

FACTORS IN THE TRANSITION FROM MEDIAEVAL TO MODERN SCIENCE

BY IVOR B. HART

I. INTRODUCTION

IT may be remarked at the outset that so far as the intellectual outlook of the Middle Ages was concerned, the views as to the scheme of the universe were those of Ptolemy, the views as to the science generally were those of Aristotle, and the views as to the relationship of man to the universe were derived from Plato's *Timaeus*. As an offshoot from this there had grown up the "pseudo science" of Alchemy, with its search for the philosophers' stone and the elixir vitae. What, however, the reader should most particularly remember is that, broadly speaking, the philosophers of the Middle Ages created nothing for themselves. Their science was not of their own production. It was almost entirely the science of the ancients in the somewhat distorted and garbled forms in which it had been passed on to Mediaeval Europe through the vicissitudes of the intervening ages.

Why should there have been this total lack of originality on the part of the philosophers of the Middle Ages? Does it not seem a little remarkable that throughout Europe, and stretching through a period of several hundreds of years, there should have been hardly anybody with something new to offer to the world? Yet there is an answer to this question, and it is to be found in the nature of the circumstances under which the glorious reign of the ancient scientists gave way to the profound and universal ignorance of the Dark Ages—the decline and fall of the Roman Empire, the devastating penetrations of the Saracen soldiery, and the narrowing restrictions of Church discipline. A world of nations cannot emerge to the fullness of wisdom from such intellectual darkness in a hurry. In these days, with our organized schemes of historical studies, the past is an open book, and each fresh scientific discovery becomes merely the jumping off point for the next stop. But in those days the posi-

tion was very different. The problem which confronted the civilizations of the early Middle Ages was first of all the recovery of the knowledge and the wisdom which had been lost or destroyed; and so there followed an era of reconstruction. In this task there was neither room nor intellectual fuel for originality. It sufficed for the students of those days to discover what it was that the Ancients had taught and written. We must remember, too, that with such brilliant exceptions as Alexander of Hales and Richard Grossteste and Roger Bacon, the mental standard of these students was not high. A keen appreciation of the wisdom of the ancients as it emerged from their efforts at reconstruction was the full extent to which they could go. The idea of criticizing what these ancients taught never so much as entered their heads. And so there developed, quietly but effectively, a tradition of the infallibility of the old Greek philosophers which amounted almost to hero-worship. Even the church was won over to their teachings, so that it came to be regarded as a heresy, for example, to deny Aristotle's doctrine that the earth was fixed, immovable, and at the center of the universe. In fact, the day of the Scholastics had begun.

Then came the Renaissance proper, with its revival of the Greek language, the passing of the Eastern Empire, the temporary diminution of the power of the papacy, the invention of printing, and the historic voyages of Columbus. Beginning in Italy early in the fifteenth century, it swept over the whole of Europe, shaping however a different course in each country, and finding its final expression, so far as science is concerned, in the Baconian philosophy of the experimental method. The early phase, in which reliance upon the schoolmen was substituted for the pronouncements of the ancients, in its turn gave way to the final overthrow of dogma and the direct appeal to experiment. In Italy, the birthplace of the Renaissance, the new spirit of Humanism, inaugurated by Petrarch (1304-1374) found its fuller development in the efforts of Marsilio Ficino (1433-1499). A word of caution in this connection is, however, to be noted. The impression has developed in recent years that the Humanistic outlook became a very general feature of the Renaissance in Italy. Humanism as an everyday attitude of the general world of culture was in fact of much later growth, even in Florence. The pioneers were there, and the movement was given a healthy beginning, but there were probably not more than a score of genuine humanistic teachers in the whole country. Their teaching was,

however, so vigorous and able that it has been easy for its early influence to become exaggerated.

