LEONARDO DA VINCI AS A PIONEER IN SCIENCE.

IT WERE easier for the mature intellect to recover that belief in fairy-tales which is the privilege and joy of childhood, than for any of us to return to a point of view which enlightened men have long since left behind. If our imagination be keen and our sympathy quick, we can perhaps understand what it was that our forerunners believed, but we shall never feel towards it as they felt. There are no dryads in the woods, no naiads in the streams, for us; the rudely hewn block of wood is no fetish to which we bow; the story of griffin or vampire does not affright; the naïve mediæval miracle wrought by some pious relic has no power to confirm our faith: in these things we detect at the most an allegory or a hallucination. The race makes certain advances, as a traveller journeys through a strange country by night, without being able to map out its course. Not only are the gates of birth and death wrapped in the mists of lethe, but so too are the thresholds of progress. Only in the realm of reason, and of morals derived from reason, do all men walk as equals and contemporaries. The mirage of fancy, the fog of superstition, vanish as the sun of reason prevails; once men regarded them as permanent realities; now we know that they were evanescent; herein lies the difference between us and our ancestors,—a difference absolute and unalterable.

As we are more learned so are we more sophisticated than our fathers. We hesitate to say of any truth "This is final," because finality implies a world bound in adamantine unchangeableness, whereas we perceive that ours is a fluent and unfolding world. This perception, which is coming to be the common property of cultivated

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men, even of those who strive most earnestly against it, distinguishes the Modern from the Middle Age. To us, all things are in process of development; to the mediæval, all things—religion, science, government—were fixed. The earth itself was to him the centre of the universe, a fixed point round which the planets, sun, and stars revolved; his religion, formulated long before according to supernatural dictation, might be neither amended, nor put in question. Philosophy was not the exploration of the infinite by finite man, but the exercise of his mind along a clearly defined path which always curved back to the starting-point. Science was a mixture of half-truths and absurdities: the dictum of Aristotle, Ptolemy, or Galen being accepted as infallible, even when plainly contradicted by the experience of every day. Government, in theory at least, was a rigid scheme foreordained from the beginning.

I am not concerned to point out what benefit the race derived from that age of formulas; benefits there were, if only in the knowledge gained that the soul cannot prosper in bondage; my purpose is to call fresh attention to the contrast between that age and our own, in order that we may measure the magnitude of the achievement of such men as Leonardo da Vinci who broke away from mediævalism, and who, though surrounded by conditions utterly unlike ours, nevertheless belongs in spirit to our time rather than to his own. That spirit was the spirit of inquiry, the modern spirit; the mediæval did not inquire, he took for granted. Not only in all those considerations which haunt serious minds—the nature of God, immortality, conscience—did he accept without demur the statements handed down to him, but also in purely physical affairs was he uncritical. Read the manual of the medical school of Salerno, and see how hearsay and superstition took the place of observation in the treatment of the simplest form of disease. Read Brunetto Latini's "Natural History" and see what fantasies were spread concerning the animal kingdom. One example will illustrate the general attitude of mediævals towards demonstrating facts: There was an old fable that salamanders can live in the hottest flame. A modern would have put a salamander in the fire and watched the effect; the mediæval, on the contrary, never thought of applying so simple a

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test,—he believed the fable, and gravely repeated it. His habitual attitude was one of credulity.

We need not wonder at this. Inquiry presupposes ignorance, a worthy desire to clear away doubts. We do not dispute over the multiplication-table. But to the mediæval the ultimate mysteries of human destiny were wholly removed from the pale of inquiry; he might not understand the strange scheme of the incarnation, of vicarious atonement, of the resurrection, but he believed it, and believing, he ceased to inquire. He did not doubt the reality of heaven or of purgatory: he was more certain of the existence of hell than of the countries beyond his native mountains. This certainty could not but discourage investigation into the primal mysteries.

Moreover, his creed tended to make him despise the material world in which he lived. The Christianity which he professed was a composite of Hebrew, Persian, and pagan beliefs, which had been fitted together at different times. That they were mutually contradictory did not trouble him, because he gave a proof of his faith when he believed impossible doctrines; that they conflicted with the simple, authentic teaching of Christ did not trouble him, because that teaching came to him after councils, doctors, and a hundred popes had stamped their several interpretations upon it. Among the strange doctrines which had wound itself round early Christianity was the Manichæan doctrine that matter is the product of an evil principle, a Devil, who wars perpetually against God, the creator of spirit. This being accepted as true, the part of the devout mediæval was plain: he strove to eschew the material world as the Devil's kingdom. This world included, of course, his own body, which he mortified to the glory of God and the discomfiture of Satan. To have allowed his attention to wander to the processes of nature and to have examined into their causes would have been unholy and perilous: unholy, because in so doing he would have given to the works of God's adversary interest which he ought to consecrate to God alone; perilous, because the Devil had cunningly sown the world of matter with lures to ensnare the souls of men. And after all what could it profit him to learn all possible knowledge concerning the material world? In God's world, in heaven, which

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he hoped to enter after a brief exile here below, such knowledge would be irrelevant, useless, impious. His body, therefore, was not merely an inert clog to salvation, it was the active ally of the Fiend, who spread before every one of the bodily senses attractions to entice the soul away from the contemplation of God. Pleasure became synonymous with sin; beauty was the mask of temptation. Only by a strenuous asceticism, a mortification of the senses, and a starving of all mundane desires, could the mediæval devotee cheat the Devil. No wonder that he walked on tiptoe, as over young ice, when one misstep would plunge him into the abyss forever! No wonder that he gave the least possible heed to the properties of laws of matter!

But in the thirteenth century Christendom began to awake, began to suspect that it had been the victim of a hideous nightmare. Dante, the first modern man, embodying the theology of the Middle Age and foreshadowing the realism of the new age, made an allegory of the actual moral condition of men on earth. The epic poets of antiquity had sung the adventures of gods and heroes; Dante wove an epic out of the experiences of the human soul on its passage from the depths of imperfection to the heights of righteousness. Hitherto, an unbridgeable chasm had yawned between pagan and Christian times; Dante, feeling profoundly the continuity of the life of the race, introduced into his vision the chief personages of pagan history and mythology, together with the saints and heroes of Christianity, and his own contemporaries, in order to complete his portrayal of human character. This was a long step gained; it was an admission that whatever might be the destiny of men in the world to come, they could all, whether born before or after the birth of Christ, be measured by the same moral scale in this world.

