

THE DEBT OF THE WORLD TO PURE SCIENCE.

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THE fundamental importance of abstruse research receives too little consideration in our time. The practical side of life is all-absorbent; the results of research are utilized promptly and full recognition is awarded to the one who utilizes, while the investigator is ignored. The student himself is liable to be regarded as a relic of medieval times, and his unconcern respecting ordinary matters is serviceable to the dramatist and newspaper witlet in their times of need.

Yet every thoughtful man, far away as his calling may be from scientific investigation, hesitates to accept such judgment as accurate. Not a few, engrossed in the strife of the marketplace, are convinced that even from the selfish standpoint of mere enjoyment less gain is found in amassing fortunes or in acquiring power over one's fellows than in the effort to solve Nature's problems. Men scoff at philosophical dreamers, but the scoffing is not according to knowledge. The exigencies of subjective philosophy brought about the objective philosophy. Error has led to the right. Alchemy prepared the way for Chemistry, Astrology for Astronomy, Cosmogony for Geology. The birth of inductive science was due to the necessities of deductive science, and the greatest development of the former has come from the trial of hypotheses belonging in the border land between science and philosophy.

My effort this evening is to show that discoveries which have proved all-important in secondary results did not burst forth full-grown; that in each case they were, so to say, the crown of

a structure reared painfully and noiselessly by men indifferent to this world's affairs, caring little for fame, and even less for wealth. Facts were gathered, principles were discovered, each falling into its own place until at last the brilliant crown shone out and the world thought it saw a miracle.

This done, I shall endeavor to draw a moral which it is hoped will be found worthy of consideration.

The heavenly bodies were objects of adoration from the earliest antiquity ; they were guides to caravans on the desert as well as to mariners far from land ; they marked the beginning of seasons or, as in Egypt, the limits of vast periods embracing many hundreds of years. Maps were made thousands of years ago showing their positions, the path of the sun was determined rudely, the influence of the sun and moon upon the earth was recognized in some degree and their influence upon man was inferred. Beyond these matters man with unaided vision and with knowledge only of elementary mathematics could not go.

Mathematical investigations by Arabian students prepared the means by which, after Europe's revival of learning, one without wealth gave a new life to astronomy. Copernicus, early trained in mathematics, during the last thirty years of his life spent the hours stolen from his work as a clerk and charity physician in mathematical and astronomical studies, which led him to reject the complex Ptolemaic system and to accept in modified form that bearing the name of Pythagoras. Tycho Brahe followed. A mere star-gazer at first, he became an earnest student, improved the instruments employed, and finally secured recognition from his sovereign. For twenty-five years he sought facts, disregarding none, but seldom recognizing economic importance in any. His associate, Kepler, profiting by his training under Brahe, carried the work far beyond that of his predecessors—and this in spite of disease, domestic sorrows and only too frequent experience of abject poverty. He divested the Copernicus hypothesis of many crudities and discovered the laws which have been utilized by astronomers in all phases of their work. He ascertained the causes of the tides ; with the aid of the newly invented telescope made studies of eclipses and oc-

cultations, and just missed discovering the law of gravitation. He laid the foundation for practical application of astronomy to every-day life.

In the eighteenth century astronomy was recognized by governments as no longer of merely curious interest and its students received abundant aid. The improvement of the telescope, the discovery of the law of gravitation and the invention of logarithms had made possible the notable advance marking the close of the seventeenth century. The increasing requirements of accuracy led to exactness in the manufacture of instruments, to calculation and recalculation of tables, to long expeditions for testing methods as well as conclusions, until finally the suggestions of Copernicus, the physician, and of Kepler, the ill-fed invalid, became fact, and astronomical results were utilized to the advantage of mankind. The voyager on the ocean, the agriculturist on land, reap benefits from the accumulated observations of three centuries, though they know nothing of the principles or of the laborers by whom the principles were discovered. The regulation of chronometers as well as the fixing of boundary lines between great nations are determined by methods due to slow accumulation of facts, slower development in analysis and calculation, and even slower improvement in instruments.

