MALLET (J. W.)

Chemistry Applied to the Arts.

A LECTURE

DELIVERED BEFORE THE

UNIVERSITY OF VIRGINIA,

MAY 30, 1868.

By J. W. MALLET, Ph.D.; M.D.; F.C.S.,
PROFESSOR OF ANALYTICAL AND APPLIED CHEMISTRY IN THE UNIVERSITY.

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CORRESPONDENCE.

UNIVERSITY OF VIRGINIA,
June 1st, 1868.

Professor J. W. MALLET,

DEAR SIR,—The undersigned committee of the members of your class earnestly request, for publication, a copy of your recent Lecture on the objects and plan of instruction in your department. We are prompted to this by the conviction that the best interests of the School of Analytical and Applied Chemistry, and of the University at large, would be advanced by bringing more before the public a Lecture that gave such universal satisfaction to those who heard it.

Hoping you will grant our request,

We remain with the greatest respect,

Your obedient servants,

KING WYLLY.	J. W. KYGER.
GARRETT WALKER.	S. T. EVANS.
H. W. JONES.	L. W. T. BRADFORD.
F. S. SAMPSON.	J. S. WALKER.
J. VAN DEVENTER.	JOHN H. POPE.

UNIVERSITY OF VIRGINIA,
June 2, 1868.

Messrs. WYLLY, WALKER, AND OTHERS,
Committee of Class in Analytical Chemistry,
University of Virginia.

GENTLEMEN,—I beg to acknowledge receipt of your note of yesterday's date.

It is naturally gratifying to me to find that the Class has been interested by the Lecture in question, the manuscript of which is at your disposal in accordance with your request.

I am, gentlemen,

Faithfully yours,

J. W. MALLET.

Chemistry Applied to the Arts.

A Lecture delivered before the University of Virginia, May 30, 1868, by J. W. Mallet, Ph. D., M. D., F. C. S., Professor of Analytical and Applied Chemistry in the University.

"*Inter signa nullum magis certum aut nobile est, quam quod ex fructibus. . . . Quocirca quemadmodum in religione cavetur ut fides ex operibus monstretur; idem etiam ad philosophiam optimè traducitur, ut ex fructibus judicetur, et vana habeatur quæ sterilis sit; atque eo magis si, loco fructuum uvae et olivae, producat disputationum et contentionum carduos et spinas.*"

—Bacon—*Novum Organum. Aphor. LXXIII.*

Gentlemen,—A desire has been expressed by the Rector of the University, and by some of my colleagues of the Faculty, that, in entering upon the duties of the recently created Chair to which I have had the honor of being elected, I should bring before the University some general views with regard to the department of knowledge to which this new Chair is to be devoted, and the object and manner of embodying its teachings with the system of instruction in this time-honored institution.

In attempting to fulfil the duty imposed upon me by such desire, I will ask your attention to a brief discussion of the following topics, viz:

First.—The reasons which seem to render it desirable that the applications of chemical science to the useful arts should be made the subject of formal instruction in the higher institutions of learning;

SECONDLY.—The character of the expectations which may be justly formed of the nature and value of such instruction; and,

LASTLY.—The special and practical form which it will probably be well to give to the teachings of the professorship in question in the University of Virginia.

Many reasons suggest themselves for the introduction, at the present day, of Applied Science, in all its forms, amongst the subjects taught in the institutions of learning of the highest order.

Prominent among these reasons is the great importance which the subject itself has assumed amongst civilized men in comparatively very modern times.

Our knowledge of the general laws and phenomena of external nature has been increased within the memory of those now living to an extent and at a rate far greater than for any equal period in the earlier history of mankind. In many of those branches of physical science which have long been recognized, investigation, constantly increasing in activity, has been rewarded by progress of the most striking character. Multitudes of new facts have been ascertained, and many new and important principles have been discovered. In several directions entirely new realms of intellect have been thrown open, and their exploration has been at once eagerly and actively entered upon. Several of the natural sciences—to-day of universally admitted interest and importance—bear names which a century ago were unknown or were employed with very different meaning. The number of those who devote their lives to the study of physical science has enormously increased, so that, instead of the few sturdy pioneers who in past times pushed forward before their fellows upon the frontier of the unknown, so far separated from each other as scarcely to exchange help or sympathy, and so far removed from the thoughts and interests of the rest of the world that their existence was often scarcely recognized, we see to-day thousands of busy laborers cultivating these recently opened fields of intellectual effort, encouraging each other by constant intercourse, and honorably known to their fellow-men for the success which they have achieved and the rich harvests which they gather into the store-houses of knowledge.

Particularly noteworthy have been the advances made in the application of our knowledge of scientific truth to the comfort and convenience of mankind. No longer are the man of learning and the artizan separated—as to a large extent they formerly were—by the distance between the unpractical speculation of the one and the unenlightened manual dexterity of the other. Nowadays each new discovery of fact or principle is at once seized upon, and its possible bearing upon any of the useful arts eagerly canvassed and examined. New wants and new desires are created as new means for their supply and gratification are brought to light. And, on the other hand, new trains of investigation are entered upon, and further efforts in abstract research are stimulated, as it becomes evident that the possession of knowledge not yet acquired can be made to minister in some particular direction to the comfort or the luxury of man.