The chief mission of the Humanists was the reconciliation of knowledge with Christianity. Yet in all this science was but little touched. It was at first the day of letters. Luckily, when art following letters, next came under the influence of the revival, there was little to draw upon. As a consequence there was a much more vigorous display of originality, producing the typical cinquecento humanism in painting of Raphael, da Vinci, Titian, and Corregio, and in sculpture of Donatello, Michelangelo, and Sansovino, and in architecture of Bramenti, Omodeo and the Venetian Lombardi. So we come to science, which, touched last of all by the Renaissance, curiously enough received its first impetus in a warfare against the logicians and materialists through the medium of men of art—Alberti, da Vinci, Toscanelli, da Porta and others. These addressed themselves in a small way to the design of scientific instruments.

II. THE FACTORS OF DEVELOPMENT

Broadly speaking, what was the general legacy of science to which the dawn of the fifteenth century found itself the heir? There was, for one thing, the mediaeval acceptance of the doctrine of macrocosm and microcosm derived initially from Plato's *Timaeus* as translated by Apuleius and commentated upon by Chalcidius. The astrological implications, indeed, in spite of a temporary setback during the fourteenth century, gained added strength from the neo-Platonic vogue of the time, and Byrhtferth's disgrammatic scheme was still representative of the ideas generally prevalent. Another fundamental acceptance was the so-called Aristotelian four-element scheme of earth, water, air and fire, regarded as being compounded in binary combination with the four primary qualities of hot, cold, moist and dry—a macrocosmic conception which was brought into its proper microcosmic relationship by linking up with elemental earth the imaginary "humour" of black bile, with water phlegm, with air red bile, and with fire the imaginary "humour" of blood. The alchemists, however, were also by now developing their well-known theories of the basic importance of their salt-mercury-sulphur scheme but without in any sense displacing the original scheme in the affections of the masses. Turning to Cosmography, the principle of geocentric spheres was still the prevailing influence,

and Dante's conception of the universe was almost completely representative of current conviction. According to this, earth, the heaviest, drossest and least aspiring of the elements tended to the center of the world, whilst floating on it was the material water, and above the water the material air. These comprised the firmament. High up in the air, far beyond the reach of man, were the eternal zones of the planets and stars, each planet moving in its own sphere; whilst just below these spheres were the three concentric zones of the upper and pure elements in ascending degrees of tenuity, namely, water, air and fire. Surrounding and embracing the whole was the sphere of the *primum mobile*.

Gradually, however, circumstances were shaping themselves towards a growing discontent with the Ptolemaic scheme. Such world-wide epidemics as the Black Death in the later fourteenth century found their reflection in a vague dissatisfaction with accepted dogmas, and by the fifteenth century we find evidences of the discontent to extend to the entire mediaeval scientific scheme.

Let us consider briefly some of the factors which, with the Renaissance developing into its full stride, were promoting this active discontent. We may sum up the chief characteristics of mediæval learning as comprising the subservience of all thought to theological purpose, the effecting of a compromise between the Church and classical teaching, and the creation of a circumscribed outlook in which the doctrine of macrocosm and microcosm was made to link up all things into one narrow and self-sufficient scheme. As against all this there began to creep into the "mental equipment chest" of the fifteenth century philosopher a love for and an increasing knowledge of mathematical processes the effect of which was to make for a greater clarity of thought. On the one hand we have the revival of trigonometry due to the work of Regiomontanus in his *De triangulis*, and on the other a development of algebra due to the labors of Fra Luca Pacioli, friend and intimate of Leonardo da Vinci—with his *Summa de Arithmetica, Geometrica, Proportionibus et Proportionalitate*, modelled after the writings of Leonardo of Pisa.

One of the obvious consequences of the clearer thinking induced by this mathematical advance was the insistent demand for the correction of the many inaccuracies in the existing copies of Ptolemy's *Almagest*, and this work of correction, in the able hands of Peurbach and Regiomontanus, undoubtedly led ultimately to the intellectual revolution in cosmography which produced the Copernican system. But this was not all. In many another direction a different