Close upon Dante followed Petrarch, Boccaccio, and the swarm of Humanists. Learning ceased to be the exclusive privilege of ecclesiastics. The conviction deepened that man's life on earth is most interesting for its own sake, irrespective of its being, or not being, the preparation for eternal life hereafter. Across a thousand years the civilisation of Greece and Rome loomed up in fascinating grandeur. Over the barrenness of ages the fresh vital air of Athens blew straight upon Italy, as a pollen-bearing wind in spring-time;

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and the Humanists breathed its freedom and joyousness as eagerly as a bedridden patient would welcome health, or an old man his vanished youth. How futile now seemed the quibbles of the schoolmen! How mistaken the crabbed precepts of mediæval theologians! How repulsive, narrow, and unnatural the life that they had led! The Greeks, the Romans, with no Christian teaching to guide them, with no ascetic fanaticism, had lifted their commonwealth to a plane of grandeur far above that of any subsequent State; and in virtues, civic or private, in poetry, in commerce, in the arts, they had surpassed their Christian successors. To recover all that could be recovered of that classic civilisation, its ideals and achievements, became therefore the passion of the Humanists; they searched each ancient manuscript as if it were a lost will in which they might find that some forgotten ancestor had bequeathed to them an incalculable fortune. That must ever be regarded as one of the noblest epochs in the history of the race when the best men joined the pursuit of things spiritual and intellectual with all the fervor and pertinacity with which their descendants a century later set out in quest of Eldorados in America and to conquer the material wealth of the Indies. The immediate result of this enthusiasm was to bring to the Humanists a sufficient knowledge of the ancient civilisation to enable them to compare this with the mediæval Christian standard which had hitherto reigned alone. From this comparison sprang criticism, the handmaid of truth.

Little enough did the early explorers suspect whither their quest would lead them. They could not guess that a search for classic manuscripts would end, as Michelet has it, in the discovery of man and of the world. Yet so it was. The spirit of inquiry, roused from its millennial torpor, hungrily investigated all things. The old answer to the riddle of existence was cast aside as unsatisfactory; a new answer must be wrested from the dumb, inscrutable universe. In their first passion for discovery, men did not dream that the solution might elude them. Wherever they looked they saw untrodden avenues leading into the heart of the mystery. Discarding mediæval preconceptions, they began to study human nature. They looked upon the earth and saw that it was fair, and its

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beauty no longer seemed to them a Satanic lure. They began to see in the world of matter orderly processes, the coursing to and fro of vivifying laws, like blood in the arteries of man. They looked upon the heavens, and their souls were awed by a premonition of vastness only consonant with the belief that God, and not the Devil, was their author. In the presence of the sublime immensity of the stellar spaces, the cramped view of human destiny as expressed by mediæval dogma, must seem impious and absurd. By the close of the fifteenth century men were beginning to rise to the conception of a cosmos, of a world forever *becoming*, alive and interrelated in all its parts. The old notion of fixity,—of one unchanging religion, of one foreordained and immutable ideal of government, of earth anchored in space, and of man the crown and centre of creation,—was doomed. The discovery that this is a living and unfolding universe was the most important event in human history since the birth of Christ.

I would not paint the achievements of the Renaissance in colors too gorgeous, nor imply that the men of that epoch understood the bearing of the movement they originated. Many of the deductions drawn from their tentative investigations have been drawn very recently. Many of the paths they opened and explored diverged into the wilderness where the footsteps of man flounder perilously and the soul of man finds no cheer. I have elsewhere stated * some of the deficiencies, the appalling, cardinal deficiencies, which, in Italy, at least, caused the Renaissance to be partial and temporary. But after deducting from it what we must, it remains a period of inestimable significance. If its very doubts were pregnant, how shall we define the truths it revealed, truths typified by the discoveries of Columbus and Copernicus, and by the invention of Gutenberg? The mission of the Renaissance was to establish reason as the final guide and judge of mankind. With the enthronement of reason, the German Reformation, the American commonwealth, the French Revolution, and every other advance which the race has made, became intelligible.

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* See *The Dawn of Italian Independence*, Vol. I, Chap. 6.

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To *rationalise* nature, to discover, that is, reason in her manifold operations, to substitute for the mediæval scheme of ignorance and miracle the idea of cosmic order, has been the particular business of science for more than four centuries. We who inherit the knowledge accumulated by the patience of countless investigators and co-ordinated and classified by a few master thinkers, cannot put ourselves back into that state of mind in which the earliest explorers set out. Immemorial traditions, habits of thought, lack of instruments, theological prejudice, were all against them. Nature lay under a ban. The world was an inert mass. To overcome these obstacles required the development of other organs, the implanting of the spirit of inquiry. The wisest men had hitherto been as babes in the presence of the majestic forces of the material universe. The laws of gravitation, of expansion, of heat and cold, worked in and through them, yet they heeded them not. Electricity sped on its errands from zenith to nadir, invisible, swift as an archangel, yet were they unaware of its passing. They were blind to nature's beauty and power, deaf to her innumerable voices. In what mysterious manner a few men began to see and hear, let those explain who know how the acorn enfolds the far-spreading oak in its shell, and how in an embryo lie dormant the intellect and soul of a possible Cæsar or Shakespeare.