It has become so common as almost to have become tiresome to refer in general terms to the great advantages which have been gained in modern times from the practical application of natural science to the arts of civilization—yet it may well be doubted whether most persons have any distinct idea of the immense influence upon the daily life of all—and especially of all except the very rich—which the progress of applied science for the last century, or even half century, has had.

Readers of MACAULAY's History of England are charmed by the distinctness with which, in one of his best known chapters, he reproduces for us a sketch of the actual condition—material, social and political—of England towards the close of the seventeenth century. We are astonished to find how striking is the contrast brought out by such a detailed picture between the habits, comforts and enjoyments of the Englishman of to-day and those of his ancestor of but five or six generations back. An equally vivid picture, from as able a pen, of the state of the civilized world at even the beginning of the present century in reference to the useful and ornamental arts would furnish an instructive standard by which to measure the progress these arts have made since the days of our grandfathers, and to estimate the blessings which the scientific industry of the last sixty or seventy years has conferred upon us.

Many of the examples most frequently quoted of the advances made during this short period are drawn from other than the chemical arts. There are numbers of men now living who need not to be reminded that they have themselves seen the development of railroads, and the transportation upon them of passengers and goods at a speed five or ten times as great as was formerly possible, and upon a scale previously unattempted—an increase of at least five fold in the size of sea-going vessels, and their propulsion by an agent that defies wind and weather and makes the ocean a punctually traversed highway—the establishment of cheap, rapid and effective communication by mail—the truly wonderful interchange of thought between distant countries and opposite continents by the electric telegraph—the production of weapons of war and means of defence such as had not formerly been dreamed of—the substitution of the labor of the untiring steam-engine for that of untold millions of men and other animals—extensions and improvements in the production of food, clothing, and shelter, such as have thrown open to the laboring man of the present day advantages of life that seventy years ago could only be enjoyed by the wealthy, and in many respects were not even at their command.

But if we confine our attention to those arts alone which depend upon Chemistry, the most hasty retrospect presents us with a surprising list of advances made within the same period.

The streets of our cities and our public buildings have been illuminated by coal-gas with a brilliancy, cleanliness, cheapness and safety formerly unknown. Our private houses are lighted in the same way, or with the rival hydro-carbons drawn in the liquid state from beneath the solid rock and refined to the limpid clearness of water. The clumsy and uncertain flint and steel have been replaced as a source of fire by the effective and convenient friction match. The smelting of iron from its ores, and its production in the various forms of cast-iron, wrought-iron, and steel, have been extended upon a scale that dwarfs the manufacture of the last century into insignificance. The important process of Mr. BESSEMER for the direct conversion of cast-iron into steel even now opens to us the prospect of vast changes in the uses which may be made, and the quantity that may be consumed of this most valuable metal. The production of sulphuric acid upon an immense scale, and the adoption of the process of LEBLANC and DIZÉ for making carbonate of soda from common salt have led the way to striking improvements in the manufacture of glass and soap, in the methods of dyeing and calico-printing, and in a hundred arts besides which require the possession of acids and alkalies in abundance and at a reasonable price. The bleaching agency of chlorine has been made practically available, and gives us the snowy whiteness of the fabrics we wear and the paper on which we write. Many improvements of detail have been made in the manufacture and decoration of porcelain. Sugar boiling and sugar refining have gained largely by the application of chemical knowledge, and the extraction of sugar from the root of the beet—suggested by MARGGRAF as early as 1747, but not practically brought into use until the dearth of colonial sugar caused by the continental wars of the first NAPOLEON—has grown up as an important and very perfect branch of chemical manufacture. Quite recently the application of the laws of osmose or liquid diffusion through porous septa has furnished an entirely new method of separating crystallizable sugar from the organic impurities which accompany it, and this method has been put in practice upon the large scale. The working of indian rubber in its thousand protean forms, and the "vulcanizing" process, by which we confer upon it at pleasure most dissimilar and most strongly marked physical properties, are discoveries of our own day.

Several new arts have arisen which depend in part upon other than chemical principles, but have drawn largely upon chemistry, both in their origin and development—such as electro-metallurgy, which produces the sharpest casts by means of metals in liquid solution at common temperatures, and coats with a brilliant film of gold or silver objects moulded in the baser metallic alloys—and photography, which fixes for us the pictures of natural objects with the fidelity of nature herself.

Other arts—as that of agriculture—, long pursued by man empirically, have begun to assume a rational form with the aid of the light which, it is now seen, chemistry is capable of throwing upon them.

A host of new and valuable substances—unknown to our forefathers—have been added to our resources by the progress of chemical discovery. Malleable platinum, indispensable to the chemist himself, and lending most important aid to the great manufacture of sulphuric acid—iodine and bromine, with the services they render in medicine and photography—quinine, morphine, strychnine and atropine; potent but reliable weapons in the struggle with disease—

chloroform, which gives blessed unconsciousness of the tortures of the surgeon's knife—citric and tartaric acids prepared in large quantity, which with salts of potash give immunity from the scurvy that formerly raged on shipboard during long voyages—carbolic acid, which as a disinfectant promises to become one of our most effectual safe-guards against pestilence in large cities—dextrine, which supplies the dyer, the calico-printer, and many another artizan with a cheap and satisfactory substitute for gum—the paraffine, stearic acid and glycerine which, with their numerous uses, have been given to the world in quantity mainly by the enlightened energy of a single manufacturing firm—the gun-cotton and nitro-glycerine which have been added to our list of explosive materials—the compound ethers, which enable us to imitate the odor and flavor of the most delicious fruits—all these form but a part of the achievements of the very recent times of which we have been speaking.

