of scientific research, it had become the instrument of scientific reasoning. In one respect it may be said that it reduced the operations of the mind to a mechanical process, for its symbols often saved the labor of thinking. The habit of mental exactness it encouraged extended to other branches of thought, and produced an intellectual revolution. No longer was it possible to be satisfied with miracle-proof, or the logic that had been relied upon throughout the middle ages. Not only did it thus influence the manner of thinking, it also changed the direction of thought. Of this we may be satisfied by comparing the subjects considered in the transactions of the various learned societies with the discussions that had occupied the attention of the middle ages.

But the use of mathematics was not limited to the verification of theories; as above indicated, it also furnished a means of predicting what had hitherto been unobserved. In this it offered a counterpart to the prophecies of ecclesiasticism. The discovery of Neptune is an instance of the kind furnished by astronomy, and that of conical refraction by the optical theory of undulations.

But, while this great instrument led to such a wonderful development in natural science, it was itself undergoing development—improvement. Let us in a few lines recall its progress.

The germ of algebra may be discerned in the works of Diophantus of Alexandria, who is supposed to have lived in the second century of our era. In that Egyptian school Euclid had formerly collected the great truths of geometry, and arranged them in logical sequence. Archimedes, in Syracuse, had attempted the solution of the higher problems by the method of ex

naustions. Such was the tendency of things that, had the patronage of science been continued, algebra would inevitably have been invented.

To the Arabians we owe our knowledge of the rudiments of algebra; we owe to them the very name under which this branch of mathematics passes. They had carefully added, to the remains of the Alexandrian School, improvements obtained in India, and had communicated to the subject a certain consistency and form. The knowledge of algebra, as they possessed it, was first brought into Italy about the beginning of the thirteenth century. It attracted so little attention, that nearly three hundred years elapsed before any European work on the subject appeared. In 1496 Paccioli published his book entitled "Arte Maggiore," or "Alghebra." In 1501, Cardan, of Milan, gave a method for the solution of cubic equations; other improvements were contributed by Scipio Ferreo, 1508, by Tartalea, by Vieta. The Germans now took up the subject. At this time the notation was in an imperfect state.

The publication of the Geometry of Descartes, which contains the application of algebra to the definition and investigation of curve lines (1637), constitutes an epoch in the history of the mathematical sciences. Two years previously, Cavalieri's work on Indivisibles had appeared. This method was improved by Torricelli and others. The way was now open for the development of the Infinitesimal Calculus, the method of Fluxions of Newton, and the Differential and Integral Calculus of Leibnitz. Though in his possession many years previously, Newton published nothing on Fluxions until 1704; the imperfect notation he employed retarded very much the application of his method. Meantime,

on the Continent, very largely through the brilliant solutions of some of the higher problems, accomplished by the Bernouillis, the Calculus of Leibnitz was universally accepted, and improved by many mathematicians. An extraordinary development of the science now took place, and continued throughout the century. To the Binomial theorem, previously discovered by Newton, Taylor now added, in his "Method of Increments," the celebrated theorem that bears his name. This was in 1715. The Calculus of Partial Differences was introduced by Euler in 1734. It was extended by D'Alembert, and was followed by that of Variations, by Euler and Lagrange, and by the method of Derivative Functions, by Lagrange, in 1772.

But it was not only in Italy, in Germany, in England, in France, that this great movement in mathematics was witnessed; Scotland had added a new gem to the intellectual diadem with which her brow is encircled, by the grand invention of Logarithms, by Napier of Merchiston. It is impossible to give any adequate conception of the scientific importance of this incomparable invention. The modern physicist and astronomer will most cordially agree with Briggs, the Professor of Mathematics in Gresham College, in his exclamation: "I never saw a book that pleased me better, and that made me more wonder!" Not without reason did the immortal Kepler regard Napier "to be the greatest man of his age, in the department to which he had applied his abilities." Napier died in 1617. It is no exag geration to say that this invention, by shortening the labors, doubled the life of the astronomer.

But here I must check myself. I must remember that my present purpose is not to give the history of mathematics, but to consider what science has done for

the advancement of human civilization. And now, at once, recurs the question, How is it that the Church produced no geometer in her autocratic reign of twelve hundred years?

With respect to pure mathematics this remark may be made: Its cultivation does not demand appliances that are beyond the reach of most individuals. Astronomy must have its observatory, chemistry its laboratory; but mathematics asks only personal disposition and a few books. No great expenditures are called for, nor the services of assistants. One would think that nothing could be more congenial, nothing more delightful, even in the retirement of monastic life.