What we do know, however, is that in the fifteenth century a few men began to scrutinise nature, very tentatively at first, and with no premonition of the results which such scrutiny would reach. Foremost among them was Leonardo da Vinci. Other investigators of that century, Copernicus the most conspicuous, have ranked higher than he in the annals of science; but none, as I hope to show, equalled him in scientific endowment. He was disenthralled from mediæval preconceptions, for he possessed a temperament so purged of theories that in approaching a new fact his sole aim was to discover the true nature of that fact, unbiassed by what others had found in it. His curiosity was insatiable; his methods were observation and experiment; his advance was from the known to the unknown, whereas the mediæval, as we have seen, took the unknown for granted, and ceased to inquire. That Leonardo's achievements

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in science and invention should never have had due recognition, is to be attributed in part to their great range—the world remembers longer him who travels farthest in a single direction, than him who travels far in many; and in part to an accident which buried them for three centuries. Even now we have but an imperfect record of them. Not as a candidate for belated fame—Leonardo's fame is secure—but as a pioneer of the modern spirit, and as a favorite whom Nature took into her confidence, let us consider him here.

The important facts in Leonardo da Vinci's life can be briefly told. The natural son of a Florentine notary, he was born at the castle of Vinci, on the Arno, between Florence and Pisa, in 1452. Vasari relates stories of his youthful precocity, which often astonished his instructors, and of his fondness for music. Being admitted early into the studio of Verrocchio, he learned not only painting and sculpture, but also the goldsmith's art, which, we may remark, had an influence not easily to be computed in giving to the Florentine School of Painting that precision, that loyalty to the line, which distinguish it from the Venetian School. How the young Leonardo painted into one of his master's pictures an angel far beyond Verrocchio's skill, and how he drew a Gorgon's head so life-like that it frightened persons who came upon it unawares, need not here be repeated. In 1472 he was already an independent artist, and during the next eight or nine years he worked in Florence, but to what purpose we can only guess, as almost all the fruits of this period have been lost. In 1480 he addressed a remarkable letter to Lodovico Sforza, tyrant of Milan, asking for employment and laying chief stress on his ability as a military engineer. The letter brought him an invitation to go to Milan, where he was engaged in mechanical and engineering enterprises, in the direction of ducal festivities, and in the construction of a colossal monument to Francesco Sforza, Lodovico's father. The fresco, "The Last Supper," is one of the few remaining authentic works of Leonardo's brush during his long residence in Lombardy, and no one now can say that a single patch of color in that ruined masterpiece was laid on by him. Indeed, fate, which showered upon Leonardo innumerable gifts, seems to have decreed that posterity should know his genius by hearsay only, so per-

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versely has fate allowed his works to be lost or mutilated. That colossal statue of Sforza was not yet completed when Louis XII. invaded the Milanese and put an end to the sculptor's work there; the great fresco has suffered irreparably from neglect, violence, and restoration; and of the half-score paintings which remain scarcely one gives us a hint of the beauty of its original coloring.

In 1500 Leonardo visited Venice and Florence. Two years later he was appointed engineer by Cæsar Borgia, who was engaged in a military expedition against those States south of the Po that had not already submitted to his tyranny. During this summer we have glimpses of Leonardo at Urbino, Pesaro, Rimini, Cesena, and Cesenatico, along the Adriatic; at Siena, Chiusi, and Orvieto in the Centre; and at Piombino near the Tuscan Sea. In the following spring he settled at Florence and painted "The Battle of Anghiari" on one wall of the council hall of the Palace of the Signory, while on another wall his young rival, Michael Angelo, painted a vast group of "Soldiers Bathing." Not a trace of either fresco survives. But Leonardo, never at his ease in Florence, returned to Milan in 1506. Thenceforward, until 1515, he seldom stayed long in any place; till Francis I. came into Italy and induced him to go back to France, where he was assigned a residence at the Château Cloux, near Amboise on the Loire, 1516. There he died May 2, 1519, and was buried in the Royal Chapel at Amboise.

In person, as in mind, Leonardo lacked no gifts. He excelled in dancing, in fencing, in horsemanship, in lute-playing. Well-known anecdotes, chiefly drawn from Vasari's precious and inexhaustible quarry, illustrate alike his unusual physical strength and his wonderful dexterity. He was genial in temper and kind in heart, and he possessed the rare combination of humor and wit. His interest in man and in nature was many-sided and unflagging; nothing being too vast or too minute for his attentive curiosity. He had the patient inquisitiveness of the specialist who pores over details; he had also the generalising faculty of the philosopher who deduces laws and discovers wider relations. His attitude towards life was, in a word, thoroughly modern and scientific. As little as possible did the past, with its traditions and dogmas, hamper him: to search

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out all things, to experiment and verify, to let his own eyes test and reason be the judge—this was Leonardo's method.

That letter which Leonardo wrote to Lodovico Sforza is still extant, and it throws so much light upon his genius and his self-knowledge that it is worth quoting almost entire:—

"Having, most illustrious lord, seen and considered the experiments of all those who repute themselves masters and inventors of warlike instruments, and having observed that their said instruments are nowise different from those in common use, I will attempt, without disparaging any one else, to explain myself to your Excellency; opening for this purpose my secrets. . . .

"1. I have a way of making bridges, very light and adapted to be carried very easily, by which to pursue or escape from an enemy; and others more secure, and indestructible by fire and battle, easy and convenient to set in position and to remove. And means for burning and destroying those of the enemy.

"2. In investing a place, I know how to remove water from fosses, and to make various scaling-ladders, and other instruments pertinent to such an expedition.

"3. *Item*, if, on account of the bank or strength of place and site, in the siege of a city cannon cannot be used, I have means of undermining every fortress, provided it be not founded on stone.

"4. I can make cannon easy and convenient to transport, by which burning stuff can be discharged, whose smoke will cause great fear to the enemy, to his serious harm and confusion.

"5. *Item*, I can make mines and narrow and winding ways to reach without noise a given [point]; and, if need be, I can make them pass under trenches or a river.

"6. *Item*, I can make covered carts, secure and indestructible, which, with their artillery, entering among the enemy, will break the strongest body of men; and behind these carts infantry can follow unwounded and without any hindrance.

"7. *Item*, if necessary, I will make cannon, mortars, and fire-arms of most useful and beautiful forms, different from those in common use.

