they could not fail to discredit the assertion that the earth is an indefinite plane. No one can doubt that the sun we see to-day is the self-same sun that we saw yesterday. His reappearance each morning irresistibly suggests that he has passed on the underside of the earth. But this is incompatible with the reign of night in those regions. It presents more or less distinctly the idea of the globular form of the earth.

The earth cannot extend indefinitely downward; for the sun cannot go through it, nor through any crevice or passage in it, since he rises and sets in different positions at different seasons of the year. The stars also move under it in countless courses. There must, therefore, be a clear way beneath.

To reconcile revelation with these innovating facts, schemes, such as that of Cosmas Indicopleustes in his Christian Topography, were doubtless often adopted. To this in particular we have had occasion on a former page to refer. It asserted that in the northern parts of the flat earth there is an immense mountain, behind which the sun passes, and thus produces night.

At a very remote historical period the mechanism of eclipses had been discovered. Those of the moon demonstrated that the shadow of the earth is always circular. The form of the earth must therefore be globular. A body which in all positions casts a circular shadow must itself be spherical. Other considerations, with which every one is now familiar, could not fail to establish that such is her figure.

But the determination of the shape of the earth by no means deposed her from her position of superiority. Apparently vastly larger than all other things, it was fitting that she should be considered not merely as the centre of the world, but, in truth, as—the world. All other objects in their aggregate seemed utterly unimportant in comparison with her.

Though the consequences flowing from an admission of the globular figure of the earth affected very profoundly existing theological ideas, they were of much less moment than those depending on a determination of her size. It needed but an elementary knowledge of geometry to perceive that correct ideas on this point could be readily obtained by measuring a degree on her surface. Probably there were early attempts to accomplish this object, the results of which have been lost. But Eratosthenes executed one between Syene and Alexandria, in Egypt, Syene being supposed to be exactly under the tropic of Cancer. The two places are, however, not on the same meridian, and the distance between them was estimated, not measured. Two centuries later, Posidonius made another attempt between Alexandria and Rhodes; the bright star Canopus just grazed the horizon at the latter place, at Alexandria it rose $7\frac{1}{2}°$. In this instance, also, since the direction lay across the sea, the distance was estimated, not measured. Finally, as we have already related, the Khalif Al-Mamun made two sets of measures, one on the shore of the Red Sea, the other near Cufa, in Mesopotamia. The general result of these various observations gave for the earth's diameter between seven and eight thousand miles.

This approximate determination of the size of the earth tended to depose her from her dominating position, and gave rise to very serious theological results. In this the ancient investigations of Aristarchus of Samos, one of the Alexandrian school, 280 B. C., powerfully aided. In his treatise on the magnitudes and distances of the sun and moon, he explains the ingenious though imperfect method to which he had resorted for the solution of that problem. Many ages previously a speculation had been brought from India to Europe by Pythagoras. It presented the sun as the centre of the system. Around him the planets revolved in circular orbits, their order of position being Mercury, Venus, Earth, Mars, Jupiter, Saturn, each of them being supposed to rotate on its axis as it revolved round the sun. According to Cicero, Nicetas suggested that, if it were admitted that the earth revolves on her axis, the difficulty presented by the inconceivable velocity of the heavens would be avoided.

There is reason to believe that the works of Aristarchus, in the Alexandrian Library, were burnt at the time of the fire of Cæsar. The only treatise of his that has come down to us is that above mentioned, on the size and distance of the sun and moon.

Aristarchus adopted the Pythagorean system as representing the actual facts. This was the result of a recognition of the sun's amazing distance, and therefore of his enormous size. The heliocentric system, thus regarding the sun as the central orb, degraded the earth to a very subordinate rank, making her only one of a company of six revolving bodies.

But this is not the only contribution conferred on astronomy by Aristarchus, for, considering that the movement of the earth does not sensibly affect the apparent position of the stars, he inferred that they are incomparably more distant from us than the sun. He, therefore, of all the ancients, as Laplace remarks, had the most correct ideas of the grandeur of the universe. He saw that the earth is of absolutely insignificant size, when compared with the stellar distances. He saw, too, that there is nothing above us but space and stars.