Shall we answer with Eusebius, "It is through contempt of such useless labor that we think so little of these matters; we turn our souls to the exercise of better things?" Better things! What can be better than absolute truth? Are mysteries, miracles, lying impostures, better? It was these that stood in the way!

The ecclesiastical authorities had recognized, from the outset of this scientific invasion, that the principles it was disseminating were absolutely irreconcilable with the current theology. Directly and indirectly, they struggled against it. So great was their detestation of experimental science, that they thought they had gained a great advantage when the Accademia del Cimento was suppressed. Nor was the sentiment restricted to Catholicism. When the Royal Society of London was founded, theological odium was directed against it with so much rancor that, doubtless, it would have been extinguished, had not King Charles II. given it his open and avowed support. It was accused of an intention of "destroying the established religion, of injuring the universities, and of upsetting ancient and solid learning."

We have only to turn over the pages of its Transactions to discern how much this society has done for the progress of humanity. It was incorporated in 1662, and has interested itself in all the great scientific movements and discoveries that have since been made. It published Newton's "Principia;" it promoted Halley's voyage, the first scientific expedition undertaken by any government; it made experiments on the transfusion of blood, and accepted Harvey's discovery of the circulation. The encouragement it gave to inoculation led Queen Caroline to beg six condemned criminals for experiment, and then to submit her own children to that operation. Through its encouragement Bradley accomplished his great discovery, the aberration of the fixed stars, and that of the nutation of the earth's axis; to these two discoveries, Delambre says, we owe the exactness of modern astronomy. It promoted the improvement of the thermometer, the measure of temperature, and in Harrison's watch, the chronometer, the measure of time. Through it the Gregorian Calendar was introduced into England, in 1752, against a violent religious opposition. Some of its Fellows were pursued through the streets by an ignorant and infuriated mob, who believed it had robbed them of eleven days of their lives; it was found necessary to conceal the name of Father Walmesley, a learned Jesuit, who had taken deep interest in the matter; and, Bradley happening to die during the commotion, it was declared that he had suffered a judgment from Heaven for his crime!

If I were to attempt to do justice to the merits of this great society, I should have to devote many pages to such subjects as the achromatic telescope of Dollond; the dividing engine of Ramsden, which first gave precision to astronomical observations; the measurement

of a degree on the earth's surface by Mason and Dixon; the expeditions of Cook in connection with the transit of Venus; his circumnavigation of the earth; his proof that scurvy, the curse of long sea-voyages, may be avoided by the use of vegetable substances; the polar expeditions; the determination of the density of the earth by Maskelyne's experiments at Schehallion, and by those of Cavendish; the discovery of the planet Uranus by Herschel; the composition of water by Cavendish and Watt; the determination of the difference of longitude between London and Paris; the invention of the voltaic pile; the surveys of the heavens by the Herschels; the development of the principle of interference by Young, and his establishment of the undulatory theory of light; the ventilation of jails and other buildings; the introduction of gas for city illumination; the ascertainment of the length of the seconds-pendulum; the measurement of the variations of gravity in different latitudes; the operations to ascertain the curvature of the earth; the polar expedition of Ross; the invention of the safety-lamp by Davy, and his decomposition of the alkalies and earths; the electro-magnetic discoveries of Oersted and Faraday; the calculating-engines of Babbage; the measures taken at the instance of Humboldt for the establishment of many magnetic observatories; the verification of contemporaneous magnetic disturbances over the earth's surface. But it is impossible, in the limited space at my disposal, to give even so little as a catalogue of its Transactions. Its spirit was identical with that which animated the Academia del Cimento, and its motto accordingly was, "Nullius in Verba." It proscribed superstition, and permitted only calculation, observation, and experiment.

Not for a moment must it be supposed that in these great attempts, these great successes, the Royal Society stood alone. In all the capitals of Europe there were Academies, Institutes, or Societies, equal in distinction, and equally successful in promoting human knowledge and modern civilization.

THE ECONOMICAL INFLUENCES OF SCIENCE.

The scientific study of Nature tends not only to correct and ennoble the intellectual conceptions of man; it serves also to ameliorate his physical condition. It perpetually suggests to him the inquiry, how he may make, by their economical application, ascertained facts subservient to his use.

