such as has never been surpassed. Equally great in perfecting old methods of observation and in suggesting new, the practice of the modern German school of astronomers is almost emphatically Bessel's practice; and he was deservedly looked upon as a guide and model, not only in Germany but by Europe.

Bessel was, of course, elected into almost every academy in Europe as an Associate. He became a Foreign Member of this Society in 1822. As he advanced in years and in reputation, distinctions of a different kind were conferred upon him; among others, the order of the Dannebrog by the King of Denmark, and that of the Red Eagle, with the title of "Geheimer Regierung's Rath," and the order of Civil Merit by his own sovereign, whose favour he con-

stantly experienced, and whose attentions during his last illness were of the most benignant kind, and soothed, though they could not alleviate, his sufferings.

The Baron Damoiseau, independently of his paper on the theory of the moon, and his tables of the satellites of *Jupiter*, contributed to the astronomy of our time a work which must form an epoch in the theory of gravitation. His tables of the moon, published in 1824, are constructed on that theory alone. From the time of Newton, till the period just mentioned, all tables had depended, more or less, on observation, not only for the numerical data necessary for the determination of the undisturbed orbit, but also for the values of some of the coefficients of perturbation. To Damoiseau we are indebted for the first tables in which all perturbations are results of the theory; and this important labour must always secure him an honourable place among the followers of Newton, independently of the peculiar excellence of his results and formulæ, which have induced the Astronomer Royal partially to adopt them in the Greenwich reductions referred to in another part of this Report.

Were it intended to describe the results of the century instead of the current year, the subject to which your Council now come would lose none of its prominent interest. The prediction of a new planet, on grounds derived from calculation only—the fulfilment of that prediction—the attainment of the solution of the inverse problem of perturbation—mark the years 1845 and 1846 with an importance which belongs to no period except that of the announcement of the theory of gravitation and of the publication of the *Principia*.

The circumstances under which the discovery was made add to the interest of the question, by throwing difficulty in the way of the settlement of points of opinion connected with its history. And the embarrassment is materially increased by the necessity of deciding national rights, and of guarding against the undue influence of national feeling.

The facts connected with this singularly splendid triumph of mind over matter have been much discussed, and are now fully published. The statement made to this Society by the Astronomer Royal in November, the memoirs of M. Le Verrier, the memoir of Mr. Adams, and the statements made by Mr. Challis, and in various numbers of the *Comptes Rendus*, have put our Fellows in such possession of the absolute circumstances of the case as renders any detailed account of them unnecessary in this Report. It fortunately happens that there is no one disputed fact; but upon the construction of the facts, and upon the meaning of words, there are differences of opinion, at least as wide as those which have always existed upon the great question of the claims of Newton and Leibnitz to the invention of fluxions.

In one thing there is general agreement, namely, in giving both to M. Le Verrier and Mr. Adams the highest order of praise and admiration. As soon as they are compared, all manner of opinions are found to prevail as to their *relative* positions; but on the absolute