But the views of Aristarchus, as respects the emplacement of the planetary bodies, were not accepted by antiquity; the system proposed by Ptolemy, and incorporated in his "Syntaxis," was universally preferred. The physical philosophy of those times was very imperfect—one of Ptolemy's objections to the Pythagorean system being that, if the earth were in motion, it would leave the air and other light bodies behind it. He therefore placed the earth in the central position, and in succession revolved round her the Moon, Mercury, Venus, the Sun, Mars, Jupiter, Saturn; beyond the orbit of Saturn came the firmament of the fixed stars. As to the solid crystalline spheres, one moving from east to west, the other from north to south, these were a fancy of Eudoxus, to which Ptolemy does not allude.

The Ptolemaic system is, therefore, essentially a geocentric system. It left the earth in her position of superiority, and hence gave no cause of umbrage to religious opinions, Christian or Mohammedan. The immense reputation of its author, the signal ability of his great work on the mechanism of the heavens, sustained it for almost fourteen hundred years—that is, from the second to the sixteenth century.

In Christendom, the greater part of this long period was consumed in disputes respecting the nature of God, and in struggles for ecclesiastical power. The authority of the Fathers, and the prevailing belief that the Scriptures contain the sum of all knowledge, discouraged any investigation of Nature. If by chance a passing interest was taken in some astronomical question, it was at once settled by a reference to such authorities as the writings of Augustine or Lactantius, not by an appeal to the phenomena of the heavens. So great was the preference given to sacred over profane learning, that Christianity had been in existence fifteen hundred years, and had not produced a single astronomer.

The Mohammedan nations did much better. Their cultivation of science dates from the capture of Alexandria, A. D. 638. This was only six years after the death of the Prophet. In less than two centuries they had not only become acquainted with, but correctly appreciated, the Greek scientific writers. As we have already mentioned, by his treaty with Michael III., the Khalif Al-Mamun had obtained a copy of the "Syntaxis" of Ptolemy. He had it forthwith translated into Arabic. It became at once the great authority of Saracen astronomy. From this basis the Saracens had advanced to the solution of some of the most important scientific problems. They had ascertained the dimensions of the earth; they had registered or catalogued all the stars visible in their heavens, giving to those of the larger magnitudes the names they still bear on our maps and globes; they determined the true length of the year, discovered astronomical refraction, invented the pendulum-clock, improved the photometry of the stars, ascertained the curvilinear path of a ray of light through the air, explained the phenomena of the horizontal sun and moon, and why we see those bodies before they have risen and after they have set; measured the height of the atmosphere, determining it to be fifty-eight miles; given the true theory of the twilight, and of the twinkling of the stars. They had built the first observatory in Europe. So accurate were they in their observations, that the ablest modern mathematicians have made use of their results. Thus Laplace, in his "Système du Monde," adduces the observations of Al-Batagni as affording incontestable proof of the diminution of the eccentricity

of the earth's orbit. He uses those of Ibn-Junis in his discussion of the obliquity of the ecliptic, and also in the case of the problems of the greater inequalities of Jupiter and Saturn.

These represent but a part, and indeed but a small part, of the services rendered by the Arabian astronomers, in the solution of the problem of the nature of the world. Meanwhile, such was the benighted condition of Christendom, such its deplorable ignorance, that it cared nothing about the matter. Its attention was engrossed by image-worship, transubstantiation, the merits of the saints, miracles, shrine-cures.

This indifference continued until the close of the fifteenth century. Even then there was no scientific inducement. The inciting motives were altogether of a different kind. They originated in commercial rivalries, and the question of the shape of the earth was finally settled by three sailors, Columbus, De Gama, and, above all, by Ferdinand Magellan.

The trade of Eastern Asia has always been a source of immense wealth to the Western nations who in succession have obtained it. In the middle ages it had centred in Upper Italy. It was conducted along two lines—a northern, by way of the Black and Caspian Seas, and camel-caravans beyond—the headquarters of this were at Genoa; and a southern, through the Syrian and Egyptian ports, and by the Arabian Sea, the headquarters of this being at Venice. The merchants engaged in the latter traffic had also made great gains in the transport service of the Crusade-wars.

The Venetians had managed to maintain amicable relations with the Mohammedan powers of Syria and Egypt; they were permitted to have consulates at Alexandria and Damascus, and, notwithstanding the military commotions of which those countries had been the scene, the trade was still maintained in a comparatively flourishing condition. But the northern or Genoese line had been completely broken up by the irruptions of the Tartars and the Turks, and the military and political disturbances of the countries through which it passed. The Eastern trade of Genoa was not merely in a precarious condition—it was on the brink of destruction.