"8. When cannon are impracticable, I will devise catapults, mangonels, mortars (*trabuchi*), and other instruments of wonderful efficacy and novelty; and, in short, according to the variety of needs, I will invent divers and many engines of offence

"9. And if by sea, I have a lot of instruments most suitable for attack and defence; and vessels that will resist the fire of the heaviest cannon; and powders and fire-stuffs.

"10. In time of peace, I believe I can give good satisfaction—in comparison with any other—in architecture, in constructing edifices, both public and private, and in conducting water from one place to another.

"*Item*, I can do in sculpture of marble, bronze, or clay, likewise in painting,

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equally as well as any other, be he who he may. Further, the work might be executed on the bronze horse, which will be the immortal glory and eternal honor of the happy memory of your father, and of the illustrious House of Sforza. And if to anybody any of the above-mentioned things seem impossible and unachievable, I offer myself most ready to make trial of them in your park, or in whatever place shall please your Excellency, to whom in all humility I commend myself."

In this letter, written when he was only twenty-seven or twenty-eight, Leonardo magnifies his ability as an engineer and speaks but briefly of his skill as an artist—briefly, but haughtily, as that phrase "equally as well as any other, be he who he may," bears witness. In a little man such an inventory of talents would sound presumptuous, but Leonardo can do all that he announces. He is seeking employment from a military tyrant who needs engines for conquering his foes more than he needs paintings or statues; and therefore Leonardo insists on his own pre-eminence as an engineer. But there shall be frescoes, too, and monuments, and rare products of the arts of peace, if only Louis "the Moor" will listen to him.

Let us now survey the circle of his achievements.

Leonardo flourished in a period of transition when mediæval weapons were being replaced by modern fire-arms. The tremendous military value of gunpowder, after its discovery by Roger Bacon in the middle of the thirteenth century, had not quickly been perceived. Cannon were used, it is true, at the battle of Crécy, in 1346; but their general adoption can hardly be dated earlier than the last quarter of the fifteenth century, when they were used by the Spaniards in the conquest of Granada, by Louis XI. in his wars with the great French feudatories, and by the Italian mercenaries in their sordid, dilatory campaigns. So among Leonardo's inventions we find some which were improvements on the pikes, cross-bows, and catapults of the earlier system, and others which, adapted to the use of gunpowder, extended the scope of the new system. He designed a huge machine, to be worked by ten men in treadmill fashion, from which a large and almost simultaneous volley of shafts could be discharged—a forerunner of the Gatling gun and the *mitrailleuse*. He also planned great catapults, and an enormous copper cannon, which he called *Architonitros*, to be exploded by steam. He

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ascertained that cannon-balls have a velocity of one hundred and ten metres per second, and that it is useless to increase the charge of powder, unless the size of the grain be increased. He experimented with fusees; he devised methods for strengthening fortifications by artillery, and for making ravelins, mines, and storming-machines. Just how far he advanced the art of fortification cannot be determined, for we cannot tell how much Vauban invented himself, and how much he borrowed from the Italian military engineers who preceded him, among whom Leonardo stands foremost. The very important principle of clearance fire, often credited to the Frenchman, appears to have been understood by his Florentine predecessor. Certainly, Leonardo made drawings of what are apparently breech-loading guns. He computed the relative speed and efficacy of stone and lead balls, and suggested that they be conical instead of round. In marine warfare and in navigation he designed improvements. He mentions the log for showing a ship's progress at sea; hitherto, the earliest reference to the log was made by Magellan in 1521. He invented swimming-belts, and, more important still, paddle-wheels by which boats might be propelled against wind or current.

A century before Stevinus, Leonardo pointed out the need of a rational treatment of mechanical problems; possibly he suspected the uniformity of mechanical laws. He found the centre of gravity of a pyramid; he explained the theory of the inclined plane; he studied the phenomena of concussion, of friction, of the resistance of springs. He invented a dynamometer. Some of his axioms deserve to be cited, for comparison with those now held to be true: "Percussion," he says, "is power reduced into a little time," and "exceeds, in equal time, every other natural force"; "An object which falls freely, acquires in every degree of its descent degrees of velocity;" "A man walking goes faster with his head than with his feet;" "That body will become lighter which occupies more air;" "No dead object moves by itself, but by another is its motion caused;" "No moving object will ever move faster than the force which moves it;" "Every action is the result of motion." In his experiments he used elastic balls suspended by threads, a device

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adopted by Borelli and later physicists. He was aware that a body can be under the influence of more than one motive force at the same time. In his researches in attrition and friction he anticipated L'Amoutons (1699), Bülfinger (1727), and Desaguliers (1832).

Although his notes on this subject are scanty we infer that he gave attention to electricity. According to Libri,* he first remarked the regular movement of dust placed on elastic surfaces in vibration. Like the inventors of our own times, he aimed at substituting a machine for a man, wherever this substitution would save labor. That he was the first to employ the *plus* and *minus* symbols, is an assertion I am unable to verify.†

Coming next to botany we find that Leonardo's priority in several important discoveries has been recently established. G. Uzielli‡ traces the advance he made in three directions, as follows:

First, Leonardo discovered the laws of phyllotaxis, or the arrangement of leaves on their stem. He was the first to observe that the order of growth in plants and trees of the same species is uniform, and that their leaves have three different modes of distribution: they may be placed opposite to each other; they may be whorled, or verticillate; they may be alternate, or spiral. He demonstrated that when leaves grow in pairs they have generally a decussate arrangement, that is, each pair is at right angles to the pair directly above or below it; and he also showed that when leaves are verticillate, those in one whorl are seldom in a direct line with the whorls above and below. He noted that the *quincuncial* form is common in the spiral arrangement, the cycle being completed by five leaves, and the sixth leaf being in a direct line with the corresponding leaf above and beneath. "Since branches grow from buds generated in the axils of leaves," he said, "the arrangement of branches on the trunk necessarily corresponds to that of the leaves on the stem." To Sir Thomas Browne, whose book, "The Garden

* Libri: *Histoire des Sciences Mathématiques en Italie.* Paris, 1840.

