BALL ROBERT STAWELL

GREAT ASTRONOMERS

Robert Ball

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Ball R.

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Содержание

Robert S. Ball
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PREFACE

It has been my object in these pages to present the life of each astronomer in such detail as to enable the reader to realise in some degree the man's character and surroundings; and I have endeavoured to indicate as clearly as circumstances would permit the main features of the discoveries by which he has become known.

There are many types of astronomers—from the stargazer who merely watches the heavens, to the abstract mathematician who merely works at his desk; it has, consequently, been necessary in the case of some lives to adopt a very different treatment from that which seemed suitable for others.

While the work was in progress, some of the sketches appeared in "Good Words." The chapter on Brinkley has been chiefly derived from an article on the "History of Dunsink Observatory," which was published on the occasion of the tercentenary celebration of the University of Dublin in 1892, and the life of Sir William Rowan Hamilton is taken, with a few alterations and omissions, from an article contributed to the "Quarterly Review" on Graves' life of the great mathematician. The remaining chapters now appear for the first time. For many of the facts contained in the sketch of the late Professor Adams, I am indebted to the obituary notice written by my friend Dr. J. W. L. Glaisher, for the Royal Astronomical Society; while with regard to the late Sir George Airy, I have a similar acknowledgment to make to Professor H. H. Turner. To my friend Dr. Arthur A. Rambaut I owe my hearty thanks for his kindness in aiding me in the revision of the work.

R.S.B.

The Observatory, Cambridge.
October, 1895

INTRODUCTION

Of all the natural sciences there is not one which offers such sublime objects to the attention of the inquirer as does the science of astronomy. From the earliest ages the study of the stars has exercised the same fascination as it possesses at the present day. Among the most primitive peoples, the movements of the sun, the moon, and the stars commanded attention from their supposed influence on human affairs.

The practical utilities of astronomy were also obvious in primeval times. Maxims of extreme antiquity show how the avocations of the husbandman are to be guided by the movements of the heavenly bodies. The positions of the stars indicated the time to plough, and the time to sow. To the mariner who was seeking a way across the trackless ocean, the heavenly bodies offered the only reliable marks by which his path could be guided. There was, accordingly, a stimulus both from intellectual curiosity and from practical necessity to follow the movements of the stars. Thus began a search for the causes of the ever-varying phenomena which the heavens display.

Many of the earliest discoveries are indeed prehistoric. The great diurnal movement of the heavens, and the annual revolution of the sun, seem to have been known in times far more ancient than those to which any human monuments can be referred. The acuteness of the early observers enabled them to single out the more important of the wanderers which we now call planets. They saw that the star-like objects, Jupiter, Saturn, and Mars, with the more conspicuous Venus, constituted a class of bodies wholly distinct from the fixed stars among which their movements lay, and to which they bear such a superficial resemblance. But the penetration of the early astronomers went even further, for they recognized that Mercury also belongs to the same group, though this particular object is seen so rarely. It would seem that eclipses and other phenomena were observed at Babylon from a very remote period, while the most ancient records of celestial observations that we possess are to be found in the Chinese annals.

The study of astronomy, in the sense in which we understand the word, may be said to have commenced under the reign of the Ptolemies at Alexandria. The most famous name in the science of this period is that of Hipparchus who lived and worked at Rhodes about the year 160BC. It was his splendid investigations that first wrought the observed facts into a coherent branch of knowledge. He recognized the primary obligation which lies on the student of the heavens to compile as complete an inventory as possible of the objects which are there to be found. Hipparchus accordingly commenced by undertaking, on a small scale, a task exactly similar to that on which modern astronomers, with all available appliances of meridian circles, and photographic telescopes, are constantly engaged at the present day. He compiled a catalogue of the principal fixed stars, which is of special value to astronomers, as being the earliest work of its kind which has been handed down. He also studied the movements of the sun and the moon, and framed theories to account for the incessant changes which he saw in progress. He found a much more difficult problem in his attempt to interpret satisfactorily the complicated movements of the planets. With the view of constructing a theory which should give some coherent account of the subject, he made many observations of the places of these wandering stars. How great were the advances which Hipparchus accomplished may be appreciated if we reflect that, as a preliminary task to his more purely astronomical labours, he had to invent that branch of mathematical science by which alone the problems he proposed could be solved. It was for this purpose that he devised the indispensable method of calculation which we now know so well as trigonometry. Without the aid rendered by this beautiful art it would have been impossible for any really important advance in astronomical calculation to have been effected.

But the discovery which shows, beyond all others, that Hipparchus possessed one of the master-minds of all time was the detection of that remarkable celestial movement known as the precession of the equinoxes. The inquiry which conducted to this discovery involved a most profound investigation, especially when it is remembered that in the days of Hipparchus the means of observation of the heavenly bodies were only of the rudest description, and the available observations of earlier dates were extremely scanty. We can but look with astonishment on the genius of the man who, in spite of such difficulties, was able to detect such a phenomenon as the precession, and to exhibit its actual magnitude. I shall endeavour to explain the nature of this singular celestial movement, for it may be said to offer the first instance in the history of science in which we find that combination of accurate observation with skilful interpretation, of which, in the subsequent development of astronomy, we have so many splendid examples.

The word equinox implies the condition that the night is equal to the day. To a resident on the equator the night is no doubt equal to the day at all times in the year, but to one who lives on any other part of the earth, in either hemisphere, the night and the day are not generally equal. There is, however, one occasion in spring, and another in autumn, on which the day and the night are each twelve hours at all places on the earth. When the night and day are equal in spring, the point which the sun occupies on the heavens is termed the vernal equinox. There is similarly another point in which the sun is situated at the time of the autumnal equinox. In any investigation of the celestial movements the positions of these two equinoxes on the heavens are of primary importance, and Hipparchus, with the instinct of genius, perceived their significance, and commenced to study them. It will be understood that we can always define the position of a point on the sky with reference to the surrounding stars. No doubt we do not see the stars near the sun when the sun is shining, but they are there nevertheless. The ingenuity of Hipparchus enabled him to determine the positions of each of the two equinoxes relatively to the stars which lie in its immediate vicinity. After examination of the celestial places of these points at different periods, he was led to the conclusion that each equinox was moving relatively to the stars, though that movement was so slow that twenty five thousand years would necessarily elapse before a complete circuit of the heavens was accomplished. Hipparchus traced out this phenomenon, and established it on an impregnable basis, so that all astronomers have ever since recognised the precession of the equinoxes as one of the fundamental facts of astronomy. Not until nearly two thousand years after Hipparchus had made this splendid discovery was the explanation of its cause given by Newton.

From the days of Hipparchus down to the present hour the science of astronomy has steadily grown. One great observer after another has appeared from time to time, to reveal some new phenomenon with regard to the celestial bodies or their movements, while from time to time one commanding intellect after another has arisen to explain the true import of the facts of observations. The history of astronomy thus becomes inseparable from the history of the great men to whose labours its development is due.

In the ensuing chapters we have endeavoured to sketch the lives and the work of the great philosophers, by whose labours the science of astronomy has been created. We shall commence with Ptolemy, who, after the foundations of the science had been laid by Hipparchus, gave to astronomy the form in which it was taught throughout the Middle Ages. We shall next see the mighty revolution in our conceptions of the universe which are associated with the name of Copernicus. We then pass to those periods illumined by the genius of Galileo and Newton, and afterwards we shall trace the careers of other more recent discoverers, by whose industry and genius the boundaries of human knowledge have been so greatly extended. Our history will be brought down late enough to include some of the illustrious astronomers who laboured in the generation which has just passed away.

PTOLEMY

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The career of the famous man whose name stands at the head of this chapter is one of the most remarkable in the history of human learning. There may have been other discoverers who have done more for science than ever Ptolemy accomplished, but there never has been any other discoverer whose authority on the subject of the movements of the heavenly bodies has held sway over the minds of men for so long a period as the fourteen centuries during which his opinions reigned supreme. The doctrines he laid down in his famous book, "The Almagest," prevailed throughout those ages. No substantial addition was made in all that time to the undoubted truths which this work contained. No important correction was made of the serious errors with which Ptolemy's theories were contaminated. The authority of Ptolemy as to all things in the heavens, and as to a good many things on the earth (for the same illustrious man was also a diligent geographer), was invariably final.

Though every child may now know more of the actual truths of the celestial motions than ever Ptolemy knew, yet the fact that his work exercised such an astonishing effect on the human intellect for some sixty generations, shows that it must have been an extraordinary production. We must look into the career of this wonderful man to discover wherein lay the secret of that marvellous success which made him the unchallenged instructor of the human race for such a protracted period.

Unfortunately, we know very little as to the personal history of Ptolemy. He was a native of Egypt, and though it has been sometimes conjectured that he belonged to the royal families of the same name, yet there is nothing to support such a belief. The name, Ptolemy, appears to have been a common one in Egypt in those days. The time at which he lived is fixed by the fact that his first recorded observation was made in 127 AD, and his last in 151 AD. When we add that he seems to have lived in or near Alexandria, or to use his own words, "on the parallel of Alexandria," we have said everything that can be said so far as his individuality is concerned.

Ptolemy is, without doubt, the greatest figure in ancient astronomy. He gathered up the wisdom of the philosophers who had preceded him. He incorporated this with the results of his own observations, and illumined it with his theories. His speculations, even when they were, as we now know, quite erroneous, had such an astonishing verisimilitude to the actual facts of nature that they commanded universal assent. Even in these modern days we not unfrequently find lovers of paradox who maintain that Ptolemy's doctrines not only seem true, but actually are true.

In the absence of any accurate knowledge of the science of mechanics, philosophers in early times were forced to fall back on certain principles of more or less validity, which they derived from their imagination as to what the natural fitness of things ought to be. There was no geometrical figure so simple and so symmetrical as a circle, and as it was apparent that the heavenly bodies pursued tracks which were not straight lines, the conclusion obviously followed that their movements ought to be circular. There was no argument in favour of this notion, other than the merely imaginary reflection that circular movement, and circular movement alone, was "perfect," whatever "perfect" may have meant. It was further believed to be impossible that the heavenly bodies could have any other movements save those which were perfect. Assuming this, it followed, in Ptolemy's opinion, and in that of those who came after him for fourteen centuries, that all the tracks of the heavenly bodies were in some way or other to be reduced to circles.

Ptolemy succeeded in devising a scheme by which the apparent changes that take place in the heavens could, so far as he knew them, be explained by certain combinations of circular movement. This seemed to reconcile so completely the scheme of things celestial with the geometrical instincts which pointed to the circle as the type of perfect movement, that we can hardly wonder Ptolemy's theory met with the astonishing success that attended it. We shall, therefore, set forth with sufficient detail the various steps of this famous doctrine.

Ptolemy commences with laying down the undoubted truth that the shape of the earth is globular. The proofs which he gives of this fundamental fact are quite satisfactory; they are indeed the same proofs as we give today. There is, first of all, the well-known circumstance of which our books on geography remind us, that when an object is viewed at a distance across the sea, the lower part of the object appears cut off by the interposing curved mass of water.

The sagacity of Ptolemy enabled him to adduce another argument, which, though not quite so obvious as that just mentioned, demonstrates the curvature of the earth in a very impressive manner to anyone who will take the trouble to understand it. Ptolemy mentions that travellers who went to the south reported, that, as they did so, the appearance of the heavens at night underwent a gradual change. Stars that they were familiar with in the northern skies gradually sank lower in the heavens. The constellation of the Great Bear, which in our skies never sets during its revolution round the pole, did set and rise when a sufficient southern latitude had been attained. On the other hand, constellations new to the inhabitants of northern climes were seen to rise above the southern horizon. These circumstances would be quite incompatible with the supposition that the earth was a flat surface. Had this been so, a little reflection will show that no such changes in the apparent movements of the stars would be the consequence of a voyage to the south. Ptolemy set forth with much insight the significance of this reasoning, and even now, with the resources of modern discoveries to help us, we can hardly improve upon his arguments.

Ptolemy, like a true philosopher disclosing a new truth to the world, illustrated and enforced his subject by a variety of happy demonstrations. I must add one of them, not only on account of its striking nature, but also because it exemplifies Ptolemy's acuteness. If the earth were flat, said this ingenious reasoner, sunset must necessarily take place at the same instant, no matter in what country the observer may happen to be placed. Ptolemy, however, proved that the time of sunset did vary greatly as the observer's longitude was altered. To us, of course, this is quite obvious; everybody knows that the hour of sunset may have been reached in Great Britain while it is still noon on the western coast of America. Ptolemy had, however, few of those sources of knowledge which are now accessible. How was he to show that the sun actually did set earlier at Alexandria than it would in a city which lay a hundred miles to the west? There was no telegraph wire by which astronomers at the two Places could communicate. There was no chronometer or watch which could be transported from place to place; there was not any other reliable contrivance for the keeping of time. Ptolemy's ingenuity, however, pointed out a thoroughly satisfactory method by which the times of sunset at two places could be compared. He was acquainted with the fact, which must indeed have been known from the very earliest times, that the illumination of the moon is derived entirely from the sun. He knew that an eclipse of the moon was due to the interposition of the earth which cuts off the light of the sun. It was, therefore, plain that an eclipse of the moon must be a phenomenon which would begin at the same instant from whatever part of the earth the moon could be seen at the time. Ptolemy, therefore, brought together from various quarters the local times at which different observers had recorded the beginning of a lunar eclipse. He found that the observers to the west made the time earlier and earlier the further away their stations were from Alexandria. On the other hand, the eastern observers set down the hour as later than that at which the phenomenon appeared at Alexandria. As these observers all recorded something which indeed appeared to them simultaneously, the only interpretation was, that the more easterly a place the later its time. Suppose there were a number of observers along a parallel of latitude, and each noted the hour of sunset to be six o'clock, then, since the eastern times are earlier than western times, 6 p.m. at one station A will correspond to 5 p.m. at a station B sufficiently to the west. If, therefore, it is sunset to the observer at A, the hour of sunset will not yet be reached for the observer at B. This proves conclusively that the time of sunset is not the same all over the earth. We have, however, already seen that the apparent time of sunset would be the same from all stations if the earth were flat. When Ptolemy, therefore, demonstrated that the time of sunset was not the same at various places, he showed conclusively that the earth was not flat.

As the same arguments applied to all parts of the earth where Ptolemy had either been himself, or from which he could gain the necessary information, it followed that the earth, instead of being the flat plain, girdled with an illimitable ocean, as was generally supposed, must be in reality globular. This led at once to a startling consequence. It was obvious that there could be no supports of any kind by which this globe was sustained; it therefore followed that the mighty object must be simply poised in space. This is indeed an astonishing doctrine to anyone who relies on what merely seems the evidence of the senses, without giving to that evidence its due intellectual interpretation. According to our ordinary experience, the very idea of an object poised without support in space, appears preposterous. Would it not fall? we are immediately asked. Yes, doubtless it could not remain poised in any way in which we try the experiment. We must, however, observe that there are no such ideas as upwards or downwards in relation to open space. To say that a body falls downwards, merely means that it tries to fall as nearly as possible towards the centre of the earth. There is no one direction along which a body will tend to move in space, in preference to any other. This may be illustrated by the fact that a stone let fall at New Zealand will, in its approach towards the earth's centre, be actually moving upwards as far as any locality in our hemisphere is concerned. Why, then, argued Ptolemy, may not the earth remain poised in space, for as all directions are equally upward or equally downward, there seems no reason why the earth should require any support? By this reasoning he arrives at the fundamental conclusion that the earth is a globular body freely lying in space, and surrounded above, below, and on all sides by the glittering stars of heaven.

The perception of this sublime truth marks a notable epoch in the history of the gradual development of the human intellect. No doubt, other philosophers, in groping after knowledge, may have set forth certain assertions that are more or less equivalent to this fundamental truth. It is to Ptolemy we must give credit, however, not only for announcing this doctrine, but for demonstrating it by clear and logical argument. We cannot easily project our minds back to the conception of an intellectual state in which this truth was unfamiliar. It may, however, be well imagined that, to one who thought the earth was a flat plain of indefinite extent, it would be nothing less than an intellectual convulsion for him to be forced to believe that he stood upon a spherical earth, forming merely a particle relatively to the immense sphere of the heavens.

What Ptolemy saw in the movements of the stars led him to the conclusion that they were bright points attached to the inside of a tremendous globe. The movements of this globe which carried the stars were only compatible with the supposition that the earth occupied its centre. The imperceptible effect produced by a change in the locality of the observer on the apparent brightness of the stars made it plain that the dimensions of the terrestrial globe must be quite insignificant in comparison with those of the celestial sphere. The earth might, in fact, be regarded as a grain of sand while the stars lay upon a globe many yards in diameter.

So tremendous was the revolution in human knowledge implied by this discovery, that we can well imagine how Ptolemy, dazzled as it were by the fame which had so justly accrued to him, failed to make one further step. Had he made that step, it would have emancipated the human intellect from the bondage of fourteen centuries of servitude to a wholly monstrous notion of this earth's importance in the scheme of the heavens. The obvious fact that the sun, the moon, and the stars rose day by day, moved across the sky in a glorious never-ending procession, and duly set when their appointed courses had been run, demanded some explanation. The circumstance that the fixed stars preserved their mutual distances from year to year, and from age to age, appeared to Ptolemy to prove that the sphere which contained those stars, and on whose surface they were believed by him to be fixed, revolved completely around the earth once every day. He would thus account for all the phenomena of rising and setting consistently with the supposition that our globe was stationary. Probably this supposition must have appeared monstrous, even to Ptolemy. He knew that the earth was a gigantic object, but, large as it may have been, he knew that it was only a particle in comparison with the celestial sphere, yet he apparently believed, and certainly succeeded in persuading other men to believe, that the celestial sphere did actually perform these movements.

Ptolemy was an excellent geometer. He knew that the rising and the setting of the sun, the moon, and the myriad stars, could have been accounted for in a different way. If the earth turned round uniformly once a day while poised at the centre of the sphere of the heavens, all the phenomena of rising and setting could be completely explained. This is, indeed, obvious after a moment's reflection. Consider yourself to be standing on the earth at the centre of the heavens. There are stars over your head, and half the contents of the heavens are visible, while the other half are below your horizon. As the earth turns round, the stars over your head will change, and unless it should happen that you have taken up your position at either of the poles, new stars will pass into your view, and others will disappear, for at no time can you have more than half of the whole sphere visible. The observer on the earth would, therefore, say that some stars were rising, and that some stars were setting. We have, therefore, two totally distinct methods, each of which would completely explain all the observed facts of the diurnal movement. One of these suppositions requires that the celestial sphere, bearing with it the stars and other celestial bodies, turns uniformly around an invisible axis, while the earth remains stationary at the centre. The other supposition would be, that it is the stupendous celestial sphere which remains stationary, while the earth at the centre rotates about the same axis as the celestial sphere did before, but in an opposite direction, and with a uniform velocity which would enable it to complete one turn in twenty-four hours. Ptolemy was mathematician enough to know that either of these suppositions would suffice for the explanation of the observed facts. Indeed, the phenomena of the movements of the stars, so far as he could observe them, could not be called upon to pronounce which of these views was true, and which was false.