The circular visible horizon and its dip at sea, the gradual appearance and disappearance of ships in the offing, cannot fail to incline intelligent sailors to a belief in the globular figure of the earth. The writings of the Mohammedan astronomers and philosophers had given currency to that doctrine throughout Western Europe, but, as might be expected, it was received with disfavor by theologians. When Genoa was thus on the very brink of ruin, it occurred to some of her mariners that, if this view were correct, her affairs might be re-established. A ship sailing through the straits of Gibraltar westward, across the Atlantic, would not fail to reach the East Indies. There were apparently other great advantages. Heavy cargoes might be transported without tedious and expensive land-carriage, and without breaking bulk.

Among the Genoese sailors who entertained these views was Christopher Columbus.

He tells us that his attention was drawn to this subject by the writings of Averroes, but among his friends he numbered Toscanelli, a Florentine, who had turned his attention to astronomy, and had become a strong advocate of the globular form. In Genoa itself Columbus met with but little encouragement. He then spent many years in trying to interest different princes in his proposed attempt. Its irreligious tendency was pointed

out by the Spanish ecclesiastics, and condemned by the Council of Salamanca; its orthodoxy was confuted from the Pentateuch, the Psalms, the Prophecies, the Gospels, the Epistles, and the writings of the Fathers—St. Chrysostom, St. Augustine, St. Jerome, St. Gregory, St. Basil, St. Ambrose.

At length, however, encouraged by the Spanish Queen Isabella, and substantially aided by a wealthy seafaring family, the Pinzons of Palos, some of whom joined him personally, he sailed on August 3, 1492, with three small ships, from Palos, carrying with him a letter from King Ferdinand to the Grand-Khan of Tartary, and also a chart, or map, constructed on the basis of that of Toscanelli. A little before midnight, October 11, 1492, he saw from the forecastle of his ship a moving light at a distance. Two hours subsequently a signal-gun from another of the ships announced that they had descried land. At sunrise Columbus landed in the New World.

On his return to Europe it was universally supposed that he had reached the eastern parts of Asia, and that therefore his voyage had been theoretically successful. Columbus himself died in that belief. But numerous voyages which were soon undertaken made known the general contour of the American coast-line, and the discovery of the Great South Sea by Balboa revealed at length the true facts of the case, and the mistake into which both Toscanelli and Columbus had fallen, that in a voyage to the West the distance from Europe to Asia could not exceed the distance passed over in a voyage from Italy to the Gulf of Guinea—a voyage that Columbus had repeatedly made.

In his first voyage, at nightfall on September 13, 1492, being then two and a half degrees east of Corvo, one of the Azores, Columbus observed that the compass-needles of the ships no longer pointed a little to the east of north, but were varying to the west. The deviation became more and more marked as the expedition advanced. He was not the first to detect the fact of variation, but he was incontestably the first to discover the line of no variation. On the return-voyage the reverse was observed; the variation westward diminished until the meridian in question was reached, when the needles again pointed due north. Thence, as the coast of Europe was approached, the variation was to the east. Columbus, therefore, came to the conclusion that the line of no variation was a fixed geographical line, or boundary, between the Eastern and Western Hemispheres. In the bull of May, 1493, Pope Alexander VI. accordingly adopted this line as the perpetual boundary between the possessions of Spain and Portugal, in his settlement of the disputes of those nations. Subsequently, however, it was discovered that the line was moving eastward. It coincided with the meridian of London in 1662.

By the papal bull the Portuguese possessions were limited to the east of the line of no variation. Information derived from certain Egyptian Jews had reached that government, that it was possible to sail round the continent of Africa, there being at its extreme south a cape which could be easily doubled. An expedition of three ships under Vasco de Gama set sail, July 9, 1497; it doubled the cape on November 20th, and reached Calicut, on the coast of India, May 19, 1498. Under the bull, this voyage to the East gave to the Portuguese the right to the India trade.

Until the cape was doubled, the course of De Gama's ships was in a general manner southward. Very soon, it was noticed that the elevation of the pole-star above the horizon was diminishing, and, soon after the equator was reached, that star had ceased to be visible. Meantime other stars, some of them forming magnificent constellations, had come into view—the stars of the Southern Hemisphere. All this was in conformity to theoretical expectations founded on the admission of the globular form of the earth.

The political consequences that at once ensued placed the Papal Government in a position of great embarrassment. Its traditions and policy forbade it to admit any other than the flat figure of the earth, as revealed in the Scriptures. Concealment of the facts was impossible, sophistry was unavailing. Commercial prosperity now left Venice as well as Genoa. The front of Europe was changed. Maritime power had departed from the Mediterranean countries, and passed to those upon the Atlantic coast.