Let me remark in passing that it is not with pride, or with a belief in great intellectual superiority on the part of the men of our own day to those of preceding centuries, that we should regard such results as have been named. It should ever be borne in mind that we have been building on foundations laid by those who came before us—that much of what has been done in modern times was only rendered possible by the results of patient toil on the part of men long passed away, who often saw little apparent success reward their labor in their own day and generation. As, when we look upon the panting locomotive or the titanic steam-hammer of the present day, we often think only of the wonderful ingenuity and skill displayed in that one machine, apparently so perfect in design and execution, and are apt to forget how many other parent machines—lathes, drills, planers, and the like—had first to be invented and constructed, before that which we admire could be built; how these in turn were preceded by others of yet simpler kind, and these by hand tools—the descendants of rude contrivances, the very names and uses of which have been forgotten.

But in the history of invention or discovery the French proverb is often applicable—it is the first step which involves the greatest difficulty. The early efforts at the investigation of nature—crude and apparently barren of immediate result as they often were—yet frequently demanded a higher order of intellect and more severe mental exertion than those of the man of modern times, who attacks more difficult problems, but with the accumulated knowledge of centuries to start from and to aid him. The grown man may smile at the seeming feebleness of the child's intellect, yet perhaps he never during life is called upon for so severe a mental effort, in proportion to the means with which it is to be made, as is involved in the acquisition of spoken and written language during the first few years of childhood.

We can hardly help, indeed, being amused as we read ARISTOTLE's grave enquiries as to the reason that sneezing may be cut short by rubbing one's eye, and why it is that men whose teeth are widely separated do not live long, or the discussion by Sir THOMAS BROWNE of the ability of unfortunate ostriches to eat iron—yet we should be in the wrong to consider that these particular passages fairly represent their author's attempts at the investigation of nature; and, even if they did, we should be bold in assuming that wise men of our own day would have made any better choice of questions, or attacked them more intelligently or successfully, had they been placed in the dim and uncertain light which the minds of antiquity possessed alone to guide them.

Without, however, any senseless boasting of our own times, or invidious comparison with the past, we may well look with admiration and gratitude upon the present rapid progress of the study of nature, and of the application of the knowledge thus acquired to the advancement of man's happiness and welfare.

In a civilized community the University should be the highest exponent of the actual condition of human knowledge. It surely, therefore, cannot be deemed right that applied science—a department of knowledge which to-day yields such magnificent results, and which absorbs the attention and engages the best efforts of thousands of able and well trained intellects throughout the civilized world, should be excluded from or neglected in the list of studies which the University recognizes as parts of a liberal education.

Nor, in fact, does any such idea prevail. It is seen that education in the principles and applications of natural science is of the highest value to the student himself, and through him to the community of which he is a member. For many years past the opinion has beensteadily gaining ground amongst intelligent men that opportunities for the study of natural science, both in its general laws and special applications, should be presented to the youth who are to form the educated classes of the State, and that where facilities for such study already exist they should be fostered, extended, and improved. In some communities this view has originated within the higher schools of learning themselves; in others it has been urged upon their attention by the pressure of public opinion from without. In some places it has been carried into practical effect; in others it remains yet in the form of an ill-defined belief that the time has come when *some* such change must be made in the system of public education; but everywhere—on both sides of the Atlantic—we find the idea in existence, and yearly growing in recognized importance.

In England the subject has been very actively discussed—particularly since 1851, in which year a strong impression was made upon the public mind by the silent teachings of the first international exhibition of industrial products, for which great lesson the nation was largely indebted to the sound, practical wisdom of the late Prince ALBERT.

In the report upon the University of Cambridge* presented to Parliament in the following year, the Royal Commissioners made the following remarks with reference to the teaching of Chemistry:

> "The Science of Chemistry is rapidly extending its ramifications into all the arts of life, and a knowledge not merely of its principles, but also the practical power of applying them, is becoming daily more and more important as a part of general as well as professional education"—

adding further on the practical recommendation:

> "But the Science is much too extensive for the teaching of one Professor: and we venture to hope that the University will eventually add a second, who may divide with the present Professor the vast range of subjects contained in this extensive Science."

Since then the study of chemistry, as well as of other branches of natural science, has been actively encouraged in all the English Universities and Colleges; technical schools of applied science of various grades have been founded—such as the Royal College of Chemistry, the Royal School of Mines, etc.—; and a system of public

*Report of Her Majesty's Commissioners appointed to enquire into the state, discipline, studies, and revenues of the University and Colleges of Cambridge. Presented to both Houses of Parliament by command of Her Majesty. London, 1852, p. 102.

examinations has been made to foster the same departments of study when carried on under private instructors.

Yet the most able and watchful guardians of public education in that country are far from believing that enough has yet been done. Just at present there is a renewal of eager interest in the subject, due in part to the stimulus of last year's International Exhibition at Paris. There have been published* extracts from replies made by a number of eminent English jurors, who attended that Exhibition to official enquiries addressed to them upon the subject of its bearing upon technical education.