Ptolemy had, therefore, to resort for guidance to indirect lines of reasoning. One of these suppositions must be true, and yet it appeared that the adoption of either was accompanied by a great difficulty. It is one of his chief merits to have demonstrated that the celestial sphere was so stupendous that the earth itself was absolutely insignificant in comparison therewith. If, then, this stupendous sphere rotated once in twenty-four hours, the speed with which the movement of some of the stars must be executed would be so portentous as to seem well-nigh impossible. It would, therefore, seem much simpler on this ground to adopt the other alternative, and to suppose the diurnal movements were due to the rotation of the earth. Here Ptolemy saw, or at all events fancied he saw, objections of the weightiest description. The evidence of the senses appeared directly to controvert the supposition that this earth is anything but stationary. Ptolemy might, perhaps, have dismissed this objection on the ground that the testimony of the senses on such a matter should be entirely subordinated to the interpretation which our intelligence would place upon the facts to which the senses deposed. Another objection, however, appeared to him to possess the gravest moment. It was argued that if the earth were rotating, there is nothing to make the air participate in this motion, mankind would therefore be swept from the earth by the furious blasts which would arise from the movement of the earth through an atmosphere at rest. Even if we could imagine that the air were carried round with the earth, the same would not apply, so thought Ptolemy, to any object suspended in the air. So long as a bird was perched on a tree, he might very well be carried onward by the moving earth, but the moment he took wing, the ground would slip from under him at a frightful pace, so that when he dropped down again he would find himself at a distance perhaps ten times as great as that which a carrier-pigeon or a swallow could have traversed in the same time. Some vague delusion of this description seems even still to crop up occasionally. I remember hearing of a proposition for balloon travelling of a very remarkable kind. The voyager who wanted to reach any other place in the same latitude was simply to ascend in a balloon, and wait there till the rotation of the earth conveyed the locality which happened to be his destination directly beneath him, whereupon he was to let out the gas and drop down! Ptolemy knew quite enough natural philosophy to be aware that such a proposal for locomotion would be an utter absurdity; he knew that there was no such relative shift between the air and the earth as this motion would imply. It appeared to him to be necessary that the air should lag behind, if the earth had been animated by a movement of rotation. In this he was, as we know, entirely wrong. There were, however, in his days no accurate notions on the subject of the laws of motion.

Assiduous as Ptolemy may have been in the study of the heavenly bodies, it seems evident that he cannot have devoted much thought to the phenomena of motion of terrestrial objects. Simple, indeed, are the experiments which might have convinced a philosopher much less acute than Ptolemy, that, if the earth did revolve, the air must necessarily accompany it. If a rider galloping on horseback tosses a ball into the air, it drops again into his hand, just as it would have done had he been remaining at rest during the ball's flight; the ball in fact participates in the horizontal motion, so that though it really describes a curve as any passer-by would observe, yet it appears to the rider himself merely to move up and down in a straight line. This fact, and many others similar to it, demonstrate clearly that if the earth were endowed with a movement of rotation, the atmosphere surrounding it must participate in that movement. Ptolemy did not know this, and consequently he came to the conclusion that the earth did not rotate, and that, therefore, notwithstanding the tremendous improbability of so mighty an object as the celestial sphere spinning round once in every twenty-four hours, there was no course open except to believe that this very improbable thing did really happen. Thus it came to pass that Ptolemy adopted as the cardinal doctrine of his system a stationary earth poised at the centre of the celestial sphere, which stretched around on all sides at a distance so vast that the diameter of the earth was an inappreciable point in comparison therewith.

Ptolemy having thus deliberately rejected the doctrine of the earth's rotation, had to make certain other entirely erroneous suppositions. It was easily seen that each star required exactly the same period for the performance of a complete revolution of the heavens. Ptolemy knew that the stars were at enormous distances from the earth, though no doubt his notions on this point came very far short of what we know to be the reality. If the stars had been at very varied distances, then it would be so wildly improbable that they should all accomplish their revolutions in the same time, that Ptolemy came to the conclusion that they must be all at the same distance, that is, that they must be all on the surface of a sphere. This view, however erroneous, was corroborated by the obvious fact that the stars in the constellations preserved their relative places unaltered for centuries. Thus it was that Ptolemy came to the conclusion that they were all fixed on one spherical surface, though we are not informed as to the material of this marvellous setting which sustained the stars like jewels.

Nor should we hastily pronounce this doctrine to be absurd. The stars do appear to lie on the surface of a sphere, of which the observer is at the centre; not only is this the aspect which the skies present to the untechnical observer, but it is the aspect in which the skies are presented to the most experienced astronomer of modern days. No doubt he knows well that the stars are at the most varied distances from him; he knows that certain stars are ten times, or a hundred times, or a thousand times, as far as other stars. Nevertheless, to his eye the stars appear on the surface of the sphere, it is on that surface that his measurements of the relative places of the stars are made; indeed, it may be said that almost all the accurate observations in the observatory relate to the places of the stars, not as they really are, but as they appear to be projected on that celestial sphere whose conception we owe to the genius of Ptolemy.

This great philosopher shows very ingeniously that the earth must be at the centre of the sphere. He proves that, unless this were the case, each star would not appear to move with the absolute uniformity which does, as a matter of fact, characterise it. In all these reasonings we cannot but have the most profound admiration for the genius of Ptolemy, even though he had made an error so enormous in the fundamental point of the stability of the earth. Another error of a somewhat similar kind seemed to Ptolemy to be demonstrated. He had shown that the earth was an isolated object in space, and being such was, of course, capable of movement. It could either be turned round, or it could be moved from one place to another. We know that Ptolemy deliberately adopted the view that the earth did not turn round; he had then to investigate the other question, as to whether the earth was animated by any movement of translation. He came to the conclusion that to attribute any motion to the earth would be incompatible with the truths at which he had already arrived. The earth, argued Ptolemy, lies at the centre of the celestial sphere. If the earth were to be endowed with movement, it would not lie always at this point, it must, therefore, shift to some other part of the sphere. The movements of the stars, however, preclude the possibility of this; and, therefore, the earth must be as devoid of any movement of translation as it is devoid of rotation. Thus it was that Ptolemy convinced himself that the stability of the earth, as it appeared to the ordinary senses, had a rational philosophical foundation.

Not unfrequently it is the lot of the philosophers to contend against the doctrines of the vulgar, but when it happens, as in the case of Ptolemy's researches, that the doctrines of the vulgar are corroborated by philosophical investigation which bear the stamp of the highest authority, it is not to be wondered at that such doctrines should be deemed well-nigh impregnable. In this way we may, perhaps, account for the remarkable fact that the theories of Ptolemy held unchallenged sway over the human intellect for the vast period already mentioned.

Up to the present we have been speaking only of those primary motions of the heavens, by which the whole sphere appeared to revolve once every twenty-four hours. We have now to discuss the remarkable theories by which Ptolemy endeavoured to account for the monthly movement of the moon, for the annual movement of the sun, and for the periodic movements of the planets which had gained for them the titles of the wandering stars.

Possessed with the idea that these movements must be circular, or must be capable, directly or indirectly, of being explained by circular movements, it seemed obvious to Ptolemy, as indeed it had done to previous astronomers, that the track of the moon through the stars was a circle of which the earth is the centre. A similar movement with a yearly period must also be attributed to the sun, for the changes in the positions of the constellations in accordance with the progress of the seasons, placed it beyond doubt that the sun made a circuit of the celestial sphere, even though the bright light of the sun prevented the stars in its vicinity, from being seen in daylight. Thus the movements both of the sun and the moon, as well as the diurnal rotation of the celestial sphere, seemed to justify the notion that all celestial movements must be "perfect," that is to say, described uniformly in those circles which were the only perfect curves.

The simplest observations, however, show that the movements of the planets cannot be explained in this simple fashion. Here the geometrical genius of Ptolemy shone forth, and he devised a scheme by which the apparent wanderings of the planets could be accounted for without the introduction of aught save "perfect" movements.

To understand his reasoning, let us first set forth clearly those facts of observation which require to be explained. I shall take, in particular, two planets, Venus and Mars, as these illustrate, in the most striking manner, the peculiarities of the inner and the outer planets respectively. The simplest observations would show that Venus did not move round the heavens in the same fashion as the sun or the moon. Look at the evening star when brightest, as it appears in the west after sunset. Instead of moving towards the east among the stars, like the sun or the moon, we find, week after week, that Venus is drawing in towards the sun, until it is lost in the sunbeams. Then the planet emerges on the other side, not to be seen as an evening star, but as a morning star. In fact, it was plain that in some ways Venus accompanied the sun in its annual movement. Now it is found advancing in front of the sun to a certain limited distance, and now it is lagging to an equal extent behind the sun.

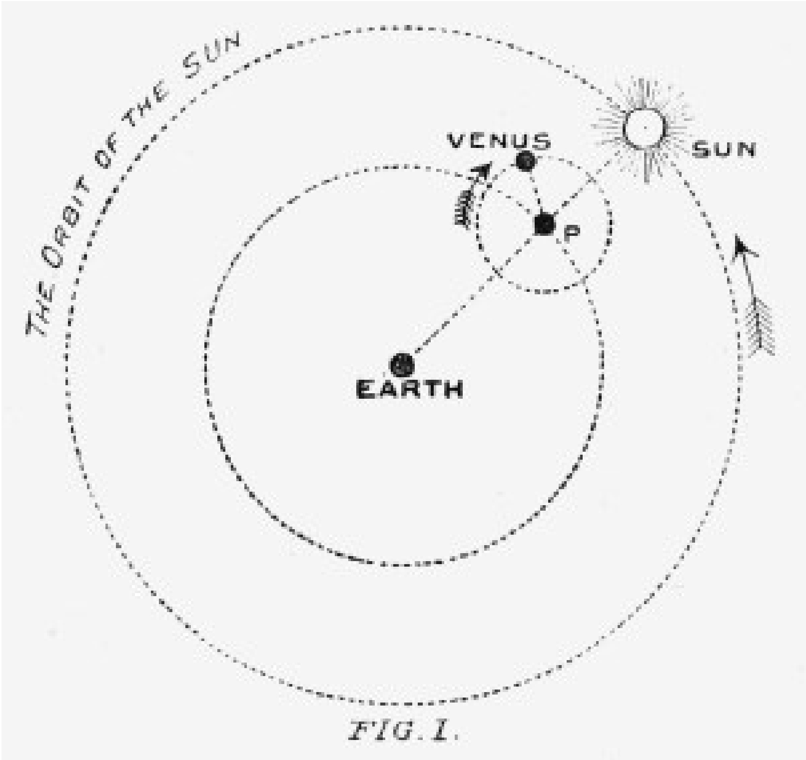


FIG. 1. PTOLEMY'S PLANETARY SCHEME.

These movements were wholly incompatible with the supposition that the journeys of Venus were described by a single motion of the kind regarded as perfect. It was obvious that the movement was connected in some strange manner with the revolution of the sun, and here was the ingenious method by which Ptolemy sought to render account of it. Imagine a fixed arm to extend from the earth to the sun, as shown in the accompanying figure (Fig. 1), then this arm will move round uniformly, in consequence of the sun's movement. At a point P on this arm let a small circle be described. Venus is supposed to revolve uniformly in this small circle, while the circle itself is carried round continuously by the movement of the sun. In this way it was possible to account for the chief peculiarities in the movement of Venus. It will be seen that, in consequence of the revolution around P, the spectator on the earth will sometimes see Venus on one side of the sun, and sometimes on the other side, so that the planet always remains in the sun's vicinity. By properly proportioning the movements, this little contrivance simulated the transitions from the morning star to the evening star. Thus the changes of Venus could be accounted for by a Combination of the "perfect" movement of P in the circle which it described uniformly round the earth, combined with the "perfect" motion of Venus in the circle which it described uniformly around the moving centre.

In a precisely similar manner Ptolemy rendered an explanation of the fitful apparitions of Mercury. Now just on one side of the sun, and now just on the other, this rarely-seen planet moved like Venus on a circle whereof the centre was also carried by the line joining the sun and the earth. The circle, however, in which Mercury actually revolved had to be smaller than that of Venus, in order to account for the fact that Mercury lies always much closer to the sun than the better-known planet.

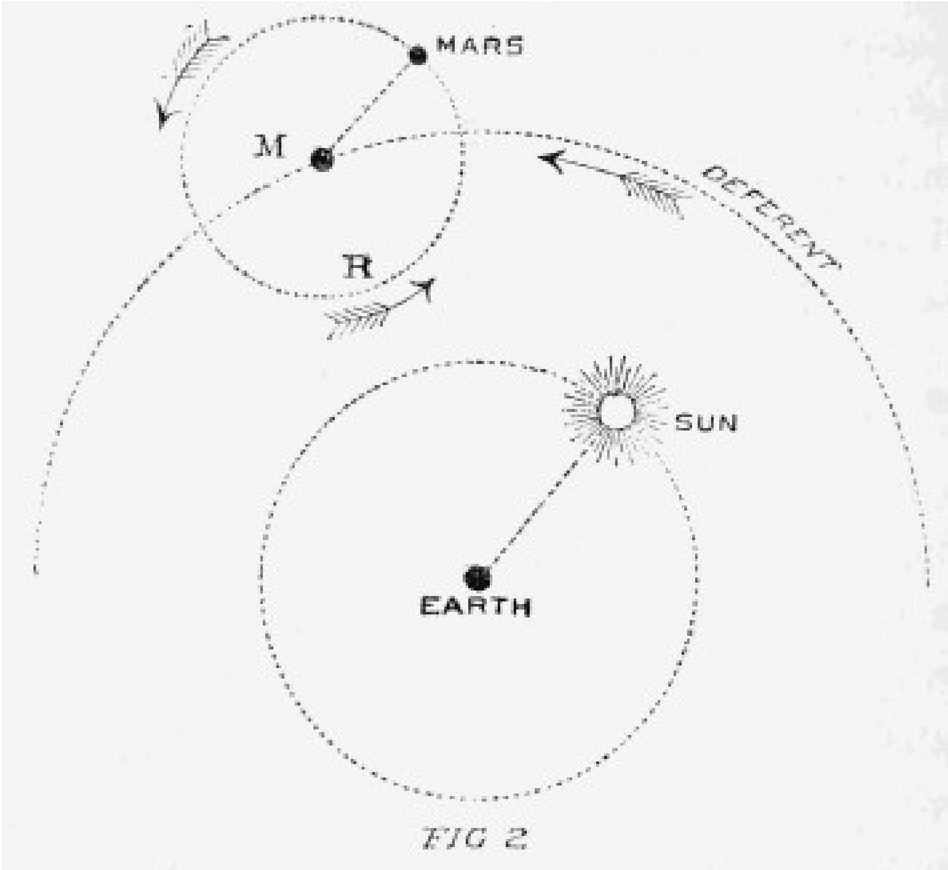


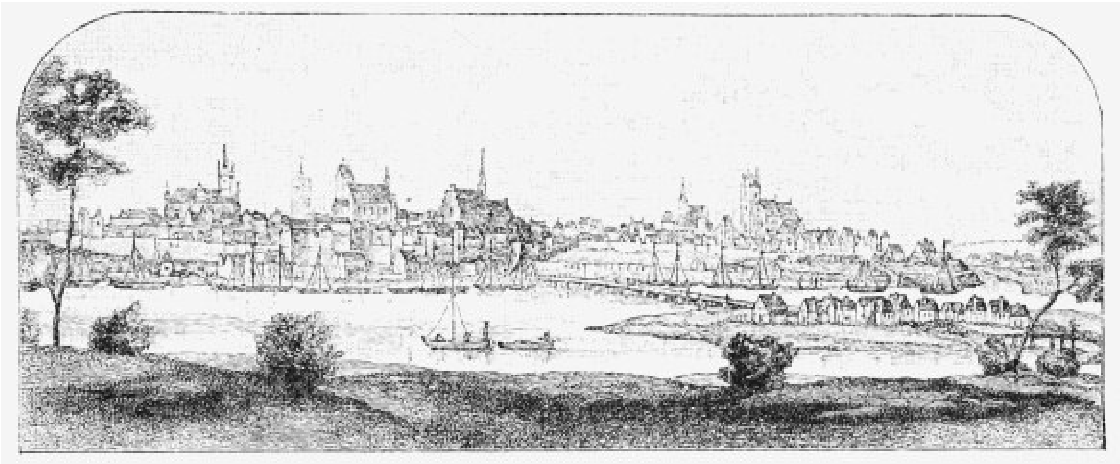
FIG. 2. PTOLEMY'S THEORY OF THE MOVEMENT OF MARS.

The explanation of the movement of an outer planet like Mars could also be deduced from the joint effect of two perfect motions. The changes through which Mars goes are, however, so different from the movements of Venus that quite a different disposition of the circles is necessary. For consider the facts which characterise the movements of an outer planet such as Mars. In the first place, Mars accomplishes an entire circuit of the heaven. In this respect, no doubt, it may be said to resemble the sun or the moon. A little attention will, however, show that there are extraordinary irregularities in the movement of the planet. Generally speaking, it speeds its way from west to east among the stars, but sometimes the attentive observer will note that the speed with which the planet advances is slackening, and then it will seem to become stationary. Some days later the direction of the planet's movement will be reversed, and it will be found moving from the east towards the west. At first it proceeds slowly and then quickens its pace, until a certain speed is attained, which afterwards declines until a second stationary position is reached. After a due pause the original motion from west to east is resumed, and is continued until a similar cycle of changes again commences. Such movements as these were obviously quite at variance with any perfect movement in a single circle round the earth. Here, again, the geometrical sagacity of Ptolemy provided him with the means of representing the apparent movements of Mars, and, at the same time, restricting the explanation to those perfect movements which he deemed so essential. In Fig. 2 we exhibit Ptolemy's theory as to the movement of Mars. We have, as before, the earth at the centre, and the sun describing its circular orbit around that centre. The path of Mars is to be taken as exterior to that of the sun. We are to suppose that at a point marked M there is a fictitious planet, which revolves around the earth uniformly, in a circle called the DEFERENT. This point M, which is thus animated by a perfect movement, is the centre of a circle which is carried onwards with M, and around the circumference of which Mars revolves uniformly. It is easy to show that the combined effect of these two perfect movements is to produce exactly that displacement of Mars in the heavens which observation discloses. In the position represented in the figure, Mars is obviously pursuing a course which will appear to the observer as a movement from west to east. When, however, the planet gets round to such a position as R, it is then moving from east to west in consequence of its revolution in the moving circle, as indicated by the arrow-head. On the other hand, the whole circle is carried forward in the opposite direction. If the latter movement be less rapid than the former, then we shall have the backward movement of Mars on the heavens which it was desired to explain. By a proper adjustment of the relative lengths of these arms the movements of the planet as actually observed could be completely accounted for.