Galvani's observation that frogs' legs twitch when near a friction machine in operation led him to test the effect of atmospheric electricity upon them. The instant action brought about the discovery that it was due, not to atmospheric influence, but to a current produced by contact of a copper hook with an iron rail. Volta pursued the investigation and constructed the pile which bears his name. With this, modified, Davy, in 1807, decomposed potash and soda, thereby isolating potassium and sodium. This experiment, repeated successfully by other chemists, was the precursor of many independent investigations which directed to many lines of research, each increasing in interest as it was followed.

Volta's crown of cups expanded into the clumsy trough batteries which were finally displaced in 1836 by Daniel's constant battery, using two fluids, one of which was cupric sulphate. De

la Rue observed that as the sulphate was reduced, the copper was deposited on the surface of the outer vessel and copied accurately all markings on that surface. Within two or three years Jacobi and Spencer made the practical application of this observation by reproducing engravings and medals. Thus was born the science of electro-metallurgy. At first mere curiosities were made, then electro-plating in a wider way, the electrotype, the utilization of copper to protect more easily destructible metals, the preparation of articles for ornament and utility by covering baser metals with copper or silver or gold; while now the development of electro-generators has led to wide applications in the reduction of metals and to the saving of materials which otherwise would go to waste.

Oersted in 1819-20, puzzling over the possible relations of voltaic electricity to magnetism, noticed that a conductor carrying an electrical current becomes itself a magnet and deflects the needle. Sturgeon, working along these lines, found that soft iron enclosed in a coil, through which a current passes becomes magnetic, but loses the power when the current ceases. This opened the way for our own Henry's all-important discovery of the reciprocating electro-magnets and the vibrating armature—the essential parts of the magnetic telegraph. Henry actually constructed a telegraph in 1832, winding the wires around his class-room in Albany and using a bell to record the making and breaking signals. Here, as he fully recognized, was everything but a simple device for receiving signals.

Several years later, Professor Morse, dreaming night and day of the telegraph, was experimenting with Moll's electro-magnet and finding only discouragement. His colleague, Professor Gale, advised him to discard the even then antiquated apparatus and to utilize the results given in Henry's discussion. At once the condition was changed and soon the ingenious recording instrument bearing Morse's name was constructed. Henry's scientific discoveries were transmuted by the inventor's ingenuity into substantial glory for Morse, and proved a source of inconceivable advantage to the whole civilized world. Steinhal's discovery that the earth can be utilized for the return current com-

pleted the series of fundamental discoveries, and since that time everything has been elaboration.

Oersted's discovery respecting the influence of an electric current closely followed by that of Arago in the same direction opened the way for Faraday's complete discovery of induction, which underlies the construction of the dynamo. This ascertained, the province of the inventor was well defined, to conjure some mechanical appliance whereby the principle might be utilized. But here, as elsewhere, the work of discovery and that of invention went on almost *pari passu*; the results of each increased those of the other. The distance from the Clark and Page machines of the middle '30's, with their cumbrous horse-shoe magnets and disproportionate expenditure of power, to the Siemens machine of the '50's was long, but it was no leap. In like manner, slow steps marked progress thence to the Gramme machine, in which one finds the outgrowth of many years of labor by many men, both investigators and inventors. In 1870, forty years after Faraday's announcement of the basal principle, the stage was reached whence progress could be rapid. Since that time the dynamo has been brought to such stage of efficiency that the electro-motor seems likely to displace not merely the steam engine, but also other agencies in direct application of force. The horse is passing away and the trolley road runs along the country highway; the longer railways are considering the wisdom of changing their power; cities are lighted brilliantly where formerly the gloom invited highwaymen to ply their trade; and even the kitchen is invaded by new methods of heating.

Long ago it was known that if the refining of pig iron be stopped just before the tendency to solidify became pronounced the wrought iron is more durable than that obtained in the completed process. This imperfectly refined metal was made frequently, though unintentionally and ignorantly. A short railroad in southwest Pennsylvania was laid in the middle 60's with iron rails of light weight. A rail's life in those days rarely exceeded five years; yet some of those light rails were in excellent condition almost fifteen years afterwards, though they had carried a heavy coke traffic for several years. But this process

was uncertain, and the best puddlers could never tell when to stop the process in order to obtain the desired grade.