† Richter, in his work on Leonardo da Vinci (London, 1880), regards this as not proved.

‡ *Il Nuovo Giornale Botanico Italiano*, Vol. I, No. 1, 1869; quoted in *Nature*, Vol. II, p. 42.

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Cyrus, or the Quincuncial Lozenge," was printed in 1658, the merit of this observation has been hitherto attributed.

Second, Leonardo discovered that the age of exogenous trees can be determined from the structure of their trunks. He writes: "The southern part of the plant shows more vigor and youth than the northern. The rings of the branches of trees show how many years they have lived, and their greater or smaller size whether they were damper or drier. They also show the direction in which they were turned, because they are larger on the north side than on the south, and for this reason the centre of the tree is nearer the bark on the south than on the north side." Malpighi and Grew (whose works appeared in 1675 and 1682 respectively) have heretofore enjoyed the honor of this discovery. But Montaigne mentions (in his "Journey into Italy," July 8, 1581) that at Pisa he bought several curiosities, and that "the person of whom I bought these things, a man of great note as a mathematical instrument maker, told me that trees have all within them as many rings and circles as they number years. He showed me examples of this in every kind of wood in his shop, for he is a turner by trade. Those trees in a forest which look northwards have these rings closer and thicker than the trees which stand in other directions; and this person told me that this was so invariably the case that by looking at a piece of timber, he could tell how old the tree was, whence it came, and in what direction it had stood." Montaigne's "Journal" was recovered only towards the end of the eighteenth century, so that Malpighi and Grew could not have borrowed from it, but it seems probable that the facts he mentions as having been disclosed to him by the Pisan turner, may have been generally known in the seventeenth century.

Third, Leonardo investigated the process of growth in exogenous stems by the formation of new wood on the bark, a process he describes thus: "The growth in the size of plants is produced by the sap, which is generated in the month of April between the outside coating (*camisia*) and the wood of the tree. At the same time this outside coating becomes converted into bark, and the bark acquires new crevices of the depth of ordinary crevices." This explanation is, I believe, no longer accepted by botanists; but, though

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Leonardo's conclusion was inaccurate, his researches must have contributed to the discovery of the truth. He made many drawings of leaves, which for exactness and beauty have never been surpassed.* He also pursued other, more fanciful, experiments, as, for instance, one for testing the effects of poison on trees, by boring a hole in the trunk and injecting arsenic, or sublimate, in alcohol. And he described how an impression of leaves may be had by smearing them with white lead, oil, and lamp-black—as ink is spread on the types—and stamping them on paper: a process which, somewhat modified, has recently been used with success by Hauer and others.

That he was a close observer of outward nature, his paintings and drawings of landscape abundantly testify; but he went deeper than the surface, and foresaw more than one vital fact which geologists have since established. Fossils, he maintained, are the remains of plants and animals of a bygone age, and not, as was commonly asserted by his contemporaries, mere "freaks of nature." When fossil shells were still in the sea, he affirmed, river-mud near the coast had penetrated into them. "They tell us that these shells were formed in the hills by the influence of the stars; *but I ask, where in the hills are the stars now forming shells of distinct ages and species?* and how can the stars explain the origin of gravel, occurring at different heights and composed of pebbles rounded as if by the motion of running water; or in what manner can such a cause account for the petrifaction in the same place of various leaves, seaweeds, and marine crabs?"† In thus proclaiming the continuity of geological causes, Leonardo proves his kinship with the masters of modern science. He attributed the denudation of mountain-peaks to the gradual subsidence of water, and saw that the direction of a falling body must be affected by the rotation of the earth—an obser-

* "I might refer in detail to four studies of bramble branches, leaves, and flowers, and fruit, in the Royal Collection at Windsor, most wonderful for patient accuracy and delicate execution; also to drawings of oak-leaves, wild guelder-roses, broom, columbine, asphodel, bull-rush, and wood-spurge in the same collection. These careful studies are as valuable for the botanist as for the artist. To render the specific character of each plant with greater precision would be impossible." J. A. Symonds, *The Renaissance in Italy: The Fine Arts*, p. 320.

† Quoted by Lyell, *Principles of Geology*, p. 19 (edit. 1862).

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vation which probably explains the following memorandum: "Write to Bartholomew the Turk about the ebb and flow of the Pontic Sea, and to find out whether a similar phenomenon exits in the Hyrcan, or Caspian Sea." He held that valleys are the beds of former rivers.

His observations of the moon are even more interesting. He it was who, long before Kepler and Galileo, demonstrated that the faint light which we see on the new moon is reflected from the earth.* Kepler, in 1596, and Galileo, a few years previous, published their explanation of this phenomenon. Leonardo believed that the solar light is radiated to the moon from those parts of the earth where there is most water: "The water which clothes a large portion of the earth receives on its surface the image of the sun, and with this shines upon the universe and becomes a star with the same splendor which makes us see the other stars." He also stated that "the moon has each month a winter and a summer, and has greater heat and cold, and her equinoxes are colder than ours." To a lunar inhabitant, he said, the earth performs an office like that which the moon performs for us by night. Although the Ptolemaic system still commonly obtained—the terrestrial explorations of Columbus, and the celestial explorations of Copernicus having as yet aroused the suspicion in only a few alert minds that Ptolemy's doctrine rested on a fallacy—Leonardo maintained that the earth is round, and showed that at a distance of fourteen miles at sea, a man's body is hidden, owing to the earth's curving surface; the distance is incorrect, but the fact of sphericity has long been undisputed. Still more daring appears his assertion that "the earth is not situated in the middle of the sun's orbit, still less at the centre of the universe," when we remember that the Church persecuted more than one man of science for hazarding this assertion, and that even to-day, the majority of otherwise intelligent persons, are unwilling to relinquish the flattering tradition which ascribes pre-eminent importance to our planet, and to ourselves as its inhabitants.

Several maps designed by Leonardo, and preserved in his "Co-

* Humboldt, *Cosmos*, IV, 483.