The other outer planets with which Ptolemy was acquainted, namely, Jupiter and Saturn, had movements of the same general character as those of Mars. Ptolemy was equally successful in explaining the movements they performed by the supposition that each planet had perfect rotation in a circle of its own, which circle itself had perfect movement around the earth in the centre.

It is somewhat strange that Ptolemy did not advance one step further, as by so doing he would have given great simplicity to his system. He might, for instance, have represented the movements of Venus equally well by putting the centre of the moving circle at the sun itself, and correspondingly enlarging the circle in which Venus revolved. He might, too, have arranged that the several circles which the outer planets traversed should also have had their centres at the sun. The planetary system would then have consisted of an earth fixed at the centre, of a sun revolving uniformly around it, and of a system of planets each describing its own circle around a moving centre placed in the sun. Perhaps Ptolemy had not thought of this, or perhaps he may have seen arguments against it. This important step was, however, taken by Tycho. He considered that all the planets revolved around the sun in circles, and that the sun itself, bearing all these orbits, described a mighty circle around the earth. This point having been reached, only one more step would have been necessary to reach the glorious truths that revealed the structure of the solar system. That last step was taken by Copernicus.

COPERNICUS



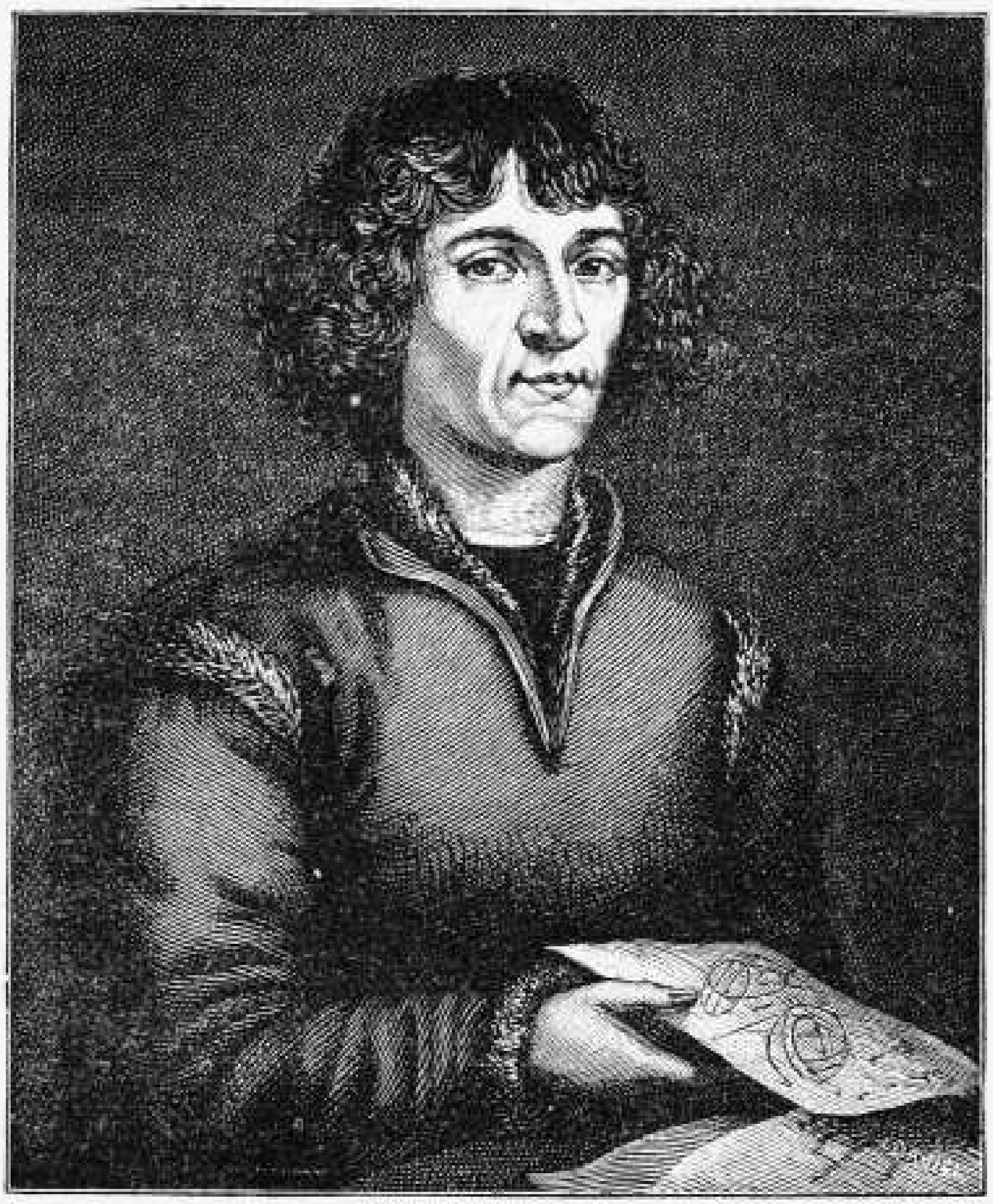
THORN, FROM AN OLD PRINT.

The quaint town of Thorn, on the Vistula, was more than two centuries old when Copernicus was born there on the 19th of February, 1473. The situation of this town on the frontier between Prussia and Poland, with the commodious waterway offered by the river, made it a place of considerable trade. A view of the town, as it was at the time of the birth of Copernicus, is here given. The walls, with their watch-towers, will be noted, and the strategic importance which the situation of Thorn gave to it in the fifteenth century still belongs thereto, so much so that the German Government recently constituted the town a fortress of the first class.

Copernicus, the astronomer, whose discoveries make him the great predecessor of Kepler and Newton, did not come from a noble family, as certain other early astronomers have done, for his father was a tradesman. Chroniclers are, however, careful to tell us that one of his uncles was a bishop. We are not acquainted with any of those details of his childhood or youth which are often of such interest in other cases where men have risen to exalted fame. It would appear that the young Nicolaus, for such was his Christian name, received his education at home until such time as he was deemed sufficiently advanced to be sent to the University at Cracow. The education that he there obtained must have been in those days of a very primitive description, but Copernicus seems to have availed himself of it to the utmost. He devoted himself more particularly to the study of medicine, with the view of adopting its practice as the profession of his life. The tendencies of the future astronomer were, however, revealed in the fact that he worked hard at mathematics, and, like one of his illustrious successors, Galileo, the practice of the art of painting had for him a very great interest, and in it he obtained some measure of success.

By the time he was twenty-seven years old, it would seem that Copernicus had given up the notion of becoming a medical practitioner, and had resolved to devote himself to science. He was engaged in teaching mathematics, and appears to have acquired some reputation. His growing fame attracted the notice of his uncle the bishop, at whose suggestion Copernicus took holy orders, and he was presently appointed to a canonry in the cathedral of Frauenburg, near the mouth of the Vistula.

To Frauenburg, accordingly, this man of varied gifts retired. Possessing somewhat of the ascetic spirit, he resolved to devote his life to work of the most serious description. He eschewed all ordinary society, restricting his intimacies to very grave and learned companions, and refusing to engage in conversation of any useless kind. It would seem as if his gifts for painting were condemned as frivolous; at all events, we do not learn that he continued to practise them. In addition to the discharge of his theological duties, his life was occupied partly in ministering medically to the wants of the poor, and partly with his researches in astronomy and mathematics. His equipment in the matter of instruments for the study of the heavens seems to have been of a very meagre description. He arranged apertures in the walls of his house at Allenstein, so that he could observe in some fashion the passage of the stars across the meridian. That he possessed some talent for practical mechanics is proved by his construction of a contrivance for raising water from a stream, for the use of the inhabitants of Frauenburg. Relics of this machine are still to be seen.



COPERNICUS.

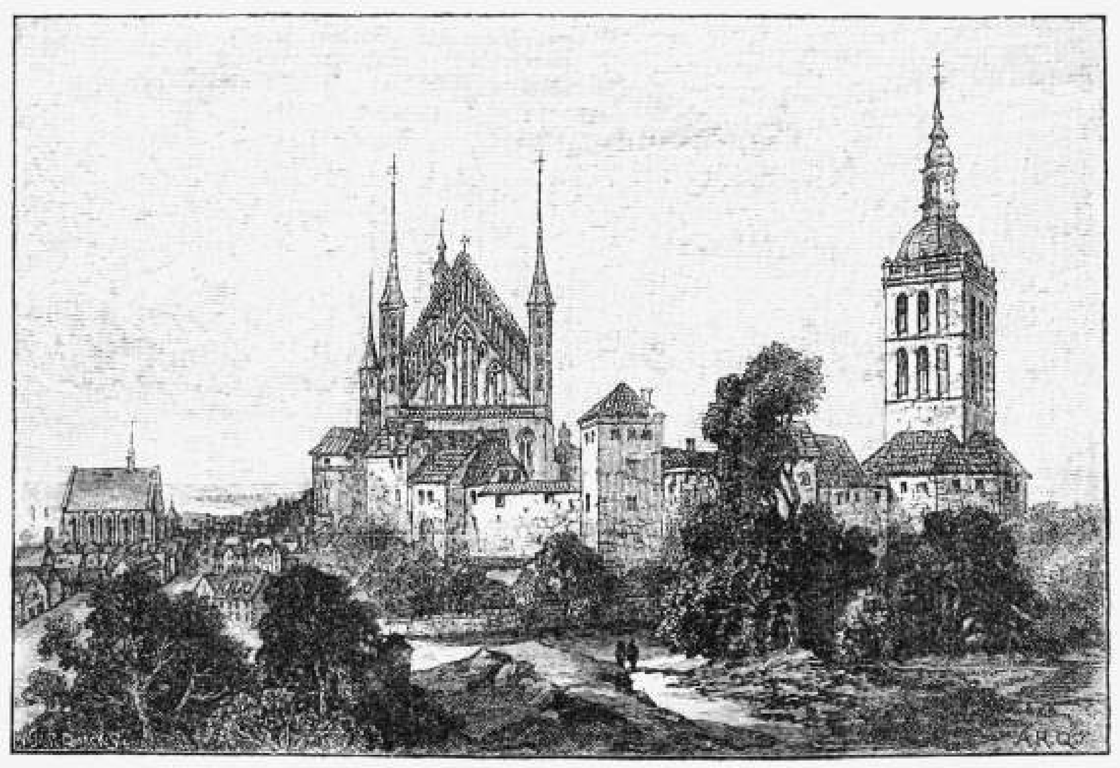
The intellectual slumber of the Middle Ages was destined to be awakened by the revolutionary doctrines of Copernicus. It may be noted, as an interesting circumstance, that the time at which he discovered the scheme of the solar system has coincided with a remarkable epoch in the world's history. The great astronomer had just reached manhood at the time when Columbus discovered the new world.

Before the publication of the researches of Copernicus, the orthodox scientific creed averred that the earth was stationary, and that the apparent movements of the heavenly bodies were indeed real movements. Ptolemy had laid down this doctrine 1,400 years before. In his theory this huge error was associated with so much important truth, and the whole presented such a coherent scheme for the explanation of the heavenly movements, that the Ptolemaic theory was not seriously questioned until the great work of Copernicus appeared. No doubt others, before Copernicus, had from time to time in some vague fashion surmised, with more or less plausibility, that the sun, and not the earth, was the centre about which the system really revolved. It is, however, one thing to state a scientific fact; it is quite another thing to be in possession of the train of reasoning, founded on observation or experiment, by which that fact may be established. Pythagoras, it appears, had indeed told his disciples that it was the sun, and not the earth, which was the centre of movement, but it does not seem at all certain that Pythagoras had any grounds which science could recognise for the belief which is attributed to him. So far as information is available to us, it would seem that Pythagoras associated his scheme of things celestial with a number of preposterous notions in natural philosophy. He may certainly have made a correct statement as to which was the most important body in the solar system, but he certainly did not provide any rational demonstration of the fact. Copernicus, by a strict train of reasoning, convinced those who would listen to him that the sun was the centre of the system. It is useful for us to consider the arguments which he urged, and by which he effected that intellectual revolution which is always connected with his name.

The first of the great discoveries which Copernicus made relates to the rotation of the earth on its axis. That general diurnal movement, by which the stars and all other celestial bodies appear to be carried completely round the heavens once every twenty-four hours, had been accounted for by Ptolemy on the supposition that the apparent movements were the real movements. As we have already seen, Ptolemy himself felt the extraordinary difficulty involved in the supposition that so stupendous a fabric as the celestial sphere should spin in the way supposed. Such movements required that many of the stars should travel with almost inconceivable velocity. Copernicus also saw that the daily rising and setting of the heavenly bodies could be accounted for either by the supposition that the celestial sphere moved round and that the earth remained at rest, or by the supposition that the celestial sphere was at rest while the earth turned round in the opposite direction. He weighed the arguments on both sides as Ptolemy had done, and, as the result of his deliberations, Copernicus came to an opposite conclusion from Ptolemy. To Copernicus it appeared that the difficulties attending the supposition that the celestial sphere revolved, were vastly greater than those which appeared so weighty to Ptolemy as to force him to deny the earth's rotation.

Copernicus shows clearly how the observed phenomena could be accounted for just as completely by a rotation of the earth as by a rotation of the heavens. He alludes to the fact that, to those on board a vessel which is moving through smooth water, the vessel itself appears to be at rest, while the objects on shore seem to be moving past. If, therefore, the earth were rotating uniformly, we dwellers upon the earth, oblivious of our own movement, would wrongly attribute to the stars the displacement which was actually the consequence of our own motion.

Copernicus saw the futility of the arguments by which Ptolemy had endeavoured to demonstrate that a revolution of the earth was impossible. It was plain to him that there was nothing whatever to warrant refusal to believe in the rotation of the earth. In his clear-sightedness on this matter we have specially to admire the sagacity of Copernicus as a natural philosopher. It had been urged that, if the earth moved round, its motion would not be imparted to the air, and that therefore the earth would be uninhabitable by the terrific winds which would be the result of our being carried through the air. Copernicus convinced himself that this deduction was preposterous. He proved that the air must accompany the earth, just as his coat remains round him, notwithstanding the fact that he is walking down the street. In this way he was able to show that all a priori objections to the earth's movements were absurd, and therefore he was able to compare together the plausibilities of the two rival schemes for explaining the diurnal movement.



FRAUENBURG, FROM AN OLD PRINT.

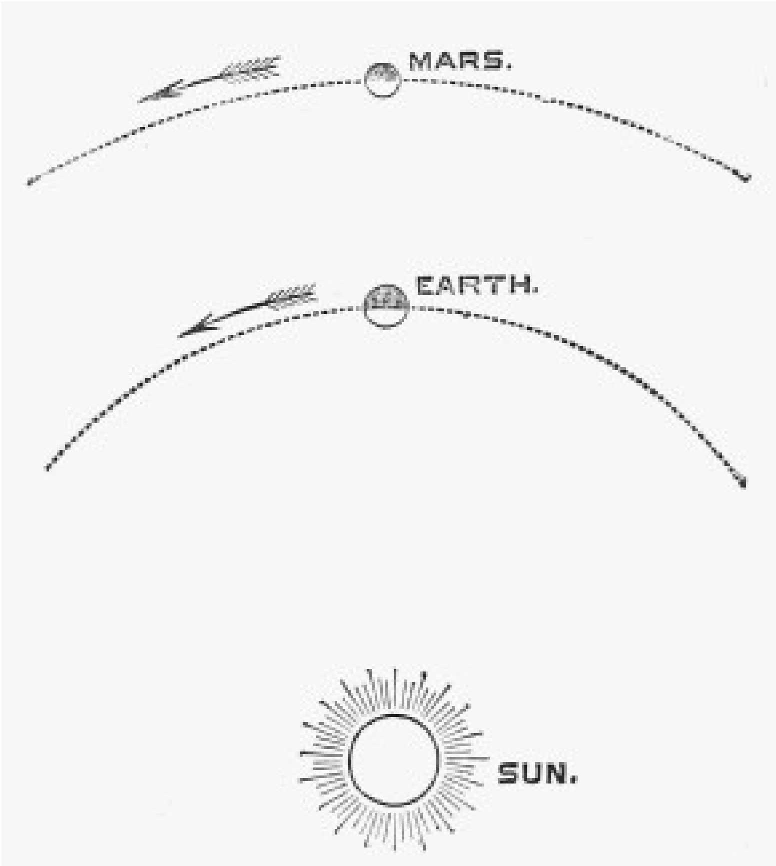
Once the issue had been placed in this form, the result could not be long in doubt. Here is the question: Which is it more likely—that the earth, like a grain of sand at the centre of a mighty globe, should turn round once in twenty-four hours, or that the whole of that vast globe should complete a rotation in the opposite direction in the same time? Obviously, the former is far the more simple supposition. But the case is really much stronger than this. Ptolemy had supposed that all the stars were attached to the surface of a sphere. He had no ground whatever for this supposition, except that otherwise it would have been well-nigh impossible to have devised a scheme by which the rotation of the heavens around a fixed earth could have been arranged. Copernicus, however, with the just instinct of a philosopher, considered that the celestial sphere, however convenient from a geometrical point of view, as a means of representing apparent phenomena, could not actually have a material existence. In the first place, the existence of a material celestial sphere would require that all the myriad stars should be at exactly the same distances from the earth. Of course, no one will say that this or any other arbitrary disposition of the stars is actually impossible, but as there was no conceivable physical reason why the distances of all the stars from the earth should be identical, it seemed in the very highest degree improbable that the stars should be so placed.

Doubtless, also, Copernicus felt a considerable difficulty as to the nature of the materials from which Ptolemy's wonderful sphere was to be constructed. Nor could a philosopher of his penetration have failed to observe that, unless that sphere were infinitely large, there must have been space outside it, a consideration which would open up other difficult questions. Whether infinite or not, it was obvious that the celestial sphere must have a diameter at least many thousands of times as great as that of the earth. From these considerations Copernicus deduced the important fact that the stars and the other celestial bodies must all be vast objects. He was thus enabled to put the question in such a form that it could hardly receive any answer but the correct one. Which is it more rational to suppose, that the earth should turn round on its axis once in twenty-four hours, or that thousands of mighty stars should circle round the earth in the same time, many of them having to describe circles many thousands of times greater in circumference than the circuit of the earth at the equator?

The obvious answer pressed upon Copernicus with so much force that he was compelled to reject Ptolemy's theory of the stationary earth, and to attribute the diurnal rotation of the heavens to the revolution of the earth on its axis.

Once this tremendous step had been taken, the great difficulties which beset the monstrous conception of the celestial sphere vanished, for the stars need no longer be regarded as situated at equal distances from the earth. Copernicus saw that they might lie at the most varied degrees of remoteness, some being hundreds or thousands of times farther away than others. The complicated structure of the celestial sphere as a material object disappeared altogether; it remained only as a geometrical conception, whereon we find it convenient to indicate the places of the stars. Once the Copernican doctrine had been fully set forth, it was impossible for anyone, who had both the inclination and the capacity to understand it, to withhold acceptance of its truth. The doctrine of a stationary earth had gone for ever.