When a modification of this refining process was attempted on a grand scale almost contemporaneously by Martien, in this country, and Bessemer, in England, the same uncertainty of product was encountered—sometimes the process was checked too soon, at others pushed too far. Here the inventor came to a halt. He could use only what was known and endeavor to improve methods of application. Under such conditions the Bessemer process was apparently a hopeless failure. Another, however, utilized the hitherto ignored work of the closet investigator. The influence of manganese in counteracting the effects of certain injurious substances and its relation to carbon when present in pig iron were understood as matters of scientific interest. Mushet recognized the bearing of these facts and utilized them in changing the process. His method proved successful, but with thorough scientific forgetfulness of the main chance, he neglected to pay some petty fees at the Patent Office and so reaped neither profit nor popular glory for his work.

The Mushet process having proved the possibility of immediate and certain conversion, the genius of the inventor found full scope. The change in form and size of the converter, the removable base, the use of trunnions and other details, largely due to the American, Holley, so increased the output and reduced the cost that Bessemer steel soon displaced iron and the world passed from the age of iron into the age of steel.

Architectural methods have been revolutionized. Buildings, ten stories high, are commonplace; those of twenty no longer excite comment, and one of thirty arouses no more than a passing pleasantry respecting possibilities at the top. Such buildings were almost impossible a score of years ago, and the weight made the cost prohibitive. The increased use of steel in construction seems likely to preserve our forests from disappearance.

In other directions the gain through this process has been more important. The costly, short-lived iron rail has disappeared and the durable steel rail has taken its place. Under the

moderate conditions of twenty-five years ago iron rails scarcely lasted more than five years ; in addition the metal was soft, the limit of load was reached quickly, and freight rates, though high, were none too profitable.

But all changed with the advent of steel rails as made by the American process. Application of abstruse laws discovered by men unknown to popular fame enabled inventors to improve methods and to cheapen manufacture until the first cost of steel rails was less than that of iron. The durability of the new rails and their resistance to load justified increased expenditure in other directions to secure permanently good condition of the road bed. Just here, our fellow member, Mr. P. H. Dudley, made his contribution, whose importance can hardly be over-estimated. With his ingenious recording apparatus it is easy to discover defects in the roadway and to ascertain their nature, thus making it possible to devise means for their correction and for preventing their recurrence. The information obtained by use of this apparatus has led him to change the shape and weight of rails, to modify the type of joints and the methods of ballasting, so that now a roadbed should remain in good condition and even improve during years of hard use.

But the advantages have not inured wholly to the railroad companies. It is true that the cost of maintenance has been reduced greatly ; that locomotives have been made heavier and more powerful ; that freight cars carry three to four times as much as they did twenty-five years ago, so that the whole cost of operation is very much less than formerly. But where the carrier has gained one dollar the consumer and shipper have gained hundreds of dollars. Grain and flour can be brought from Chicago to the seaboard as cheaply by rail, as by water ; the farmer in Dakota raises wheat for shipment to Europe ; coal mined in West Virginia can be sold on the docks of New York at a profit for less than half the freight rate of twenty-five years ago. Our internal commercial relations have been changed and the revolution is still incomplete. The influence of the Holley-Mushet-Bessemer process upon civilization is hardly inferior to that of the electric telegraph.

Sixty years ago an obscure German chemist obtained an oily liquid from coal-tar oil, which gave a beautiful tint with calcium chloride; five years later another separated a similar liquid from a derivative of coal-tar oil. Still later, Hofmann, then a student in Liebig's laboratory, investigated these substances and proved their identity with an oil obtained long before by Zinin, from indigo, and applied to them all Zinin's term, Anilin. The substance was curiously interesting and Hofmann worked out its reactions, discovering that with many materials it gives brilliant colors. The practical application of these discoveries was not long delayed, for Perkins made it in 1856. The marvelous dyes, beginning with Magenta and Solferino, have become familiar to all. The anilin colors, especially the reds, greens and blues, are among the most beautiful known. They have given rise to new industries and have expanded old ones. Their usefulness has led to deeper studies of coal-tar products, to which is due the discovery of such substances as antipyrin, phenacetin, ichthyol and saccharin, which have proved so important in medicine.

One is tempted to dwell for a little upon Meteorology, that border land where physics, chemistry and geology meet, and to speak of the Signal Service system, the outgrowth of studies by an obscure school teacher in Philadelphia, but the danger of trespassing too far upon your endurance makes proper only this passing reference.

