Garnett William

Heroes of Science: Physicists

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Содержание

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PREFACE

The following pages claim no originality, and no merits beyond that of bringing within reach of every boy and girl material which would otherwise be available only to those who had extensive libraries at their command, and much time at their disposal. In the schools and colleges in which the principles of physical science are well taught, the history of the discoveries whereby those principles have been established has been too much neglected. The series to which the present volume belongs is intended, in some measure, to meet this deficiency.

A complete history of physical science would, if it could be written, form a library of considerable dimensions. The following pages deal only with the biographies of a few distinguished men, who, by birth, were British subjects, and incidental allusions only are made to living philosophers; but, notwithstanding these narrow restrictions, the foundations of the Royal Society of London, of the American Philosophical Society, of the great Library of Pennsylvania, and of the Royal Institution, are events, some account of which comes within the compass of the volume. The gradual development of our knowledge of electricity, of the mechanical theory of heat, and of the undulatory theory of optics, will be found delineated in the biographies selected, though no continuous history is traced in the case of any one of these branches of physics.

The sources from which the matter contained in the following pages has been derived have been, in addition to the published works of the subjects of the several sketches, the following: —

"The Encyclopædia Britannica."

"Memoir of the Honourable Robert Boyle," by Thomas Birch, M.A., prefixed to the folio edition of his works, which was published in London in 1743.

"Life of Benjamin Franklin," from his own writings, by John Bigelow.

Dr. G. Wilson's "Life of Cavendish," which forms the first volume of the publications of the Cavendish Society; and the "Electrical Researches of the Hon. Henry Cavendish, F.R.S.," edited by the late Professor James Clerk Maxwell.

"The Life of Sir Benjamin Thompson, Count Rumford," by George E. Ellis, published by the American Academy of Arts and Sciences, in connection with the complete edition of his works.

"Memoir of Thomas Young," by the late Dean Peacock.

Dr. Bence Jones's "Life of Faraday;" and Professor Tyndall's "Faraday as a Discoverer."

"Life of James Clerk Maxwell," by Professor Lewis Campbell and William Garnett.

It is hoped that the perusal of the following sketches may prove as instructive to the reader as their preparation has been to the writer.

WM. GARNETT.

Newcastle-upon-Tyne,
December, 1885.

INTRODUCTION

The dawn of true ideas respecting mechanics has been described in the volume of this series devoted to astronomers. At the time when the first of the following biographies opens there were a few men who held sound views respecting the laws of motion and the principles of hydrostatics. Considerable advance had been made in the subject of geometrical optics; the rectilinear propagation of light and the laws of reflection having been known to the Greeks and Arabians, whilst Willebrod Snellius, Professor of Mathematics at Leyden, had correctly enunciated the laws of refraction very early in the seventeenth century. Pliny mentions the action of a sphere of rock-crystal and of a glass globe filled with water in bringing light to a focus. Roger Bacon used segments of a glass sphere as lenses; and in the eleventh century Alhazen made many measurements of the angles of incidence and refraction, though he did not succeed in discovering the law. Huyghens developed to a great extent the undulatory theory; while Newton at the same time made great contributions to the subject of geometrical optics, decomposed white light by means of a prism, investigated the colours of thin plates, and some cases of diffraction, and speculated on the nature, properties, and functions of the ether, which was equally necessary to the corpuscular as to the undulatory theory of light, if any of the phenomena of interference were to be explained. The velocity of light was first measured by Roemer, in 1676. The camera obscura was invented by Baptista Porta, a wealthy Neapolitan, in 1560; and Kepler explained the action of the eye as an optical instrument, in 1604. Antonio de Dominis, Archbishop of Spalatro, discovered the fringe of colours produced by sunlight once reflected from the interior of a globe of water, and this led, in Newton's hands, to the complete explanation of the rainbow.

The germ of the mechanical theory of heat is to be found in the writings of Lord Bacon. The first thermometers which were blown in glass with a bulb and tube hermetically sealed, were made by a craftsman in Florence, in the time of Torricelli. The graduations on these thermometers were made by attaching little beads of coloured glass to their stems, and they were carried about Europe by members of the Florentine Academy, in order to learn whether ice melted at the same temperature in all latitudes.

In electricity the attraction of light bodies by amber when rubbed, was known at least six hundred years before the Christian era, and the shocks of the torpedo were described by Pliny and by Aristotle; but the phenomena were not associated in men's minds until recent times. Dr. Gilbert, of Colchester, Physician to Queen Elizabeth, may be regarded as the founder of the modern science. He distinguished two classes of bodies, viz. electrics, or those which would attract light bodies when rubbed; and non-electrics, or those which could not be so excited. The first electric machine was constructed by Otto von Guericke, the inventor of the Magdeburg hemispheres, who mounted a ball of sulphur so that it could be made rapidly to rotate while it was excited by the friction of the hand. He observed the repulsion which generally follows the attraction of a light body by an electrified object after the two have come in contact. He also noticed that certain bodies placed near to electrified bodies possessed similar powers of attraction to those of the electrified bodies themselves. Newton replaced the sulphur globe of Otto von Guericke by a globe of glass. Stephen Gray discovered the conduction of electricity, in 1729, when he succeeded in transmitting a charge to a distance of 886 feet along a pack-thread suspended by silk strings so as to insulate it from the earth. Desaguliers showed that Gilbert's "electrics" were simply those bodies which could not conduct electricity, while all conductors were "non-electrics;" and Dufay showed that all bodies could be electrified by friction if supported on insulating stands. He also showed that there were two kinds of electrification, and called one *vitreous*, the other *resinous*. Gray, Hawksbee, and Dr. Wall all noticed the similarity between lightning and the electric discharge. The prime conductor was first added to the electric machine by Boze, of Wittenberg; and Winkler, of Leipsic, employed a cushion instead of the hand to produce friction against the glass. The accumulation of electricity in the Leyden jar was discovered accidentally by Cuneus, a pupil of Muschenbroeck, of Leyden, about 1745, while attempting to electrify water in a bottle held in his hand. A nail passed through the cork, by which the electricity was communicated to the water. On touching the nail after charging the water, he received the shock of the Leyden jar. This brings the history of electrical discovery down to the time of Franklin.

ROBERT BOYLE

Robert Boyle was descended from a family who, in Saxon times, held land in the county of Hereford, and whose name in the Doomsday Book is written Biuvile. His father was Richard Boyle, Earl of Cork, to whom the fortunes of the family were largely due. Richard Boyle was born in the city of Canterbury, October 3, 1566. He was educated at Bene't College (now Corpus Christi College), Cambridge, and afterwards became a member of the Middle Temple. Finding his means insufficient for the prosecution of his legal studies, he determined to seek his fortune abroad. In 1595 he married, at Limerick, one of the daughters of William Apsley, who brought him land of the value of £500 per annum. In his autobiography the Earl of Cork writes: —

> When first I arrived at Dublin, in Ireland, the 23rd of June 1588, all my wealth then was twenty-seven pounds three shillings in money, and two tokens which my mother had given me, viz. a diamond ring, which I have ever since and still do wear, and a bracelet of gold worth about ten pounds; a taffety doublet cut with and upon taffety, a pair of black velvet breeches laced, a new Milan fustian suit laced and cut upon taffety, two cloaks, competent linen, and necessaries, with my rapier and dagger. And since, the blessing of God, whose heavenly providence guided me hither, hath enriched my weak estate, in beginning with such a fortune, as I need not envy any of my neighbours, and added no care or burthen of my conscience thereunto. And the 23rd of June, 1632, I have served my God, Queen Elizabeth, King James, and King Charles, full forty-four years, and so long after as it shall please God to enable me.

Richard Boyle's property in Ireland increased so rapidly that he was accused to Queen Elizabeth of receiving pay from some foreign power. When about to visit England in order to clear himself of this charge, the rebellion in Munster broke out; his lands were wasted, and his income for the time destroyed. Reaching London, he returned to his old chambers in the Middle Temple, until he entered the service of the Earl of Essex, to whom the government of Ireland had been entrusted. The charges against him were then resumed, and he was made a prisoner, and kept in confinement until the Earl of Essex had gone over to Ireland. At length he obtained a hearing before the queen, who fully acquitted him of the charges, gave him her hand to kiss, and promised to employ him in her own service; at the same time she dismissed Sir Henry Wallop, who was Treasurer for Ireland, and prominent among Boyle's accusers, from his office.

A few days afterwards, Richard Boyle was appointed by the queen Clerk to the Council of Munster, and having purchased a ship of Sir Walter Raleigh, he returned to Ireland with ammunition and provisions.

"Then, as Clerk of the Council, I attended the Lord President in all his employments, and waited upon him at the siege of Kingsale, and was employed by his Lordship to her Majesty, with the news of that happy victory; in which employment I made a speedy expedition to the court; for I left my Lord President at Shannon Castle, near Corke, on the Monday morning, about two of the clock, and the next day, being Tuesday, I delivered my packet, and supped with Sir Robert Cecil, being then principal Secretary of State, at his house in the Strand; who, after supper, held me in discourse till two of the clock in the morning; and by seven that morning called upon me to attend him to the court, where he presented me to her Majesty in her bed-chamber, who remembered me, calling me by my name, and giving me her hand to kiss, telling me that she was glad that I was the happy man to bring the first news of that glorious victory … and so I was dismissed with grace and favour."

In reading of this journey from Cork to London, it is almost necessary to be reminded that it took place two hundred and fifty years before the introduction of steam-boats and railways. At the close of the rebellion, Richard Boyle purchased from Sir Walter Raleigh all his lands in Munster; and on July 25, 1603, he married his second wife, Catharine, the only daughter of Sir Geoffrey Fenton, principal Secretary of State, and Privy Councillor in Ireland, "with whom I never demanded any marriage portion, neither promise of any, it not being in my consideration; yet her father, after my marriage, gave me one thousand pounds in gold with her. But that gift of his daughter unto me I must ever thankfully acknowledge as the crown of all my blessings; for she was a most religious, virtuous, loving, and obedient wife unto me all the days of her life." He was knighted by the Lord Deputy of Ireland, Sir George Carew, on his wedding-day; was sworn Privy Councillor of State of the Kingdom of Ireland in 1612; created Lord Boyle, Baron of Youghall, September 29, 1616; Lord Viscount of Dungarvon and Earl of Cork, October 26, 1620; one of the Lords Justices of Ireland, with a salary of £1200 per annum, in 1629; and Lord High Treasurer of Ireland, November 9, 1631.

Robert Boyle, the seventh son of the Earl of Cork, was born January 25, 1627. His mother died February 16, 1630. The earl lived in prosperity in Ireland till the breaking out of the rebellion in 1641, and died at Youghall in September, 1643. It is said that when Cromwell saw the vast improvements which the earl had made on his estate in Munster, he declared that "if there had been an Earl of Cork in every province, it would have been impossible for the Irish to have raised a rebellion."

At a very early age Robert was sent by his father to a country nurse, "who, by early inuring him, by slow degrees, to a coarse but cleanly diet, and to the usual passion of the air, gave him so vigorous a complexion that both hardships were made easy to him by custom, and the delights of conveniences and ease were endeared to him by their rarity." Making the acquaintance of some children who stuttered in their speech, he, by imitation, acquired the same habit, "so contagious and catching are men's faults, and so dangerous is the familiar commerce of those condemnable customs, that, being imitated but in jest, come to be learned and acquired in earnest." Before going to school he studied French and Latin, and showed considerable aptitude for scholarship. He was then sent to Eton, where his master took much notice of him, and "would sometimes give him unasked play-days, and oft bestow upon him such balls and tops and other implements of idleness as he had taken away from others that had unduly used them."