Copernicus having established a theory of the celestial movements which deliberately set aside the stability of the earth, it seemed natural that he should inquire whether the doctrine of a moving earth might not remove the difficulties presented in other celestial phenomena. It had been universally admitted that the earth lay unsupported in space. Copernicus had further shown that it possessed a movement of rotation. Its want of stability being thus recognised, it seemed reasonable to suppose that the earth might also have some other kinds of movements as well. In this, Copernicus essayed to solve a problem far more difficult than that which had hitherto occupied his attention. It was a comparatively easy task to show how the diurnal rising and setting could be accounted for by the rotation of the earth. It was a much more difficult undertaking to demonstrate that the planetary movements, which Ptolemy had represented with so much success, could be completely explained by the supposition that each of those planets revolved uniformly round the sun, and that the earth was also a planet, accomplishing a complete circuit of the sun once in the course of a year.



EXPLANATION OF PLANETARY MOVEMENTS.

It would be impossible in a sketch like the present to enter into any detail as to the geometrical propositions on which this beautiful investigation of Copernicus depended. We can only mention a few of the leading principles. It may be laid down in general that, if an observer is in movement, he will, if unconscious of the fact, attribute to the fixed objects around him a movement equal and opposite to that which he actually possesses. A passenger on a canal-boat sees the objects on the banks apparently moving backward with a speed equal to that by which he is himself advancing forwards. By an application of this principle, we can account for all the phenomena of the movements of the planets, which Ptolemy had so ingeniously represented by his circles. Let us take, for instance, the most characteristic feature in the irregularities of the outer planets. We have already remarked that Mars, though generally advancing from west to east among the stars, occasionally pauses, retraces his steps for awhile, again pauses, and then resumes his ordinary onward progress. Copernicus showed clearly how this effect was produced by the real motion of the earth, combined with the real motion of Mars. In the adjoining figure we represent a portion of the circular tracks in which the earth and Mars move in accordance with the Copernican doctrine. I show particularly the case where the earth comes directly between the planet and the sun, because it is on such occasions that the retrograde movement (for so this backward movement of Mars is termed) is at its highest. Mars is then advancing in the direction shown by the arrow-head, and the earth is also advancing in the same direction. We, on the earth, however, being unconscious of our own motion, attribute, by the principle I have already explained, an equal and opposite motion to Mars. The visible effect upon the planet is, that Mars has two movements, a real onward movement in one direction, and an apparent movement in the opposite direction. If it so happened that the earth was moving with the same speed as Mars, then the apparent movement would exactly neutralise the real movement, and Mars would seem to be at rest relatively to the surrounding stars. Under the actual circumstances represented, however, the earth is moving faster than Mars, and the consequence is, that the apparent movement of the planet backwards exceeds the real movement forwards, the net result being an apparent retrograde movement.

With consummate skill, Copernicus showed how the applications of the same principles could account for the characteristic movements of the planets. His reasoning in due time bore down all opposition. The supreme importance of the earth in the system vanished. It had now merely to take rank as one of the planets.

The same great astronomer now, for the first time, rendered something like a rational account of the changes of the seasons. Nor did certain of the more obscure astronomical phenomena escape his attention.

He delayed publishing his wonderful discoveries to the world until he was quite an old man. He had a well-founded apprehension of the storm of opposition which they would arouse. However, he yielded at last to the entreaties of his friends, and his book was sent to the press. But ere it made its appearance to the world, Copernicus was seized by mortal illness. A copy of the book was brought to him on May 23, 1543. We are told that he was able to see it and to touch it, but no more, and he died a few hours afterwards. He was buried in that Cathedral of Frauenburg, with which his life had been so closely associated.

TYCHO BRAHE

The most picturesque figure in the history of astronomy is undoubtedly that of the famous old Danish astronomer whose name stands at the head of this chapter. Tycho Brahe was alike notable for his astronomical genius and for the extraordinary vehemence of a character which was by no means perfect. His romantic career as a philosopher, and his taste for splendour as a Danish noble, his ardent friendships and his furious quarrels, make him an ideal subject for a biographer, while the magnificent astronomical work which he accomplished, has given him imperishable fame.

The history of Tycho Brahe has been admirably told by Dr. Dreyer, the accomplished astronomer who now directs the observatory at Armagh, though himself a countryman of Tycho. Every student of the career of the great Dane must necessarily look on Dr. Dreyer's work as the chief authority on the subject. Tycho sprang from an illustrious stock. His family had flourished for centuries, both in Sweden and in Denmark, where his descendants are to be met with at the present day. The astronomer's father was a privy councillor, and having filled important positions in the Danish government, he was ultimately promoted to be governor of Helsingborg Castle, where he spent the last years of his life. His illustrious son Tycho was born in 1546, and was the second child and eldest boy in a family of ten.

It appears that Otto, the father of Tycho, had a brother named George, who was childless. George, however, desired to adopt a boy on whom he could lavish his affection and to whom he could bequeath his wealth. A somewhat singular arrangement was accordingly entered into by the brothers at the time when Otto was married. It was agreed that the first son who might be born to Otto should be forthwith handed over by the parents to George to be reared and adopted by him. In due time little Tycho appeared, and was immediately claimed by George in pursuance of the compact. But it was not unnatural that the parental instinct, which had been dormant when the agreement was made, should here interpose. Tycho's father and mother receded from the bargain, and refused to part with their son. George thought he was badly treated. However, he took no violent steps until a year later, when a brother was born to Tycho. The uncle then felt no scruple in asserting what he believed to be his rights by the simple process of stealing the first-born nephew, which the original bargain had promised him. After a little time it would seem that the parents acquiesced in the loss, and thus it was in Uncle George's home that the future astronomer passed his childhood.

When we read that Tycho was no more than thirteen years old at the time he entered the University of Copenhagen, it might be at first supposed that even in his boyish years he must have exhibited some of those remarkable talents with which he was afterwards to astonish the world. Such an inference should not, however, be drawn. The fact is that in those days it was customary for students to enter the universities at a much earlier age than is now the case. Not, indeed, that the boys of thirteen knew more then than the boys of thirteen know now. But the education imparted in the universities at that time was of a much more rudimentary kind than that which we understand by university education at present. In illustration of this Dr. Dreyer tells us how, in the University of Wittenberg, one of the professors, in his opening address, was accustomed to point out that even the processes of multiplication and division in arithmetic might be learned by any student who possessed the necessary diligence.

It was the wish and the intention of his uncle that Tycho's education should be specially directed to those branches of rhetoric and philosophy which were then supposed to be a necessary preparation for the career of a statesman. Tycho, however, speedily made it plain to his teachers that though he was an ardent student, yet the things which interested him were the movements of the heavenly bodies and not the subtleties of metaphysics.

TYCHO BRAHE.

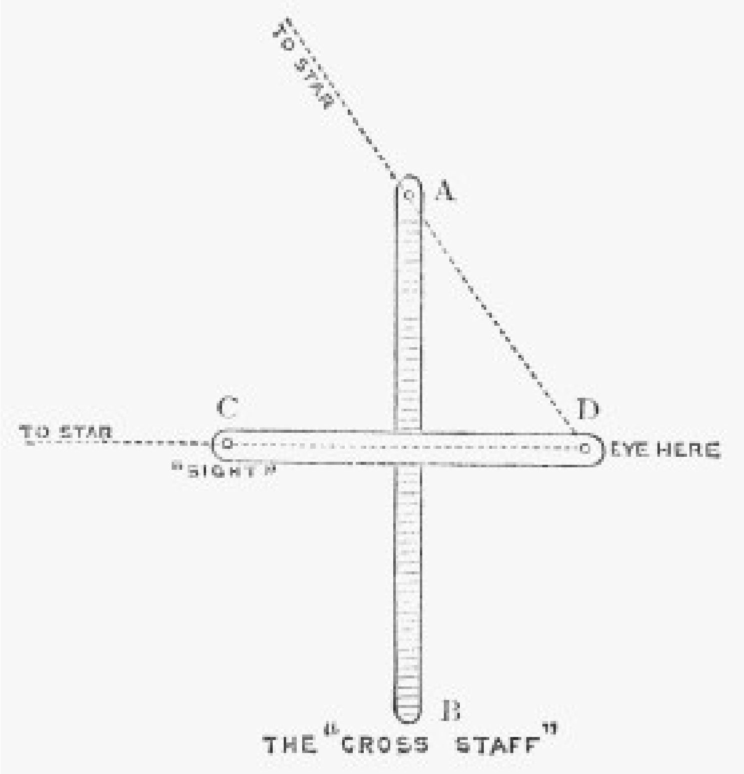
On the 21st October, 1560, an eclipse of the sun occurred, which was partially visible at Copenhagen. Tycho, boy though he was, took the utmost interest in this event. His ardour and astonishment in connection with the circumstance were chiefly excited by the fact that the time of the occurrence of the phenomenon could be predicted with so much accuracy. Urged by his desire to understand the matter thoroughly, Tycho sought to procure some book which might explain what he so greatly wanted to know. In those days books of any kind were but few and scarce, and scientific books were especially unattainable. It so happened, however, that a Latin version of Ptolemy's astronomical works had appeared a few years before the eclipse took place, and Tycho managed to buy a copy of this book, which was then the chief authority on celestial matters. Young as the boy astronomer was, he studied hard, although perhaps not always successfully, to understand Ptolemy, and to this day his copy of the great work, copiously annotated and marked by the schoolboy hand, is preserved as one of the chief treasures in the library of the University at Prague.

After Tycho had studied for about three years at the University of Copenhagen, his uncle thought it would be better to send him, as was usual in those days, to complete his education by a course of study in some foreign university. The uncle cherished the hope that in this way the attention of the young astronomer might be withdrawn from the study of the stars and directed in what appeared to him a more useful way. Indeed, to the wise heads of those days, the pursuit of natural science seemed so much waste of good time which might otherwise be devoted to logic or rhetoric or some other branch of study more in vogue at that time. To assist in this attempt to wean Tycho from his scientific tastes, his uncle chose as a tutor to accompany him an intelligent and upright young man named Vedel, who was four years senior to his pupil, and accordingly, in 1562, we find the pair taking up their abode at the University of Leipzig.

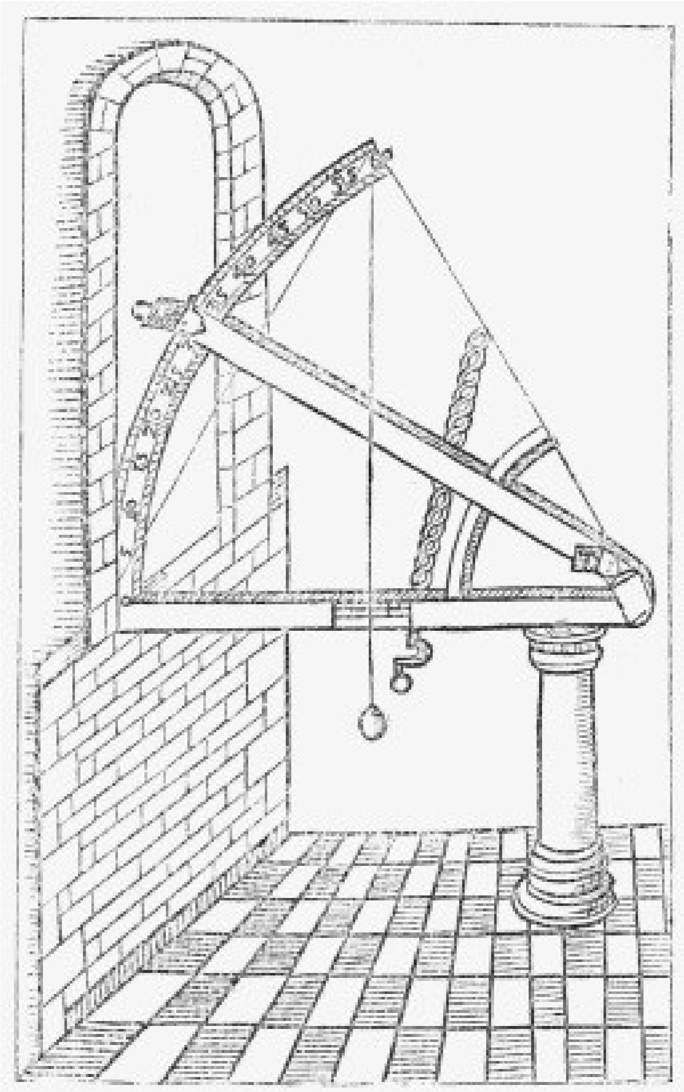
The tutor, however, soon found that he had undertaken a most hopeless task. He could not succeed in imbuing Tycho with the slightest taste for the study of the law or the other branches of knowledge which were then thought so desirable. The stars, and nothing but the stars, engrossed the attention of his pupil. We are told that all the money he could obtain was spent secretly in buying astronomical books and instruments. He learned the name of the stars from a little globe, which he kept hidden from Vedel, and only ventured to use during the latter's absence. No little friction was at first caused by all this, but in after years a fast and enduring friendship grew up between Tycho and his tutor, each of whom learned to respect and to love the other.

Before Tycho was seventeen he had commenced the difficult task of calculating the movements of the planets and the places which they occupied on the sky from time to time. He was not a little surprised to find that the actual positions of the planets differed very widely from those which were assigned to them by calculations from the best existing works of astronomers. With the insight of genius he saw that the only true method of investigating the movements of the heavenly bodies would be to carry on a protracted series of measurements of their places. This, which now seems to us so obvious, was then entirely new doctrine. Tycho at once commenced regular observations in such fashion as he could. His first instrument was, indeed, a very primitive one, consisting of a simple pair of compasses, which he used in this way. He placed his eye at the hinge, and then opened the legs of the compass so that one leg pointed to one star and the other leg to the other star. The compass was then brought down to a divided circle, by which means the number of degrees in the apparent angular distance of the two stars was determined.

His next advance in instrumental equipment was to provide himself with the contrivance known as the "cross-staff," which he used to observe the stars whenever opportunity offered. It must, of course, be remembered that in those days there were no telescopes. In the absence of optical aid, such as lenses afford the modern observers, astronomers had to rely on mechanical appliances alone to measure the places of the stars. Of such appliances, perhaps the most ingenious was one known before Tycho's time, which we have represented in the adjoining figure.



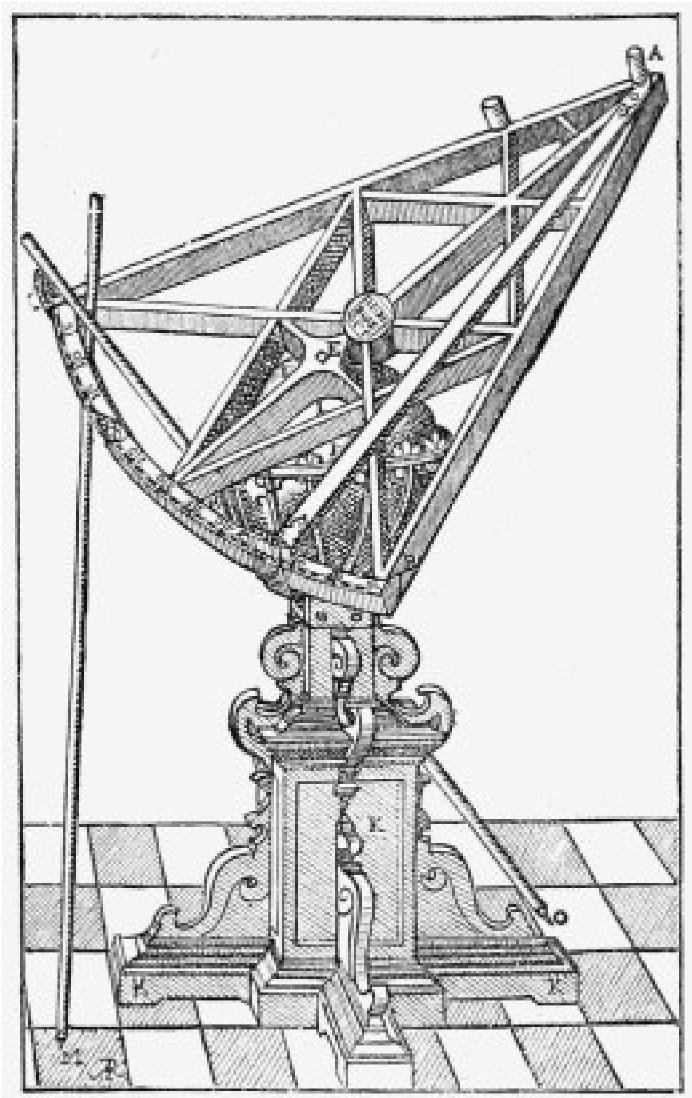
Let us suppose that it be desired to measure the angle between two stars, then if the angle be not too large it can be determined in the following manner. Let the rod AB be divided into inches and parts of an inch, and let another rod, CD, slide up and down along AB in such a way that the two always remain perpendicular to each other. "Sights," like those on a rifle, are placed at A and C, and there is a pin at D. It will easily be seen that, by sliding the movable bar along the fixed one, it must always be possible when the stars are not too far apart to bring the sights into such positions that one star can be seen along DC and the other along DA. This having been accomplished, the length from A to the cross-bar is read off on the scale, and then, by means of a table previously prepared, the value of the required angular distance is obtained. If the angle between the two stars were greater than it would be possible to measure in the way already described, then there was a provision by which the pin at D might be moved along CD into some other position, so as to bring the angular distance of the stars within the range of the instrument.



TYCHO'S "NEW STAR" SEXTANT OF 1572.
(The arms, of walnut wood, are about 5 1/2 ft. long.)