atmosphere was creeping over mankind. The spirit of adventure was abroad. The great geographical discoveries of Columbus and his contemporaries filled Europe with wonder, and fired the imaginations of all thinking men. Leisure for thought was increasing also as a result of commercial prosperity. In Germany the Hanseatic League was monopolizing the trade of the north, whilst in the south there were close commercial relations with Italy. In this latter country, in spite of continual warfare, such towns as Venice and Florence were prospering commercially, so that more time was available for cultural development, and in the furtherance of this one need scarcely stress the importance of the advent of printing. It was consequently in these countries that the first Renaissance in science was to be found. It was in Germany, too, that Church authority was first successfully fought. The issue of the conflict against the dogmas of Rome carried with it the issue for science. In this fight, Italy, too, played its part, and we may justly regard Pomponazzi (1462-1525) as the great fifteenth century exponent of a new outlook on the relations between science and theology. In his great work *De immortalitate animi*, he boldly attacked the Aristotelianism of St. Thomas Aquinas upon which the whole theological standpoint of Rome was founded. Pomponazzi claimed the right of independent study and interpretation of Aristotle (a heresy in itself!), and in the exercise of that right he followed the Averroists in the contention that immortality does not imply the eternal separate existence of an individual soul. He went further. Following the second century contentions of Alexander of Arodisias, he taught that as soul is the form of the body, it must perish with the body. Here then was a philosophical materialism new to the fifteenth century world of theology. "Virtue for its own sake," by contrast with "virtue for the sake of the after-life," was a wholly new doctrine. It carried with it implications of importance in scientific method. Developing his views further (we must remember that Pomponazzi throughout claimed his adherence to the Catholic Faith) in his *De incantatione*, he definitely insists on the orderly sequence of cause and effect in nature, and so heralds the teachings of Francis Bacon a century later.

In the direction of applied science, too, we find the beginnings of a new spirit in the era under consideration. That commercial prosperity to which we have already alluded was beginning to make its inevitable demands on improvements in mechanical, constructional and manufacturing processes. Allied to this was the ever-present

stimulus of war. Happily fitting in with the new needs and the new demands, the search for classical manuscripts which characterized the early part of the fifteenth century brought to light such treasures as Vitruvius' *De Architectura* (discovered by Poggio Bracciolini in the monastery of St. Gallen in 1416, and first printed in 1486), the *De aquoeductibus* (and other works on military strategem) of Frontinus, and Hero's *Pneumatica*. These works at once received the enthusiastic attention of such illustrious Italian cinquecentist artists as Alberti, Duver, Bramente and da Vinci, men who were at one and the same time artists, architects and engineers, and of German technologists of the type of Konrad Kyesor. Their labors led directly to the great advance in scientific technology a century later in the hands of Georg Agricola in Germany, and Jacob Besson and Agostino Ramelli in France.

III. THE INFLUENCE OF NICHOLAS OF CUSA

Such then were the general conditions of science in the fifteenth century, and the general forces at work to promote the larger developments yet to come. The changing conditions were not sudden in their advent. The progress was slow and gradual, halting even. Yet they were definite enough, and indeed began to manifest themselves early in the century through the teachings of the illustrious German philosopher and divine, Nicholas of Cusa who, fittingly enough, was born in the first year of the new era. At an early age, he was sent to the then famous School of the Brothers of Common Life at Deventer, in Holland, under the patronage of Count Ulrich, who evidently had great faith in his protegee's future. The reality of the influence of this school on Nicholas is clear from the fact that at his death he left a sum of money to be devoted to the foundation of scholarships tenable at the school. In 1417 Nicholas proceeded to Padua, and here he remained for six years, primarily for the study of canon law, but in addition taking up the study of Latin, Greek, Hebrew and Arabic. His stay at Padua is important to us also from the fact that he here developed a friendship with Paolo dal Pozzo Toscanelli. Toscanelli, as we have already pointed out, became famous as a cosmographer, and he is credited with a correspondence with Christopher Columbus the effect of which was supposed to have considerably influenced the great discoverer in undertaking his famous voyages. In this friendship, too, we see a link

with Leonardo da Vinci the importance of which it is difficult to gauge. Toscanelli spent much of his life at Florence, and here Leonardo must have known both him and his work. Moreover, Toscanelli must himself have been in constant correspondence with Cusa, and was indeed called to the latter's deathbed in 1464. Hence it is not unreasonable to suppose that da Vinci must to some extent have been aware of the work and the views of Nicholas of Cusa.