The investigation of principles is quickly followed by practical inventions. This, indeed, is the characteristic feature of our times. It has produced a great revolution in national policy.

In former ages wars were made for the procuring of slaves. A conqueror transported entire populations, and extorted from them forced labor, for it was only by human labor that human labor could be relieved. But when it was discovered that physical agents and mechanical combinations could be employed to incomparably greater advantage, public policy underwent a change; when it was recognized that the application of a new principle, or the invention of a new machine, was better than the acquisition of an additional slave, peace became preferable to war. And not only so, but nations possessing great slave or serf populations, as was the case in America and Russia, found that considerations of humanity were supported by considerations of interest, and set their bondmen free.

Thus we live in a period of which a characteristic is

the supplanting of human and animal labor by machines. Its mechanical inventions have wrought a social revolution. We appeal to the natural, not to the supernatural, for the accomplishment of our ends. It is with the "modern civilization" thus arising that Catholicism refuses to be reconciled. The papacy loudly proclaims its inflexible repudiation of this state of affairs, and insists on a restoration of the medieval condition of things.

That a piece of amber, when rubbed, will attract and then repel light bodies, was a fact known six hundred years before Christ. It remained an isolated, uncultivated fact, a mere trifle, until sixteen hundred years after Christ. Then dealt with by the scientific methods of mathematical discussion and experiment, and practical application made of the result, it has permitted men to communicate instantaneously with each other across continents and under oceans. It has centralized the world. By enabling the sovereign authority to transmit its mandates without regard to distance or to time, it has revolutionized statesmanship and condensed political power.

In the Museum of Alexandria there was a machine invented by Hero, the mathematician, a little more than one hundred years before Christ. It revolved by the agency of steam, and was of the form that we should now call a reaction-engine. This, the germ of one of the most important inventions ever made, was remembered as a mere curiosity for seventeen hundred years.

Chance had nothing to do with the invention of the modern steam-engine. It was the product of meditation and experiment. In the middle of the seventeenth century several mechanical engineers attempted to utilize the properties of steam; their labors were

brought to perfection by Watt in the middle of the eighteenth.

The steam-engine quickly became the drudge of civilization. It performed the work of many millions of men. It gave, to those who would have been condemned to a life of brutal toil, the opportunity of better pursuits. He who formerly labored might now think.

Its earliest application was in such operations as pumping, wherein mere force is required. Soon, however, it vindicated its delicacy of touch in the industrial arts of spinning and weaving. It created vast manufacturing establishments, and supplied clothing for the world. It changed the industry of nations.

In its application, first to the navigation of rivers, and then to the navigation of the ocean, it more than quadrupled the speed that had heretofore been attained. Instead of forty days being requisite for the passage, the Atlantic might now be crossed in eight. But, in land transportation, its power was most strikingly displayed. The admirable invention of the locomotive enabled men to travel farther in less than an hour than they formerly could have done in more than a day.

The locomotive has not only enlarged the field of human activity, but, by diminishing space, it has increased the capabilities of human life. In the swift transportation of manufactured goods and agricultural products, it has become a most efficient incentive to human industry

The perfection of ocean steam-navigation was greatly promoted by the invention of the chronometer, which rendered it possible to find with accuracy the place of a ship at sea. The great drawback on the advancement of science in the Alexandrian School was the want of an instrument for the measurement of

time, and one for the measurement of temperature—the chronometer and the thermometer; indeed, the invention of the latter is essential to that of the former. Clepsydras, or water-clocks, had been tried, but they were deficient in accuracy. Of one of them, ornamented with the signs of the zodiac, and destroyed by certain primitive Christians, St. Polycarp significantly remarked, "In all these monstrous demons is seen an art hostile to God." Not until about 1680 did the chronometer begin to approach accuracy. Hooke, the contemporary of Newton, gave it the balance-wheel, with the spiral spring, and various escapements in succession were devised, such as the anchor, the dead-beat, the duplex, the remontoir. Provisions for the variation of temperature were introduced. It was brought to perfection eventually by Harrison and Arnold, in their hands becoming an accurate measure of the flight of time. To the invention of the chronometer must be added that of the reflecting sextant by Godfrey. This permitted astronomical observations to be made, notwithstanding the motion of a ship.

Improvements in ocean navigation are exercising a powerful influence on the distribution of mankind. They are increasing the amount and altering the character of colonization.