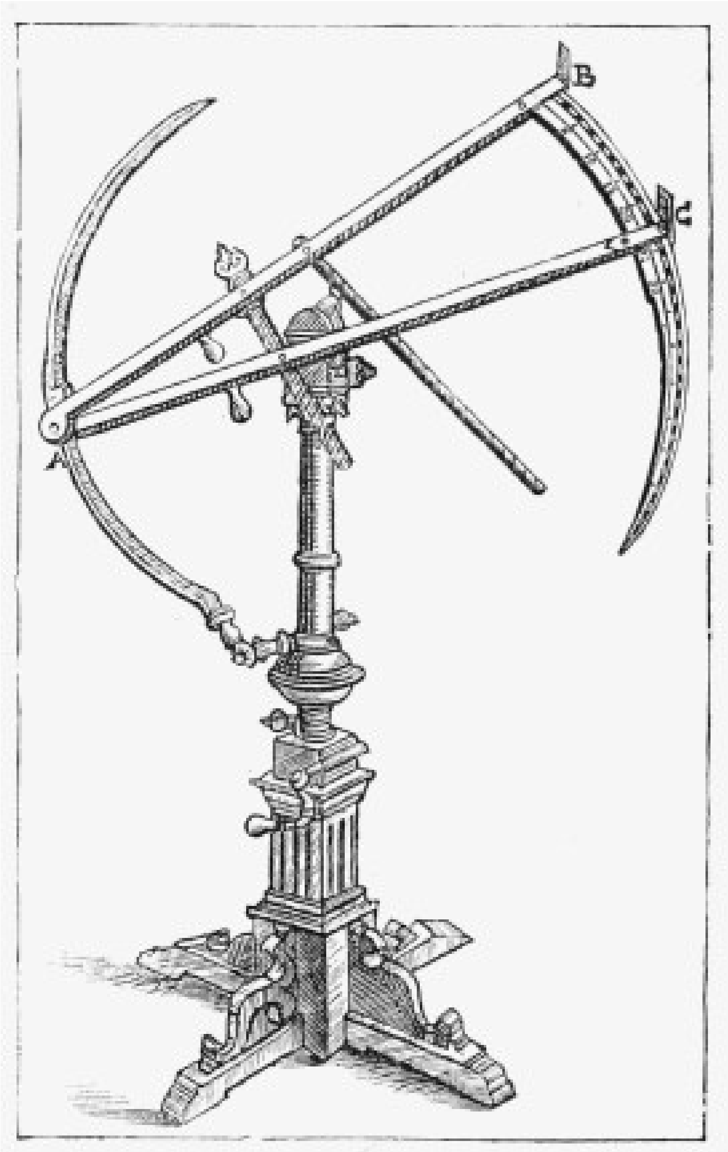
No doubt the cross-staff is a very primitive contrivance, but when handled by one so skilful as Tycho it afforded results of considerable accuracy. I would recommend any reader who may have a taste for such pursuits to construct a cross-staff for himself, and see what measurements he can accomplish with its aid.

To employ this little instrument Tycho had to evade the vigilance of his conscientious tutor, who felt it his duty to interdict all such occupations as being a frivolous waste of time. It was when Vedel was asleep that Tycho managed to escape with his cross staff and measure the places of the heavenly bodies. Even at this early age Tycho used to conduct his observations on those thoroughly sound principles which lie at the foundation of all accurate modern astronomy. Recognising the inevitable errors of workmanship in his little instrument, he ascertained their amount and allowed for their influence on the results which he deduced. This principle, employed by the boy with his cross-staff in 1564, is employed at the present day by the Astronomer Royal at Greenwich with the most superb instruments that the skill of modern opticians has been able to construct.

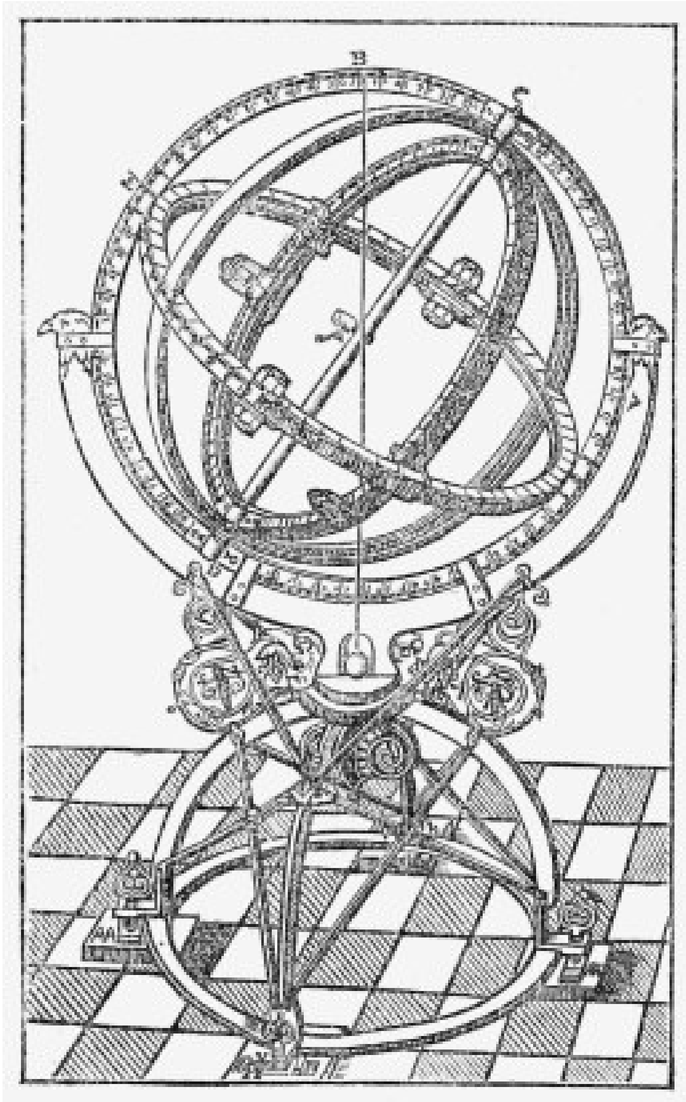


TYCHO'S TRIGONIC SEXTANT.
(The arms, AB and AC, are about 5 1/2 ft. long.)

After the death of his uncle, when Tycho was nineteen years of age, it appears that the young philosopher was no longer interfered with in so far as the line which his studies were to take was concerned. Always of a somewhat restless temperament, we now find that he shifted his abode to the University of Rostock, where he speedily made himself notable in connection with an eclipse of the moon on 28th October, 1566. Like every other astronomer of those days, Tycho had always associated astronomy with astrology. He considered that the phenomena of the heavenly bodies always had some significance in connection with human affairs. Tycho was also a poet, and in the united capacity of poet, astrologer, and astronomer, he posted up some verses in the college at Rostock announcing that the lunar eclipse was a prognostication of the death of the great Turkish Sultan, whose mighty deeds at that time filled men's minds. Presently news did arrive of the death of the Sultan, and Tycho was accordingly triumphant; but a little later it appeared that the decease had taken place BEFORE the eclipse, a circumstance which caused many a laugh at Tycho's expense.

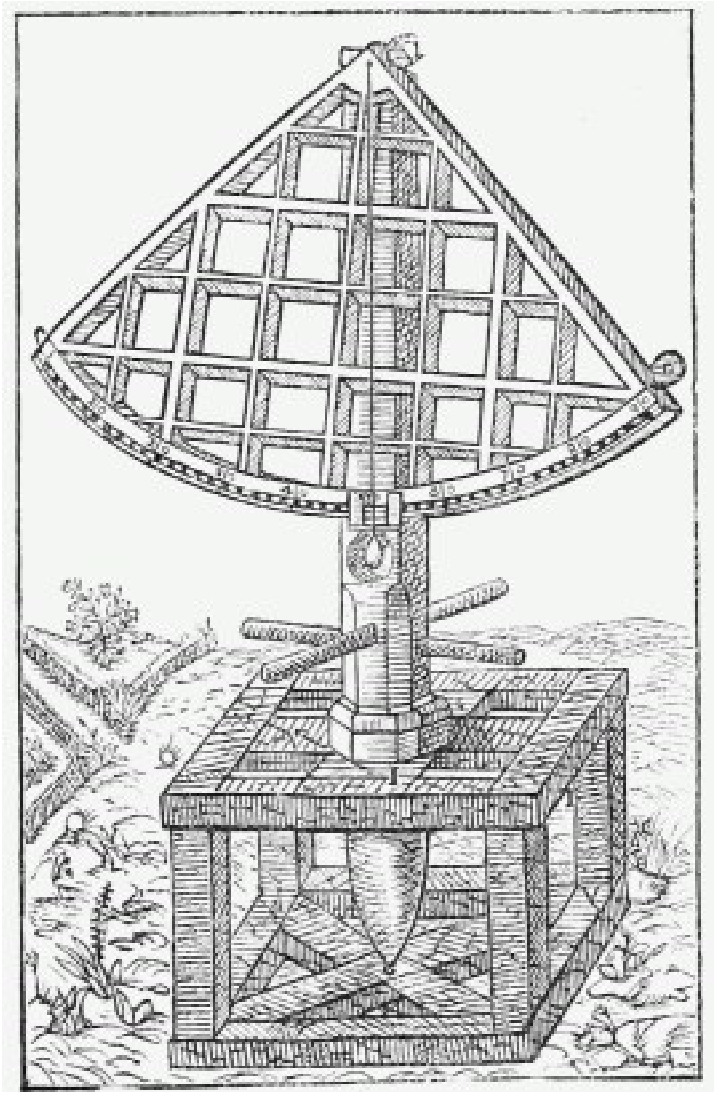


TYCHO'S ASTRONOMIC SEXTANT.
(Made of steel; the arms, A B, A C, measure 4ft.)

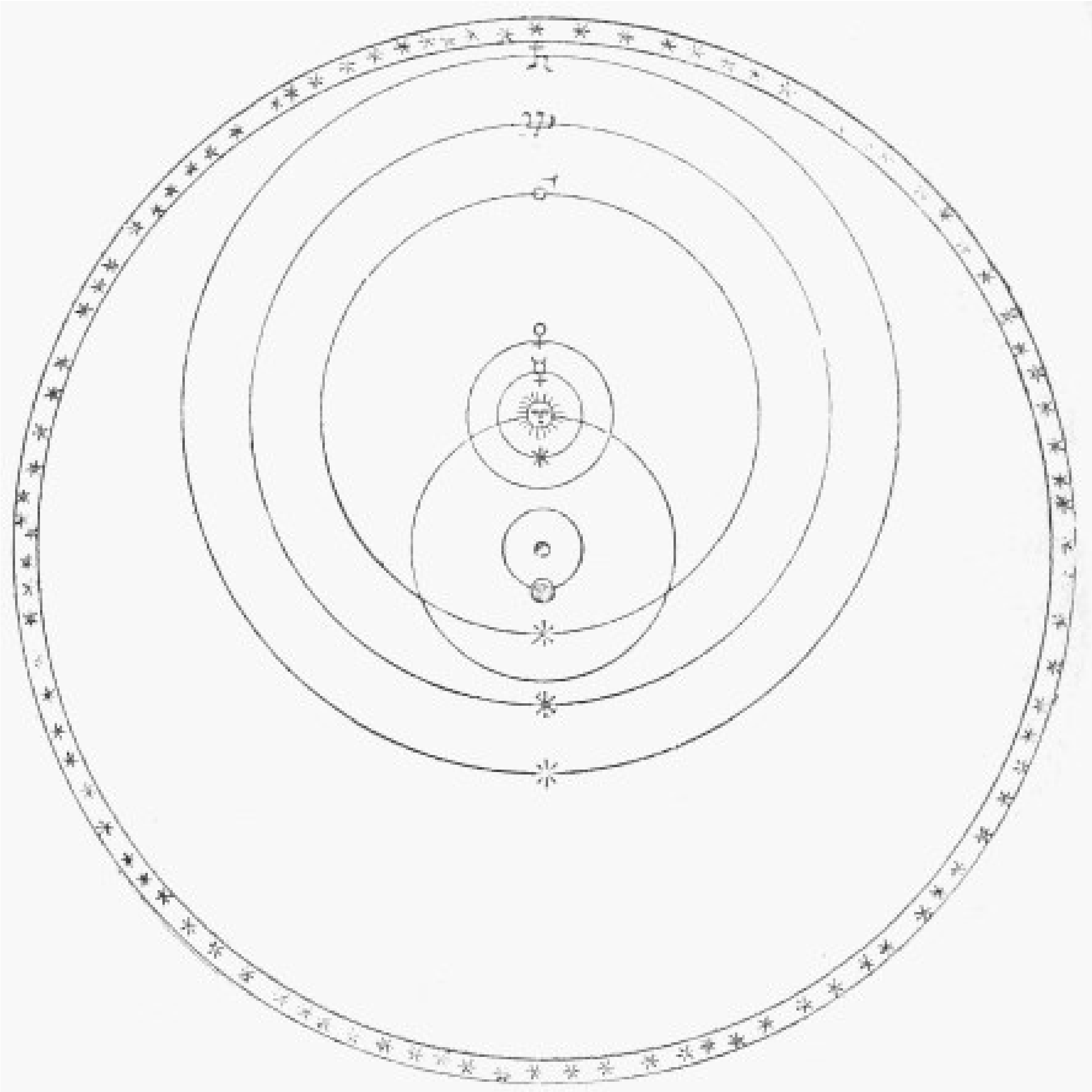


TYCHO'S EQUATORIAL ARMILLARY.
(The meridian circle, E B C A D, made of solid steel, is nearly 6 ft. in diameter.)

Tycho being of a somewhat turbulent disposition, it appears that, while at the University of Rostock, he had a serious quarrel with another Danish nobleman. We are not told for certain what was the cause of the dispute. It does not, however, seem to have had any more romantic origin than a difference of opinion as to which of them knew the more mathematics. They fought, as perhaps it was becoming for two astronomers to fight, under the canopy of heaven in utter darkness at the dead of night, and the duel was honourably terminated when a slice was taken off Tycho's nose by the insinuating sword of his antagonist. For the repair of this injury the ingenuity of the great instrument-maker was here again useful, and he made a substitute for his nose "with a composition of gold and silver." The imitation was so good that it is declared to have been quite equal to the original. Dr. Lodge, however, pointedly observes that it does not appear whether this remark was made by a friend or an enemy.

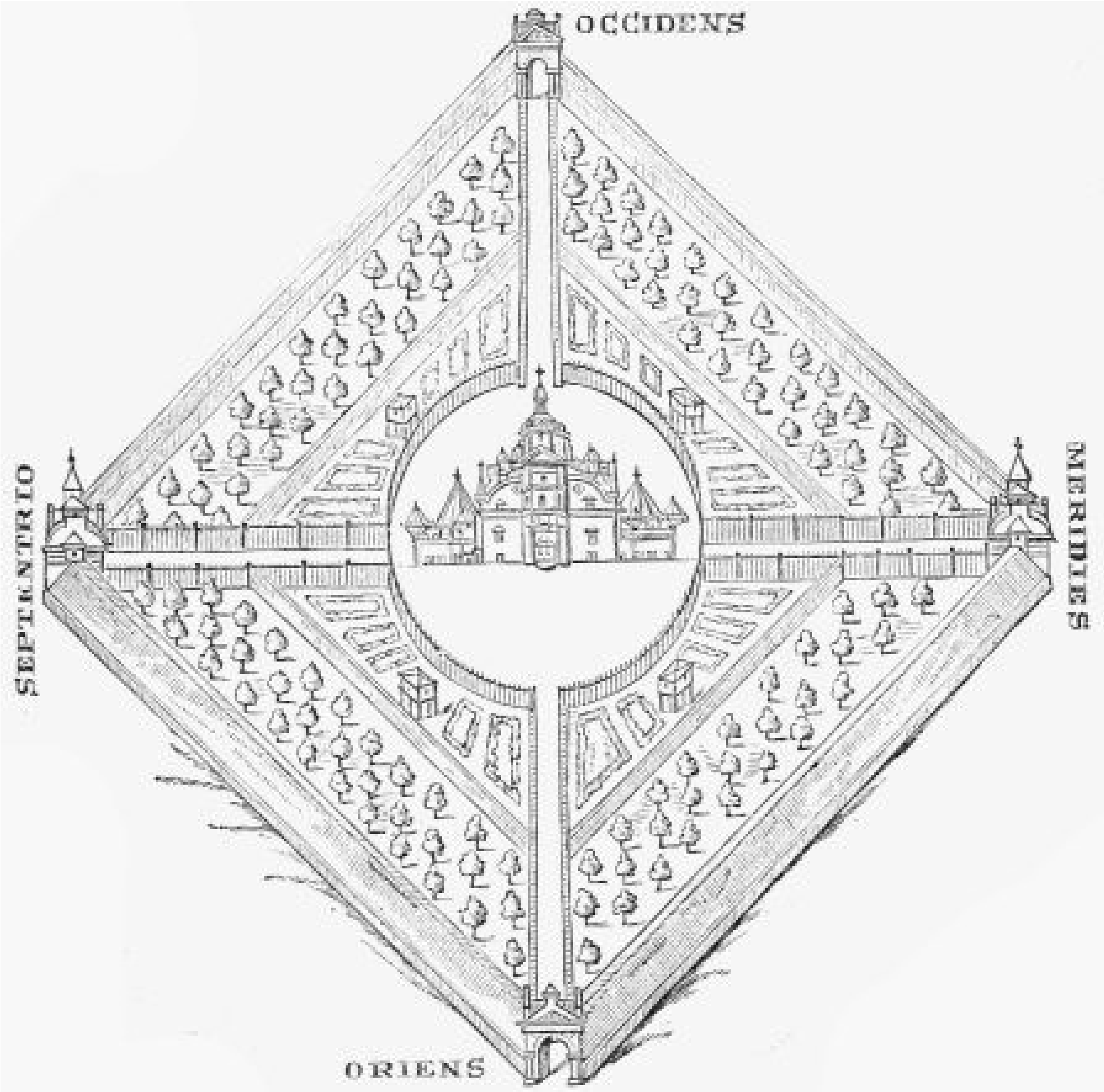


THE GREAT AUGSBURG QUADRANT.

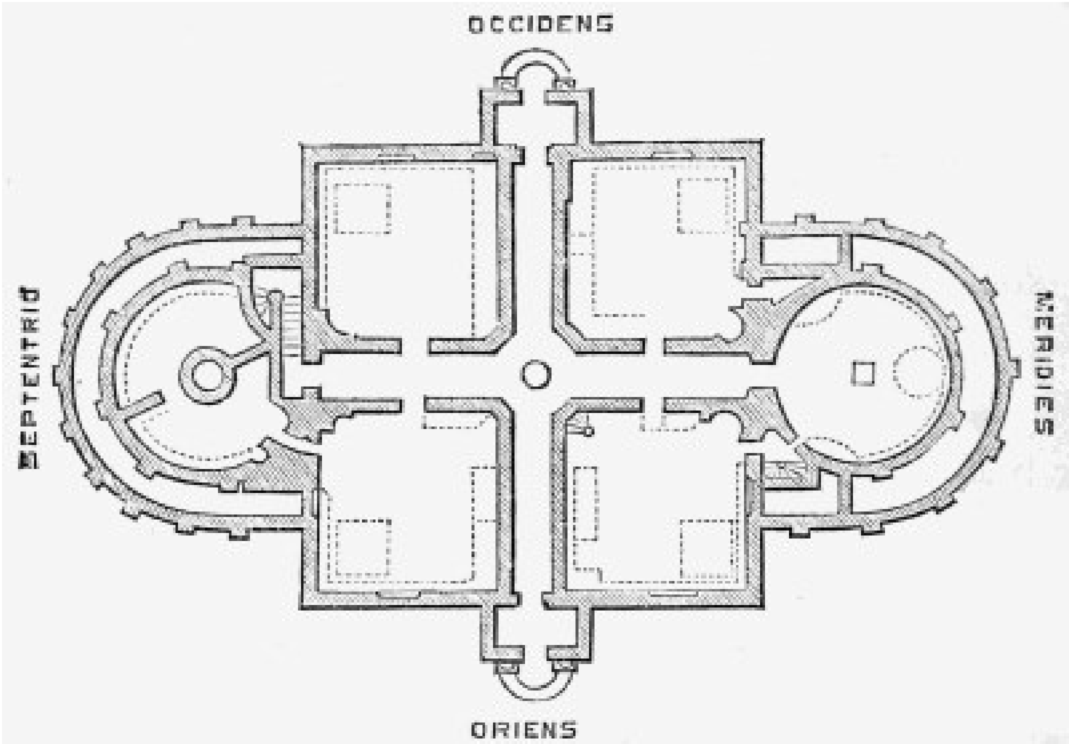


TYCHO'S "NEW SCHEME OF THE TERRESTRIAL SYSTEM," 1577.