While men of wealth and leisure wasted their energies in literary and philosophical discussions respecting the nature and origin of things, William Smith, earning a living as a land surveyor, plodded over England, anxious only to learn, in no haste to explain. His work was done honestly and slowly; when finished as far as was possible with his means, it had been done so well that its publication checked theorizing and brought men back to study. His geological map of England was the basis upon which the British Survey began preparation of the detailed sheets, showing Britain's mineral resources.

In our country Vanuxem and Morton early studied the New Jersey Cretaceous and Eocene, containing vast beds of marl.

Scientific interest was aroused, and eventually a geological survey of the State was ordered by the Legislature. The appropriation was insignificant, and many of the legislators voted for it, hoping that some economic discovery might be made to justify their course in squandering the people's money. Yet there were lingering doubts in their minds and some found more than lingering doubts in the minds of their constituents. But when the marls were proved to contain materials which the chemist, Liebig, had shown to be all-important for plants, the conditions were changed and criticism ceased. The dismal sands of eastern New Jersey, affording only a scanty living for pines and grasses, were converted by application of the marl into gardens of unsurpassed fertility. Vanuxem's study of the stratigraphy and Morton's study of the fossils had made clear the distribution of marls and the survey scattered the information broadcast.

Morton and Conrad, with others scarcely less devoted, labored in season and out of season to systematize the study of fossil animals. There were not wanting educated men who wondered why students of such undoubted ability wasted themselves in trifling employment instead of doing something worthy of themselves so as to acquire money and fame. Much nearer to our own time, there were wise legislators who questioned the wisdom of "wasting money on pictures of clams and salamanders," though the same men appreciated the geologist who could tell them the depth of a coal bed below the surface. But the lead diggers of Illinois and Iowa long ago learned the use of palæontology, for the "lead fossil" was their guide in prospecting. The importance and practical application of this science, so largely the outgrowth of unappreciated toil in this country as well as in Europe, is told best in Professor Hall's reply to a patronizing politician's query, "And what are your old fossils good for?" "For this. Take me blindfolded in a balloon; drop me where you will; if I can find some fossils, I'll tell you in ten minutes for what mineral you may look and for what mineral you need not look."

Many regard Botany as a pleasing study, well fitted for women and dilettanti, but hardly deserving attention by strong men.

Those who speak thus only exercise the prerogative of ignorance, which is to despise that which one is too old or too lazy to learn. The botanist's work is not complete when the carefully gathered specimen has been placed in the herbarium with its proper label. That is but the beginning, for he seeks the relation of plants in all phases. In seeking these he discovers facts which often prove to be of cardinal importance. The rust which destroys wheat in the last stage of ripening, the disgusting fungus which blasts Indian corn, the poisonous ergot in rye, the blight of the pear and other fruits fall as much within the botanist's study as do the flowers of the garden or the sequoias of the Sierra. Not a few of the plant diseases which have threatened famine or disaster have been studied by botanists, unknown to the world, whose explanations have led to palliation or cure.

The ichthyologist, studying the habit of fishes, discovered characteristics which promptly commended themselves to men of practical bent. The important industry of artificial fertilization and the transportation of fish eggs, which has enabled man to restock exhausted localities and to stock new ones, is but the outgrowth of closet studies which have shown how to utilize Nature's superabundant supply.

The entomologist has always been an interesting phenomenon to a large part of our population. Insects of beauty are attractive, those of large size are curious, while many of the minuter forms are efficient in gaining attention. But that men should devote their lives to the study of unattractive forms is to many a riddle. Yet entomology yields to no branch of science in the importance of its economic bearings. The study of the life habits of insects, their development, their food, their enemies, a study involving such minute details as to shut men off from many of the pleasures of life and to convert them into typical students, has come to be so fraught with relations to the public weal that the State Entomologist's mail has more anxious letters than that of any other officer.