While at school, in the early morning, a part of the wall of the bedroom, with the bed, chairs, books, and furniture of the room above, fell on him and his brother. "His brother had his band torn about his neck, and his coat upon his back, and his chair crushed and broken under him; but by a lusty youth, then accidentally in the room, was snatched from out the ruins, by which [Robert] had, in all probability, been immediately oppressed, had not his bed been curtained by a watchful Providence, which kept all heavy things from falling on it; but the dust of the crumbled rubbish raised was so thick that he might there have been stifled had not he remembered to wrap his head in the sheet, which served him as a strainer, through which none but the purer air could find a passage." At Eton he spent nearly four years, "in the last of which he forgot much of that Latin he had got, for he was so addicted to more solid parts of knowledge that he hated the study of bare words naturally, as something that relished too much of pedantry to consort with his disposition and designs." On leaving Eton he joined his father at Stalbridge, in Dorsetshire, and was sent to reside with "Mr. W. Douch, then parson of that place," who took the supervision of his studies. Here he renewed his acquaintance with Latin, and devoted some attention to English verse, spending some of his idle hours in composing verses, "most of which, the day he came of age, he sacrificed to Vulcan, with a design to make the rest perish by the same fate." A little later he returned to his father's house in Stalbridge, and was placed under the tutelage of a French gentleman, who had been tutor to two of his brothers.

In October, 1638, Robert Boyle and his brother were sent into France. After a short stay at Lyons, they reached Geneva, where Robert remained with his tutor for about a year and three quarters. During his residence here an incident occurred which he regarded as the most important event of his life, and which we therefore give in his own words.

"To frame a right apprehension of this, you must understand that, though his inclinations were ever virtuous, and his life free from scandal and inoffensive, yet had the piety he was master of already so diverted him from aspiring unto more, that Christ, who long had lain asleep in his conscience (as He once did in the ship), must now, as then, be waked by a storm. For at a time which (being the very heat of summer) promised nothing less, about the dead of night, that adds most terror to such accidents, [he] was suddenly waked in a fright with such loud claps of thunder (which are oftentimes very terrible in those hot climes and seasons), that he thought the earth would owe an ague to the air, and every clap was both preceded and attended with flashes of lightning, so frequent and so dazzling that [he] began to imagine them the sallies of that fire that must consume the world. The long continuance of that dismal tempest, where the winds were so loud as almost drowned the noise of the very thunder, and the showers so hideous as almost quenched the lightning ere it could reach his eyes, confirmed him in his apprehensions of the day of judgment's being at hand. Whereupon the consideration of his unpreparedness to welcome it, and the hideousness of being surprised by it in an unfit condition, made him resolve and vow that, if his fears were that night disappointed, all his further additions to his life should be more religiously and watchfully employed. The morning came, and a serene, cloudless sky returned, when he ratified his determinations so solemnly, that from that day he dated his conversion, renewing, now he was past danger, the vow he had made whilst he believed himself to be in it; and though his fear was (and he blushed it was so) the occasion of his resolution of amendment, yet at least he might not owe his more deliberate consecration of himself to piety to any less noble motive than that of its own excellence."

After leaving Geneva, he crossed the Alps and travelled through Northern Italy. Here he spent much time in learning Italian; "the rest of his spare hours he spent in reading the modern history in Italian, and the new paradoxes of the great stargazer Galileo, whose ingenious books, perhaps because they could not be so otherwise, were confuted by a decree from Rome; his highness the Pope, it seems, presuming, and that justly, that the infallibility of his chair extended equally to determine points in philosophy as in religion, and loth to have the stability of that earth questioned in which he had established his kingdom."

Having visited Rome, he at length returned to France, and was detained at Marseilles, awaiting a remittance from the earl to enable him to continue his travels. Through some miscarriage, the money which the earl sent did not arrive, and Robert and his brother had to depend on the credit of the tutor to procure the means to enable them to return home. They reached England in the summer of 1644, "where we found things in such confusion that, although the manor of Stalbridge were, by my father's decease, descended unto me, yet it was near four months before I could get thither." On reaching London, Robert Boyle resided for some time with his sister, Lady Ranelagh, and was thus prevented from entering the Royalist Army. Later on he returned for a short time to France; visited Cambridge in December, 1645, and then took up his residence at Stalbridge till May, 1650, where he commenced the study of chemistry and natural philosophy.

It was in October, 1646, that Boyle first made mention of the "*invisible college*," which afterwards developed into the Royal Society. Writing to a Fellow of Magdalen College, Cambridge, in February, 1647, he says, "The corner-stones of the *invisible*, or, as they term themselves, the *philosophical college*, do now and then honour me with their company." It appears that a desire to escape from the troubles of the times had induced several persons to take refuge in philosophical pursuits, and, meeting together to discuss the subjects of their study, they formed the "invisible college." Boyle says, "I will conclude their praises with the recital of their chiefest fault, which is very incident to almost all good things, and that is, that there is not enough of them." Dr. Wallis, one of the first members of the society, states that Mr. Theodore Hooke, a German of the Palatinate, then resident in London, "gave the first occasion and first suggested those meetings and many others. These meetings we held sometimes at Dr. Goddard's lodging, in Wood Street (or some convenient place near), on occasion of his keeping an operator in his house, for grinding glasses for telescopes and microscopes, and sometimes at a convenient place in Cheapside; sometimes at Gresham College, or some place near adjoining. Our business was (precluding theology and State affairs) to discourse and consider of philosophical inquiries, and such as related thereunto; as physic, anatomy, geometry, astronomy, navigation, statics, magnetics, chemics, mechanics, and natural experiments, with the state of these studies as then cultivated at home and abroad. About the year 1648-49 some of us being removed to Oxford, first Dr. Wilkins, then I, and soon after Dr. Goddard, our company divided. Those in London continued to meet there as before, and we with them when we had occasion to be there. And those of us at Oxford, with Dr. Ward, since Bishop of Salisbury, Dr. Ralph Bathurst, now President of Trinity College in Oxford, Dr. Petty, since Sir William Petty, Dr. Willis, then an eminent physician in Oxford, and divers others, continued such meetings in Oxford, and brought those studies into fashion there; meeting first at Dr. Petty's lodgings, in an apothecary's house, because of the convenience of inspecting drugs and the like, as there was occasion; and after his remove to Ireland (though not so constantly) at the lodgings of Dr. Wilkins, then Warden of Wadham College; and after his removal to Trinity College in Cambridge, at the lodgings of the Honourable Mr. Robert Boyle, then resident for divers years in Oxford. These meetings in London continued, and after the king's return, in 1660, were increased with the accession of divers worthy and honourable persons, and were afterwards incorporated by the name of the *Royal Society*, and so continue to this day."

Boyle was only about twenty years of age when he wrote his "Free Discourse against Swearing;" his "Seraphic Love; or, Some Motives and Incentives to the Love of God;" and his "Essay on Mistaken Modesty." "Seraphic Love" was the last of a series of treatises on love, but the only one of the series that he published, as he considered the others too trifling to be published alone or in conjunction with it. In a letter to Lady Ranelagh, he refers to his laboratory as "a kind of Elysium," and there were few things which gave him so much pleasure as his furnaces and philosophical experiments. In 1652 he visited Ireland, returning in the following summer. In the autumn he was again obliged to visit Ireland, and remained there till the summer of 1654, though residence in that country was far from agreeable to him. He styled it "a barbarous country, where chemical spirits were so misunderstood, and chemical instruments so unprocurable, that it was hard to have any hermetic thoughts in it." On his return he settled in Oxford, and there his lodgings soon became the centre of the scientific life of the university. Boyle and his friends may be regarded as the pioneers of experimental philosophy in this country. To Boyle the methods of Aristotle appeared little more than discussions on words; for a long time he refused to study the philosophy of Descartes, lest he should be turned aside from reasoning based strictly on the results of experiment. The method pursued by these philosophers had been fully discussed by Lord Bacon, but at best his experimental methods, though most complete and systematic, existed only upon paper, and it was reserved for Boyle and his friends to put the Baconian philosophy into actual practice.

It was during his residence at Oxford that he invented the air-pump, which was afterwards improved for him by Hooke, and with which he conducted most of those experiments on the "spring" and weight of the air, which led up to the investigations that have rendered his name inseparably connected with "the gaseous laws." The experiments of Galileo and of Torricelli had shown that the pressure of the air was capable of supporting a column of water about thirty-four feet in height, or a column of mercury nearly thirty inches high. The younger Pascal, at the request of Torricelli, had carried a barometer to the summit of the Puy de Dome, and demonstrated that the height of the column of mercury supported by the air diminishes as the altitude is increased. Otto von Guericke had constructed the Magdeburg hemispheres, and shown that, when exhausted, they could not be separated by sixteen horses, eight pulling one way and eight the other. He was aware that the same traction could have been produced by eight horses if one of the hemispheres had been attached to a fixed obstacle; but, with the instincts of a popular lecturer, he considered that the spectacle would thus be rendered less striking, and it was prepared for the king's entertainment. Boyle wished for an air-pump with an aperture in the receiver sufficiently large for the introduction of various objects, and an arrangement for exhausting it without filling the receiver with water or otherwise interfering with the objects placed therein. His apparatus consisted of a large glass globe capable of containing about three gallons or thereabouts, terminating in an open tube below, and with an aperture of about four inches diameter at the top. Around this aperture was cemented a turned brass ring, the inner surface being conical, and into this conical seat was fitted a brass plate with a thick rim, but drilled with a small hole in the centre. To this hole, which was also conical, was fitted a brass stopper, which could be turned round when the receiver was exhausted. By attaching a string to this stopper, which was so long as to enter the receiver to the depth of two or three inches, and turning the stopper in its seat, the string could be wound up, and thus objects could be moved within the receiver. The tube at the bottom of the receiver communicated with a stop-cock, and this with the upper end of the pumpbarrel, which was inverted, so that this stop-cock, which was at the top of the barrel, took the place of the foot-valve. The piston was solid, made of wood, and surrounded with sole leather, which was kept well greased. There being no valve in the piston, it was necessary to place an exhaust-valve in the upper end of the cylinder. This consisted of a small brass plug closing a conical hole so that it could be removed at pleasure. The construction of the cylinder was, therefore, similar to that of an ordinary force-pump, except that the valves had to be moved by hand (as in the early forms of the steam-engine). The piston was raised and depressed by means of a rack and pinion. The pumps could be used either for exhausting the receiver or for forcing air into it, according to the order in which the "valves" were opened. If the stop-cock communicating with the receiver were open while the piston was being drawn down, and the brass plug removed so as to open the exhaust-valve when the piston was being forced up, the receiver would gradually be exhausted. If the brass plug were removed during the descent of the piston, and the stop-cock opened during its ascent, air would be forced into the receiver. In the latter case it was necessary to take special precautions to prevent the brass plate at the top of the receiver being raised from its seat. All joints were made air-tight with "diachylon," and when, through the bursting of a glass bulb within it, the receiver became cracked, the crack was rendered air-tight by the same means. Other receivers of smaller capacity were also provided, on account of the greater readiness with which they could be exhausted.