Having graduated at Padua as a Doctor of Canon Law, Nicholas entered the Church in 1425. For the next three years he studied divinity at the University of Cologne, and shortly after he began that career of ecclesiastical diplomacy and affairs which kept him wandering over one part and another of Europe until his death. Associating himself initially with the claims of the Council of Basle (later transferred to Ferrara) as against the powers of the papacy, during which time he wrote his plea for Catholic unity, *De concordantia catholica*, he later withdrew from this standpoint, receiving clerical advancement as a mark of Pope Eugenius IV's appreciation. During this period, too, he wrote his *Reparatis Calendarii* pleading for a reform of the calendar, a work which undoubtedly contributed materially to the institution of the Gregorian Calendar of 1582. For the next few years he was engaged on various missions as Papal Legate, and in 1460 his activities brought him into conflict with Sigismund, Duke of Austria, who, in defiance of the Pope (now Pius II), imprisoned and ill-treated Cusa. From this ill-treatment Nicholas never recovered. He escaped to Rome, and afterwards resumed his wanderings on Church business. He died at Todi in Italy in 1464 in the presence of his old friend Toscanelli.

Such was his life. It is remarkable that amidst all the wanderings he should have found so much time for philosophical and scientific speculation. He was, however, essentially a thoughtful man, and he wrote extensively. The basis of his views was metaphysical. He was profoundly interested in all matters of observation and experiment, but this interest was at all times subservient to the larger metaphysical purpose. Standing in the forefront was his discussion on the movement of bodies, outlined in his *De docta ignorantia*, written between 1439 and 1440. In this work Cusa's main thesis is that "all human knowledge is mere conjecture, and man's wisdom is to recognize his ignorance." The discussion centers round his definition of the finite and the infinite, and pleads for a system of philosophy tending to the unity of all experience. He embraces in this the principle of the union of contraries in the divine unity of

God. Applying these conceptions to the problem of motion, he initiated an attack on the mediaeval standpoint of a fixed earth which, willy nilly, persisted and developed throughout the next two centuries, and led ultimately to the enunciation by Copernicus of his famous system as an hypothesis, to the definite declaration of this system as a conviction by Bruno, and to its final establishment on mathematical grounds as a truism by Newton.

Let us briefly trace his argument. Soul, the spirit, is the universal motor—is moved by God. Movement is therefore a fundamental attribute of existence and matter, united with and impregnated with the world soul, has ceaseless motion—all things move. There can, therefore, be no such thing as a center of the universe, so that the earth itself is not at the center of the universe, and neither is it at rest. "I have long considered that this earth cannot be fixed, but moves as do the other stars," he writes, and in a further note, undiscovered until after his death, he says, "To my mind the earth revolves upon its axis once in a day and night." Cusa never got as far as a heliocentric theory; nor did he abandon the conception of homocentric spheres. Nevertheless in so far as he did attack the Aristotelian doctrine of a fixed earth (a courageous standpoint for a Churchman to take up), he was a true inaugurator of a scientific revolution.

But there was another aspect of this inauguration—the institution of a definite experimental bias in philosophical enquiry. Not only do we find traces of this in his *De docta ignorantia*, but we find it in full swing in the *De staticis experimentis*, the fourth book of a series of papers entitled *Idiotae libri quatuor*. In this work, purporting to be a discussion between two characters, the "Idiot" and the "Orator," the first two books are on "Wisdom," the third on "Mind" and the fourth on "Statical Experiments." In this last work Cusa gives his fundamental ideas on the use of the balance in medicine and in science generally. He quotes Vitruvius, recently rediscovered by Poggio, and gets ideas therefrom for a number of his problems, such as the estimation of the speed of ships, a problem, incidentally, which later fascinated both Leon Battista Alberti and Leonardo da Vinci. Throughout Cusa's contention is that by accurate comparisons by weight, various physical facts and properties are capable of investigation. So he suggests the comparison of waters from different springs, or water from the same spring at different times, of the blood and urine from old and young men, or of the same man in health and in sickness, and so on: suggestions

which led directly to Sanctorius' work on metabolic studies and to Van Helmont's gravimetric analysis of urine. Another suggestion, virtually on plant respiration, constitutes in effect the first biological experiment of modern times, and offers the first formal proof that the air has weight.