Insects are no longer regarded as visitations from an angry Deity, to be borne in silence and with penitential awe. The intimate study of individual groups has taught in many cases how

to antagonize them. The scale threatened to destroy orange culture in California; the Colorado beetle seemed likely to ruin one of our important food crops; minute aphides terrified raisers of fruit and cane in the Sandwich Islands. But the scale is no longer a frightful burden in California; the potato bug is now only an annoyance, and the introduction of lady birds swept aphides from the Sandwich Islands. The gypsy moth, believed for more than a hundred years to be a special judgment, is no longer thought of as more than a very expensive nuisance. The curculio, the locust, the weevil, the chinch bug and others have been subjected to detailed investigation. In almost all cases methods have been devised whereby the ravages have been diminished. Even the borers which endangered some of the most important timber species are now understood and the possibility of their extermination has been changed into probability.

Having begun with the "infinitely great," we may close this summary with a reference to the "infinitely small." The study of fermentation processes was attractive to chemists and naturalists, each claiming ownership of the agencies. Pasteur, with a patience almost incredible, revised the work of his predecessors and supplemented it with original investigations, proving that a very great part of changes in organic substances exposed to the atmosphere are due primarily to the influence of low animals or plants whose germs exist in the atmosphere.

One may doubt whether Pasteur had any conception of the possibilities hidden in his determination of the matters at issue. The canning of meats and vegetables is no longer attended with uncertainty, and scurvy is no longer the bane of explorers; pork, which has supplied material for the building of railroads, the digging of canals, the construction of ships, can be eaten without fear. Flavorless butter can be rendered delicious by introduction of the proper bacteria; sterilized milk saves the lives of many children; some of the most destructive plagues are understood and the antidotes are prepared by the culture of antagonistic germs; antiseptic treatment has robbed surgery of half its terrors and has rendered almost commonplace opera-

tions which less than two decades ago were regarded as justifiable only as a last resort. The practice of medicine has been advanced by outgrowths of Pasteur's work almost as much as it was by Liebig's chemical investigations more than half a century ago.

In this review, the familiar has been chosen for illustration in preference to the wonderful, that your attention might not be diverted from the main issue, that the foundation of industrial advance was laid by workers in pure science, for the most part ignorant of utility and caring little about it. There is here no disparagement of the inventor; without his perception of the practical and his powers of combination the world would have reaped little benefit from the student's researches. But the investigator takes the first step and makes the inventor possible. Thereafter the inventor's work aids the investigator in making new discoveries to be utilized in their turn.

Investigation, as such, rarely receives proper recognition. It is usually regarded as quite a secondary affair in which scientific men find their recreation. If a geologist spends his summer vacation in an effort to solve some perplexing structural problem he finds on his return congratulations because of his glorious outing; the astronomer, the physicist and the chemist are all objects of semi-jealous regard because they are able to spend their leisure hours in congenial amusements; while the naturalist, enduring all kinds of privation, is not looked upon as a laborer because of the physical enjoyment which most good people think his work must bring.

It is true that investigation, properly so-called, is made secondary, but this because of necessity. Scientific men in government service are hampered constantly by the demand for immediately useful results. Detailed investigation is interrupted because matters apparently more important must be considered. The conditions are even more unfavorable in most of our colleges and none too favorable in our greater universities. The "literary leisure" supposed to belong to college professors does not fall to the lot of teachers of science, and very little of it can be discovered by college instructors in any department. The

The entire right trunk, carrying its secondary branches *A'* and *A''*, has shifted cephalad on the stem-bronchus, becoming "eparterial," while on the left side the trunk maintains its original position below the artery.

The secondary branch *B'* on the left side appears reduced.

The cardiac bronchus is large, arising below the origin of *B'* from the medial margin of the stem-bronchus. The corresponding artery reaches the ventral surface of the cardiac bronchus by crossing obliquely meso-caudad over the stem-bronchus below the origin *B'*.

VI. *Auchenia glama-pacos*—Llama-Alpaca.

Corrosion of bronchial system and pulmonary artery. Columbia University Museum, No. 585. Pl. XXI.

The arrangement of the bronchial system on the right side follows in the main the artiodactyl type as represented by *Dicotyles*, with certain minor exceptions to be presently mentioned. The same number and disposition of the main branches is to be noted.

On the left side further extension cephalad of the apical portion of the lung has led to a division of the cephalic trunk *A*, repeating the one found on the right side.

The lateral branch *A''* occupies the position corresponding to the same branch on the right side, below the pulmonary artery. The apical branch *A'* has migrated cephalad, appearing as an "eparterial" bronchus arising close to the tracheal bifurcation from the left primary bronchus.