The next few years Tycho spent in various places ardently pursuing somewhat varied branches of scientific study. At one time we hear of him assisting an astronomical alderman, in the ancient city of Augsburg, to erect a tremendous wooden machine—a quadrant of 19-feet radius—to be used in observing the heavens. At another time we learn that the King of Denmark had recognised the talents of his illustrious subject, and promised to confer on him a pleasant sinecure in the shape of a canonry, which would assist him with the means for indulging his scientific pursuits. Again we are told that Tycho is pursuing experiments in chemistry with the greatest energy, nor is this so incompatible as might at first be thought with his devotion to astronomy. In those early days of knowledge the different sciences seemed bound together by mysterious bonds. Alchemists and astrologers taught that the several planets were correlated in some mysterious manner with the several metals. It was, therefore hardly surprising that Tycho should have included a study of the properties of the metals in the programme of his astronomical work.



URANIBORG AND ITS GROUNDS.



GROUND-PLAN OF THE OBSERVATORY.

An event, however, occurred in 1572 which stimulated Tycho's astronomical labours, and started him on his life's work. On the 11th of November in that year, he was returning home to supper after a day's work in his laboratory, when he happened to lift his face to the sky, and there he beheld a brilliant new star. It was in the constellation of Cassiopeia, and occupied a position in which there had certainly been no bright star visible when his attention had last been directed to that part of the heavens. Such a phenomenon was so startling that he found it hard to trust the evidence of his senses. He thought he must be the subject of some hallucination. He therefore called to the servants who were accompanying him, and asked them whether they, too, could see a brilliant object in the direction in which he pointed. They certainly could, and thus he became convinced that this marvellous object was no mere creation of the fancy, but a veritable celestial body—a new star of surpassing splendour which had suddenly burst forth. In these days of careful scrutiny of the heavens, we are accustomed to the occasional outbreak of new stars. It is not, however, believed that any new star which has ever appeared has displayed the same phenomenal brilliance as was exhibited by the star of 1572.

This object has a value in astronomy far greater than it might at first appear. It is true, in one sense, that Tycho discovered the new star, but it is equally true, in a different sense, that it was the new star which discovered Tycho. Had it not been for this opportune apparition, it is quite possible that Tycho might have found a career in some direction less beneficial to science than that which he ultimately pursued.

THE OBSERVATORY OF URANIBORG, ISLAND OF HVEN.

When he reached his home on this memorable evening, Tycho immediately applied his great quadrant to the measurement of the place of the new star. His observations were specially directed to the determination of the distance of the object. He rightly conjectured that if it were very much nearer to us than the stars in its vicinity, the distance of the brilliant body might be determined in a short time by the apparent changes in its distance from the surrounding points. It was speedily demonstrated that the new star could not be as near as the moon, by the simple fact that its apparent place, as compared with the stars in its neighbourhood, was not appreciably altered when it was observed below the pole, and again above the pole at an interval of twelve hours. Such observations were possible, inasmuch as the star was bright enough to be seen in full daylight. Tycho thus showed conclusively that the body was so remote that the diameter of the earth bore an insignificant ratio to the star's distance. His success in this respect is the more noteworthy when we find that many other observers, who studied the same object, came to the erroneous conclusion that the new star was quite as near as the moon, or even much nearer. In fact, it may be said, that with regard to this object Tycho discovered everything which could possibly have been discovered in the days before telescopes were invented. He not only proved that the star's distance was too great for measurement, but he showed that it had no proper motion on the heavens. He recorded the successive changes in its brightness from week to week, as well as the fluctuations in hue with which the alterations in lustre were accompanied.

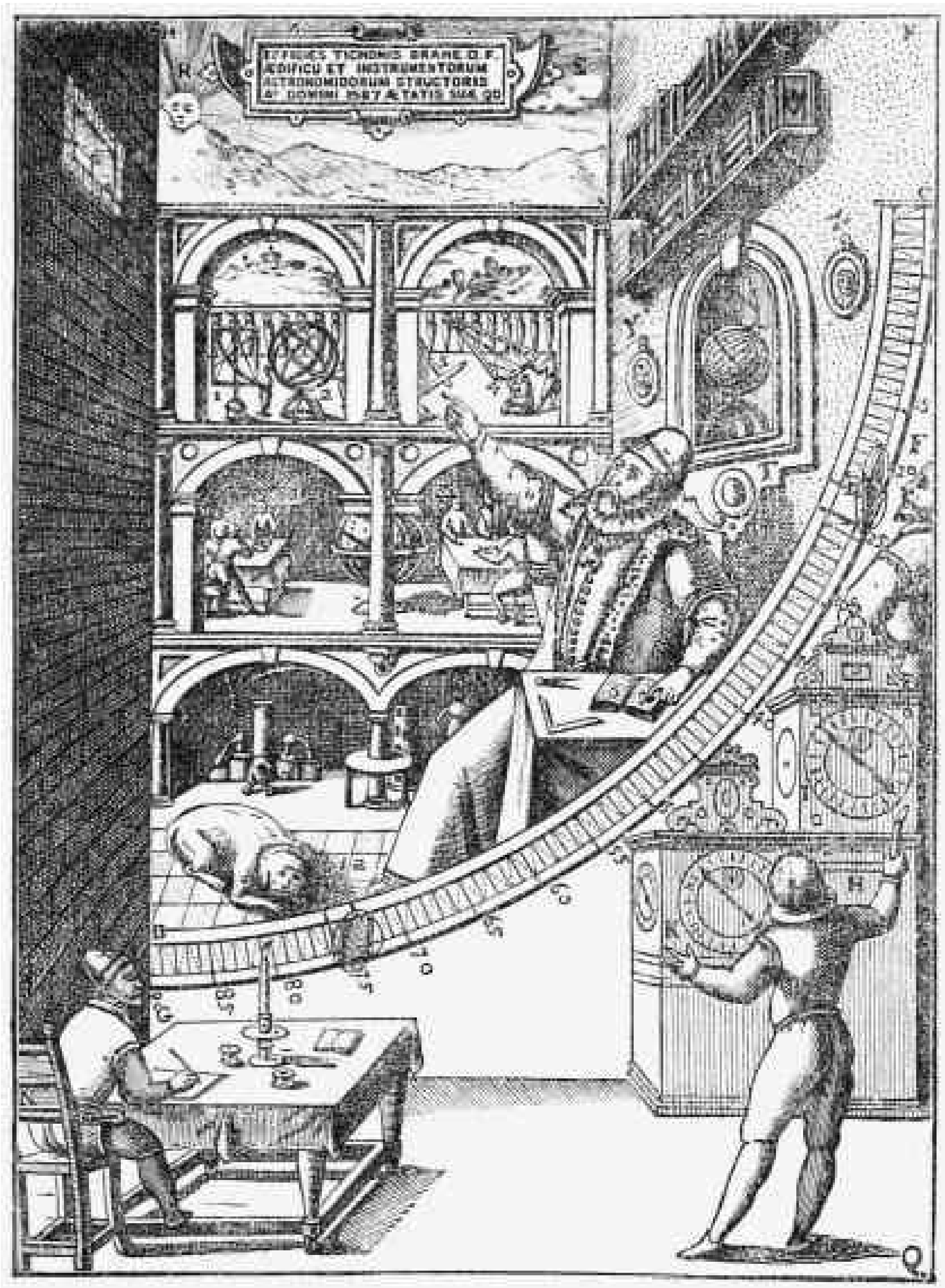
It seems, nowadays, strange to find that such thoroughly scientific observations of the new star as those which Tycho made, possessed, even in the eyes of the great astronomer himself, a profound astrological significance. We learn from Dr. Dreyer that, in Tycho's opinion, "the star was at first like Venus and Jupiter, and its effects will therefore, first, be pleasant; but as it then became like Mars, there will next come a period of wars, seditions, captivity, and death of princes, and destruction of cities, together with dryness and fiery meteors in the air, pestilence, and venomous snakes. Lastly, the star became like Saturn, and thus will finally come a time of want, death, imprisonment, and all kinds of sad things!" Ideas of this kind were, however, universally entertained. It seemed, indeed, obvious to learned men of that period that such an apparition must forebode startling events. One of the chief theories then held was, that just as the Star of Bethlehem announced the first coming of Christ, so the second coming, and the end of the world, was heralded by the new star of 1572.

The researches of Tycho on this object were the occasion of his first appearance as an author. The publication of his book was however, for some time delayed by the urgent remonstrances of his friends, who thought it was beneath the dignity of a nobleman to condescend to write a book. Happily, Tycho determined to brave the opinion of his order; the book appeared, and was the first of a series of great astronomical productions from the same pen.

EFFIGY ON TYCHO'S TOMB AT PRAGUE.

The fame of the noble Dane being now widespread, the King of Denmark entreated him to return to his native country, and to deliver a course of lectures on astronomy in the University of Copenhagen. With some reluctance he consented, and his introductory oration has been preserved. He dwells, in fervent language, upon the beauty and the interest of the celestial phenomena. He points out the imperative necessity of continuous and systematic observation of the heavenly bodies in order to extend our knowledge. He appeals to the practical utility of the science, for what civilised nation could exist without having the means of measuring time? He sets forth how the study of these beautiful objects "exalts the mind from earthly and trivial things to heavenly ones;" and then he winds up by assuring them that "a special use of astronomy is that it enables us to draw conclusions from the movements in the celestial regions as to human fate."

An interesting event, which occurred in 1572, distracted Tycho's attention from astronomical matters. He fell in love. The young girl on whom his affections were set appears to have sprung from humble origin. Here again his august family friends sought to dissuade him from a match they thought unsuitable for a nobleman. But Tycho never gave way in anything. It is suggested that he did not seek a wife among the highborn dames of his own rank from the dread that the demands of a fashionable lady would make too great an inroad on the time that he wished to devote to science. At all events, Tycho's union seems to have been a happy one, and he had a large family of children; none of whom, however, inherited their father's talents.



TYCHO'S MURAL QUADRANT PICTURE, URANIBORG.

Tycho had many scientific friends in Germany, among whom his work was held in high esteem. The treatment that he there met with seemed to him so much more encouraging than that which he received in Denmark that he formed the notion of emigrating to Basle and making it his permanent abode. A whisper of this intention was conveyed to the large-hearted King of Denmark, Frederick II. He wisely realised how great would be the fame which would accrue to his realm if he could induce Tycho to remain within Danish territory and carry on there the great work of his life. A resolution to make a splendid proposal to Tycho was immediately formed. A noble youth was forthwith despatched as a messenger, and ordered to travel day and night until he reached Tycho, whom he was to summon to the king. The astronomer was in bed on the morning of 11th February, 1576, when the message was delivered. Tycho, of course, set off at once and had an audience of the king at Copenhagen. The astronomer explained that what he wanted was the means to pursue his studies unmolested, whereupon the king offered him the Island of Hven, in the Sound near Elsinore. There he would enjoy all the seclusion that he could desire. The king further promised that he would provide the funds necessary for building a house and for founding the greatest observatory that had ever yet been reared for the study of the heavens. After due deliberation and consultation with his friends, Tycho accepted the king's offer. He was forthwith granted a pension, and a deed was drawn up formally assigning the Island of Hven to his use all the days of his life.

The foundation of the famous castle of Uraniborg was laid on 30th August, 1576. The ceremony was a formal and imposing one, in accordance with Tycho's ideas of splendour. A party of scientific friends had assembled, and the time had been chosen so that the heavenly bodies were auspiciously placed. Libations of costly wines were poured forth, and the stone was placed with due solemnity. The picturesque character of this wonderful temple for the study of the stars may be seen in the figures with which this chapter is illustrated.

One of the most remarkable instruments that has ever been employed in studying the heavens was the mural quadrant which Tycho erected in one of the apartments of Uraniborg. By its means the altitudes of the celestial bodies could be observed with much greater accuracy than had been previously attainable. This wonderful contrivance is represented on the preceding page. It will be observed that the walls of the room are adorned by pictures with a lavishness of decoration not usually to be found in scientific establishments.

A few years later, when the fame of the observatory at Hven became more widely spread, a number of young men flocked to Tycho to study under his direction. He therefore built another observatory for their use in which the instruments were placed in subterranean rooms of which only the roofs appeared above the ground. There was a wonderful poetical inscription over the entrance to this underground observatory, expressing the astonishment of Urania at finding, even in the interior of the earth, a cavern devoted to the study of the heavens. Tycho was indeed always fond of versifying, and he lost no opportunity of indulging this taste whenever an occasion presented itself.

Around the walls of the subterranean observatory were the pictures of eight astronomers, each with a suitable inscription—one of these of course represented Tycho himself, and beneath were written words to the effect that posterity should judge of his work. The eighth picture depicted an astronomer who has not yet come into existence. Tychonides was his name, and the inscription presses the modest hope that when he does appear he will be worthy of his great predecessor. The vast expenses incurred in the erection and the maintenance of this strange establishment were defrayed by a succession of grants from the royal purse.

For twenty years Tycho laboured hard at Uraniborg in the pursuit of science. His work mainly consisted in the determination of the places of the moon, the planets, and the stars on the celestial sphere. The extraordinary pains taken by Tycho to have his observations as accurate as his instruments would permit, have justly entitled him to the admiration of all succeeding astronomers. His island home provided the means of recreation as well as a place for work. He was surrounded by his family, troops of friends were not wanting, and a pet dwarf seems to have been an inmate of his curious residence. By way of change from his astronomical labours he used frequently to work with his students in his chemical laboratory. It is not indeed known what particular problems in chemistry occupied his attention. We are told, however, that he engaged largely in the production of medicines, and as these appear to have been dispensed gratuitously there was no lack of patients.

Tycho's imperious and grasping character frequently brought him into difficulties, which seem to have increased with his advancing years. He had ill-treated one of his tenants on Hven, and an adverse decision by the courts seems to have greatly exasperated the astronomer. Serious changes also took place in his relations to the court at Copenhagen. When the young king was crowned in 1596, he reversed the policy of his predecessor with reference to Hven. The liberal allowances to Tycho were one after another withdrawn, and finally even his pension was stopped. Tycho accordingly abandoned Hven in a tumult of rage and mortification. A few years later we find him in Bohemia a prematurely aged man, and he died on the 24th October, 1601.

GALILEO

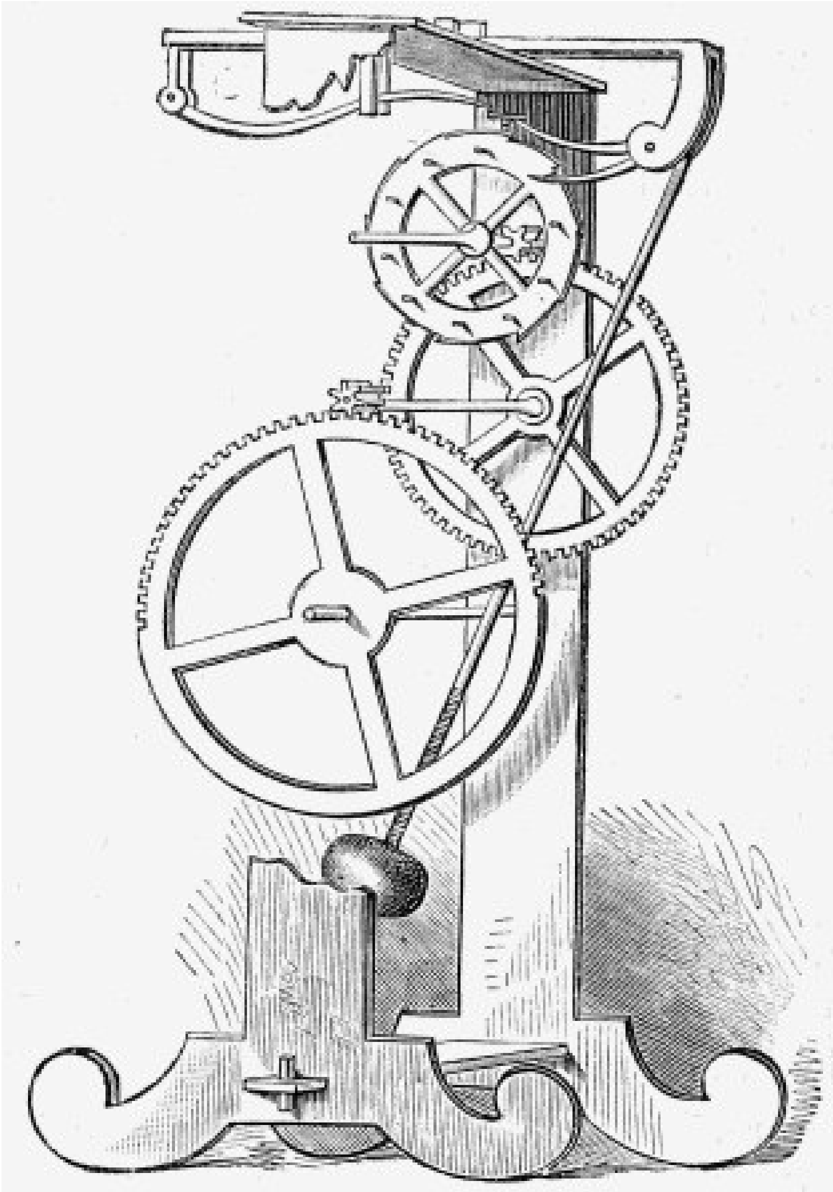
Among the ranks of the great astronomers it would be difficult to find one whose life presents more interesting features and remarkable vicissitudes than does that of Galileo. We may consider him as the patient investigator and brilliant discoverer. We may consider him in his private relations, especially to his daughter, Sister Maria Celeste, a woman of very remarkable character; and we have also the pathetic drama at the close of Galileo's life, when the philosopher drew down upon himself the thunders of the Inquisition.

The materials for the sketch of this astonishing man are sufficiently abundant. We make special use in this place of those charming letters which his daughter wrote to him from her convent home. More than a hundred of these have been preserved, and it may well be doubted whether any more beautiful and touching series of letters addressed to a parent by a dearly loved child have ever been written. An admirable account of this correspondence is contained in a little book entitled "The Private Life of Galileo," published anonymously by Messrs. Macmillan in 1870, and I have been much indebted to the author of that volume for many of the facts contained in this chapter.