With this apparatus Boyle carried out a long series of experiments. He could reduce the pressure in the large receiver to somewhat less than that corresponding to an inch of mercury, or about a foot of water. Squeezing a bladder so as to expel nearly all the air, tying the neck, and then introducing it into the receiver, he found, on working the pump, that the bladder swelled so that at length it became completely distended. In order to account for this great expansibility, Boyle pictured the constitution of the air in the following way. He supposed the air to consist of separate particles, each resembling a spiral spring, which became tightly wound when exposed to great pressure, but which expanded so as to occupy a larger circle when the pressure was diminished. Each of these little spirals he supposed to rotate about a diameter so as to exclude every other body from the sphere in which it moved. Increasing the length of the diameter tenfold would increase the volume of one of these spheres, and therefore the volume of the gas, a thousandfold. Possibly this was only intended as a mental illustration, exhibiting a mechanism by which very great expansion might conceivably be produced, and scarcely pretending to be considered a *theory* of the constitution of the air. Boyle's first idea seems to have been derived from a lock of wool in which the elasticity of each fibre caused the lock to expand after it had been compressed in the hand. In another passage he speaks of the air as consisting of a number of bodies capable of striking against a surface exposed to them. He demonstrated the weight of the air by placing a delicate balance within the receiver, suspending from one arm a bladder half filled with water, and balancing it with brass weights. On exhausting the air, the bladder preponderated, and, by repeating the experiment with additional weights on the other arm until a balance was effected in the exhausted receiver, he determined the amount of the preponderance. In another experiment he compressed air in a bladder by tying a pack-thread round it, balanced it from one arm of his balance in the open air; then, pricking the bladder so as to relieve the pressure, he found that with the escape of the compressed air the weight diminished.

One of the most important of his experiments with the air-pump was the following. He placed within the receiver the cistern of a mercurial barometer, the tube of which was made to pass through the central hole in the brass plate, from which the stopper had been removed. The space around the tube was filled up with cement, and the receiver exhausted. At each stroke of the pump the mercury in the barometer tube descended, but through successively diminishing distances, until at length it stood only an inch above the mercury in the cistern. The experiment was then repeated with a tube four feet long and filled with water. This constituted the nineteenth experiment referred to later on. A great many strokes of the pump had to be made before the water began to descend. At length it fell till the surface in the tube stood only about a foot above that in the tank. Placing vessels of ordinary spring-water and of distilled rain-water in the receiver, he found that, after the exhaustion had reached a certain stage, bubbles of gas were copiously evolved from the spring-water, but not from the distilled water. On another occasion he caused warm water to boil by a few strokes of the pump; and, continuing the exhaustion, the water was made to boil at intervals until it became only lukewarm. The experiment was repeated with several volatile liquids. He also noticed the cloud formed in the receiver when the air was allowed rapidly to expand; but the mechanical theory of heat had not then made sufficient progress to enable him to account for the condensation by the loss of heat due to the work done by the expanding air. The very minute accuracy of his observations is conspicuous in the descriptions of most of his experiments. That the air is the usual medium for the conveyance of sound was shown by suspending a watch by a linen thread within the receiver. On exhausting the air, the ticking of the watch ceased to be heard. A pretty experiment consisted in placing a bottle of a certain fuming liquid within the receiver; on exhausting the air, the fumes fell over the neck of the bottle and poured over the stand on which it was placed like a stream of water. Another experiment, the thirty-second, is worthy of mention on account of the use to which it was afterwards applied in the controversy respecting the cause of suction. The receiver, having been exhausted, was removed from the cylinder, the stop-cock being turned off, and a small brass valve, to which a scale-pan was attached, was placed just under the aperture of the tube below the stop-cock. On turning the latter, the stream of air raised the valve, closing the aperture, and the atmospheric pressure supported it until a considerable weight had been placed in the scale-pan. Because the receiver could not be exhausted so thoroughly as the pump-cylinder, Boyle attempted to measure the pressure of the air by determining what weight could be supported by the piston. He found first that a weight of twenty-eight pounds suspended directly from the piston was sufficient to overcome friction when air was admitted above the piston. When the access of air to the top of the piston was prevented, more than one hundred pounds additional weight was required to draw down the piston. The diameter of the cylinder was about three inches.

Boyle's style of reasoning is well illustrated by the following from his paper on "The Spring of the Air: " —

"In the next place, these experiments may teach us what to judge of the vulgar axiom received for so many ages as an undoubted truth in the peripatetick schools, that Nature abhors and flieth a vacuum, and that to such a degree that no human power (to go no higher) is able to make one in the universe; wherein heaven and earth would change places, and all its other bodies rather act contrary to their own nature than suffer it… It will not easily, then, be intelligibly made out how hatred or aversation, which is a passion of the soul, can either for a vacuum or any other object be supposed to be in water, or such like inanimate body, which cannot be presumed to know when a vacuum would ensue, if they did not bestir themselves to prevent it; nor to be so generous as to act contrary to what is most conducive to their own particular preservation for the public good of the universe. As much, then, of intelligible and probable truth as is contained in this metaphorical expression seems to amount but to this – that by the wise Author of nature (who is justly said to have made all things in number, weight, and measure) the universe, and the parts of it, are so contrived that it is hard to make a vacuum in it, as if they studiously conspired to prevent it. And how far this itself may be granted deserves to be further considered.

"For, in the next place, our experiments seem to teach that the supposed aversation of Nature to a vacuum is but accidental, or in consequence, partly of the weight and fluidity, or, at least, fluxility of the bodies here below; and partly, and perhaps principally, of the air, whose restless endeavour to expand itself every way makes it either rush in itself or compel the interposed bodies into all spaces where it finds no greater resistance than it can surmount. And that in those motions which are made *ob fugam vacui* (as the common phrase is), bodies act without such generosity and consideration as is wont to be ascribed to them, is apparent enough in our thirty-second experiment, where the torrent of air, that seemed to strive to get into the emptied receiver, did plainly prevent its own design, by so impelling the valve as to make it shut the only orifice the air was to get [in] at. And if afterwards either Nature or the internal air had a design the external air should be attracted, they seemed to prosecute it very unwisely by continuing to suck the valve so strongly, when they found that by that suction the valve itself could not be drawn in; whereas, by forbearing to suck, the valve would, by its own weight, have fallen down and suffered the excluded air to return freely, and to fill again the exhausted vessel…

"And as for the care of the public good of the universe ascribed to dead and stupid bodies, we shall only demand why, in our nineteenth experiment, upon the exsuction of the ambient air, the water deserted the upper half of the glass tube, and did not ascend to fill it up till the external air was let in upon it. Whereas, by its easy and sudden rejoining that upper part of the tube, it appeared both that there was then much space devoid of air, and that the water might, with small or no resistance, have ascended into it, if it could have done so without the impulsion of the readmitted air; which, it seems, was necessary to mind the water of its formerly neglected duty to the universe."

Boyle then goes on to explain the phenomena correctly by the pressure of the air. Elsewhere he accounts for the diminished pressure on the top of a mountain by the diminished weight of the superincumbent column of air.

The treatise on "The Spring of the Air" met with much opposition, and Boyle considered it necessary to defend his doctrine against the objections of Franciscus Linus and Hobbes. In this defence he described the experiment in connection with which he is most generally remembered. Linus had admitted that the air might possess a certain small amount of elasticity, but maintained that the force with which mercury rose in a barometer tube was due mainly to a totally different action, as though a string were pulling upon it from above. This was his funicular hypothesis. Boyle undertook to show that the pressure of the air might be made to support a much higher column of mercury than that of the barometer. To this end he took a glass tube several feet in length, and bent so as to form two vertical legs connected below. The shorter leg was little more than a foot long, and hermetically closed at the top. The longer leg was nearly eight feet in length, and open at the top. The tube was suspended by strings upon the staircase, the bend at the bottom pressing lightly against the bottom of a box placed to receive the mercury employed in case of accident. Each leg of the tube was provided with a paper scale. Mercury was poured in at the open end, the tube being tilted so as to allow some of the air to escape from the shorter limb until the mercury stood at the same level in both legs when the tube was vertical. The length of the closed tube occupied by the air was then just twelve inches. The height of the barometer was about 29-1/8 inches. Mercury was gently poured into the open limb by one operator, while another watched its height in the closed limb. The results of the experiments are given in the table on the opposite page.

In this table the third column gives the result of adding to the second column the height of the barometer, which expresses in inches of mercury the pressure of the air on the free surface of the mercury in the longer limb. The fourth column gives the total pressure, in inches of mercury, on the hypothesis that the pressure of the air varies inversely as the volume. The agreement between the third and fourth columns is very close, considering the roughness of the experiment and that no trouble appears to have been taken to *calibrate* the shorter limb of the tube, and justified Boyle in concluding that the hypothesis referred to expresses the relation between the volume and pressure of a given mass of air.

Length of closed tube occupied by air.	Height of mercury in open tube above that in closed tube.	Total pressure on air in inches of mercury.	Total pressure according to Boyle's law.
12	0	29-2/16	29-2/16
11-1/2	1-7/16	30-9/16	30-6/16
11	2-13/16	31-15/16	31-12/16
10-1/2	4-6/16	33-8/16	33-1/7
10	6-3/16	35-5/16	35
9-1/2	7-14/16	37	36-15/19
9	10-1/16	39-3/16	38-7/8
8-1/2	12-8/16	41-10/16	41-2/17
8	15-1/16	44-3/16	43-11/16
7-1/2	17-15/16	47-1/16	46-3/5
7	21-3/16	50-5/16	50
6-1/2	25-3/16	54-5/16	53-10/13
6	29-11/16	58-13/16	58-2/8
5-3/4	32-3/16	61-5/16	60-13/23
5-1/2	34-15/16	64-1/16	63-6/11
5-1/4	37-15/16	67-1/16	66-4/7
5	41-9/16	70-11/16	70
4-3/4	45	74-2/16	73-11/19
4-1/2	48-12/16	77-14/16	77-2/3
4-1/4	53-11/16	82-13/16	82-4/17
4	58-2/16	87-14/16	87-1/8
3-3/4	63-15/16	93-1/16	93-1/5
3-1/2	71-5/16	100-7/16	99-6/7
3-1/4	78-11/16	107-13/16	107-7/13
3	88-7/16	117-9/16	116-4/8

To extend the investigation so as to include expansion below atmospheric pressure, a different apparatus was employed. It consisted of a glass tube about six feet in length, closed at the lower end and filled with mercury. Into this bath of mercury was plunged a length of quill tube, and the upper end was sealed with wax. When the wax and air in the tube had cooled, a hot pin was passed through the wax, making a small orifice by which the amount of air in the tube was adjusted so as to occupy exactly one inch of its length as measured by a paper scale attached thereto, after again sealing the wax. The quill tube was then raised, and the height of the surface of the mercury in the tube above that in the bath noticed, together with the length of the tube occupied by the air. The difference between the height of the barometer and the height of the mercury in the tube above that in the bath gave the pressure on the imprisoned air in inches of mercury. The result showed that the volume varied very nearly in the inverse ratio of the pressure. A certain amount of air, however, clung to the sides of the quill tube when immersed in the mercury, and no care was taken to remove it by boiling the mercury or otherwise; in consequence of this, as the mercury descended, this air escaped and joined the rest of the air in the tube. This made the pressure rather greater than it should have been towards the end of the experiment, and when the tube was again pressed down into the bath it was found that, when the surfaces of the mercury within and without the tube were at the same level, the air occupied nearly 1-1/8 inch instead of one inch of the tube. These experiments first established the truth of the great law known as "Boyle's law," which states that *the volume of a given mass of a perfect gas varies inversely as the pressure to which it is exposed*.

Another experiment, to show that the pressure of the air was the cause of suction, Boyle succeeded in carrying out at a later date. Two discs of marble were carefully polished, so that when a little spirit of turpentine was placed between them the lower disc, with a pound weight suspended from it, was supported by the upper one. The apparatus was introduced into the air-pump, and a considerable amount of shaking proved insufficient to separate the discs. After sixteen strokes of the pump, on opening the communication between the receiver and cylinder, when no mechanical vibration occurred, the discs separated.