So we find in Nicholas of Cusa, in spite of the burden of mediæval theology which he carried throughout his career, the first fifteenth century philosopher with a truly modern outlook. We must neither underestimate the importance of his work nor of his influence. He was the starting point of the Renaissance in science in many a direction. In the world of philosophy he was the forerunner of an illustrious line of thinkers, from Pomponazzi and Ramus to Francis Bacon and Descartes; in his conceptions of the nature of matter he foreshadowed the work of Paracelsus, and so led to the dawn of modern chemistry; and in astronomy he was the first of a line which led through Peurbach and Regiomontanus and Paul of Middleburg to Copernicus and Kepler.

IV. THE BEGINNINGS OF APPLIED SCIENCE: LEONARDO DA VINCI

It is no part of our task in this paper to comment upon the more obvious features of the beginnings of modern science. Detailed references to Copernicus, Kepler, Galileo, Gilbert and the other well-known pioneers of modern science are here superfluous. We have yet, however, to note in some greater detail the repercussions of the forces of progress in scientific thought at the close of the mediæval period upon applied science. We have already remarked upon the fact that in the Renaissance of the intellectual life of Western Europe, science was touched after letters and art. We have now to note that, in the wake of science, the study of mechanism and of mechanical technology generally began to be taken seriously.

From this point of view, as well as from the nature of his contributions to practically every branch of scientific enquiry in his day, the name of Leonardo da Vinci (1452-1519) stands out pre-eminent. Living as he did at the full crest of the wave of the Italian Renaissance, he practically embodied in his being the full expressions of its manifold activities. It is only within comparatively recent years that the vast collection of notes and sketches accumulated by Leonardo da Vinci has been given the attention it deserves. Unfortunately, circumstances were such that after his death they were lost

sight of, and it was only after the lapse of centuries that they once again came to light. This loss was a serious misfortune to science. Leonardo's work was in itself so fruitful and varied, and his outlook on nature was so vastly superior to those about him, that if only those who followed after him could have had access to his writings, and to his many anticipations of later discoveries in different fields of intellectual activity, there is no doubt that the course of scientific history would have been materially different in a number of important directions.

Leonardo very happily combined within himself those excellent qualities which produce both the theorist in science and the technologist who blends his theory with practice, and what is equally important, his practice with theory.

Formal mechanics occupied a large share of his time and thought. In it, as in science generally, we find in Leonardo every evidence of that spirit of independence and experimental enquiry which gave to Galileo, a hundred years after him, the title of "Father of Experimental Science." Galileo deserved this title, but it was accorded him in ignorance of the labors of da Vinci. It neither detracts from his glory nor does injustice to his forerunner, therefore, if we plead for Leonardo the corresponding title of "Grandfather of Experimental Science."

What were his achievements in mechanics, the study to which he lovingly referred as "The paradise of the mathematical sciences"? Virtually, we may say of him that he created the study of dynamics. He knew of the principle of inertia. He tells us that "no body can move of itself, but by the action of some other, and that other is force"; of moving bodies, too, he tells us that "all movement tends to maintenance"; whilst what he knew of the law of reactions is clear from his reference that "an object offers as much resistance to the air as the air does to the object." His study of falling bodies is interesting from several points of view. We may epitomise this philosophy of the falling body by the following quotation: "Why does not the weight remain in its place? . . . Because it has no resistance. Where will it move to? . . . It will move towards the center of the earth. And why by no other line? . . . Because a weight which has no support falls by the shortest road to the lowest point, which is the center of the world. And why does the weight know how to find it by so short a line? . . . Because it does not depend and does not move about in various directions." Here we

get Leonardo's philosophy of the falling body in a nutshell, so to speak.