Dr. Lyon Playfair says:

"When he found some of our chief mechanical and civil engineers lamenting the want of progress in their industries, and pointing to the wonderful advances which other nations are making; when he found our chemical, and even textile manufacturers uttering similar complaints, he naturally devoted attention to elicit their views as to the causes. So far as could be gathered by conversation, the one cause upon which there was most unanimity of conviction, was that France, Prussia, Austria, Belgium, and Switzerland possess good systems of industrial education for the masters and managers of factories and workshops, and that England possesses none."

In the last expression the word "none" must of course be understood in a relative sense only.

Professor Tyndall, F.R.S. "expresses a general concurrence in the views of Dr. Playfair," and says:

"The facilities for scientific education are far greater on the Continent than in England, and, when such differences exist, England is sure to fall behind as regards those industries into which the scientific element enters."

Dr. Frankland, F.R.S. says:

"He refers the want of progress in the manufactures of this country (England) chiefly to the almost utter lack of a good preparatory education for those destined to take part in industrial pursuits. This great defect in the school and college education of England affects the masters and managers of our factories even more deeply than the workmen themselves. The former have but rarely had any opportunities of making themselves acquainted with the fundamental laws and principles of physics and chemistry; they, therefore, find themselves engaged in pursuits for which their previous education has afforded them no preparation, and hence their inability to originate inventions and improvements. It is true that such men

* Chemical News—*August 16th 1867*—(Supp'l)—p. 89.

not unfrequently imagine themselves inventors, and the yearly files of patent specifications abound with instances of their so-called inventions. The great loss of time and money attending these futile patents would be rendered impossible by a very moderate, if accurate, knowledge of chemical and physical science. In the polytechnic schools of Germany and Switzerland the future manufacturer or manager is made familiar with those laws and applications of the great natural forces which must always form the basis of every intelligent and progressive industry. It seems that at length this superiority in previous training is more than counterbalancing the undoubted advantages which this country (England) possesses in raw material."

Dr. DAVID S. PRICE says :

"His firm belief is that extended scientific education is of the highest consequence to us if we wish to retain our present position in the scale of nations."

And other writers express similar convictions.*

France has long recognized the value of the application of science to the arts and of scientific training for those who are to engage in industrial pursuits.

Le Conservatoire Impérial des Arts et Métiers, the Imperial Mint, the great establishments of Sèvres and the Gobelins, L'École des Mines, and especially of late years L'École Centrale des Arts et Manufactures, have all been, and remain, luminous centres of education and intelligence. They are supplemented by other, less known, schools, both in Paris and in the provinces, and keen interest is manifested in adding whatever there may be found advantageous in the systems of other nations.

Quoting again from the official correspondence* just referred to:

DUMAS, so long known as the eminent Professor of Chemistry at the Sorbonne,

"Asserts that technical education had given a great impulse to the industry of France. In going through the exhibition, whenever anything excellent in French manufacture struck his attention, his invariable question was, 'Was the manager of this establishment a pupil of the École Centrale des Arts et Manufactures?' and in the great majority of cases he received a reply in the affirmative. General MORIN, so well known as the Director

* The announcement has very recently been made that Mr. WHITWORTH—the well known maker of machine tools, and inventor of the rifle and rifled cannon which bear his name—has presented to the British nation £90,000 sterling, or about $600,000 in United States currency, for the purpose of founding thirty scholarships, to be obtained by competition in Applied Science, and to be held for some years by workmen who will go through a thorough course of scientific and artistic training."

of the Conservatoire des Arts et Métiers, has lately sat on a commission to examine into the state of technical education in other countries and to extend it in France, and their recommendations are likely to be promptly and largely acted upon. General MORIN was of opinion that the best system for the technical education of *workmen* is to be found in Austria, though the higher instruction of masters and managers is better illustrated in France, Prussia, and Switzerland."

Not only in Prussia and Austria, and in the minor states of Western Europe—in Holland, Belgium, Saxony and Switzerland—has this subject received great attention of late years, but the same remark applies to Russia, the government of which country both presses forward scientific and technical education at home, and frequently sends forth at the public expense intelligent men to study abroad the arts and manufactures of foreign nations.

Upon this side of the Atlantic considerable activity has already been displayed by the Northern States, and the last few years have seen the foundation of the scientific schools of Harvard and Yale Colleges, the School of Mines of Columbia College, N. Y., the Massachusetts Institute of Technology, and similar scientific branches attached to several other of the higher institutions of learning both in the East and West.

These schools—in some cases founded by the parent colleges, in others the offspring of private liberality—are said to have already exhibited a rapid growth and gratifying results. Intelligent men look to their teachings and influence as of the highest importance to the future development of the industrial energies of the country.

But, turning our attention to the Southern States, weighty reasons of a special kind may be urged in favor of extending the teachings of applied science here amongst ourselves; reasons drawn from a consideration of the condition in which our country is at present, unfortunately, found.

Exhausted by recent war—her fields not yet recovered from the ravages of armies, the weeds of enforced neglect, and the destructive inundations due to ruined public works—a large proportion of her few manufacturing establishments burnt—her former system of labor destroyed, and as yet unreplaced by any efficient substitute—the accumulated wealth of her past history entirely swept away—the South has no foundation on which to rear again the edifice

* Chem. News—loc. cit.

of future material prosperity, except the indestructible gifts of nature which a kind Providence has bestowed upon her, and the enlightened energy and industry of the sons who love her and mean yet to raise her from the dust.