Upon the Restoration in 1660, the Earl of Clarendon, who was Lord Chancellor of England, endeavoured to persuade Boyle to enter holy orders, urging the interest of the Church as the chief motive for the proceeding. This made some impression upon Boyle, but he declined for two reasons – first, because he thought that he would have a greater influence for good if he had no share in the patrimony of the Church; and next, because he had never felt "an inward motion to it by the Holy Ghost."

In 1649 an association was incorporated by Parliament, to be called "the President and Society for the Propagation of the Gospel in New England," whose object should be "to receive and dispose of moneys in such manner as shall best and principally conduce to the preaching and propagating the gospel among the natives, and for the maintenance of schools and nurseries of learning for the education of the children of the natives; for which purpose a general collection was appointed to be made in and through all the counties, cities, towns, and parishes of England and Wales, for a charitable contribution, to be as the foundation of so pious and great an undertaking." The society was revived by special charter in 1661, and Boyle was appointed president, an office he continued to hold until shortly before his death. The society afterwards enlarged its sphere of operations, and became the Society for the Propagation of the Gospel in Foreign Parts.

In the same year (1661) Boyle published "Some Considerations on the Usefulness of Experimental Natural Philosophy," etc., and in 1663 an extremely interesting paper on "Experiments and Considerations touching Colours." In the course of this paper he describes some very beautiful experiments with a tincture of *Lignum nephriticum*, wherein the dichroism of the extract is made apparent. Boyle found that by transmitted light it appeared of a bright golden colour, but when viewed from the side from which it was illuminated the light emitted was sky blue, and in some cases bright green. By arranging experiments so that some parts of the liquid were seen by the transmitted light and some by the scattered light, very beautiful effects were produced. Boyle endeavoured to learn something of the nature of colours by projecting spectra on differently coloured papers, and observing the appearance of the papers when illuminated by the several spectral rays. He also passed sunlight, concentrated by a lens, through plates of differently coloured glass superposed, allowing the light to fall on a white paper screen, and observing the tint of the light which passed through each combination. But the most interesting of these experiments was the actual mixture of light of different colours by forming two spectra, one by means of a fixed prism, the other by a prism held in the hand, and superposing the latter on the former so that different colours were made to coincide. This experiment was repeated in a modified form, nearly two hundred years later, by Helmholtz, who found that the mixture of blue and yellow lights produced pink. Unfortunately, Boyle's spectra were far from pure, for, the source of light being of considerable dimensions, the different colours overlapped one another, as in Newton's experiments, and in consequence some of his conclusions were inaccurate. Thus blue paper in the yellow part of the spectrum appeared to Boyle green instead of black, but this was due to the admixture of green light with the yellow. He concluded that bodies appear black because they damp the light so as to reflect very little to the eye, but that the surfaces of white bodies consist of innumerable little facets which reflect the light in all directions. In the same year he published some "Observations on a Diamond, which shines in the Dark;" and an extensive treatise on "Some Considerations touching the Style of the Holy Scriptures." Next year appeared several papers from his pen, the most important being "Occasional Reflections upon Several Subjects," the wide scope of which may be gathered from the title. His "New Experiments and Observations touching Cold" were printed in 1665. In this paper he discussed the cause of the force exerted by water in freezing, methods of measuring degrees of cold, the action of freezing-mixtures, and many other questions. He contended that cold was probably only privative, and not a positive existence.

Lord Bacon had asserted that the "essential self" of heat was probably motion and nothing more, and had adduced several experiments and observations in support of this opinion. In his paper on the mechanical origin of heat and cold, Boyle maintained that heat was motion, but motion of the very small particles of bodies, very intense, and taking place in all directions; and that heat could be produced by any means whatever by which the particles of bodies could be agitated. On one occasion he caused two pieces of brass, one convex and the other concave, to be pressed against each other by a spring, and then rubbed together in a vacuum by a rotary motion communicated by a shaft which passed air-tight through the hole in the cover of the receiver, a little emery being inserted between them. In the second experiment the brasses became so hot that he "could not endure to hold [his] hand on either of them." This experiment was intended, like the rubbing of the blocks of ice in vacuo by Davy, to meet the objection that the heat developed by friction was due to the action of the air. The following extract from a paper intended to show that the sense of touch cannot be relied upon for the estimation of temperature, shows that Boyle possessed a very clear insight into the question: – "The account upon which we judge a body to be cold seems to be that we feel its particles less vehemently agitated than those of our fingers or other parts of the organ of touching; and, consequently, if the temper of that organ be changed, the object will appear more or less cold to us, though itself continue of one and the same temperature." To determine the expansion of water in freezing, he filled the bulb and part of the stem of a "bulb tube," or, as it was then generally called, "a philosophical egg," with water, and applying a freezing-mixture, at first to the bottom of the bulb, he succeeded in freezing the water without injury to the glass, and found that 82 volumes of water expanded to 91-1/8 volumes of ice – an expansion of about 11-1/8 per cent. Probably air-bubbles caused the ice to appear to have a greater volume than it really possessed, the true expansion being about nine per cent. of the volume of the water at 4 °C. The expansion of water in freezing he employed in order to compress air to a greater extent than he had been able otherwise to compress it. Having nearly filled a tube with water, but left a little air above, and then having sealed the top of the tube, he froze the water from the bottom upwards, so that in expanding it compressed the air to one-tenth of its former volume.

Magnetism and electricity came in for some share of Boyle's attention. He carried out a number of experiments on magnetic induction, and found that lodestones, as well as pieces of iron, when heated and allowed to cool, became magnetized by the induction of the earth. His later experiments with exhausted receivers were not made with his first pump, but with a two-barrelled pump, in which the pistons were connected by a cord passing over a large fixed pulley, so that, when the receiver was nearly exhausted, the pressure of the air on the descending piston during the greater part of the stroke nearly balanced that on the ascending piston. In this respect the pump differed only from Hawksbee's in having the pulley and cord instead of the pinion and two racks. It also resembled Hawksbee's pump in having self-closing valves in the pistons and at the bottom of the cylinders, which, in this pump, had their open ends at the top. The pistons were alternately raised and lowered by the feet of the operator, which were placed in stirrups, of which one was fixed on each piston. The lower portions of the barrels were filled with water, through which the air bubbled, and this, occupying the clearance, enabled a much higher degree of exhaustion to be produced than could be obtained without its employment.

In 1665 Boyle was nominated Provost of Eton, but declined to accept the appointment. His "Hydrostatical Paradoxes," published about this time, contain all the ordinary theorems respecting the pressure of fluids under the action of gravity demonstrated experimentally.

In 1677 Boyle printed, at his own expense, five hundred copies of the four Gospels and the Acts of the Apostles in the Malayan tongue. This was but one of his many contributions towards similar objects.

On November 30, 1680, the Royal Society chose Boyle for President. He, however, declined to accept the appointment, because he had conscientious objections to taking the oath required of the President by the charter of the Society.

It appears that very many of Boyle's manuscripts, which were written in bound books, were taken away, and others mutilated by "corrosive liquors." In May, 1688, he made this known to his friends, but, though these losses put him on his guard, he complained afterwards that all his care and circumspection had not prevented the loss of "six centuries of matters of fact in one parcel," besides many other smaller papers. His works, however, which have been published are so numerous that it would take several pages for the bare enumeration of their titles, many of them being devoted to medical subjects. The edition published in London in 1743 comprises nearly three thousand pages of folio. Boyle always suffered from weak eyes, and in consequence he declined to revise his proofs. In the advertisement to the original edition of his works the publisher mentioned this, and at the same time pleaded his own business engagements as an excuse for not revising the proofs himself! It was partly on account of the injury to his manuscripts, and partly through failing health, that in 1689 he set apart two days in the week, during which he declined to receive visitors, that he might devote himself to his work, and especially to the reparation of the injured writings. About this time he succeeded in procuring the repeal of an Act passed in the fifth year of Henry IV. to the effect "that none from thenceforth should use to multiply gold or silver, or use the craft of multiplication; and if any the same do, they should incur the pain of felony." By this repeal it was made legal to extract gold and silver from ores, or from their mixtures with other metals, in this country provided that the gold and silver so procured should be put to no other use than "the increase of moneys." It is curious that Boyle seems always to have believed in the possibility of transmuting other metals into gold.

His sister, Lady Ranelagh, died on December 23, 1691, and Boyle survived her but a few days, for he died on December 30, and his body was interred near his sister's grave in the chancel of St. Martin's-in-the-Fields. Dr. Shaw, in his preface to Boyle's works, writes, "The men of wit and learning have, in all ages, busied themselves in explaining nature by words; but it is Mr. Boyle alone who has wholly laid himself out in showing philosophy in action. The single point he perpetually keeps in view is to render his reader, not a talkative or a speculative, but an actual and practical philosopher. Himself sets the example; he made all the experiments he possibly could upon natural bodies, and communicated them with all desirable candour and fidelity." The second part of his treatise on "The Christian Virtuoso," Boyle concluded with a number of aphorisms, of which the following well represent his views respecting science: —

"I think it becomes Christian philosophers rather to try whether they can investigate the final causes of things than, without trial, to take it for granted that they are undiscoverable."

"The book of Nature is a fine and large piece of tapestry rolled up, which we are not able to see all at once, but must be content to wait for the discovery of its beauty and symmetry, little by little, as it gradually comes to be more unfolded or displayed."

BENJAMIN FRANKLIN

Among those whose contributions to physics have immortalized their names in the annals of science, there is none that holds a more prominent position in the history of the world than Benjamin Franklin. At one time a journeyman printer, living in obscure lodgings in London, he became, during the American War of Independence, one of the most conspicuous figures in Europe, and among Americans his reputation was probably second to none, General Washington not excepted.

Professor Laboulaye says of Franklin: "No one ever started from a lower point than the poor apprentice of Boston. No one ever raised himself higher by his own unaided forces than the inventor of the lightning-rod. No one has rendered greater service to his country than the diplomatist who signed the treaty of 1783, and assured the independence of the United States. Better than the biographies of Plutarch, this life, so long and so well filled, is a source of perpetual instruction to all men. Every one can there find counsel and example."

A great part of the history of his life was written by Franklin himself, at first for the edification of the members of his own family, and afterwards at the pressing request of some of his friends in London and Paris. His autobiography does not, however, comprise much more than the first fifty years of his life. The first part was written while he was the guest of the Bishop of St. Asaph, at Twyford; the second portion at Passy, in the house of M. de Chaumont; and the last part in Philadelphia, when he was retiring from public life at the age of eighty-two. The former part of this autobiography was translated into French, and published in Paris, in 1793, though it is not known how the manuscript came into the publisher's hands. The French version was translated into English, and published in England and America, together with such other of Franklin's works as could be collected, before the latter part was given to the world by Franklin's grandson, to whom he had bequeathed his papers, and who first published them in America in 1817.

For a period of three hundred years at least Franklin's family lived on a small freehold of about thirty acres, in the village of Ecton, in Northamptonshire, the eldest son, who inherited the property, being always brought up to the trade of a smith. Franklin himself "was the youngest son of the youngest son for five generations back." His grandfather lived at Ecton till he was too old to follow his business, when he went to live with his second son, John, who was a dyer at Banbury. To this business Franklin's father, Josiah, was apprenticed. The eldest son, Thomas, was brought up a smith, but afterwards became a solicitor; the other son, Benjamin, was a silk-dyer, and followed Josiah to America. He was fond of writing poetry and sermons. The latter he wrote in a shorthand of his own inventing, which he taught to his nephew and namesake, in order that he might utilize the sermons if, as was proposed, he became a Presbyterian minister. Franklin's father, Josiah, took his wife and three children to New England, in 1682, where he practised the trade of a tallow-chandler and soap-boiler. Franklin was born in Boston on January 6 (O.S.), 1706, and was the youngest of seventeen children, of whom thirteen grew up and married.