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dice Atlantico," illustrate his geographical range: to them we may add topographical plans of many parts of Italy where he was engaged in engineering. During his life-time he was best known as an engineer—always excepting his renown as an artist—and as an engineer his name is still familiar to many who have no definite notion of the versatility of his genius. All travellers have seen specimens at Milan of his mechanical drawings, and have been told that the canal system perfected by him still supplies Lombardy with water. The Martesana canal had already been partly excavated when he took charge of it; but he invented the locks which are still in use, and which superseded the clumsier Saracenic gates previously employed. He proposed a method for draining the marshes of Piombino; he drew a plan for changing the course of the Arno by means of a canal, which has subsequently been carried out; he made sketches, when in France, for the so-called Romorontin canal; he devised a big auger for boring artesian wells; he proposed to fertilise the sterile plains of Prato and Pistoja by collecting vegetable slime or muck in reservoirs, and applying it to the soil. When but yet a youth, he offered to raise the Baptistery at Florence, in order that its foundations might be strengthened and heightened: his project, then laughed at as well-nigh crazy, has been commonly adopted in our American cities during the past twenty years, and the raising or removing of huge buildings no longer excites our wonder. He understood also the art of tunnelling. Among his drawings we find a device "by which a stream not navigable, either by reason of too little depth, or from liability to failure in time of drought, may be made useful, by dividing it into sections by diagonal dams provided at the small angle with locks." Derricks, furnished with automatic dumping-hods, like those now used, for excavating canals, are drawn and described by him, as well as a machine for raising water from a stream to the top of a tower by means of Archimedean screws.

"Mechanics," said Leonardo, "is the paradise of mathematical sciences." He invented more than thirty kinds of mills. He made files by machinery, and made machines for sawing marble, for spinning, for shearing the nap of cloth, for planing iron, for making vises, saws, and planes, and for erecting marble columns—according

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to a principle recently followed in setting up Cleopatra's Needle on the Thames Embankment. Suction and force-pumps, water-wheels, and hydraulic presses were also constructed by him. He experimented in the distillation of oils and poisonous vapors to be used in warfare. In some of his sketches boats furnished with paddle-wheels are seen; in others, we find a diver's apparatus, with glass eyes and a tube for air, but no air-pump. Among his other inventions may be mentioned a proportional compass, similar to that invented by Burgi in 1603, and still known to engineers; a surgical probe, having longitudinal sections, and a screw for expanding the mouth of the wound; a gold-beater's hammer; a machine for tilling the earth by the wind's agency; cranes, windlasses, and plummets. But the most important of all, if we judge by the labor it has saved and by its universal adoption in Europe and America, is the wheelbarrow, which the French long attributed to Pascal. It would be tedious to ennumerate all the suggestions and contrivances which have already been discovered from Leonardo's only partially edited manuscripts, but a few more must be recorded, in order to show that his incessant ingenuity busied itself not less with the smallest than with the largest inventions. Among devices directly applicable to the commonplace needs of life are an automatic turn-spit, or roasting-jack; a door-latch; a three-legged stool for artists; a color-grinder, and a hood for chimneys.

In the fifteenth century even the best-informed men had but the meagrest knowledge of hydrostatics, a science to which Leonardo devoted himself, and of which he deduced many of the principles from his personal observations. "The gravity of liquids," he wrote, "is twofold: that, namely by which the whole mass tends towards the centre of the elements, and that which, tending towards the centre of the mass, creates the sphericity of water: but of this latter quality I see no method by human intellect to give a clear explanation, other than by saying that, even as the loadstone attracts the iron, so this virtue is a hidden property, of which infinite numbers exist in nature." He studied the evaporation of water at different altitudes; he studied also the motion of eddies. He anticipated Newton in explaining the motion of waves, which he compared to

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that of wind in a cornfield; as the corn bends, but does not leave its place, so waves pass over the surface, but the water remains. He threw into the water a straw tied to a stone, by which it was quickly seen how the straw rose and fell. He pointed out that waves recede in a circle from the centre of agitation. Perceiving that drops of water are mutually attracted and coalesce into larger drops, he argued that rain-drops are largest when they reach the ground. His numerous experiments with siphons taught him, among other things, the specific gravity of liquids; and having observed that cotton absorbs moisture, he constructed a balance with cotton on one side and wax on the other, in order to know when stormy weather threatened: this was the first hygrometer.

From the study of the exterior of the human body, Leonardo was naturally led to the study of its anatomy; and in this he soon advanced beyond the scanty knowledge of his time, and explored new regions so thoroughly that subsequent investigators have been able but to confirm his discoveries. Anatomy was then a budding science. The little which European physicians knew about it during the Middle Age, they derived from the Arabs; but these were forbidden by their religion to dissect bodies, so that a true understanding of anatomical laws could not be reached. About the beginning of the fourteenth century Mondino de' Luzzi (died in 1326) dissected three bodies; but he and his immediate followers, Zerbi, Achilli, Sylvius, Massa, and others, sought merely to confirm the dogmas of Galen, and not to establish truth by an unprejudiced reference to nature; so that when their experiments failed to confirm Galen, they set it aside as fallacious and worthless. But when the authority of the Greek physician began to wane, the first principles of modern anatomy were arrived at. Foremost among the pioneers was Leonardo, who deserves the title of founder of the science of comparative anatomy. According to Vasari, he studied with Marcantonio della Torre, the director of an anatomical school at Pavia. He made the famous division of animals into two classes —those which have their skeleton inside, and those which have it outside. He scrutinised minutely the movements of living bodies, and distinguished the voluntary from the involuntary muscles, watch-