In discussing the immediate future, the prospects of recuperation, and the direction which public and private effort should take, there seems to be no point upon which thinking men are more generally agreed than the necessity of varying the forms of Southern industry and Southern products, instead of attempting to revive the purely agricultural policy of the past, which resulted in the Southern States producing for sale to the rest of the world little or nothing beside her magnificent crops of four or five valuable staples, while depending upon other states or countries for domestic supplies of almost every article of necessity or convenience. Agriculture must, of course, still be pursued, as the basis of all prosperity, and, doubtless, to be successful, must be practised with much more intelligent skill than ever before—but with the uncertain character and amount of the labor upon which Southern farmers will obviously have to rely for a long time to come, it is clearly to be desired that other forms of industry should be developed, less vitally dependant upon labor—and, above all, labor in connection with particular seasons—as a condition of success.

Already the tendency in this direction is becoming well marked, and receives additional stimulus from the poverty of the country, and the necessity that presses upon almost every one of getting, in some form or other, to work. All over the land there are parents anxiously looking for employment for their sons, and thousands of young men themselves—and, indeed, of older men as well—are seeking new and profitable occupation for their hands and brains.

Surely the country and the times in which we live most urgently demand such educational facilities as shall—so far as formal education can conduce to that end—indicate the directions in which industrial effort may hope for success, and the methods and conditions by which such success is to be attained.

If, then, it be confessedly desirable that applied science should constitute a branch of public education of the higher grade, let us glance briefly at the nature of such teaching and the expectations which may fairly be entertained with regard to its benefits.

There are two principal advantages to be derived from education, in the sense in which the word is generally used—the one, mental discipline and the increase of intellectual strength — the other, the acquisition of special knowledge, with the power to make practical use of it.

In some quarters objection has been made to the modern tendency to embody the study of natural science in the system of University instruction, on the ground that this amounts to, at least partially, setting aside the time-honoured and well-proved subjects of disciplinary education—more particularly mathematics and the classical languages—in favor of lighter and more easily mastered subjects, less calculated to strengthen and to train the intellect.

But this objection rests in great part upon the assumption that the study of natural science is taken up, or permitted to be taken up, in such an easy form, and with so little earnestness and thoroughness, that no better result could be looked for than the production of mere smatterers, destitute alike of mental training and of really acquired knowledge.

With the rapid extension, yet imperfection, of our acquaintance with the laws of nature, with the wonderful correlation existing among these laws themselves, and with their innumerable and often highly complex applications to the production of facts and phenomena in themselves familiar, the mind can find abundant material for arduous labor and severe discipline. "In this, as in every other field of labor, no man can put aside the curse pronounced upon him—that by the sweat of his brow he shall reap his harvest."

If a man will content himself with picking up at second-hand a few statements of so-called "popular science," or will amuse himself merely with philosophical toys and the repetition of a few showy experiments, the effort will certainly be a very easy one—if, however, he aim at really mastering the facts, principles, and applications of even but a single branch of physical science, and at becoming in time himself an "interpreter of nature," he will find that no lazy or untrained intellect will serve his purpose.

In some respects the investigation of nature possesses peculiar advantages, and specially educates particular faculties of the mind. Admitting that of all studies that of mathematics is best fitted to develope the power of reasoning in its most abstract form, we must also admit that the mathematician is apt in his arguments sometimes to overlook the examination of the assumed facts which are his premises, in his stern pursuit of the consequences to which they logically lead. On the other hand, nothing so perpetually occupies the attention of the student of natural science as the discovery, the examination, and the verification of *facts*. Sometimes he is able to collect a number of facts together in the form of a principle, more or less general—sometimes he must content himself for the moment with the simple determination of an apparently isolated truth—but at all times, whether he can refer it to its cause or not, the truth as it is in nature is the object towards which he strains his eyes. He learns humility and a wise distrust of hasty speculation as he finds how many cherished errors he is called upon to give up, and how much labor he has sometimes wasted, because misdirected—he learns judgment and the power of discriminating between truth and the errors which resemble it, as he over and over again submits to the test of experiment the knowledge he supposes he has gained—and he learns love and reverence for the truth itself, as he finds himself permitted to question at the awful shrine of Nature, which never returns a false, though often an oracular and imperfectly-understood reply.

In reference, however, to the study of natural science probably most persons think chiefly of the value of the special knowledge which is to be acquired, and the practical use which may be made of it. This consideration is more particularly before us at present. It may be well, therefore, to notice a few of the chief points deserving of attention as to the true relation between the laws and phenomena of nature and the application of them to the service of man.

The student of pure science occupies himself solely with facts and principles, regardless of any artificial bearing that may be given them upon the wants and comforts of the human race. He who devotes himself to applied science must not only study with equal attention these same facts and principles of nature, but in addition must notice the direction and the form in which they may be made subservient to the purposes of daily life.

The latter, therefore, is called upon to examine the *wants of society*, constantly varying in character and urgency.