Benjamin being the youngest of ten sons, his father intended him for the service of the Church, and sent him to the grammar school when eight years of age, where he continued only a year, although he made very rapid progress in the school; for his father concluded that he could not afford the expense of a college education, and at the end of the year removed him to a private commercial school. At the age of ten young Benjamin was taken home to assist in cutting the wicks of candles, and otherwise to make himself useful in his father's business. His enterprising character as a boy is shown by the following story, which is in his own words: —

> There was a salt marsh that bounded part of the mill-pond, on the edge of which, at high-water, we used to stand to fish for minnows. By much trampling we had made it a mere quagmire. My proposal was to build a wharf there fit for us to

> stand upon, and I showed my comrades a large heap of stones, which were intended for a new house near the marsh, and which would very well suit our purpose. Accordingly, in the evening, when the workmen were gone, I assembled a number of my play-fellows, and working with them diligently, like so many emmets, sometimes two or three to a stone, we brought them all away and built our little wharf. The next morning the workmen were surprised at missing the stones, which were found in our wharf. Inquiry was made after the removers; we were discovered and complained of; several of us were corrected by our fathers; and, though I pleaded the usefulness of the work, mine convinced me that nothing was useful which was not honest.

Until twelve years of age Benjamin continued in his father's business, but as he manifested a great dislike for it, and his parents feared that he might one day run away to sea, they set about finding some trade which would be more congenial to his tastes. With this view his father took him to see various artificers at their work, that he might observe the tastes of the boy. This experience was very valuable to him, as it taught him to do many little jobs for himself when workmen could not readily be procured. During this time Benjamin spent most of his pocket-money in purchasing books, some of which he sold when he had read them, in order to buy others. He read through most of the books in his father's very limited library. These mainly consisted of works on theological controversy, which Franklin afterwards considered to have been not very profitable to him.

"There was another bookish lad in the town, John Collins by name, with whom I was intimately acquainted. We sometimes disputed, and very fond we were of argument, and very desirous of confuting one another, which disputatious turn, by the way, is apt to become a very bad habit, making people often very disagreeable in company by the contradiction that is necessary to bring it into practice; and thence, besides souring and spoiling the conversation, is productive of disgusts and perhaps enmities when you may have occasion for friendship. I had caught it by reading my father's books of dispute about religion. Persons of good sense, I have since observed, seldom fall into it, except lawyers, university men, and men of all sorts that have been bred at Edinburgh."

At length Franklin's fondness for books caused his father to decide to make him a printer. His brother James had already entered that business, and had set up in Boston with a new press and types which he had brought from England. He signed his indentures when only twelve years old, thereby apprenticing himself to his brother until he should attain the age of twenty-one. The acquaintance which he formed with booksellers through the printing business enabled him to borrow a better class of books than he had been accustomed to, and he frequently sat up the greater part of the night to read a book which he had to return in the morning.

While working with his brother, the young apprentice wrote two ballads, which he printed and sold in the streets of Boston. His father, however, ridiculed the performance; so he "escaped being a poet." He adopted at this time a somewhat original method to improve his prose writing. Meeting with an odd volume of the *Spectator*, he purchased it and read it "over and over," and wished to imitate the style. "Making short notes of the sentiment in each sentence," he laid them by, and afterwards tried to write out the papers without looking at the original. Then on comparison he discovered his faults and corrected them. Finding his vocabulary deficient, he turned some of the tales into verse, then retranslated them into prose, believing that the attempt to make verses would necessitate a search for several words of the same meaning. "I also sometimes jumbled my collection of hints into confusion, and after some weeks endeavoured to reduce them into the best order, before I began to form the full sentence and complete the paper. This was to teach me method in the arrangement of my thoughts."

Meeting with a book on vegetarianism, Franklin determined to give the system a trial. This led to some inconvenience in his brother's house-keeping, so Franklin proposed to board himself if his brother would give him half the sum he paid for his board, and out of this he was able to save a considerable amount for the purpose of buying books. Moreover, the time required for meals was so short that the dinner hour afforded considerable leisure for reading. It was on his journey from

Boston to Philadelphia that he first violated vegetarian principles; for, a large cod having been caught by the sailors, some small fishes were found in its stomach, whereupon Franklin argued that if fishes ate one another, there could be no reason against eating them, so he dined on cod during the rest of the journey.

After reading Xenophon's "Memorabilia," Franklin took up strongly with the Socratic method of discussion, and became so "artful and expert in drawing people, even of superior knowledge, into concessions, the consequence of which they did not foresee," that some time afterwards one of his employers, before answering the most simple question, would frequently ask what he intended to infer from the answer. This practice he gradually gave up, retaining only the habit of expressing his opinions with "modest diffidence."

In 1720 or 1721 James Franklin began to print a newspaper, the *New England Courant*. To this paper, which he helped to compose and print, Benjamin became an anonymous contributor. The members of the staff spoke highly of his contributions, but when the authorship became known, James appears to have conceived a jealousy of his younger brother, which ultimately led to their separation. An article in the paper having offended the Assembly, James was imprisoned for a month and forbidden to print the paper. He then freed Benjamin from his indentures, in order that the paper might be published in his name. At length, some disagreement arising, Benjamin took advantage of the cancelling of his indentures to quit his brother's service. As he could get no employment in Boston, he obtained a passage to New York, whence he was recommended to go to Philadelphia, which he reached after a very troublesome journey. His whole stock of cash then consisted of a Dutch dollar and about a shilling's worth of coppers. The coppers he gave to the boatmen with whom he came across from Burlington. His first appearance in Philadelphia, about eight o'clock on a Sunday morning, was certainly striking. A youth between seventeen and eighteen years of age, dressed in his working clothes, which were dirty through his journey, with his pockets stuffed out with stockings and shirts, his aspect was not calculated to command respect.

"Then I walked up the street, gazing about till near the market-house I met a boy with bread. I had made many a meal on bread, and, inquiring where he got it, I went immediately to the baker's he directed me to, in Second Street, and ask'd for bisket, intending such as we had in Boston; but they, it seems, were not made in Philadelphia. Then I asked for a threepenny loaf, and was told they had none such. So, not considering or knowing the difference of money, and the greater cheapness, nor the name of his bread, I bad him give me three-penny-worth of any sort. He gave me, accordingly, three great puffy rolls. I was surpriz'd at the quantity, but took it, and having no room in my pockets, walk'd off with a roll under each arm, and eating the other. Thus I went up Market Street as far as Fourth Street, passing by the door of Mr. Read, my future wife's father; when she, standing at the door, saw me, and thought I made, as I certainly did, a most awkward, ridiculous appearance. Then I turned and went down Chestnut Street and part of Walnut Street, eating my roll all the way, and, coming round, found myself again at Market Street Wharf, near the boat I came in, to which I went for a draught of the river water; and, being filled out with one of my rolls, gave the other two to a woman and her child that came down the river in the boat with us, and were waiting to go further."

In Philadelphia Franklin obtained an introduction, through a gentleman he had met at New York, to a printer, named Keimer, who had just set up business with an old press which he appeared not to know how to use, and one pair of cases of English type. Here Franklin obtained employment when the business on hand would permit, and he put the press in order and worked it. Keimer obtained lodgings for him at the house of Mr. Read, and, by industry and economical living, Franklin found himself in easy circumstances. Sir William Keith was then Governor of Pennsylvania, and hearing of Franklin, he called upon him at Keimer's printing-office, invited him to take wine at a neighbouring tavern, and promised to obtain for him the Government printing if he would set up for himself. It was then arranged that Franklin should return to Boston by the first ship, in order to see what help his father would give towards setting him up in business. In the mean while he was frequently invited to dine at the governor's house. Notwithstanding Sir William Keith's recommendation, Josiah Franklin thought his son too young to take the responsibility of a business, and would only promise to assist him if, when he was twenty-one, he had himself saved sufficient to purchase most of the requisite plant. On his return to Philadelphia, he delivered his father's letter to Sir William Keith, whereon the governor, stating that he was determined to have a good printer there, promised to find the means of equipping the printing-office himself, and suggested the desirability of Franklin's making a journey to England in order to purchase the plant. He promised letters of introduction to various persons in England, as well as a letter of credit to furnish the money for the purchase of the printing-plant. These letters Franklin was to call for, but there was always some excuse for their not being ready. At last they were to be sent on board the ship, and Franklin, having gone on board, awaited the letters. When the governor's despatches came, they were all put into a bag together, and the captain promised to let Franklin have his letters before landing. On opening the bag off Plymouth, there were no letters of the kind promised, and Franklin was left without introductions and almost without money, to make his own way in the world. In London he learned that Governor Keith was well known as a man in whom no dependence could be placed, and as to his giving a letter of credit, "he had no credit to give."

A friend of Franklin's, named Ralph, accompanied him from America, and the two took lodgings together in Little Britain at three shillings and sixpence per week. Franklin immediately obtained employment at Palmer's printing-office, in Bartholomew Close; but Ralph, who knew no trade, but aimed at literature, was unable to get any work. He could not obtain employment, even among the law stationers as a copying clerk, so for some time the wages which Franklin earned had to support the two. At Palmer's Franklin was employed in composing Wollaston's "Religion of Nature." On this he wrote a short critique, which he printed. it was entitled "A Dissertation on Liberty and Necessity, Pleasure and Pain." The publication of this he afterwards regretted, but it obtained for him introductions to some literary persons in London. Subsequently he left Palmer's and obtained work at Watts's printing-office, where he remained during the rest of his stay in London. The beer-drinking capabilities of some of his fellow-workmen excited his astonishment. He says: —

> We had an alehouse boy who attended always in the house to supply the workmen. My companion at the press drank every day a pint before breakfast, a pint at breakfast with his bread and cheese, a pint between breakfast and dinner, a pint at dinner, a pint in the afternoon about six o'clock, and another when he had done his day's work. I thought it a detestable custom, but it was necessary, he suppos'd, to drink *strong* beer, that he might be *strong* to labour. I endeavoured to convince him that the bodily strength afforded by beer could only be in proportion to the grain or flour of the barley dissolved in the water of which it was made; that there was more flour in a pennyworth of bread; and therefore, if he would eat that with a pint of water, it would give him more strength than a quart of beer. He drank on, however, and had four or five shillings to pay out of his wages every Saturday night for that muddling liquor; an expense I was free from. And thus these poor devils keep themselves always under.

Afterwards Franklin succeeded in persuading several of the compositors to give up "their muddling breakfast of beer and bread and cheese," for a porringer of hot-water gruel, with pepper, breadcrumbs, and butter, which they obtained from a neighbouring house at a cost of three halfpence.

Among Franklin's fellow-passengers from Philadelphia to England was an American merchant, a Mr. Denham, who had formerly been in business in Bristol, but failed and compounded with his creditors. He then went to America, where he soon acquired a fortune, and returned in Franklin's ship. He invited all his old creditors to dine with him. At the dinner each guest found under his plate a cheque for the balance which had been due to him, with interest to date. This gentleman always remained a firm friend to Franklin, who, during his stay in London, sought his advice when any important questions arose. When Mr. Denham returned to Philadelphia with a quantity of merchandise, he offered Franklin an appointment as clerk, which was afterwards to develop into a commission agency. The offer was accepted, and, after a voyage of nearly three months, Franklin reached Philadelphia on October 11, 1726. Here he found Governor Keith had been superseded by Major Gordon, and, what was of more importance to him, that Miss Read, to whom he had become engaged before leaving for England, and to whom he had written only once during his absence, had married. Shortly after starting in business, Mr. Denham died, and thus left Franklin to commence life again for himself. Keimer had by this time obtained a fairly extensive establishment, and employed a number of hands, but none of them were of much value; and he made overtures to Franklin to take the management of his printing-office, apparently with the intention of getting his men taught their business, so that he might afterwards be able to dispense with the manager. Franklin set the printing-house in order, started type-founding, made the ink, and, when necessary, executed engravings. As the other hands improved under his superintendence, Keimer began to treat his manager less civilly, and apparently desired to curtail his stipend. At length, through an outbreak of temper on the part of Keimer, Franklin left, but was afterwards induced to return in order to prepare copper-plates and a press for printing paper money for New Jersey.