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ing the action of the former in lifting, drawing, pushing, swinging, throwing, and other acts. He advised his pupils, if they would observe the natural working of the involuntary muscles, to go among the common people, whose emotions—whether of joy or pain, of anger or hate—paint themselves clearly on the features and are not hidden behind a mask of propriety or restraint. He used to invite peasants to dine with him, in order that he might study their expression, and, according to a well-known anecdote, he sometimes followed for many hours a stranger whom he casually met in the streets, and whose countenance interested him. Leonardo's notebooks abound in caricatures, which it would be impossible to match; they show how quick he was to detect the humorous and the monstrous hints in human lineaments, and how adept he was in giving them that prominence which is the basis of caricature. While working on the statue of Sforza, he studied the anatomy of the horse, and in his experiments for flying-machines he dissected birds in order to discover the secret of flight. In 1538, Vesale published a work on anatomy illustrated by many drawings which resemble closely those found at Kensington in the eighteenth century; for a long time Titian was supposed to be the author of the drawings in Vesale's book, but they are now attributed to Leonardo, and prove beyond dispute the breadth, profundity, and accuracy of his anatomical knowledge.* Knox declares that from Leonardo's design of the half-moon shaped traps of the aorta he must have understood their functions and thus antedated Harvey by a century in tracing the circulation of the blood. Hunter says: "I hold Leonardo as the best anatomist and physiologist of his time; he and his pupils first knew how to awake the spirit of anatomical studies." The following passage, in which Leonardo describes his method of procedure, is interesting enough to be quoted: "I wish to demonstrate the difference among a man, a horse, and other animals. I begin with the bones, and let follow next all those muscles which are joined without tendons to two bones; then those which at each end or at one end are provided with a tendon. I place the anatomy of

* The Kensington collection comprises 235 folios and 779 drawings.

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the bones as far as the hip for this purpose and show the different muscle-layers, veins, arteries, nerves, tendons, and bones; afterwards, however, one must saw through them, in order to learn their thickness."

From painting and anatomy to the investigation of the structure of the eye and to optics was a natural step. Optics and perspective were interchangeable terms in Leonardo's time, and we know that he intended to publish a separate treatise on this subject. Some of the results of his experiments are included in his "Treatise on Painting," but by far the greater part are scattered among those thick note-books of his, from which an encyclopædia might almost be compiled. He preceded Cardanus (1530) and Della Porta (1558) in the discovery of the *camera oscura*, and Kircher and others in that of the megascope. "Perspective," he said, "is the rudder of painting," and he laid down the rule for getting correct images of bodies seen in perspective by outlining them upon an intervening glass plate, whereby he anticipated Albert Dürer. From his knowledge of the laws of vision he formulated the axiom that "a painting can never be as clear as a natural scene, for in nature we behold everything with two eyes, each of which gets a little different view from that of its mate"—a fact which may be recommended to those painters who believe that the aim of art is to reproduce nature with servile and finical minuteness. To Leonardo has also been attributed the invention of the stereoscope—he was familiar, at least, with its principles—and of the telescope. He knew that a crystalline lens produces ocular images. "I assert," he wrote, "that the crystalline sphere is sufficient to convey appearances [or images] to be received into man's mind; but for this purpose a dark place is necessary"—that is, a *camera oscura*. He showed how rays of light enter the eye upside down, and he noted that the pupil of the eye dilates in the dark and contracts in the light, and that nocturnal animals are peculiarly sensitive in this respect. He was mistaken in supposing that the scintillation of the stars is due to our eyelashes and lids, but he was correct in stating that "images are retained in the eye for a length of time proportionate to the luminosity of the body by which they are caused." He mentioned that effect

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of radiation by which dark bodies on a light ground, and light bodies on a dark ground, appear respectively larger and smaller. Libri claims that Leonardo discovered the law of diffraction, but Black gives the credit of this discovery to Grimaldi (1665). It is not disputed, however, that Leonardo preceded Francesco Maurolico in observing that light, in passing through a hole, assumes the form of the object from which it is radiated, and not that of the hole. Moreover, he suggested the means (first applied by Bouguer in 1729) of measuring the intensity of light, stating the problem thus: "Given two opposite shadows produced upon a single object between two lights of double power, these lights being of equal density; to discover what is the proportion of distances between the lights and the object." We have his designs for convex, concave, spherical, and parabolic mirrors, and it is supposed that he employed concave glasses in chemical analysis. He observed the bluish shadows projected by the yellow light from the north in a clear sky behind various objects; also, that an object in front of an opening through which we look with both eyes may be invisible. It seems almost certain that he regarded light and sound as being produced in a similar manner, that is, by a series of waves.

In acoustics his researches were profitable. By studying echoes he concluded that sound requires a constant time to traverse a given distance. "It is possible to know by the ear the distance of thunder," he said, "if we have first seen the lightning, by analogy with the echo." He recognised that the action of wind interferes with the velocity of sound. Here is one of his experiments: "A blow given to a bell corresponds with and will communicate motion to another and similar bell; the string of a lute being struck will reply and give motion to a string of similar tone in another lute; and this can be rendered visible by placing a straw upon the string of the second lute." Of another acoustical problem he said: "Is the sound in the hammer or in the anvil? I say: seeing that the anvil is not suspended it cannot resound; but the hammer resounds from the leap it makes just after the blow; and were the anvil to resound . . . . just as a bell, no matter by what material it be struck, yields the same depth of tone, so would the anvil, struck by no matter what hammer.

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If, therefore, you hear various sounds from hammers of various sizes, the sound proceeds from the hammer and not from the anvil."

Among what we may call the vagaries of Leonardo's scientific and inventive curiosity, we may mention designs for flying-ships, flying-men, and aërial chairs: but, should the secret of flight ever be discovered, and adapted to general use, it may turn out that his experiments were not so fantastic as they now appear. So, too, of his proposition to walk with wooden shoes on the water. In his youth he was fascinated by that chimera—perpetual motion—which still had a potent charm for investigators. But experience taught him wisdom and he called "sophistical" the arguments of those who were deluded as he had been. "It is impossible," he said, "to create by any instrument a movement of water from below to above, by means of the descent of which it shall be possible to raise a similar weight of water to the height from which this descended."