But not alone have these great discoveries and inventions, the offspring of scientific investigation, changed the lot of the human race; very many minor ones, perhaps individually insignificant, have in their aggregate accomplished surprising effects. The commencing cultivation of science in the fourteenth century gave a wonderful stimulus to inventive talent, directed mainly to useful practical results; and this, subsequently, was greatly encouraged by the system of patents, which

secure to the originator a reasonable portion of the benefits of his skill. It is sufficient to refer in the most cursory manner to a few of these improvements; we appreciate at once how much they have done. The introduction of the saw-mill gave wooden floors to houses, banishing those of gypsum, tile, or stone; improvements cheapening the manufacture of glass gave windows, making possible the warming of apartments. However, it was not until the sixteenth century that glazing could be well done. The cutting of glass by the diamond was then introduced. The addition of chimneys purified the atmosphere of dwellings, smoky and sooty as the huts of savages; it gave that indescribable blessing of northern homes—a cheerful fireside. Hitherto a hole in the roof for the escape of the smoke, a pit in the midst of the floor to contain the fuel, and to be covered with a lid when the curfew-bell sounded or night came, such had been the cheerless and inadequate means of warming.

Though not without a bitter resistance on the part of the clergy, men began to think that pestilences are not punishments inflicted by God on society for its religious shortcomings, but the physical consequences of filth and wretchedness; that the proper mode of avoiding them is not by praying to the saints, but by insuring personal and municipal cleanliness. In the twelfth century it was found necessary to pave the streets of Paris, the stench in them was so dreadful. At once dysenteries and spotted fever diminished; a sanitary condition approaching that of the Moorish cities of Spain, which had been paved for centuries, was attained. In that now beautiful metropolis it was forbidden to keep swine, an ordinance resented by the monks of the abbey of St. Anthony, who demanded that

the pigs of that saint should go where they chose; the government was obliged to compromise the matter by requiring that bells should be fastened to the animals' necks. King Philip, the son of Louis the Fat, had been killed by his horse stumbling over a sow. Prohibitions were published against throwing slops out of the windows. In 1870 an eye-witness, the author of this book, at the close of the pontifical rule in Rome, found that, in walking the ordure-defiled streets of that city, it was more necessary to inspect the earth than to contemplate the heavens, in order to preserve personal purity. Until the beginning of the seventeenth century, the streets of Berlin were never swept. There was a law that every countryman, who came to market with a cart, should carry back a load of dirt!

Paving was followed by attempts, often of an imperfect kind, at the construction of drains and sewers. It had become obvious to all reflecting men that these were necessary to the preservation of health, not only in towns, but in isolated houses. Then followed the lighting of the public thoroughfares. At first houses facing the streets were compelled to have candles or lamps in their windows; next the system that had been followed with so much advantage in Cordova and Granada—of having public lamps—was tried, but this was not brought to perfection until the present century, when lighting by gas was invented. Contemporaneously with public lamps were improved organizations for night-watchmen and police.

By the sixteenth century, mechanical inventions and manufacturing improvements were exercising a conspicuous influence on domestic and social life. There were looking-glasses and clocks on the walls, mantels over the fireplaces. Though in many districts the kitchen-fire

was still supplied with turf, the use of coal began to prevail. The table in the dining-room offered new delicacies; commerce was bringing to it foreign products; the coarse drinks of the North were supplanted by the delicate wines of the South. Ice-houses were constructed. The bolting of flour, introduced at the windmills, had given whiter and finer bread. By degrees things that had been rarities became common—Indian-corn, the potato, the turkey, and, conspicuous in the long list, tobacco. Forks, an Italian invention, displaced the filthy use of the fingers. It may be said that the diet of civilized men now underwent a radical change. Tea came from China, coffee from Arabia, the use of sugar from India, and these to no insignificant degree supplanted fermented liquors. Carpets replaced on the floors the layer of straw; in the chambers there appeared better beds, in the wardrobes cleaner and more frequently-changed clothing. In many towns the aqueduct was substituted for the public fountain and the street-pump. Ceilings which in the old days would have been dingy with soot and dirt, were now decorated with ornamental frescoes. Baths were more commonly resorted to; there was less need to use perfumery for the concealment of personal odors. An increasing taste for the innocent pleasures of horticulture was manifested, by the introduction of many foreign flowers in the gardens—the tuberose, the auricula, the crown imperial, the Persian lily, the ranunculus, and African marigolds. In the streets there appeared sedans, then close carriages, and at length hackney-coaches.