While working for Keimer, Franklin formed a club, which was destined to exert considerable influence on American politics. The club met on Friday evenings, and was called the Junto. It was essentially a debating society, the subject for each evening's discussion being proposed at the preceding meeting. One of the rules was that the existence of the club should remain a secret, and that its members should be limited to twelve. Afterwards other similar clubs were formed by its members; but the existence of the Junto was kept a secret from them. The club lasted for about forty years, and became the nucleus of the American Philosophical Society, of which Franklin was the first president. This, and the fact that many of the great questions that arose previously to the Declaration of Independence were discussed in the Junto in the first instance, give to the club a special importance. The following are specimens of subjects discussed by the club: —

"Is sound an entity or body?"

"How may the phenomena of vapours be explained?"

"Is self-interest the rudder that steers mankind, the universal monarch to whom all are tributaries?"

"Which is the best form of government? and what was that form which first prevailed among mankind?"

"Can any one particular form of government suit all mankind?"

"What is the reason that the tides rise higher in the Bay of Fundy than the Bay of Delaware?"

"Is the emission of paper money safe?"

"What is the reason that men of the greatest knowledge are not the most happy?"

"How may the possessions of the Lakes be improved to our advantage?"

"Why are tumultuous, uneasy sensations united with our desires?"

"Whether it ought to be the aim of philosophy to eradicate the passions."

"How may smoky chimneys be best cured?"

"Why does the flame of a candle tend upwards in a spire?"

"Which is least criminal – a bad action joined with a good intention, or a good action with a bad intention?"

"Is it consistent with the principles of liberty in a free government to punish a man as a libeller when he speaks the truth?"

On leaving Keimer's, Franklin went into partnership with one of his fellow-workmen, Hugh Meredith, whose father found the necessary capital, and a printing-office was started which soon excelled its two rivals in Philadelphia. Franklin's industry attracted the attention of the townsfolk, and inspired the merchants with confidence in the prospects of the new concern. Keimer started a newspaper, which he had not the ability to carry on; Franklin purchased it from him for a trifle, remodelled it, and continued it in a very spirited manner under the title of the *Pennsylvania Gazette*. His political articles soon attracted the attention of the principal men of the state; the number of subscribers increased rapidly, and the paper became a source of considerable profit. Soon after, the printing for the House of Representatives came into the hands of the firm. Meredith never took to the business, and was seldom sober, and at length was bought out by his partner, on July 14, 1730. The discussion in the Junto on paper currency induced Franklin to publish a paper entitled "The Nature and Necessity of a Paper Currency." This was a prominent subject before the House, but the introduction of paper money was opposed by the capitalists. They were unable, however, to answer Franklin's arguments; the point was carried in the House, and Franklin was employed to print the money. The amount of paper money in Pennsylvania in 1739 amounted to £80,000; during the war it rose to more than £350,000.

"In order to secure my credit and character as a tradesman, I took care not only to be in *reality* industrious and frugal, but to avoid all appearances to the contrary. I drest plainly; I was seen at no places of idle diversion. I never went out a-fishing or shooting; a book, indeed, sometimes debauch'd me from my work, but that was seldom, snug, and gave no scandal; and, to show that I was not above my business, I sometimes brought home the paper I purchas'd at the stores thro' the streets on a wheelbarrow. Thus being esteem'd an industrious, thriving young man, and paying duly for what I bought, the merchants who imported stationery solicited my custom; others proposed supplying me with books, and I went on swimmingly. In the mean time, Keimer's credit and business declining daily, he was at last forc'd to sell his printing-house to satisfy his creditors."

On September 1, 1730, Franklin married his former *fiancée*, whose previous husband had left her and was reported to have died in the West Indies. The marriage was a very happy one, and continued over forty years, Mrs. Franklin living until the end of 1774. Industry and frugality reigned in the household of the young printer. Mrs. Franklin not only managed the house, but assisted in the business, folding and stitching pamphlets, and in other ways making herself useful. The first part of Franklin's autobiography concludes with an account of the foundation of the first subscription library. By the co-operation of the members of the Junto, fifty subscribers were obtained, who each paid in the first instance forty shillings, and afterwards ten shillings per annum. "We afterwards obtained a charter, the company being increased to one hundred. This was the mother of all the North American subscription libraries, now so numerous. It is become a great thing itself, and continually increasing. These libraries have improved the general conversation of the Americans, made the common tradesmen and farmers as intelligent as most gentlemen from other countries, and perhaps have contributed in some degree to the stand so generally made throughout the colonies in defence of their privileges."

Ten years ago this library contained between seventy and eighty thousand volumes.

Franklin's success in business was attributed by him largely to his early training. "My circumstances, however, grew daily easier. My original habits of frugality continuing, and my father having, among his instructions to me when a boy, frequently repeated a proverb of Solomon, 'Seest thou a man diligent in his business? he shall stand before kings; he shall not stand before mean men,' I from thence considered industry as a means of obtaining wealth and distinction, which encourag'd me, tho' I did not think that I should ever literally *stand before kings*, which, however, has since happened; for I have stood before *five*, and even had the honour of sitting down with one, the King of Denmark, to dinner."

After his marriage, Franklin conceived the idea of obtaining moral perfection. He was not altogether satisfied with the result, but thought his method worthy of imitation. Assuming that he possessed complete knowledge of what was right or wrong, he saw no reason why he should not always act in accordance therewith. His principle was to devote his attention to one virtue only at first for a week, at the end of which time he expected the practice of that virtue to have become a habit.

He then added another virtue to his list, and devoted his attention to the same for the next week, and so on, until he had exhausted his list of virtues. He then commenced again at the beginning. As his moral code comprised thirteen virtues, it was possible to go through the complete curriculum four times in a year. Afterwards he occupied a year in going once through the list, and subsequently employed several years in one course. A little book was ruled, with a column for each day and a line for each virtue, and in this a mark was made for every failure which could be remembered on examination at the end of the day. It is easy to believe his statement: "I am surprised to find myself so much fuller of faults than I had imagined; but I had the satisfaction of seeing them diminish."

"This my little book had for its motto these lines from Addison's 'Cato': —

"'Here will I hold. If there's a Power above us
(And that there is, all Nature cries aloud
Thro' all her work), He must delight in virtue;
And that which He delights in must be happy.'

"Another from Cicero: —

"'O vitæ Philosophia dux! O virtutum indagatrix expultrixque vitiorum! Unus dies ex præceptis tuis actus, peccanti immortalitati est anteponendus.'

"Another from the Proverbs of Solomon, speaking of wisdom and virtue: —

"'Length of days is in her right hand; and in her left hand riches and honour. Her ways are ways of pleasantness, and all her paths are peace.'

"And conceiving God to be the fountain of wisdom, I thought it right and necessary to solicit His assistance for obtaining it; to this end I formed the following little prayer, which was prefixed to my tables of examination, for daily use: —

"'O powerful Goodness! bountiful Father! merciful Guide! increase in me that wisdom which discovers my truest interest. Strengthen my resolutions to perform what that wisdom dictates. Accept my kind offices to Thy other children as the only return in my power for Thy continual favours to me.'

"I used also sometimes a little prayer which I took from Thomson's Poems, viz.: —

"'Father of light and life, Thou Good Supreme!
Oh teach me what is good; teach me Thyself!
Save me from folly, vanity, and vice,
From every low pursuit; and fill my soul
With knowledge, conscious peace, and virtue pure;
Sacred, substantial, never-failing bliss!'"

The senses in which Franklin's thirteen virtues were to be understood were explained by short precepts which followed them in his list. The list was as follows: —

"1. Temperance

"Eat not to dulness; drink not to elevation.

"2. Silence

"Speak not but what may benefit others or yourself; avoid trifling conversation.

"3. Order

"Let all your things have their places; let each part of your business have its time.

"4. Resolution

"Resolve to perform what you ought; perform without fail what you resolve.

"5. Frugality

"Make no expense but to do good to others or yourself; *i. e.* waste nothing.

"6. Industry

"Lose no time; be always employed in something useful; cut off all unnecessary actions.

"7. Sincerity

"Use no hurtful deceit; think innocently and justly; and, if you speak, speak accordingly.

"8. Justice

"Wrong none by doing injuries, or omitting the benefits that are your duty.

"9. Moderation

"Avoid extremes; forbear resenting injuries so much as you think they deserve.

"10. Cleanliness

"Tolerate no uncleanness in body, clothes, or habitation.

"11. Tranquillity

"Be not disturbed at trifles, or accidents common or unavoidable.

"12. Chastity

"13. Humility

"Imitate Jesus and Socrates."

The last of these was added to the list at the suggestion of a Quaker friend. Franklin claims to have acquired a good deal of the *appearance* of it, but concluded that in reality there was no passion so hard to subdue as *pride*. "For even if I could conceive that I had completely overcome it, I should probably be proud of my humility." The virtue which gave him most trouble, however, was order, and this he never acquired.

In 1732 appeared the first copy of "Poor Richard's Almanack." This was prepared, printed, and published by Franklin for about twenty-five years in succession, and nearly ten thousand copies were sold annually. Besides the usual astronomical information, it contained a collection of entertaining anecdotes, verses, jests, etc., while the "little spaces that occurred between the remarkable events in the calendar" were filled with proverbial sayings, inculcating industry and frugality as helps to virtue. These sayings were collected and prefixed to the almanack of 1757, whence they were copied into the American newspapers, and afterwards reprinted as a broad-sheet in England and in France.

In 1733 Franklin commenced studying modern languages, and acquired sufficient knowledge of French, Italian, and Spanish to be able to read books in those languages. In 1736 he was chosen Clerk to the General Assembly, an office to which he was annually re-elected until he became a member of the Assembly about 1750. There was one member who, on the second occasion of his election, made a long speech against him. Franklin determined to secure the friendship of this member. Accordingly he wrote to him to request the loan of a very scarce and curious book which was in his library. The book was lent and returned in about a week, with a note of thanks. The member ever after manifested a readiness to serve Franklin, and they became great friends – "Another instance of the truth of an old maxim I had learned, which says, '*He that has once done you a kindness will be more ready to do you another than he whom you yourself have obliged*.' And it shows how much more profitable it is prudently to remove, than to resent, return, and continue inimical proceedings."

In 1737 Franklin was appointed Deputy-Postmaster-General for Pennsylvania. He was afterwards made Postmaster-General of the Colonies. He read a paper in the Junto on the organization of the City watch, and the propriety of rating the inhabitants on the value of their premises in order to support the same. The subject was also discussed in the other clubs which had sprung from the Junto, and thus the way was prepared for the law which a few years afterwards carried Franklin's proposals into effect. His next scheme was the formation of a fire brigade, in which he met with his usual success, and other clubs followed, until most of the men of property in the city were members of one club or another. The original brigade, known as the Union Fire Company, was formed December 7, 1736. It was in active service in 1791.