In this matter-of-fact world, and under the organized system of commerce of modern times, the measure of the urgency of such wants is the money price which the means of satisfying them can command—and hence the student of applied science, in dealing with the question of the attainment of any particular object, has to consider—

1st.—The possibility of its attainment.

2d.—The cost of its attainment.

3d.—The price which society will be willing to pay for its attainment.

A proposed object may involve in its very conception a contradiction of some great law of nature—in which case it may at once be pronounced impossible of attainment. Thus, we are well assured that the aggregate amount of matter and that of force in the universe, so far as revealed to us, are unchangeable, and it is useless to discuss the details of any scheme, however plausible, which includes the idea of the creation of either the one or the other, though but to the smallest extent—many a laborious attempt has been made at mechanical, and not a few at chemical, improvements, which a recognition of this truth would at once have shewn to be absurd.

But we must be certain that the supposed law of nature has been deduced from sufficient observation. Before the time of Mitscherlich it might have been stated as such a law that different substances refuse to crystallize together when mixed in variable proportions, and may therefore be separated from one another by the process of crystallization; but he shewed that, while this is generally true, it is not invariably so—that there are certain bodies which do crystallize together, no matter in what proportion they may be mixed, and hence that such substances cannot be separated by the process in question.

Moreover, we must be cautious that we correctly apply a natural law, though it be itself well established. Thus, as has been well instanced,* a man acquainted with the law of gravitation, and its action in causing bodies to fall to the earth, might not unnaturally declare the fact of a balloon rising when released to the height of several thousand feet above the earth impossible; yet, when properly examined, this fact is seen, not only not to contradict the law of gravitation, but even in part to be a direct result of it.

We may set before us a particular object, which does not involve any conflict with the known laws of nature, and which therefore cannot be pronounced necessarily impossible—and yet it may be *practi-*

* By Liebig.

cally impossible for us in the present condition of our knowledge, having resisted all attempts at its attainment by the application of known principles in any way hitherto tried. A notable example of this is afforded by the question of the artificial production of the diamond. We know that the diamond is simply crystallized carbon; we can procure carbon in abundance; and in the case of a vast number of other substances we can by well-known methods readily cause them to assume the crystalline form—we can even crystallize a kindred element, boron, and give it properties closely resembling those of the diamond—but, with regard to carbon, hundreds of chemists have tried all known means of inducing crystallization in diamond form, without success. So many such efforts have been made as to render it very unlikely that any further experiment will be more fortunate, unless tried in some as yet unforeseen direction, and this research cannot be recommended to any one as a profitable occupation. Yet it would not surprise chemists if a method for producing genuine diamonds were to be discovered to-morrow—surprise is rather felt on the contrary that no such method has as yet been found.

But the object at which we aim may be entirely possible in principle, and attainable in point of scientific fact; and yet its attainment may, under existing conditions, be *commercially* impossible, if either it cost too much or will command too small a price.

The element of cost generally depends upon many and various conditions—some of which belong properly to the domain of science, while others are of a purely commercial, a social, or even a political character.

Thus, in some cases, the costliness of a product of art may be due to the rarity in nature of the material necessary for its production; and, if this material be indispensable, and it cannot be had more abundantly, there is little use in improving the processes of its after treatment.

Here chemistry teaches us to carefully distinguish between the elementary substances—of which some 64 are now known, and which we are unable to convert into each other—and the compounds of these elements, which may be built up from their constituents in various ways. If the absolute scarcity of an *element* be the cause of the great cost of some product in which it forms an essential constituent, there is but one way in which we can get over the difficulty—

we must search in nature for some as yet undiscovered source of the element in question.

Any discovery which might be made at present, of no matter how useful a kind, if it involved the use of the metal Bismuth upon a large scale, would have little immediate practical value—since this metal is so far only known to occur at but few localities and in comparatively small quantity.

An instance has recently occurred of the successful development upon a large scale of a new source of supply of an elementary substance of great value. I allude to the working for compounds of potassium of the immense deposit, at Stassfurt in Prussian Saxony, of chloride of potassium and magnesium, which occurs there associated with rock salt—this has at once enormously reduced the price of potash in the great markets of the world, and has at the same time furnished by-products of the manufacture which are highly valuable as manures. Another—though minor—source of the same element in an available form, which has heretofore been overlooked, is the fleece of the sheep in its rough state. This, it has been found, contains a considerable amount of potash in combination with fatty acids. The water in which the wool is washed has hitherto been thrown away, but now in France it is made to yield potash to the extent of from 7 to 9 p. c. of the weight of the unwashed wool.

In the relation of which we are speaking a striking difference is observable between inorganic and organic products. The former are much more prominently characterized by the particular elements which they contain—the latter are composed of but few, and generally the same, elements, and their properties depend chiefly upon the manner in which these elements are combined. To this fact is largely due the magnificent and often unexpected results which the arts of late years have gained from the extended study of organic chemistry.

Amongst inorganic substances, however, there have been striking examples of increased economy of production following a change in the selection of the particular natural source of the material desired The carbonate of soda so essential to the prosperity of the manufactures of glass and soap was formerly derived from the ash of marine plants, and when Leblanc had shown how it might be obtained from common salt the quantity manufactured was enormously increased, and the cost was correspondingly diminished.