The arterial distribution is symmetrical; the vessels accompanying the branch *A'* are on both sides derived from the beginning of the pulmonary artery, coursing on the ventral aspect of the corresponding bronchus.

This form, noted already by Aeby, constitutes the type which he describes as "bilateral eparterial bronchus, tracheal on right, bronchial on left side."

The cardiac bronchus is also shifted cephalad, arising from

duties of science teaching, involving too often much physical labor, from which teachers of other subjects are happily free, should conduct investigations at their own expense and in hours devoted by others to relaxation. Even were the pecuniary cost comparatively small, to impose that would be unjust, for, with few exceptions, the results are given to the world without compensation. Scientific men are accustomed to regard patents much as regular physicians regard advertising.

America owes much to closet students as well as to educated inventors who have been trained in scientific modes of thought. The extraordinary development of our material resources—our manufacturing, mining and transporting interests—shows that the strengthening of our educational institutions on the scientific side brings actual profit to the community. But most of this strengthening is due primarily to the unremunerated toil of men dependent on the meagre salary of college instructors or government officials in subordinate positions. Their aptitude to fit others for usefulness, coming only from long training, was acquired in hours stolen from sleep or from time needed for recuperation. But the labors of such men have been so fruitful in results that we can no longer depend on the surplus energy of scientific men, unless we consent to remain stationary. If the rising generation is to make the most of our country's opportunities it must be educated by men who are not compelled to acquire aptness at the cost of vitality. The proper relation of teaching labor to investigation labor should be recognized, and investigation, rather than social, religious or political activity, should be a part of the duty assigned to college instructors.

Our universities and scientific societies ought to have endowments specifically for aid in research. The fruits of investigations due to *Smithson's* bequest have multiplied his estate hundreds of times over to the world's advantage. He said well that his name would be remembered long after the names and memory of the *Percy* and *Northumberland* families had passed away. *Hodgson's* bequest to the *Smithsonian* is still too recent to have borne much fruit, but men already wonder at the fruitfulness of a field supposed to be well explored. *Nobel*

knew how to supply the results of science ; utilizing the chemist's results, he applied nitro-glycerine to industrial uses ; similarly, he developed the petroleum industry of Russia, and, like that of our American petroleum manufacturers, his influence was felt in many other industries of his own land and of the Continent. At his death he bequeathed millions of dollars to the Swedish Academy of Science, that the income might be expended in encouraging pure research. Smithson, Hodgson and Nobel have marked out a path which should be crowded with Americans.

The endowment of research is demanded now as never before. The development of technical education, the intellectual training of men to fit them for positions formerly held by mere tyros, has changed the material conditions in America. The surveyor has disappeared ; none but a civil engineer is trusted to lay out even town lots ; the founder at an iron furnace is no longer merely a graduate of the casting-house—he must be a graduate in metallurgy ; the manufacturer of paints cannot entrust his factory to any but a chemist of recognized standing ; no graduate from the pick is placed in charge of mines—a mining engineer alone can gain confidence ; and so everywhere. With the will to utilize the results of science there has come an intensity of competition in which victory belongs only to the best equipped. The profit awaiting successful inventors is greater than ever and the anxious readiness to supply scientific discoveries is shown by the daily records. The Roentgen rays were seized at once and efforts made to find profitable application ; the properties of zirconia and other earths interested inventors as soon as they were announced ; the possibility of telegraphing without wire incited inventors everywhere as soon as the principle was announced.

Nature's secrets are still unknown and the field of investigation is as broad as ever. We are only on the threshold of discovery, and the coming century will disclose wonders far beyond any yet disclosed. The atmosphere, studied by hundreds of chemists and physicists for a full century, proved for Rayleigh and Ramsay an unexplored field within this decade. We

know nothing yet. We have gathered a few large pebbles from the shore, but the mass of sands is yet to be explored.

And now the moral has been drawn. The pointing is simple. If America, which, more than other nations, has profited by science, is to retain her place Americans must encourage, even urge, research, must strengthen her scientific societies and her universities, that under the new and more complicated conditions her scientific men and her inventors may place and keep her in the front rank of nations.

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