Franklin founded the American Philosophical Society in 1743. The head-quarters of the society were fixed in Philadelphia, where it was arranged that there should always be at least seven members, viz. a physician, a botanist, a mathematician, a chemist, a mechanician, a geographer, and a general natural philosopher, besides a president, treasurer, and secretary. The other members might be resident in any part of America. Correspondence was to be kept up with the Royal Society of London and the Dublin Society, and abstracts of the communications were to be sent quarterly to all the members. Franklin became the first secretary.

Spain, having been for some years at war with England, was joined at length by France. This threatened danger to the American colonies, as France then held Canada, and no organization for their defence existed. Franklin published a pamphlet entitled "Plain Truth," setting forth the unarmed condition of the colonies, and recommending the formation of a volunteer force for defensive purposes. The pamphlet excited much attention. A public meeting was held and addressed by Franklin; at this meeting twelve hundred joined the association. At length the number of members enrolled exceeded ten thousand. These all provided themselves with arms, formed regiments and companies, elected their own officers, and attended once a week for military drill. Franklin was elected colonel of the Philadelphia Regiment, but declined the appointment, and served as a private soldier. The provision of war material was a difficulty with the Assembly, which consisted largely of Quakers, who, though they appeared privately to be willing that the country should be put in a state of defence, hesitated to vote in opposition to their peace principles. Hence it was that, when the Government of New England asked a grant of gunpowder from Pennsylvania, the Assembly voted

£3000 "for the purchasing of bread, flour, wheat, or *other grain*." Pebble-powder was not then in use. When it was proposed to devote £60, which was a balance in the hands of the Union Fire Company, as a contribution towards the erection of a battery below the town, Franklin suggested that it should be proposed that a fire-engine be purchased with the money, and that the committee should "buy a great gun, which is certainly a *fire-engine*."

The "Pennsylvania fireplace" was invented in 1742. A patent was offered to Franklin by the Governor of Pennsylvania, but he declined it on the principle "*that, as we enjoy great advantages from the inventions of others, we should be glad of an opportunity to serve others by any invention of ours; and this we should do freely and generously*." An ironmonger in London made slight alterations, which were not improvements, in the design, and took out a patent for the fireplace, whereby he made a "small fortune." Franklin never contested the patent, "having no desire of profiting by patents himself," and "hating disputes." This fireplace was designed to burn wood, but, unlike the German stoves, it was completely open in front, though enclosed at the sides and top. An air-chamber was formed in the middle of the stove, so arranged that, while the burning wood was in contact with the front of the chamber, the flame passed above and behind it on its way to the flue. Through this chamber a constant current of air passed, entering the room heated, but not contaminated, by the products of combustion. In this way the stove furnished a constant supply of fresh warm air to the room, while it possessed all the advantages of an open fireplace. Subsequently Franklin contrived a special fireplace for the combustion of coal. In the scientific thought which he devoted to the requirements of the domestic economist, as in very many other particulars, Franklin strongly reminds us of Count Rumford.

The next important enterprise which Franklin undertook, partly through the medium of the Junto, was to establish an academy which soon developed into the University of Philadelphia. The members of the club having taken up the subject, the next step was to enlist the sympathy of a wider constituency, and this Franklin effected, in his usual way, by the publication of a pamphlet. He then set on foot a subscription, the payments to extend over five years, and thereby obtained about £5000. A house was taken and schools opened in 1749. The classes soon became too large for the house, and the trustees of the academy then took over a large building, or "tabernacle," which had been erected for George Whitefield when he was preaching in Philadelphia. The hall was divided into stories, and at a very small expense adapted to the requirements of the classes. Franklin, having taken a partner in his printing business, took the oversight of the work. Afterwards the funds were increased by English subscriptions, by a grant from the Assembly, and by gifts of land from the proprietaries; and thus was established the University of Philadelphia.

Having practically retired from business, Franklin intended to devote himself to philosophical studies, having commenced his electrical researches some time before in conjunction with the other members of the Library Company. Public business, however, crowded upon him. He was elected a member of the Assembly, a councillor and afterwards an alderman of the city, and by the governor was made a justice of the peace. As a member of the Assembly, he was largely concerned in providing the means for the erection of a hospital, and in arranging for the paving and cleansing of the streets of the city. In 1753 he was appointed, in conjunction with Mr. Hunter, Postmaster-General of America. The post-office of the colonies had previously been conducted at a loss. In a few years, under Franklin's management, it not only paid the stipends of himself and Mr. Hunter, but yielded a considerable revenue to the Crown. But it was not only in the conduct of public business that Franklin's merits were recognized. By this time he had secured his reputation as an electrician, and both Yale College and Cambridge University (New England) conferred on him the honorary degree of Master of Arts. In the same year that he was made Postmaster-General of America he was awarded the Copley Medal and elected a Fellow of the Royal Society of London, the usual fees being remitted in his case.

Before his election as member, Franklin had for several years held the appointment of Clerk to the Assembly, and he used to relieve the dulness of the debates by amusing himself in the construction of magic circles and squares, and "acquired such a knack at it" that he could "fill the cells of any magic square of reasonable size with a series of numbers as fast as" he "could write them." Many years afterwards Mr. Logan showed Franklin a French folio volume filled with magic squares, and afterwards a magic "square of 16," which Mr. Logan thought must have been a work of great labour, though it possessed only the common properties of making 2056 in every row, horizontal, vertical, and diagonal. During the evening Franklin made the square shown on the opposite page. "This I sent to our friend the next morning, who, after some days, sent it back in a letter, with these words: 'I return to thee thy astonishing and most stupendous piece of the magical square, in which – ;' but the compliment is too extravagant, and therefore, for his sake as well as my own, I ought not to repeat it. Nor is it necessary; for I make no question that you will readily allow this square of 16 to be the most magically magical of any magic square ever made by any magician."

The square has the following properties: – Every straight row of sixteen numbers, whether vertical, horizontal, or diagonal, makes 2056.

Every bent row of sixteen numbers, as shown by the diagonal lines in the figure, makes 2056.

If a square hole be cut in a piece of paper, so as to show through it just sixteen of the little squares, and the paper be laid on the magic square, then, wherever the paper is placed, the sum of the sixteen numbers visible through the hole will be 2056.

200	217	232	249	8	25	40	57	72	89	104	121	136	153	168	181
58	39	26	7	250	231	218	199	186	167	154	135	122	103	90	71
198	219	230	251	6	27	38	59	70	91	102	123	134	155	166	187
60	37	28	5	252	229	220	197	188	165	156	133	124	101	92	69
201	216	233	248	9	24	41	56	73	88	105	120	137	152	169	184
55	42	23	10	247	234	215	202	183	170	151	138	119	106	87	74
20	214	235	240	11	22	43	54	75	86	107	118	139	150	171	182
53	44	21	12	245	236	213	204	181	172	149	140	117	108	85	76
205	212	237	244	13	20	45	52	77	84	109	116	141	148	173	180
51	46	19	14	243	238	211	206	179	174	147	142	115	110	83	78
207	210	239	242	15	18	47	50	79	82	111	114	143	146	175	178
49	48	17	16	241	240	209	208	177	176	145	144	113	112	81	80
196	221	228	253	4	29	36	61	68	93	100	125	132	157	164	189
62	35	30	3	254	227	222	195	190	163	158	131	126	99	94	67
194	223	226	255	2	31	34	63	66	95	98	127	130	159	162	191
64	33	32	1	256	225	224	193	192	161	160	129	128	97	96	65

200	217	232	249	8	25	40	57	72	89	104	121	136	153	168	185
58	39	26	7	250	231	218	199	186	167	154	135	122	103	90	71
198	219	230	251	6	27	38	59	70	91	102	123	134	155	166	187
60	37	28	5	252	229	220	197	188	165	156	133	124	101	92	69
201	216	233	248	9	24	41	56	73	88	105	120	137	152	169	184
55	42	23	10	247	234	215	202	183	170	151	138	119	106	87	74
203	214	235	246	11	22	43	54	75	86	107	118	139	150	171	182
53	44	21	12	245	236	213	204	181	172	149	140	117	108	85	76
205	212	237	244	13	20	45	52	77	84	109	116	141	148	173	180
51	46	19	14	243	238	211	206	179	174	147	142	115	110	83	78
207	210	239	242	15	18	47	50	79	82	111	114	143	146	175	178
49	48	17	16	241	240	209	208	177	176	145	144	113	112	81	80
196	221	228	253	4	29	36	61	68	93	100	125	132	157	164	189
62	35	30	3	254	227	222	195	190	163	158	131	126	99	94	67
194	223	226	255	2	31	34	63	66	95	98	127	130	159	162	191
64	33	32	1	256	225	224	193	192	161	160	129	128	97	96	65

In 1754 war with France appeared to be again imminent, and a Congress of Commissioners from the several colonies was arranged for. Of course, Franklin was one of the representatives of Pennsylvania, and was also one of the members who independently drew up a plan for the union of all the colonies under one government, for defensive and other general purposes, and his was the plan finally approved by Congress for the union, though it was not accepted by the Assemblies or by the English Government, being regarded by the former as having too much of the *prerogative* in it, by the latter as being too *democratic*. Franklin wrote respecting this scheme: "The different and contrary reasons of dislike to my plan makes me suspect that it was really the true medium; and I am still of opinion that it would have been happy for both sides of the water if it had been adopted. The colonies, so united, would have been sufficiently strong to have defended themselves; there would then have been no need of troops from England; of course, the subsequent pretence for taxing America, and the bloody contest it occasioned, would have been avoided."

With this war against France began the struggle of the Assemblies and the proprietaries on the question of taxing the estates of the latter. The governors received strict instructions to approve no bills for the raising of money for the purposes of defence, unless the estates of the proprietaries were specially exempted from the tax. The Assembly of Pennsylvania resolved to contribute £10,000 to assist the Government of Massachusetts Bay in an attack upon Crown Point, but the governor refused his assent to the bill for raising the money. At this juncture Franklin proposed a scheme by which the money could be raised without the consent of the governor. His plan was successful, and the difficulty was surmounted for the time, but was destined to recur again and again during the progress of the war.

The British Government, not approving of the scheme of union, whereby the colonies might have defended themselves, sent General Braddock to Virginia, with two regiments of regular troops. On their arrival they found it impossible to obtain waggons for the conveyance of their baggage, and the general commissioned Franklin to provide them in Pennsylvania. By giving his private bond for their safety, Franklin succeeded in engaging one hundred and fifty four-horse waggons, and two hundred and fifty-nine pack-horses. His modest warnings against Indian ambuscades were disregarded by the general, the little army was cut to pieces, and the remainder took to flight, sacrificing the whole of their baggage and stores. Franklin was never fully recouped by the British Government for the payments he had to make on account of provisions which the general had instructed him to procure for the use of the army.

After this, Franklin appeared for some time in a purely military capacity, having yielded to the governor's persuasions to undertake the defence of the north-western frontier, to raise troops, and to build a line of forts. After building and manning three wooden forts, he was recalled by the Assembly, whose relations with the governor had become more and more strained. At length the Assembly determined to send Franklin to England, to present a petition to the king respecting the conduct of the proprietaries, viz. Richard and Thomas Penn, the successors of William Penn. A bill had been framed by the House to provide £60,000 for the king's use in the defence of the province. This the governor refused to pass, because the proprietary estates were not exempted from the taxation. The petition to the king was drawn up, and Franklin's baggage was on board the ship which was to convey him to England, when General Lord Loudon endeavoured to make an arrangement between the parties. The governor pleaded his instructions, and the bond he had given for carrying them out, and the Assembly was prevailed upon to reconstruct the bill in accordance with the governor's wishes. This was done under protest; in the mean time Franklin's ship had sailed, carrying his baggage. After a great deal of unnecessary delay on account of the general's inability to decide upon the despatch of the packet-boats, Franklin at last got away from New York, and, having narrowly escaped shipwreck off Falmouth, he reached London on July 27, 1757.