Galileo was born at Pisa, on 18th February, 1564. He was the eldest son of Vincenzo de' Bonajuti de' Galilei, a Florentine noble. Notwithstanding his illustrious birth and descent, it would seem that the home in which the great philosopher's childhood was spent was an impoverished one. It was obvious at least that the young Galileo would have to be provided with some profession by which he might earn a livelihood. From his father he derived both by inheritance and by precept a keen taste for music, and it appears that he became an excellent performer on the lute. He was also endowed with considerable artistic power, which he cultivated diligently. Indeed, it would seem that for some time the future astronomer entertained the idea of devoting himself to painting as a profession. His father, however, decided that he should study medicine. Accordingly, we find that when Galileo was seventeen years of age, and had added a knowledge of Greek and Latin to his acquaintance with the fine arts, he was duly entered at the University of Pisa.

Here the young philosopher obtained some inkling of mathematics, whereupon he became so much interested in this branch of science, that he begged to be allowed to study geometry. In compliance with his request, his father permitted a tutor to be engaged for this purpose; but he did so with reluctance, fearing that the attention of the young student might thus be withdrawn from that medical work which was regarded as his primary occupation. The event speedily proved that these anxieties were not without some justification. The propositions of Euclid proved so engrossing to Galileo that it was thought wise to avoid further distraction by terminating the mathematical tutor's engagement. But it was too late for the desired end to be attained. Galileo had now made such progress that he was able to continue his geometrical studies by himself. Presently he advanced to that famous 47th proposition which won his lively admiration, and on he went until he had mastered the six books of Euclid, which was a considerable achievement for those days.

The diligence and brilliance of the young student at Pisa did not, however, bring him much credit with the University authorities. In those days the doctrines of Aristotle were regarded as the embodiment of all human wisdom in natural science as well as in everything else. It was regarded as the duty of every student to learn Aristotle off by heart, and any disposition to doubt or even to question the doctrines of the venerated teacher was regarded as intolerable presumption. But young Galileo had the audacity to think for himself about the laws of nature. He would not take any assertion of fact on the authority of Aristotle when he had the means of questioning nature directly as to its truth or falsehood. His teachers thus came to regard him as a somewhat misguided youth, though they could not but respect the unflagging industry with which he amassed all the knowledge he could acquire.

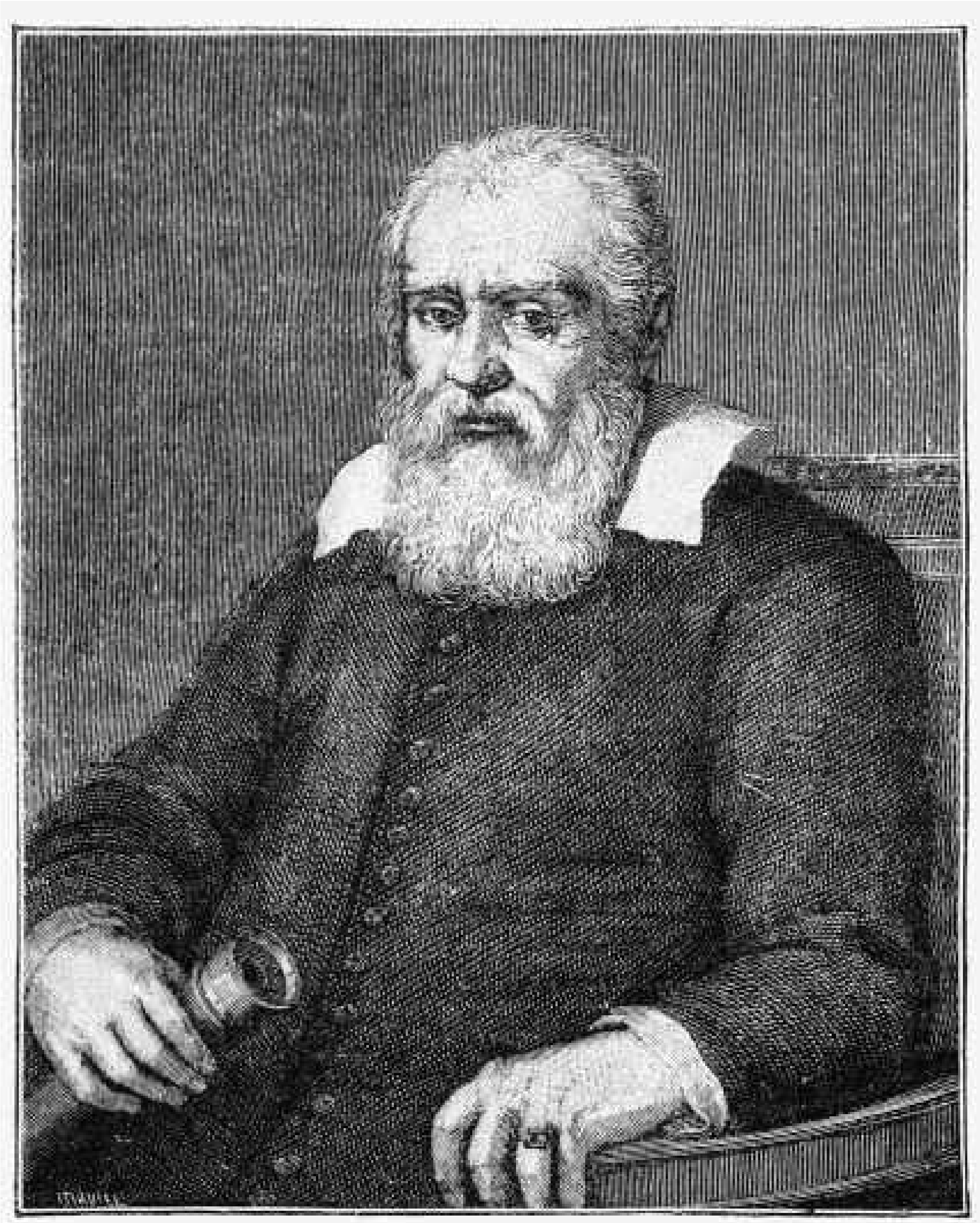


GALILEO'S PENDULUM.

We are so accustomed to the use of pendulums in our clocks that perhaps we do not often realise that the introduction of this method of regulating time-pieces was really a notable invention worthy the fame of the great astronomer to whom it was due. It appears that sitting one day in the Cathedral of Pisa, Galileo's attention became concentrated on the swinging of a chandelier which hung from the ceiling. It struck him as a significant point, that whether the arc through which the pendulum oscillated was a long one or a short one, the time occupied in each vibration was sensibly the same. This suggested to the thoughtful observer that a pendulum would afford the means by which a time-keeper might be controlled, and accordingly Galileo constructed for the first time a clock on this principle. The immediate object sought in this apparatus was to provide a means of aiding physicians in counting the pulses of their patients.

The talents of Galileo having at length extorted due recognition from the authorities, he was appointed, at the age of twenty-five, Professor of Mathematics at the University of Pisa. Then came the time when he felt himself strong enough to throw down the gauntlet to the adherents of the old philosophy. As a necessary part of his doctrine on the movement of bodies Aristotle had asserted that the time occupied by a stone in falling depends upon its weight, so that the heavier the stone the less time would it require to fall from a certain height to the earth. It might have been thought that a statement so easily confuted by the simplest experiments could never have maintained its position in any accepted scheme of philosophy. But Aristotle had said it, and to anyone who ventured to express a doubt the ready sneer was forthcoming, "Do you think yourself a cleverer man than Aristotle?" Galileo determined to demonstrate in the most emphatic manner the absurdity of a doctrine which had for centuries received the sanction of the learned. The summit of the Leaning Tower of Pisa offered a highly dramatic site for the great experiment. The youthful professor let fall from the overhanging top a large heavy body and a small light body simultaneously. According to Aristotle the large body ought to have reached the ground much sooner than the small one, but such was found not to be the case. In the sight of a large concourse of people the simple fact was demonstrated that the two bodies fell side by side, and reached the ground at the same time. Thus the first great step was taken in the overthrow of that preposterous system of unquestioning adhesion to dogma, which had impeded the development of the knowledge of nature for nearly two thousand years.

This revolutionary attitude towards the ancient beliefs was not calculated to render Galileo's relations with the University authorities harmonious. He had also the misfortune to make enemies in other quarters. Don Giovanni de Medici, who was then the Governor of the Port of Leghorn, had designed some contrivance by which he proposed to pump out a dock. But Galileo showed up the absurdity of this enterprise in such an aggressive manner that Don Giovanni took mortal offence, nor was he mollified when the truths of Galileo's criticisms were abundantly verified by the total failure of his ridiculous invention. In various ways Galileo was made to feel his position at Pisa so unpleasant that he was at length compelled to abandon his chair in the University. The active exertions of his friends, of whom Galileo was so fortunate as to have had throughout his life an abundant supply, then secured his election to the Professorship of Mathematics at Padua, whither he went in 1592.



PORTRAIT OF GALILEO.

It was in this new position that Galileo entered on that marvellous career of investigation which was destined to revolutionize science. The zeal with which he discharged his professorial duties was indeed of the most unremitting character. He speedily drew such crowds to listen to his discourses on Natural Philosophy that his lecture-room was filled to overflowing. He also received many private pupils in his house for special instruction. Every moment that could be spared from these labours was devoted to his private study and to his incessant experiments.

Like many another philosopher who has greatly extended our knowledge of nature, Galileo had a remarkable aptitude for the invention of instruments designed for philosophical research. To facilitate his practical work, we find that in 1599 he had engaged a skilled workman who was to live in his house, and thus be constantly at hand to try the devices for ever springing from Galileo's fertile brain. Among the earliest of his inventions appears to have been the thermometer, which he constructed in 1602. No doubt this apparatus in its primitive form differed in some respects from the contrivance we call by the same name. Galileo at first employed water as the agent, by the expansion of which the temperature was to be measured. He afterwards saw the advantage of using spirits for the same purpose. It was not until about half a century later that mercury came to be recognised as the liquid most generally suitable for the thermometer.

The time was now approaching when Galileo was to make that mighty step in the advancement of human knowledge which followed on the application of the telescope to astronomy. As to how his idea of such an instrument originated, we had best let him tell us in his own words. The passage is given in a letter which he writes to his brother-in-law, Landucci.

"I write now because I have a piece of news for you, though whether you will be glad or sorry to hear it I cannot say; for I have now no hope of returning to my own country, though the occurrence which has destroyed that hope has had results both useful and honourable. You must know, then, that two months ago there was a report spread here that in Flanders some one had presented to Count Maurice of Nassau a glass manufactured in such a way as to make distant objects appear very near, so that a man at the distance of two miles could be clearly seen. This seemed to me so marvellous that I began to think about it. As it appeared to me to have a foundation in the Theory of Perspective, I set about contriving how to make it, and at length I found out, and have succeeded so well that the one I have made is far superior to the Dutch telescope. It was reported in Venice that I had made one, and a week since I was commanded to show it to his Serenity and to all the members of the senate, to their infinite amazement. Many gentlemen and senators, even the oldest, have ascended at various times the highest bell-towers in Venice to spy out ships at sea making sail for the mouth of the harbour, and have seen them clearly, though without my telescope they would have been invisible for more than two hours. The effect of this instrument is to show an object at a distance of say fifty miles, as if it were but five miles."

The remarkable properties of the telescope at once commanded universal attention among intellectual men. Galileo received applications from several quarters for his new instrument, of which it would seem that he manufactured a large number to be distributed as gifts to various illustrious personages.

But it was reserved for Galileo himself to make that application of the instrument to the celestial bodies by which its peculiar powers were to inaugurate the new era in astronomy. The first discovery that was made in this direction appears to have been connected with the number of the stars. Galileo saw to his amazement that through his little tube he could count ten times as many stars in the sky as his unaided eye could detect. Here was, indeed, a surprise. We are now so familiar with the elementary facts of astronomy that it is not always easy to realise how the heavens were interpreted by the observers in those ages prior to the invention of the telescope. We can hardly, indeed, suppose that Galileo, like the majority of those who ever thought of such matters, entertained the erroneous belief that the stars were on the surface of a sphere at equal distances from the observer. No one would be likely to have retained his belief in such a doctrine when he saw how the number of visible stars could be increased tenfold by means of Galileo's telescope. It would have been almost impossible to refuse to draw the inference that the stars thus brought into view were still more remote objects which the telescope was able to reveal, just in the same way as it showed certain ships to the astonished Venetians, when at the time these ships were beyond the reach of unaided vision.

Galileo's celestial discoveries now succeeded each other rapidly. That beautiful Milky Way, which has for ages been the object of admiration to all lovers of nature, never disclosed its true nature to the eye of man till the astronomer of Padua turned on it his magic tube. The splendid zone of silvery light was then displayed as star-dust scattered over the black background of the sky. It was observed that though the individual stars were too small to be seen severally without optical aid, yet such was their incredible number that the celestial radiance produced that luminosity with which every stargazer was so familiar.

But the greatest discovery made by the telescope in these early days, perhaps, indeed, the greatest discovery that the telescope has ever accomplished, was the detection of the system of four satellites revolving around the great planet Jupiter. This phenomenon was so wholly unexpected by Galileo that, at first, he could hardly believe his eyes. However, the reality of the existence of a system of four moons attending the great planet was soon established beyond all question. Numbers of great personages crowded to Galileo to see for themselves this beautiful miniature representing the sun with its system of revolving planets.

Of course there were, as usual, a few incredulous people who refused to believe the assertion that four more moving bodies had to be added to the planetary system. They scoffed at the notion; they said the satellites may have been in the telescope, but that they were not in the sky. One sceptical philosopher is reported to have affirmed, that even if he saw the moons of Jupiter himself he would not believe in them, as their existence was contrary to the principles of common-sense!

There can be no doubt that a special significance attached to the new discovery at this particular epoch in the history of science. It must be remembered that in those days the doctrine of Copernicus, declaring that the sun, and not the earth, was the centre of the system, that the earth revolved on its axis once a day, and that it described a mighty circle round the sun once a year, had only recently been promulgated. This new view of the scheme of nature had been encountered with the most furious opposition. It may possibly have been that Galileo himself had not felt quite confident in the soundness of the Copernican theory, prior to the discovery of the satellites of Jupiter. But when a picture was there exhibited in which a number of relatively small globes were shown to be revolving around a single large globe in the centre, it seemed impossible not to feel that the beautiful spectacle so displayed was an emblem of the relations of the planets to the sun. It was thus made manifest to Galileo that the Copernican theory of the planetary system must be the true one. The momentous import of this opinion upon the future welfare of the great philosopher will presently appear.

It would seem that Galileo regarded his residence at Padua as a state of undesirable exile from his beloved Tuscany. He had always a yearning to go back to his own country and at last the desired opportunity presented itself. For now that Galileo's fame had become so great, the Grand Duke of Tuscany desired to have the philosopher resident at Florence, in the belief that he would shed lustre on the Duke's dominions. Overtures were accordingly made to Galileo, and the consequence was that in 1616 we find him residing at Florence, bearing the title of Mathematician and Philosopher to the Grand Duke.

Two daughters, Polissena and Virginia, and one son, Vincenzo, had been born to Galileo in Padua. It was the custom in those days that as soon as the daughter of an Italian gentleman had grown up, her future career was somewhat summarily decided. Either a husband was to be forthwith sought out, or she was to enter the convent with the object of taking the veil as a professed nun. It was arranged that the two daughters of Galileo, while still scarcely more than children, should both enter the Franciscan convent of St. Matthew, at Arcetri. The elder daughter Polissena, took the name of Sister Maria Celeste, while Virginia became Sister Arcangela. The latter seems to have been always delicate and subject to prolonged melancholy, and she is of but little account in the narrative of the life of Galileo. But Sister Maria Celeste, though never leaving the convent, managed to preserve a close intimacy with her beloved father. This was maintained only partly by Galileo's visits, which were very irregular and were, indeed, often suspended for long intervals. But his letters to this daughter were evidently frequent and affectionate, especially in the latter part of his life. Most unfortunately, however, all his letters have been lost. There are grounds for believing that they were deliberately destroyed when Galileo was seized by the Inquisition, lest they should have been used as evidence against him, or lest they should have compromised the convent where they were received. But Sister Maria Celeste's letters to her father have happily been preserved, and most touching these letters are.

We can hardly read them without thinking how the sweet and gentle nun would have shrunk from the idea of their publication.

Her loving little notes to her "dearest lord and father," as she used affectionately to call Galileo, were almost invariably accompanied by some gift, trifling it may be, but always the best the poor nun had to bestow. The tender grace of these endearing communications was all the more precious to him from the fact that the rest of Galileo's relatives were of quite a worthless description. He always acknowledged the ties of his kindred in the most generous way, but their follies and their vices, their selfishness and their importunities, were an incessant source of annoyance to him, almost to the last day of his life.

On 19th December, 1625, Sister Maria Celeste writes:—

"I send two baked pears for these days of vigil. But as the greatest treat of all, I send you a rose, which ought to please you extremely, seeing what a rarity it is at this season; and with the rose you must accept its thorns, which represent the bitter passion of our Lord, whilst the green leaves represent the hope we may entertain that through the same sacred passion we, having passed through the darkness of the short winter of our mortal life, may attain to the brightness and felicity of an eternal spring in heaven."

When the wife and children of Galileo's shiftless brother came to take up their abode in the philosopher's home, Sister Maria Celeste feels glad to think that her father has now some one who, however imperfectly, may fulfil the duty of looking after him. A graceful note on Christmas Eve accompanies her little gifts. She hopes that—

"In these holy days the peace of God may rest on him and all the house. The largest collar and sleeves I mean for Albertino, the other two for the two younger boys, the little dog for baby, and the cakes for everybody, except the spice-cakes, which are for you. Accept the good-will which would readily do much more."

The extraordinary forbearance with which Galileo continually placed his time, his purse, and his influence at the service of those who had repeatedly proved themselves utterly unworthy of his countenance, is thus commented on by the good nun.—

"Now it seems to me, dearest lord and father, that your lordship is walking in the right path, since you take hold of every occasion that presents itself to shower continual benefits on those who only repay you with ingratitude. This is an action which is all the more virtuous and perfect as it is the more difficult."