When we remember that four hundred years ago alchemy had not developed into the science of chemistry, nor astrology into astronomy, and that fact and superstition had parted company in but few minds, we shall realise more adequately the vigorous independence of Leonardo, who boldly cast off authority, and chose reason and nature as his guides. He not only called "sophistical" the attempt to demonstrate perpetual motion, and ridiculed those who wasted their time in trying to square the circle, but he also denounced alchemists as "liars." He, too, turned his insatiable curiosity to fantastic experiments, in order to make sure that he had overlooked no possible entrance into the mystery of the universe; but here, as elsewhere, he was deceived by no hallucinations, and accepted or rejected the products of his researches according to the sole standard of reason. He insists, in his "Treatise on Painting," on the infallibility of nature, "the mistress of masters." "A painter," he says, "ought never to imitate the manner of any other; because in that case he cannot be called the *child,* but the *grandchild,* of nature. It is always better to have recourse to nature, who is replete with just abundance of objects, than to the productions of other masters, who learnt everything from her." To her, therefore, he went in quest of scientific truth. He practised, a century before

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Bacon, that inductive method which now obtains among all men of science. He preached the need of experiments. "Experience [or experiment] never deceives, but our judgments are deceived," is one of his maxims. "If then you ask me," he says, "'What fruit do your rules yield, or for what are they good?' I reply that they bridle investigators, and prevent them from promising impossibilities to themselves and others, and from being rated as fools or cheats." Four hundred years ago Leonardo rebuked spiritualistic frauds in this calm fashion: "There cannot be a voice where there is not motion and percussion of air: there cannot be a percussion of this air where there is no instrument; there can be no incorporeal instrument. This being so, a spirit can have neither voice, nor form, nor force, and if it takes body, it cannot penetrate nor enter where the doors are locked. And if any one should say through air collected and packed together spirit takes bodies of various forms, and through that means speaks and moves forcibly, to him I reply that where there are not nerves and bones force cannot be exercised in any motion caused by the pretended spirits."

Such is the epitome of Leonardo's discoveries—an epitome compiled almost wholly from the reports of those who have edited one volume alone of his autograph memoranda. A strange fatality has followed those manuscripts of his. At his death, he bequeathed them to his pupil Francesco Melzi, who took them back from France to Milan. There they were soon scattered, and no one could decipher them; for Leonardo wrote backwards, from right to left. It was supposed that he used a secret script, and for three hundred years nobody succeeded in reading it. When Napoleon invaded Italy he carried fourteen of these folio volumes to Paris, where they still remain. Others, including many drawings, are in England. One volume, the so-called "Codice Atlantico," is preserved at Milan; it alone has been carefully studied, and in part transcribed and photographed. What rich ore lies buried in the thousands of pages still unedited, may be inferred from what has already been brought to light.

To the accident of handwriting is due the long ignorance of the world of Leonardo's attainments in science and discovery. Gen-

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erations of investigators, unaware of his work, gradually explored the fields which he had traversed, and when at length his memoranda were deciphered, science had in many directions passed beyond him. Later men had the credit of his forgotten discoveries. But the inventory of those discoveries suffices to establish his claim to rank among the supreme men of science of all time. Whatever may be the relative worth of any one of his investigations, there can be no dispute as to the absolute quality of his mind. His methods are the methods of experiment and observation by which man advances victoriously into the mystery which wraps him round.

Leonardo's contemporaries were unprepared to appreciate his scientific accomplishment. Even recent critics have deplored that one who had only four or five peers in art should waste his time in scientific inquiries. He lived so near to the mediæval superstition that his insight was mistaken for wizardry, and his researches into the properties of matter seemed whimsical or perverse. Doubtless, the incompleteness and multitude of his investigations hindered other men from understanding their importance. He did not publish his discoveries; he did not even arrange them in formal order for demonstration. Those many thick volumes are but note-books in which he jotted down day by day the experiments he was making, or the conclusions and axioms he had reached, in many subjects. At the outset, he probably intended to collect and classify these various memoranda in separate treatises, but the revelations came so fast that he had barely time to record them.

Had Adam been created at night, imagine with what astonishment he must have beheld the first faint dappling of dawn! How his wonder must have grown as the East became rosy, and the sun rolled above the horizon, and from some unseen source light was poured through the heavens and flooded the earth! Forms and then colors emerged from the darkness; sounds—of birds, of lisping foliage, the hum of insects, the ripple of brook, or quieter lapping of stream—emerged from the silence. With what delight, with what unworn curiosity must Adam have wandered amid this pageant and listened to this music: everything a miracle, untarnished by the

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touch of any yesterdays; himself unconscious of time or bound, the personification of instant and immeasurable wonder.

To Leonardo the world unfolded itself in almost equal freshness, as it would to all of us if custom did not dull our perception. It was, indeed, a new world! The mediæval has looked and seen only the handiwork of Satan,—a chaos from which issued spasmodic miracles and caprice—a prison, in which the soul was detained for a few mortal years before it flew heavenwards. Leonardo looked upon this world and saw in it a divine creation, a cosmos of law, a home every nook of which had revelations for the soul. Like the Scandinavian god who could hear the grass grow, his senses were preternaturally keen. He penetrated the cuticle of things; nature lay transparent to his gaze. He saw the ebb-and-flow of cause and effect. In the least phenomenon he discerned the principle linking it to a class; in every object, in every creature he beheld the end of a clew which led back and up to the infinite. Thus almost at the beginning of the new age, he was the man whom Nature took into her confidence. To him she granted an apocalyptic vision of her secrets.

Subsequent investigators have gone farther. Every acre of the domain of science whose hither boundaries he explored, is now occupied by a specialist. But none has surpassed him in the highest qualities of a man of science—patience to analyse special facts without prejudice, and power to deduce general laws after having accumulated sufficient information. His were the qualities and the methods by which alone mankind are slowly rationalising the world in which we live. Less than any other man who died before our century would he be surprised at the advance in science and at the mechanical inventions of which we boast; for he had, what many men think they have, but have not, a vivid sense of the infinitude of the natural world and of the incalculable possibilities of human achievement. "What is that," he asks, "which does not give itself to human comprehension, and which, if it did, would not exist? It is the infinite, which, if it could so give itself, would be done and ended."

CAMBRIDGE, MASS. WILLIAM R. THAYER.

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