On arriving in London, Franklin was introduced to Lord Granville, who told him that the king's instructions were laws in the colonies. Franklin replied that he had always understood that the Assemblies made the laws, which then only required the king's consent. "I recollected that, about twenty years before, a clause in a bill brought into Parliament by the Ministry had proposed to make the king's instructions laws in the colonies, but the clause was thrown out by the Commons, for which we adored them as our friends and the friends of liberty, till, by their conduct towards us in 1765, it seem'd that they had refus'd that point of sovereignty to the king only that they might reserve it for themselves." A meeting was shortly afterwards arranged between Franklin and the proprietaries at Mr. T. Penn's house; but their views were so discordant that, after some discussion, Franklin was requested to give them in writing the heads of his complaints, and the whole question was submitted to the opinion of the attorney- and solicitor-general. It was nearly a year before this opinion was given. The proprietaries then communicated directly with the Assembly, but in the mean while Governor Denny had consented to a bill for raising £100,000 for the king's use, in which it was provided that the proprietary estates should be taxed with the others. When this bill reached England, the proprietaries determined to oppose its receiving the royal assent. Franklin engaged counsel on behalf of the Assembly, and on his undertaking that the assessment should be fairly made between the estates of the proprietaries and others, the bill was allowed to pass.

By this time Franklin's career as a scientific investigator was practically at an end. Political business almost completely occupied his attention, and in one sense the diplomatist replaced the philosopher. His public scientific career was of short duration. It may be said to have begun in 1746, when Mr. Peter Collinson presented an "electrical tube" to the Library Company in Philadelphia, which was some time after followed by a present of a complete set of electrical apparatus from the proprietaries, but by 1755 Franklin's time was so much taken up by public business that there was very little opportunity for experimental work. Throughout his life he frequently expressed in his letters his strong desire to return to philosophy, but the opportunity never came, and when, at the age of eighty-two, he was liberated from public duty, his strength was insufficient to enable him to complete even his autobiography.

It was on a visit to Boston in 1746 that Franklin met with Dr. Spence, a Scotchman, who exhibited some electrical experiments. Soon after his return to Philadelphia the tube arrived from Mr. Collinson, and Franklin acquired considerable dexterity in its use. His house was continually full of visitors, who came to see the experiments, and, to relieve the pressure upon his time, he had a number of similar tubes blown at the glass-house, and these he distributed to his friends, so that there were soon a number of "performers" in Philadelphia. One of these was Mr. Kinnersley, who, having no other employment, was induced by Franklin to become an itinerant lecturer. Franklin drew up a scheme for the lectures, and Kinnersley obtained several well-constructed instruments from Franklin's rough and home-made models. Kinnersley and Franklin appear to have worked together a good deal, and when Kinnersley was travelling on his lecture tour, each communicated to the other the results of his experiments. Franklin sent his papers to Mr. Collinson, who presented them to the Royal Society, but they were not at first judged worthy of a place in the "Transactions." The paper on the identity of lightning and electricity was sent to Dr. Mitchell, who read it before the Royal Society, when it "was laughed at by the connoisseurs." The papers were subsequently published in a pamphlet, but did not at first receive much attention in England. On the recommendation of Count de Buffon, they were translated into French. The Abbé Nollet, who had previously published a theory of his own respecting electricity, wrote and published a volume of letters defending his theory, and denying the accuracy of some of Franklin's experimental results. To these letters Franklin made no reply, but they were answered by M. le Roy. M. de Lor undertook to repeat in Paris all Franklin's experiments, and they were performed before the king and court. Not content with the experiments which Franklin had actually performed, he tried those which had been only suggested, and so was the first to obtain electricity from the clouds by means of the pointed rod. This experiment produced a great sensation everywhere, and was afterwards repeated by Franklin at Philadelphia. Franklin's papers were translated into Italian, German, and Latin; his theory met with all but universal acceptance, and great surprise was expressed that his papers had excited so little interest in England. Dr. Watson then drew up a summary of all Franklin's papers, and this was published in the "Philosophical Transactions;" Mr. Canton verified the experiment of procuring electricity from the clouds by means of a pointed rod, and the Royal Society awarded to Franklin the Copley Medal for 1753, which was conveyed to him by Governor Denny.

We must now give a short account of Franklin's contributions to electrical science.

"The first is the wonderful effect of pointed bodies, both in *drawing off* and *throwing off* the electrical fire."

It will be observed that this statement is made in the language of the *one*-fluid theory, of which Franklin may be regarded as the author. This theory will be again referred to presently. Franklin electrified a cannon-ball so that it repelled a cork. On bringing near it the point of a bodkin, the repulsion disappeared. A blunt body had to be brought near enough for a spark to pass in order to produce the same effect. "To prove that the electrical fire is *drawn off* by the point, if you take the blade of the bodkin out of the wooden handle, and fix it in a stick of sealing-wax, and then present it at the distance aforesaid, or if you bring it very near, no such effect follows; but sliding one finger along the wax till you touch the blade, and the ball flies to the shot immediately. If you present the point in the dark, you will see, sometimes at a foot distance or more, a light gather upon it like that of a fire-fly or glow-worm; the less sharp the point, the nearer you must bring it to observe the light; and at whatever distance you see the light, you may draw off the electrical fire, and destroy the repelling."

By laying a needle upon the shot, Franklin showed "that points will *throw off* as well as *draw off* the electrical fire." A candle-flame was found to be equally efficient with a sharp point in drawing off the electricity from a charged conductor. The effect of the candle-flame Franklin accounted for by supposing the particles separated from the candle to be first "attracted and then repelled, carrying off the electric matter with them." The effect of points is a direct consequence of the law of electrical repulsion. When a conductor is electrified, the density of the electricity is greatest where the curvature is greatest. Thus, if a number of spheres are electrified from the same source, the density of the electricity on the different spheres will vary inversely as their diameters. The force tending to drive the electricity off a conductor is everywhere proportional to the density, and hence in the case of the spheres will be greatest for the smallest sphere. On this principle, the density of electricity on a perfectly sharp point, if such could exist, on a charged conductor, would be infinite and the force tending to drive it off would be infinite also. Hence a moderately sharp point is sufficient to dissipate the electricity from a highly charged conductor, or to neutralize it if the point is connected to earth and brought near the conductor so as to be electrified by induction.

Franklin next found that, if the person rubbing the electric tube stood upon a cake of resin, and the person taking the charge from the tube stood also on an insulating stand, a stronger spark would pass between these two persons than between either of them and the earth; that, after the spark had passed, neither person was electrified, though each had appeared electrified before. These experiments suggested the idea of *positive* and *negative* electrification; and Franklin, regarding the electric fluid as corresponding to positive electrification, remarked that "you may circulate it as Mr. Watson has shown; you may also accumulate or subtract it upon or from any body, as you connect that body with the rubber or with the receiver, the common stock being cut off." Thus Franklin regarded electricity as a fluid, of which everything in its normal state possesses a certain amount; that, by appropriate means, some of the fluid may be removed from one body and given to another. The former is then electrified negatively, the latter positively, and all processes by which bodies are electrified consist in the removal of electricity from one body or system and giving it to another. He regarded the electric fluid as repelling itself and attracting matter. Æpinus afterwards added the supposition that matter, when devoid of electricity, is self-repulsive, and thus completed the "one-fluid theory," and accounted for the repulsion observed between negatively electrified bodies.

It had been usual to employ water for the interior armatures of Leyden jars, or phials, as they were then generally called. Franklin substituted granulated lead for the water, thereby improving the insulation by keeping the glass dry. With these phials he contrived many ingenious experiments, and imitated lightning by discharging them through the gilding of a mirror or the gold lines on the cover of a book. He found that the inner and outer armatures of his Leyden jars were oppositely electrified. "Here we have a bottle containing at the same time a *plenum* of electrical fire and a *vacuum* of the same fire; and yet the equilibrium cannot be restored between them but by a communication *without*! though the plenum presses violently to expand, and the hungry vacuum seems to attract as violently in order to be filled." The charging of Leyden jars by cascade, that is by insulating all the jars except the last, connecting the outer armature of the first with the inner armature of the second, and so on throughout the series, was well understood by Franklin, and he knew too that by this method the extent to which each jar could be charged from a given source varied inversely as the number of jars. The discharge of the Leyden jar by alternate contacts was also carried out by him; and he found that, if the jar is first placed on an insulating stand, it may be held by the hook (or knob) without discharging it. Franklin, in fact, appears to have known almost as much about the Leyden jar as is known to-day. He found that, when the armatures were removed from a jar, no discharge would pass between them, but when a fresh pair of armatures were supplied to the glass, the jar could be discharged. "We are of opinion that there is really no more electrical fire in the phial after what is called its *charging* than before, nor less after its *discharging*; excepting only the small spark that might be given to and taken from the non-electric matter, if separated from the bottle, which spark may not be equal to a five-hundredth part of what is called the explosion.

"The phial will not suffer what is called a *charging* unless as much fire can go out of it one way as is thrown in by another.

"When a bottle is charged in the common way, its *inside* and *outside* surfaces stand ready, the one to give fire by the hook, the other to receive it by the coating; the one is full and ready to throw out, the other empty and extremely hungry; yet, as the first will not *give out* unless the other can at the same time *receive in*, so neither will the latter receive in unless the first can at the same time give out. When both can be done at once, it is done with inconceivable quickness and violence."

Then follows a very beautiful illustration of the condition of the glass in the Leyden jar.

"So a straight spring (though the comparison does not agree in every particular), when forcibly bent, must, to restore itself, contract that side which in the bending was extended, and extend that which was contracted; if either of these two operations be hindered, the other cannot be done.

"Glass, in like manner, has, within its substance, always the same quantity of electrical fire, and that a very great quantity in proportion to the mass of the glass, as shall be shown hereafter.

"This quantity proportioned to the glass it strongly and obstinately retains, and will have neither more nor less, though it will suffer a change to be made in its parts and situation; *i. e.* we may take away part of it from one of the sides, provided we throw an equal quantity into the other."

"The whole force of the bottle, and power of giving a shock, is in the glass itself; the non-electrics in contact with the two surfaces serving only to *give* and *receive* to and from the several parts of the glass, that is, to give on one side and take away from the other."

All these statements were, as far as possible, fully substantiated by experiment. They are perfectly consistent with the views held by Cavendish and by Clerk Maxwell, and, though the phraseology is not that of the modern text-books, the statements themselves can hardly be improved upon to-day.

One of Franklin's early contrivances was an electro-motor, which was driven by the alternate electrical attraction and repulsion of leaden bullets which discharged Leyden jars by alternate contacts. Franklin concluded his account of these experiments as follows: —

> Chagrined a little that we have been hitherto able to produce nothing in this way of use to mankind, and the hot weather coming on, when electrical experiments are not so agreeable, it is proposed to put an end to them for this season, somewhat humorously, in a party of pleasure, on the banks of Skuylkil. Spirits, at the same time, are to be fired by a spark sent from side to side through the river, without any other conductor than the water – an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by the *electrical shock*, and roasted by the *electrical jack* before a fire kindled by the *electrified bottle*, when the healths of all the famous electricians in England, Holland, France, and Germany, are to be drunk in *electrified bumpers*, under the discharge of guns from the *electrical battery*.

Franklin's electrical battery consisted of eleven large panes of glass coated on each side with sheet lead. The electrified bumper was a thin tumbler nearly filled with wine and electrified as a Leyden jar, so as to give a shock through the lips.

Конец ознакомительного фрагмента.