Among the dull rustics mechanical improvements forced their way, and gradually attained, in the implements for ploughing, sowing, mowing, reaping, thrashing, the perfection of our own times.

It began to be recognized, in spite of the preaching of the mendicant orders, that poverty is the source of crime, the obstruction to knowledge; that the pursuit of riches by commerce is far better than the acquisition of power by war. For, though it may be true, as Montesquieu says, that, while commerce unites nations, it antagonizes individuals, and makes a traffic of morality, it alone can give unity to the world; its dream, its hope, is universal peace.

Though, instead of a few pages, it would require volumes to record adequately the ameliorations that took place in domestic and social life after science began to exert its beneficent influences, and inventive talent came to the aid of industry, there are some things which cannot be passed in silence. From the port of Barcelona the Spanish khalifs had carried on an enormous commerce, and they with their coadjutors—Jewish merchants—had adopted or originated many commercial inventions, which, with matters of pure science, they had transmitted to the trading communities of Europe. The art of book-keeping by double entry was thus brought into Upper Italy. The different kinds of insurance were adopted, though strenuously resisted by the clergy. They opposed fire and marine insurance, on the ground that it is a tempting of Providence. Life insurance was regarded as an act of interference with the consequences of God's will. Houses for lending money on interest and on pledges, that is, banking and pawnbroking establishments, were bitterly denounced, and especially was indignation excited against the taking of high rates of interest, which was stigmatized as usury—a feeling existing in some backward communities up to the present day. Bills of exchange in the present form and terms were adopted, the office of the public notary

established, and protests for dishonored obligations resorted to. Indeed, it may be said, with but little exaggeration, that the commercial machinery now used was thus introduced. I have already remarked that, in consequence of the discovery of America, the front of Europe had been changed. Many rich Italian merchants, and many enterprising Jews, had settled in Holland, England, France, and brought into those countries various mercantile devices. The Jews, who cared nothing about papal maledictions, were enriched by the pontifical action in relation to the lending of money at high interest; but Pius II., perceiving the mistake that had been made, withdrew his opposition. Pawnbroking establishments were finally authorized by Leo X., who threatened excommunication of those who wrote against them. In their turn the Protestants now exhibited a dislike against establishments thus authorized by Rome. As the theological dogma, that the plague, like the earthquake, is an unavoidable visitation from God for the sins of men, began to be doubted, attempts were made to resist its progress by the establishment of quarantines. When the Mohammedan discovery of inoculation was brought from Constantinople in 1721, by Lady Mary Wortley Montagu, it was so strenuously resisted by the clergy, that nothing short of its adoption by the royal family of England brought it into use. A similar resistance was exhibited when Jenner introduced his great improvement, vaccination; yet a century ago it was the exception to see a face unpitted by smallpox—now it is the exception to see one so disfigured. In like manner, when the great American discovery of anæsthetics was applied in obstetrical cases, it was discouraged, not so much for physiological reasons, as under the pretense that it was an impious attempt to escape

from the curse denounced against all women in Genesis iii. 16.

Inventive ingenuity did not restrict itself to the production of useful contrivances, it added amusing ones. Soon after the introduction of science into Italy, the houses of the virtuosi began to abound in all kinds of curious mechanical surprises, and, as they were termed, magical effects. In the latter the invention of the magic-lantern greatly assisted. Not without reason did the ecclesiastics detest experimental philosophy, for a result of no little importance ensued—the juggler became a successful rival to the miracle-worker. The pious frauds enacted in the churches lost their wonder when brought into competition with the tricks of the conjurer in the market-place: he breathed flame, walked on burning coals, held red-hot iron in his teeth, drew basketfuls of eggs out of his mouth, worked miracles by marionettes. Yet the old idea of the supernatural was with difficulty destroyed. A horse, whose master had taught him many tricks, was tried at Lisbon in 1601, found guilty of being possessed by the devil, and was burnt. Still later than that many witches were brought to the stake.

Once fairly introduced, discovery and invention have unceasingly advanced at an accelerated pace. Each continually reacted on the other, continually they sapped supernaturalism. De Dominis commenced, and Newton completed, the explanation of the rainbow; they showed that it was not the weapon of warfare of God, but the accident of rays of light in drops of water. De Dominis was decoyed to Rome through the promise of an archbishopric, and the hope of a cardinal's hat. He was lodged in a fine residence, but carefully watched. Accused of having suggested a concord between Rome