But the Spanish Government did not submit to the advantage thus gained by its commercial rival without an effort. It listened to the representations of one Ferdinand Magellan, that India and the Spice Islands could be reached by sailing to the west, if only a strait or passage through what had now been recognized as 'the American Continent" could be discovered; and, if this should be accomplished, Spain, under the papal bull, would have as good a right to the India trade as Portugal. Under the command of Magellan, an expedition of five ships, carrying two hundred and thirty-seven men, was dispatched from Seville, August 10, 1519.

Magellan at once struck boldly for the South American coast, hoping to find some cleft or passage through the continent by which he might reach the great South

Sea. For seventy days he was becalmed on the line; his sailors were appalled by the apprehension that they had drifted into a region where the winds never blew, and that it was impossible for them to escape. Calms, tempests, mutiny, desertion, could not shake his resolution. After more than a year he discovered the strait which now bears his name, and, as Pigafetti, an Italian, who was with him, relates, he shed tears of joy when he found that it had pleased God at length to bring him where he might grapple with the unknown dangers of the South Sea, "the Great and Pacific Ocean."

Driven by famine to eat scraps of skin and leather with which his rigging was here and there bound, to drink water that had gone putrid, his crew dying of hunger and scurvy, this man, firm in his belief of the globular figure of the earth, steered steadily to the northwest, and for nearly four months never saw inhabited land. He estimated that he had sailed over the Pacific not less than twelve thousand miles. He crossed the equator, saw once more the pole-star, and at length made land—the Ladrones. Here he met with adventurers from Sumatra. Among these islands he was killed, either by the savages or by his own men. His lieutenant, Sebastian d'Elcano, now took command of the ship, directing her course for the Cape of Good Hope, and encountering frightful hardships. He doubled the cape at last, and then for the fourth time crossed the equator. On September 7, 1522, after a voyage of more than three years, he brought his ship, the San Vittoria, to anchor in the port of St. Lucar, near Seville. She had accomplished the greatest achievement in the history of the human race. She had circumnavigated the earth.

The San Vittoria, sailing westward, had come back

to her starting-point. Henceforth the theological doctrine of the flatness of the earth was irretrievably overthrown.

Five years after the completion of the voyage of Magellan, was made the first attempt in Christendom to ascertain the size of the earth. This was by Fernel, a French physician, who, having observed the height of the pole at Paris, went thence northward until he came to a place where the height of the pole was exactly one degree more than at that city. He measured the distance between the two stations by the number of revolutions of one of the wheels of his carriage, to which a proper indicator had been attached, and came to the conclusion that the earth's circumference is about twenty-four thousand four hundred and eighty Italian miles.

Measures executed more and more carefully were made in many countries: by Snell in Holland; by Norwood between London and York in England; by Picard, under the auspices of the French Academy of Sciences, in France. Picard's plan was to connect two points by a series of triangles, and, thus ascertaining the length of the arc of a meridian intercepted between them, to compare it with the difference of latitudes found from celestial observations. The stations were Malvoisine in the vicinity of Paris, and Sourdon near Amiens. The difference of latitudes was determined by observing the zenith-distances of δ Cassiopeia. There are two points of interest connected with Picard's operation: it was the first in which instruments furnished with telescopes were employed; and its result, as we shall shortly see, was to Newton the first confirmation of the theory of universal gravitation.

At this time it had become clear from mechanical considerations, more especially such as had been deduced by Newton, that, since the earth is a rotating body, her form cannot be that of a perfect sphere, but must be that of a spheroid, oblate or flattened at the poles. It would follow, from this, that the length of a degree must be greater near the poles than at the equator.

The French Academy resolved to extend Picard's operation, by prolonging the measures in each direction, and making the result the basis of a more accurate map of France. Delays, however, took place, and it was not until 1718 that the measures, from Dunkirk on the north to the southern extremity of France, were completed. A discussion arose as to the interpretation of these measures, some affirming that they indicated a prolate, others an oblate spheroid; the former figure may be popularly represented by a lemon, the latter by an orange. To settle this, the French Government, aided by the Academy, sent out two expeditions to measure degrees of the meridian—one under the equator, the other as far north as possible; the former went to Peru, the latter to Swedish Lapland. Very great difficulties were encountered by both parties. The Lapland commission, however, completed its observations long before the Peruvian, which consumed not less than nine years. The results of the measures thus obtained confirmed the theoretical expectation of the oblate form. Since that time many extensive and exact repetitions of the observation have been made, among which may be mentioned those of the English in England and in India, and particularly that of the French on the occasion of the introduction of the metric system of weights and measures. It was begun by Delambre and Mechain, from Dunkirk to Barcelona, and thence extended, by Biot and Arago, to the island of Formentera near Minorca. Its length was nearly twelve and a half degrees