Ultramarine was formerly prepared from the rare mineral *Lapis Lazuli*, and then ranked amongst the most costly pigments, and was found only in the hands of portrait painters and artists of the highest order. GUIMET discovered the method of so combining the silicic acid, alumina, soda and sulphur, which are the essential components of the natural mineral and of the pigment prepared from it, as to reproduce perfectly the desired color, and at a cost more than a hundred fold less than formerly necessary, so that artificial ultramarine is now used upon the great scale for decorating wall paper and for other common purposes of the arts.

Very often, therefore, a reduction in the cost of an article admits of being obtained by an improvement in the method of preparing it. And this remark applies, not only to money cost, but sometimes also to the expenditure of human life and human health. In factories of lucifer matches the introduction of the amorphous phosphorus discovered by SCHRÖTTER, in place of the long known form of this element, has largely diminished the danger from fire and explosion, and has obviated all necessity for the sufferings previously endured by the operatives from carious disease of the lower jaw produced by the fumes of the ordinary phosphorus.

As has been stated, there are many other conditions which affect the cost of a process or of its product—the supply of fuel and water, of labor and machine power—the distance and cost of necessary transportation. Many of these conditions require other than purely scientific examination, and must depend upon other than purely scientific means for improvement, but all must be taken into account, and their effect carefully estimated, before any reasonable assurance of success can be entertained in a question of economically applied science.

Should, however, the object we aim at be physically possible of attainment, and attainable at a moderate or even a trifling cost, there remains to be considered whether when attained it is one which mankind will value—for which society will be willing to pay.

There are thousands of substances whose names are to be found in text-books of chemistry, the properties of which are either such as have no recognized use and value, or such as are presented by other bodies, already found in commerce, in greater perfection or more convenient form. It is of no use at present to manufacture substances with which we know not what to do when we have obtained them.

But we should cautiously guard against pronouncing a substance or a process intrinsically valueless simply because no important use for it has as yet been found. Sometimes a material, whose properties may for a long time have been thoroughly known, but not usefully applied, suddenly becomes of great value as new demands—arising often from very remote causes—render evident the direction in which it may be made of service. The value of a product often changes enormously with the course of time and the general progress of the world's industry. Two hundred years ago the metal platinum would have been of little use—the arts in connection with which it is employed to-day with very great advantage had not then arisen.

Sometimes, too, a substance may have been examined, but not thoroughly—some of its characteristics ascertained, but not all—and such an imperfect knowledge of its properties may cause it to be neglected as valueless, until further research or some fortunate accident reveals the use which may be made of it. SOUBEIRAN, when in 1831 he discovered chloroform, and DUMAS and LIEBIG—eminent chemists as they were—, who followed him in examining it, did not ascertain its effect upon the animal body when respired in the form of vapor, and little suspected what a "blessing in disguise" the material they had under their hands would in a few years prove to be.

In like manner, errors of observation or experiment upon a new substance, or a failure to obtain it in a state of purity, may lead to its true properties and value remaining long concealed. The ideas entertained for many years with respect to the metal aluminum, founded upon experiments made with very small quantities of the element in an impure condition, were found to be quite erroneous when it had been prepared on a larger scale and free from other substances—that which was formerly supposed to be of no use was found to possess some quite valuable properties.

Sometimes we find science suggesting a want, as well as the means of supplying it, and society—recognizing the importance of the suggestion—coming back upon science with demands upon a scale so much greater than was originally foreseen that fresh researches and new discoveries have to be made in order to respond to them. The great demand for bones to be used in various forms as manure was created by the teachings of science as to the value of the phosphate of lime which they contain; this value becoming fully recognized in commerce, the demand has, of late years, so increased in England as to seriously threaten its exceeding the means of supply—but the fresh activity given by this fact to scientific research has recently resulted in the discovery of large quantities of fossil phosphate of lime, in the form of coprolites, and the manufacture of this material upon so large a scale that, in place of importing, England now exports phosphatic manures.

It is often extremely interesting to notice the history, in order of time, of the steps by which an invention or discovery is developed by science and rendered available for the purposes of commerce.

Sometimes—but very rarely—a novel object is attained without having been before specially sought for, its value at once recognized, the means for its attainment put into a commercially practicable form, and its results given to the world, by the exertions of a single man, and within a comparatively short period of time. Of this the most remarkable instance in our own day has been the production and rapidly spreading use of the peculiar kind of steel, sometimes called "homogeneous metal," but now more generally known by the name of the man—Mr. BESSEMER—who originated the idea of its manufacture, surmounted the practical difficulties that attended its production at first, demonstrated its value and the uses which may be made of it, introduced it into commerce, and now enjoys the personal reward of his labors in the form of a princely income—larger perhaps than has ever before been derived from a patented invention.

Sometimes a material or a process fulfilling certain particular conditions is called for by society, and long sought for with the aid of science before success comes to crown the efforts made—under such circumstances a powerful stimulus is given to research by the certainty and the immediate character of the reward to be looked for by the successful discoverer or inventor. It was notorious that the supply of illuminating and lubricating oil from the whale fisheries of the world was fast diminishing, and that a substitute was urgently demanded, when, some years ago, active scientific research led after a time—first to the production of kerosene or photogene oils, from the dry distillation of highly bituminous coals and schists—and later to the discovery of large supplies of petroleum in the older rocks, and the perfecting of methods for the purification of this new material. Even now there are many industrial objects aimed at by scientific men, the means of securing which have not yet been ascertained—but which we may reasonably hope will yet successfully be accomplished. A most tempting problem of this kind is that of the production of artificial quinine, which is not deemed by any means hopeless, though it has already been eagerly essayed by several chemists of great ability.