Not the least interesting of Leonardo's mechanical researches concern themselves with the principle of work. He did not, of course, use the term work. He did, however, appreciate the fact of a value in, and a measure of what we may speak of as the "achievement" of a force. Thus he writes that "if a force carries a weight in a certain time through a definite distance, the same force will carry half the body in the same time through double the path." He recognized, in effect, a definite limit to the results for a given effort, and that this effort was not alone a question of the magnitude of the force, but also of the distance through which it acts. If the one be increased, it can only be at the expense of the other.

Intimately linked up with this principle of work was the age-old myth of perpetual motion. If the principle of work be true, then the achievement of perpetual motion is impossible. On this matter Leonardo had no illusions whatever. There were, however, many contemporary with him who thought otherwise, and with these da Vinci had no patience. "Oh speculators on perpetual motion," he writes, "how many vain projects of like character you have created! Go and be the companions of the searchers after gold." Leonardo's dynamics also included studies of motion down an inclined plane, and the collision of bodies. When, however, we turn to statics, we find an even wider range of scientific activity on the part of our philosopher. We must remember, however, that here he was trading on less virgin soil. The works of Aristotle, Archimedes, Euclid, Hero, Pappus and others during the Greek era, and of Jordanus Nemorarius, Albert of Saxony and others in the Middle Ages, were known to him. On their foundation, however, he built very securely and his notes show clearly and conclusively that he fully understood the lever principle, centers of gravity, pulley systems and their mechanical advantage, and many other important branches of modern statics. We may sum up, in fact, by saying that the theoretical basis of his work in engineering and technology was not only sound but was in extent far beyond his times.

Turning, then, to the technology and engineering of Leonardo da Vinci we may say at once that his notes cover a range which almost beggars description. Designs of almost every conceivable kind of machine required for every conceivable kind of technological process are scattered liberally through his manuscripts. Planing machines, filing machines, polishing machines, grinding machines, lathes,

mechanical hammers, wire-drawing machines, oil presses, screw cutting machines, designs for roller bearings, needle manufacturing machines, spinning machines, machines for rope making and cloth shearing, pumps, cranes, jacks and other lifting gear, water wheels, designs for irrigation and drainage, the cutting of canals, the erection of harbors and docks, and the design of cannons and other weapons and engines of war—all these interested our philosopher and prompted him to write notes and draw sketches and designs.

We will do no more than refer the reader in this connection to some such work as Feldhaus' *Leonardo da Vinci als Technik und Erfinder*."

V. APPLIED SCIENCE: THE SIXTEENTH CENTURY

The era inaugurated by Leonardo da Vinci developed by the sixteenth century into the true beginnings of what we might call "the phase of application." In particular, three writers of this period stand out prominently as pointing the way and as showing the possibilities, namely, Georg Agricola, Jacob Besson, and Agostino Ramelli; and as evidence of the widespread nature of this new spirit, it is significant that these three were respectively a German, a Frenchman, and an Italian. Georg Agricola (Latinized form of Georg Bauer) was a German scholar and scientist whose researches in applied chemistry, mineralogy, geology and in mining technology formed a notable advance beyond the mediaevalism of former writers on these subjects. His books gave a stimulus to both formal and applied science which, taken into conjunction with the writings of Besson and Ramelli, created a wholly new spirit which was to reflect itself in the notable advances and achievements of the century to follow. This new spirit, emanating from Germany, soon became transmitted to France, and here Jacob Besson, who taught Natural Philosophy at Orleans, and Agostino Ramelli, an Italian philosopher of versatile interests who had migrated to Paris, soon came to the fore. Besson's *Theatrum Instrumentorum et Machinarum* was published in 1578, whilst Ramelli's *Le diverse et artificiose machine* was issued ten years later. Both dealt fully and scientifically with the whole subject of the applications of mechanics to mechanisms and machinery, whilst Besson's book included a study of the production and properties of steam. Both works became standards of reference for subsequent writers for a long time.