Besides this method of direct measurement, the figure of the earth may be determined from the observed number of oscillations made by a pendulum of invariable length in different latitudes. These, though they confirm the foregoing results, give a somewhat greater ellipticity to the earth than that found by the measurement of degrees. Pendulums vibrate more slowly the nearer they are to the equator. It follows, therefore, that they are there farther from the centre of the earth.

From the most reliable measures that have been made, the dimensions of the earth may be thus stated:

Greater or equatorial diameter..........	7,925	miles.
Less or polar diameter..................	7,899	"
Difference or polar compression..........	26	"

Such was the result of the discussion respecting the figure and size of the earth. While it was yet undetermined, another controversy arose, fraught with even more serious consequences. This was the conflict respecting the earth's position with regard to the sun and the planetary bodies.

Copernicus, a Prussian, about the year 1507, had completed a book "On the Revolutions of the Heavenly Bodies." He had journeyed to Italy in his youth, had devoted his attention to astronomy, and had taught mathematics at Rome. From a profound study of the Ptolemaic and Pythagorean systems, he had come to a conclusion in favor of the latter, the object of his book being to sustain it. Aware that his doctrines were totally opposed to revealed truth, and foreseeing that they would bring upon him the punishments of the Church, he expressed himself in a cautious and apologetic manner, saying that he had only taken the liberty of trying whether, on the supposition of the earth's motion, it was possible to find better explanations than the ancient ones of the revolutions of the celestial orbs; that in doing this he had only taken the privilege that had been allowed to others, of feigning what hypothesis they chose. The preface was addressed to Pope Paul III.

Full of misgivings as to what might be the result, he refrained from publishing his book for thirty-six years, thinking that "perhaps it might be better to follow the examples of the Pythagoreans and others, who delivered their doctrine only by tradition and to friends." At the entreaty of Cardinal Schomberg he at length published it in 1543. A copy of it was brought to him on his death-bed. Its fate was such as he had anticipated. The Inquisition condemned it as heretical. In their decree, prohibiting it, the Congregation of the Index denounced his system as "that false Pythagorean doctrine utterly contrary to the Holy Scriptures."

Astronomers justly affirm that the book of Copernicus, "De Revolutionibus," changed the face of their science. It incontestably established the heliocentric theory. It showed that the distance of the fixed stars is infinitely great, and that the earth is a mere point in the heavens. Anticipating Newton, Copernicus imputed gravity to the sun, the moon, and heavenly bodies, but he was led astray by assuming that the celestial motions must be circular. Observations on the orbit of Mars, and his different diameters at different times, had led Copernicus to his theory.

In thus denouncing the Copernican system as being in contradiction to revelation, the ecclesiastical authorities were doubtless deeply moved by inferential considerations. To dethrone the earth from her central dominating position, to give her many equals and not a

few superiors, seemed to diminish her claims upon the Divine regard. If each of the countless myriads of stars was a sun, surrounded by revolving globes, peopled with responsible beings like ourselves, if we had fallen so easily and had been redeemed at so stupendous a price as the death of the Son of God, how was it with them? Of them were there none who had fallen or might fall like us? Where, then, for them could a Savior be found?

During the year 1608 one Lippershey, a Hollander, discovered that, by looking through two glass lenses, combined in a certain manner together, distant objects were magnified and rendered very plain. He had invented the telescope. In the following year Galileo, a Florentine, greatly distinguished by his mathematical and scientific writings, hearing of the circumstance, but without knowing the particulars of the construction, invented a form of the instrument for himself. Improving it gradually, he succeeded in making one that could magnify thirty times. Examining the moon, he found that she had valleys like those of the earth, and mountains casting shadows. It had been said in the old times that in the Pleiades there were formerly seven stars, but a legend related that one of them had mysteriously disappeared. On turning his telescope toward them, Galileo found that he could easily count not fewer than forty. In whatever direction he looked, he discovered stars that were totally invisible to the naked eye.

On the night of January 7, 1610, he perceived three small stars in a straight line, adjacent to the planet Jupiter, and, a few evenings later, a fourth. He found that these were revolving in orbits round the body of the planet, and, with transport, recognized that they