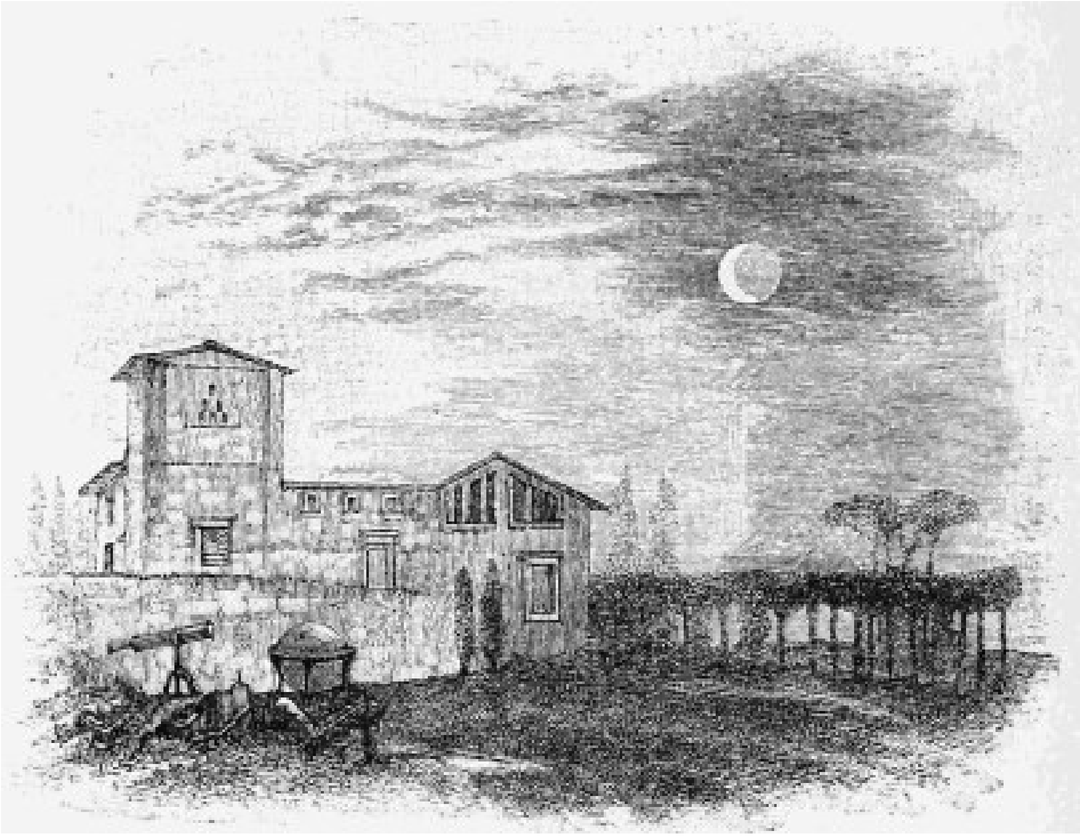
When the plague was raging in the neighbourhood, the loving daughter's solicitude is thus shown:—

"I send you two pots of electuary as a preventive against the plague. The one without the label consists of dried figs, walnuts, rue, and salt, mixed together with honey. A piece of the size of a walnut to be taken in the morning, fasting, with a little Greek wine."

The plague increasing still more, Sister Maria Celeste obtained with much difficulty, a small quantity of a renowned liqueur, made by Abbess Ursula, an exceptionally saintly nun. This she sends to her father with the words:—

"I pray your lordship to have faith in this remedy. For if you have so much faith in my poor miserable prayers, much more may you have in those of such a holy person; indeed, through her merits you may feel sure of escaping all danger from the plague."

Whether Galileo took the remedy we do not know, but at all events he escaped the plague.



THE VILLA ARCETRI. Galileo's residence, where Milton visited him.

From Galileo's new home in Florence the telescope was again directed to the skies, and again did astounding discoveries reward the astronomer's labours. The great success which he had met with in studying Jupiter naturally led Galileo to look at Saturn. Here he saw a spectacle which was sufficiently amazing, though he failed to interpret it accurately. It was quite manifest that Saturn did not exhibit a simple circular disc like Jupiter, or like Mars. It seemed to Galileo as if the planet consisted of three bodies, a large globe in the centre, and a smaller one on each side. The enigmatical nature of the discovery led Galileo to announce it in an enigmatical manner. He published a string of letters which, when duly transposed, made up a sentence which affirmed that the planet Saturn was threefold. Of course we now know that this remarkable appearance of the planet was due to the two projecting portions of the ring. With the feeble power of Galileo's telescope, these seemed merely like small globes or appendages to the large central body.

The last of Galileo's great astronomical discoveries related to the libration of the moon. I think that the detection of this phenomenon shows his acuteness of observation more remarkably than does any one of his other achievements with the telescope. It is well known that the moon constantly keeps the same face turned towards the earth. When, however, careful measurements have been made with regard to the spots and marks on the lunar surface, it is found that there is a slight periodic variation which permits us to see now a little to the east or to the west, now a little to the north or to the south of the average lunar disc.

But the circumstances which make the career of Galileo so especially interesting from the biographer's point of view, are hardly so much the triumphs that he won as the sufferings that he endured. The sufferings and the triumphs were, however, closely connected, and it is fitting that we should give due consideration to what was perhaps the greatest drama in the history of science.

On the appearance of the immortal work of Copernicus, in which it was taught that the earth rotated on its axis, and that the earth, like the other planets, revolved round the sun, orthodoxy stood aghast. The Holy Roman Church submitted this treatise, which bore the name "De

Revolutionibus Orbium Coelestium," to the Congregation of the Index. After due examination it was condemned as heretical in 1615. Galileo was suspected, on no doubt excellent grounds, of entertaining the objectionable views of Copernicus. He was accordingly privately summoned before Cardinal Bellarmine on 26th February 1616, and duly admonished that he was on no account to teach or to defend the obnoxious doctrines. Galileo was much distressed by this intimation. He felt it a serious matter to be deprived of the privilege of discoursing with his friends about the Copernican system, and of instructing his disciples in the principles of the great theory of whose truth he was perfectly convinced. It pained him, however, still more to think, devout Catholic as he was, that such suspicions of his fervent allegiance to his Church should ever have existed, as were implied by the words and monitions of Cardinal Bellarmine.

In 1616, Galileo had an interview with Pope Paul V., who received the great astronomer very graciously, and walked up and down with him in conversation for three-quarters of an hour. Galileo complained to his Holiness of the attempts made by his enemies to embarrass him with the authorities of the Church, but the Pope bade him be comforted. His Holiness had himself no doubts of Galileo's orthodoxy, and he assured him that the Congregation of the Index should give Galileo no further trouble so long as Paul V. was in the chair of St. Peter.

On the death of Paul V. in 1623, Maffeo Barberini was elected Pope, as Urban VIII. This new Pope, while a cardinal, had been an intimate friend of Galileo's, and had indeed written Latin verses in praise of the great astronomer and his discoveries. It was therefore not unnatural for Galileo to think that the time had arrived when, with the use of due circumspection, he might continue his studies and his writings, without fear of incurring the displeasure of the Church. Indeed, in 1624, one of Galileo's friends writing from Rome, urges Galileo to visit the city again, and added that—

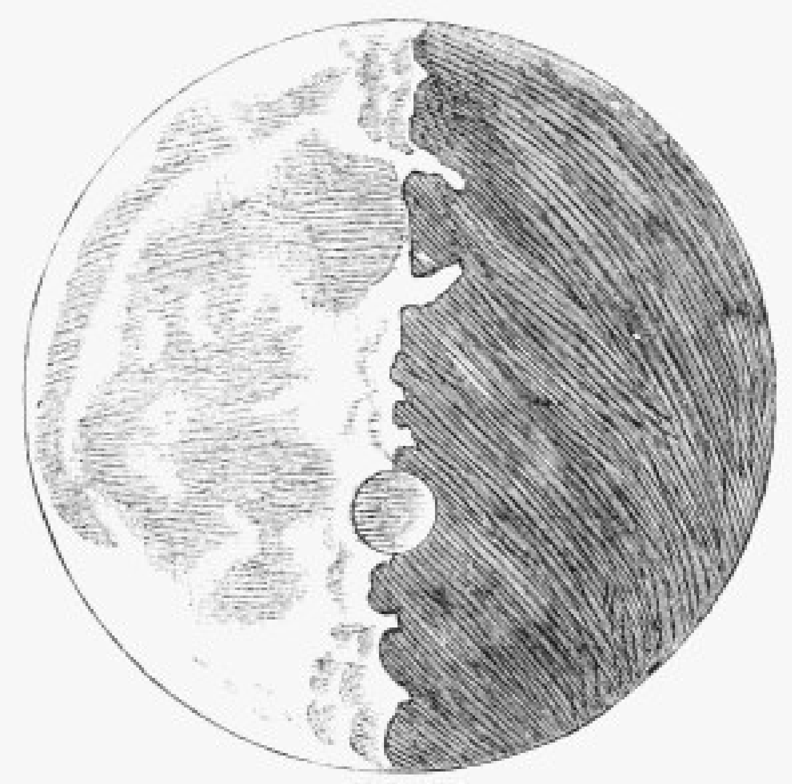
"Under the auspices of this most excellent, learned, and benignant Pontiff, science must flourish. Your arrival will be welcome to his Holiness. He asked me if you were coming, and when, and in short, he seems to love and esteem you more than ever."

The visit was duly paid, and when Galileo returned to Florence, the Pope wrote a letter from which the following is an extract, commanding the philosopher to the good offices of the young Ferdinand, who had shortly before succeeded his father in the Grand Duchy of Tuscany.

"We find in Galileo not only literary distinction, but also the love of piety, and he is also strong in those qualities by which the pontifical good-will is easily obtained. And now, when he has been brought to this city to congratulate us on our elevation, we have very lovingly embraced him; nor can we suffer him to return to the country whither your liberality calls him, without an ample provision of pontifical love. And that you may know how dear he is to us, we have willed to give him this honourable testimonial of virtue and piety. And we further signify that every benefit which you shall confer upon him, imitating or even surpassing your father's liberality, will conduce to our gratification."

The favourable reception which had been accorded to him by Pope Urban VIII. seems to have led Galileo to expect that there might be some corresponding change in the attitude of the Papal authorities on the great question of the stability of the earth. He accordingly proceeded with the preparation of the chief work of his life, "The Dialogue of the two Systems." It was submitted for inspection by the constituted authorities. The Pope himself thought that, if a few conditions which he laid down were duly complied with, there could be no objection to the publication of the work. In the first place, the title of the book was to be so carefully worded as to show plainly that the Copernican doctrine was merely to be regarded as an hypothesis, and not as a scientific fact. Galileo was also instructed to conclude the book with special arguments which had been supplied by the Pope himself, and which appeared to his Holiness to be quite conclusive against the new doctrine of Copernicus.

Formal leave for the publication of the Dialogue was then given to Galileo by the Inquisitor General, and it was accordingly sent to the press. It might be thought that the anxieties of the astronomer about his book would then have terminated. As a matter of fact, they had not yet seriously begun. Riccardi, the Master of the Sacred Palace, having suddenly had some further misgivings, sent to Galileo for the manuscript while the work was at the printer's, in order that the doctrine it implied might be once again examined. Apparently, Riccardi had come to the conclusion that he had not given the matter sufficient attention, when the authority to go to press had been first and, perhaps, hastily given. Considerable delay in the issue of the book was the result of these further deliberations. At last, however, in June, 1632, Galileo's great work, "The Dialogue of the two Systems," was produced for the instruction of the world, though the occasion was fraught with ruin to the immortal author.



FACSIMILE SKETCH OF LUNAR SURFACE BY GALILEO.

The book, on its publication, was received and read with the greatest avidity. But presently the Master of The Sacred Palace found reason to regret that he had given his consent to its appearance. He accordingly issued a peremptory order to sequestrate every copy in Italy. This sudden change in the Papal attitude towards Galileo formed the subject of a strong remonstrance addressed to the Roman authorities by the Grand Duke of Tuscany. The Pope himself seemed to have become impressed all at once with the belief that the work contained matter of an heretical description. The general interpretation put upon the book seems to have shown the authorities that they had mistaken its true tendency, notwithstanding the fact that it had been examined again and again by theologians deputed for the duty. To the communication from the Grand Duke the Pope returned answer, that he had decided to submit the book to a congregation of "learned, grave, and saintly men," who would weigh every word in it. The views of his Holiness personally on the subject were expressed in his belief that the Dialogue contained the most perverse matter that could come into a reader's hands.

The Master of the Sacred Palace was greatly blamed by the authorities for having given his sanction to its issue. He pleaded that the book had not been printed in the precise terms of the original manuscript which had been submitted to him. It was also alleged that Galileo had not adhered to his promise of inserting properly the arguments which the Pope himself had given in support of the old and orthodox view. One of these had, no doubt, been introduced, but, so far from mending Galileo's case, it had made matters really look worse for the poor philosopher. The Pope's argument had been put into the mouth of one of the characters in the Dialogue named "Simplicio." Galileo's enemies maintained that by adopting such a method for the expression of his Holiness's opinion, Galileo had intended to hold the Pope himself up to ridicule. Galileo's friends maintained that nothing could have been farther from his intention. It seems, however, highly probable that the suspicions thus aroused had something to say to the sudden change of front on the part of the Papal authorities.

On 1st October, 1632, Galileo received an order to appear before the Inquisition at Rome on the grave charge of heresy. Galileo, of course, expressed his submission, but pleaded for a respite from compliance with the summons, on the ground of his advanced age and his failing health. The Pope was, however, inexorable; he said that he had warned Galileo of his danger while he was still his friend. The command could not be disobeyed. Galileo might perform the journey as slowly as he pleased, but it was imperatively necessary for him to set forth and at once.

On 20th January, 1633, Galileo started on his weary journey to Rome, in compliance with this peremptory summons. On 13th February he was received as the guest of Niccolini, the Tuscan ambassador, who had acted as his wise and ever-kind friend throughout the whole affair. It seemed plain that the Holy Office were inclined to treat Galileo with as much clemency and consideration as was consistent with the determination that the case against him should be proceeded with to the end. The Pope intimated that in consequence of his respect for the Grand Duke of Tuscany he should permit Galileo to enjoy the privilege, quite unprecedented for a prisoner charged with heresy, of remaining as an inmate in the ambassador's house. He ought, strictly, to have been placed in the dungeons of the Inquisition. When the examination of the accused had actually commenced, Galileo was confined, not, indeed, in the dungeons, but in comfortable rooms at the Holy Office.

By the judicious and conciliatory language of submission which Niccolini had urged Galileo to use before the Inquisitors, they were so far satisfied that they interceded with the Pope for his release. During the remainder of the trial Galileo was accordingly permitted to go back to the ambassador's, where he was most heartily welcomed. Sister Maria Celeste, evidently thinking this meant that the whole case was at an end, thus expresses herself:—

"The joy that your last dear letter brought me, and the having to read it over and over to the nuns, who made quite a jubilee on hearing its contents, put me into such an excited state that at last I got a severe attack of headache."

In his defence Galileo urged that he had already been acquitted in 1616 by Cardinal Bellarmine, when a charge of heresy was brought against him, and he contended that anything he might now have done, was no more than he had done on the preceding occasion, when the orthodoxy of his doctrines received solemn confirmation. The Inquisition seemed certainly inclined to clemency, but the Pope was not satisfied. Galileo was accordingly summoned again on the 21st June. He was to be threatened with torture if he did not forthwith give satisfactory explanations as to the reasons which led him to write the Dialogue. In this proceeding the Pope assured the Tuscan ambassador that he was treating Galileo with the utmost consideration possible in consequence of his esteem and regard for the Grand Duke, whose servant Galileo was. It was, however, necessary that some exemplary punishment be meted out to the astronomer, inasmuch as by the publication of the Dialogue he had distinctly disobeyed the injunction of silence laid upon him by the decree of 1616. Nor was it admissible for Galileo to plead that his book had been sanctioned by the Master of the Sacred College, to whose inspection it had been again and again submitted. It was held, that if the Master of the Sacred College had been unaware of the solemn warning the philosopher had already received sixteen years previously, it was the duty of Galileo to have drawn his attention to that fact.

On the 22nd June, 1633, Galileo was led to the great hall of the Inquisition, and compelled to kneel before the cardinals there assembled and hear his sentence. In a long document, most elaborately drawn up, it is definitely charged against Galileo that, in publishing the Dialogue, he committed the essentially grave error of treating the doctrine of the earth's motion as open to discussion. Galileo knew, so the document affirmed, that the Church had emphatically pronounced this notion to be contrary to Holy Writ, and that for him to consider a doctrine so stigmatized as having any shadow of probability in its favour was an act of disrespect to the authority of the Church which could not be overlooked. It was also charged against Galileo that in his Dialogue he has put the strongest arguments into the mouth, not of those who supported the orthodox doctrine, but of those who held the theory as to the earth's motion which the Church had so deliberately condemned.

After due consideration of the defence made by the prisoner, it was thereupon decreed that he had rendered himself vehemently suspected of heresy by the Holy Office, and in consequence had incurred all the censures and penalties of the sacred canons, and other decrees promulgated against such persons. The graver portion of these punishments would be remitted, if Galileo would solemnly repudiate the heresies referred to by an abjuration to be pronounced by him in the terms laid down.

At the same time it was necessary to mark, in some emphatic manner, the serious offence which had been committed, so that it might serve both as a punishment to Galileo and as a warning to others. It was accordingly decreed that he should be condemned to imprisonment in the Holy Office during the pleasure of the Papal authorities, and that he should recite once a week for three years the seven Penitential Psalms.

Then followed that ever-memorable scene in the great hall of the Inquisition, in which the aged and infirm Galileo, the inventor of the telescope and the famous astronomer, knelt down to abjure before the most eminent and reverend Lords Cardinal, Inquisitors General throughout the Christian Republic against heretical depravity. With his hands on the Gospels, Galileo was made to curse and detest the false opinion that the sun was the centre of the universe and immovable, and that the earth was not the centre of the same, and that it moved. He swore that for the future he will never say nor write such things as may bring him under suspicion, and that if he does so he submits to all the pains and penalties of the sacred canons. This abjuration was subsequently read in Florence before Galileo's disciples, who had been specially summoned to attend.

It has been noted that neither on the first occasion, in 1616, nor on the second in 1633, did the reigning Pope sign the decrees concerning Galileo. The contention has accordingly been made that Paul V. and Urban VIII. are both alike vindicated from any technical responsibility for the attitude of the Romish Church towards the Copernican doctrines. The significance of this circumstance has been commented on in connection with the doctrine of the infallibility of the Pope.

We can judge of the anxiety felt by Sister Maria Celeste about her beloved father during these terrible trials. The wife of the ambassador Niccolini, Galileo's steadfast friend, most kindly wrote to give the nun whatever quieting assurances the case would permit. There is a renewed flow of these touching epistles from the daughter to her father. Thus she sends word—

"The news of your fresh trouble has pierced my soul with grief all the more that it came quite unexpectedly."

And again, on hearing that he had been permitted to leave Rome, she writes—

"I wish I could describe the rejoicing of all the mothers and sisters on hearing of your happy arrival at Siena. It was indeed most extraordinary. On hearing the news the Mother Abbess and many of the nuns ran to me, embracing me and weeping for joy and tenderness."

The sentence of imprisonment was at first interpreted leniently by the Pope. Galileo was allowed to reside in qualified durance in the archbishop's house at Siena. Evidently the greatest pain that he endured arose from the forced separation from that daughter, whom he had at last learned to love with an affection almost comparable with that she bore to him. She had often told him that she never had any pleasure equal to that with which she rendered any service to her father. To her joy, she discovers that she can relieve him from the task of reciting the seven Penitential Psalms which had been imposed as a Penance:—

Конец ознакомительного фрагмента.