A further word or two regarding the work of Agricola is perhaps advisable before leaving this subject. Georg Agricola has a two-fold interest for us. First and foremost he was the forerunner of modern metallurgical science and its applications to mining technology. As a secondary consideration, however, he is important as affording to us a check on our judgment as to how far Leonardo's mechanical investigations were of practical utility in his day. Da Vinci wrote no text-book. He left merely his vast accumulation of notes. His notes and drawings give little indication as to the relative extent to which they were merely detached investigations and the extent to which they were practically applied by industry. With Agricola the position is different. He lived his life, after completing his university training early in the sixteenth century, at Joachimsthal on the eastern slope of the Erzgebirge in Bohemia. This was right in the heart of the metal-bearing areas of Central Europe. Here Agricola's main occupation (apart from his professional work as a medical man) was the investigation not only of the conditions of the mining industry, but also of the scientific basis of that industry.

His classical work, *De Re Metallica*, was first published in 1556, and was the main fruit of this study. A very fine English translation of this work by H. C. and L. H. Hoover was published in 1912.

Agricola recorded in great detail in this book all the implements of mechanical appliances used in the best mining practice of the day. Consequently we are able to obtain from it a very clear picture of the extent to which mechanical practice was involved in the sixteenth century.

The main theme in Agricola's work, namely, the study of metallurgy and of mining practice, is dealt with in Book VII of his *De Re Metallica*, from which the following interesting passage is taken. "By tests of this kind, miners can determine with certainty whether ores are contained in the metal or not; or if it has already been indicated that the ore contains one or more metals the tests show whether it is much or little; the miners also ascertain by such tests the method by which the metal can be separated from that part of the ore devoid of it; and further by these tests they determine that part in which there is much metal from that part in which there is little. Unless these tests have been carefully applied before the metals are melted out, ore cannot be smelted without great loss to the owners, for the parts which do not easily melt out in the fire carry the metals off with them or consume them."

We see here a real scientific attack upon an essentially industrial problem. It is not claimed that Agricola was the first assayer. Perhaps one of the most striking attributes to Agricola lies in the statement recently made by an expert metallurgist that "those familiar with the art will be astonished at the small progress made since his time, for in his pages are most of the reagents and most of the critical operations of today.

Why were these writings of Agricola of such importance in the history of industrial science? If we make a broad comparison of the tools, implements, and machinery of industry in the sixteenth century with those of today, the most striking feature of difference lies in the fact that where today they are largely made of metal—iron and steel in one form or another—they were then largely made of wood. Metal was only employed as strengthening pieces and at joints. This is a most vital consideration from the historical standpoint. Wooden machinery and appliances possessed the most obvious limitations. With them production was inevitably both limited and wasteful. Nor were manufacturers of those days unaware of this. They were, however, helpless simply because of the limitations imposed by a lack of knowledge and large-scale metal productions.

Here then lies the great importance of Agricola's work in metallurgical science. By placing on record in text-book form a complete scientific and ordered record of all the processes and principles known to his day underlying the whole range of the mining industries he provided the incentive to further study, and laid the foundations for future development of an industry which constitutes the very life-cord of modern manufacturing processes.

VI. CONCLUSION

We have thus considered some of the broad tendencies in pure and applied science that characterized the passage from mediaeval to modern times, and that made possible the epoch-making contributions of Copernicus, Galileo, Gilbert and others. As a consequence the sixteenth and seventeenth centuries carry us past the Middle Ages through the transition stage and right into what was undoubtedly a brilliant beginning of the modern era of scientific progress. The sixteenth century pioneers of the doctrine of experimental science, Galileo in Italy and William Gilbert in England, had pointed the way. Working along different lines, too, were Rene

Descartes and Francis Bacon, and the tremendous stimulus to scientific research induced in their several ways by those different philosophers saw its reflection in the advent of that remarkable galaxy of seventeenth century scientists who were headed by the illustrious Newton, and who included such famous men as Huyghens, Boyle, Leibnitz, Hooke and Halley. In their hands the tide of discovery became strong and broad and the boundaries of knowledge were rapidly extended. The era of modern science was definitely established.