Sometimes the order of time is reversed, and a substance or a phenomenon may be said to be presented by science to the world in anticipation of any demand for it, but with a good deal of confidence that some day or other it will be found to be useful. Thus, the substance naphthaline has been known for many years as one of the results of the dry distillation of coal in the manufacture of gas—it has been a mere waste product, accumulated and thrown away in large quantity—but chemists have long felt confident that it could be turned to useful account, and quite recently a method has been discovered by which a magnificent violet color may be obtained from it, which has at once come into use as a dye. In like manner, bi-sulphuret of carbon was for a long time a mere chemical curiosity—only to be found in small quantities in scientific laboratories—but known to possess properties which would most likely in the end render it commercially valuable. It is now prepared upon a very large scale, and used for dissolving indian rubber, extracting colza and other oils, destroying weevil in grain, and various other purposes. As an example of a body—at present useless—but with some properties which perhaps indicate for it an important future, I may mention the element silicon, as not very long ago prepared and described by the eminent French chemist, DEVILLE.

Most usually, however, the history of an invention or discovery is a complex one, and presents us with many partial additions to knowledge—often following one another at long intervals—and many partial applications of the knowledge thus gained—sometimes in the direct line of the original enquiry, sometimes in quite a different direction—the exertions of many independent workers often conspiring to the final result.

It may not be without interest to present you with one or two examples—such as are afforded by the history of the alkaline and earthy metals and that of the coloring materials derived from coal tar.

In the year 1807 Sir Humphrey Davy, who had just before discovered the compound nature of potash, extending his research to soda, found that it too—on being subjected to the action of a powerful galvanic current—separated into oxygen and a new metallic substance. This new metal, however, was obtained only in minute globules, most of which burned again immediately in the air, reproducing soda. Its extreme lightness, causing it to float upon water, and the fact that it may be inflamed by mere contact with water, while it possesses the lustre and other of the physical characters of the long known metals, were properties which excited a lively interest in sodium, as in the kindred metal potassium, but these promised nothing of practical utility.

By further experiments Davy satisfied himself that not only the alkalies but the earths, including magnesia and alumina, are compound bodies, each consisting of oxygen united to a peculiar metal—he did not succeed, however, in obtaining the metals themselves in quantity or condition to exhibit their properties.

Soon after, Gay Lussac and Thénard devised a better process for preparing potassium and sodium, by heating the alkalies with iron—and, still later, charcoal was found to be a yet more convenient reducing agent. Soon sodium could be found for sale, but as a curiosity merely—in little globules not larger than a pea, and at a price that even in 1830 was fifty times greater than that at which it can now be sold. It was long ago pointed out by Gregory, however, that the high price of sodium was due to its being prepared only in small quantity as a scientific curiosity—that, if any demand for it in larger quantity should arise, it could be furnished at a price not much exceeding that of zinc.

Meanwhile, Wöhler had, in 1827, produced aluminum—the metallic basis of the earth alumina—in quantity sufficiently visible to admit of examining many of its properties, some of which, however, were very imperfectly exhibited—the metal being impure, and not united into compact masses. Bussy, in 1830, made a similar improved but imperfect examination of magnesium. Neither of these researches seemed to indicate any useful application of the metals as probable—in fact it was supposed that they could not be preserved in the air from speedy oxidation and re-conversion into the earths.

Up to the year 1853 sodium was to be found only in chemical laboratories, and very few, even of scientific chemists, had ever seen the smallest specimen of aluminum or magnesium. In that year DEVILLE—the illustrious chemist who has lately replaced DUMAS as Professor in the Faculty of Sciences of Paris—occupied himself with the preparation of aluminum upon the large scale and in a state of almost perfect purity. He shewed that this—the characteristic constituent of common clay—possesses a number of remarkable properties, some of which can be turned to useful account.

The metal, as you see it in this bar, is only about twice and-a-half as heavy as water, has a bright white color, a high metallic lustre, and considerable malleability and ductility combined with a certain hardness, is highly sonorous, and can be melted, cast, hammered, rolled, soldered, and alloyed with other metals. It remains untarnished in an atmosphere which turns silver black, and resists the action of some, but not all, of the most energetic chemical solvents. Greater expectations were perhaps formed of its utility than have yet been fully justified—but its production has been continued upon a considerable scale, and it is used in the manufacture of jewelry* and ornamental articles of many kinds, in the construction of surgical and musical instruments, and by chemists as a convenient material for the smallest standards of weight. Its alloy with silver is coming into use as a cheap substitute—of good color—for the latter metal itself; and alloyed—to the extent of 10 per cent.—with copper it exhibits remarkable tenacity, and has lately, amongst other applications, been employed in France for the production of the little punches with which the perforations in sheets of postage stamps are made—the steel punches formerly used were worn out in a single day, while those of this "aluminum bronze" are found to last for many months in good condition.

Attention was now again drawn to magnesium, and its preparation upon a larger scale than before developed previously unsuspected capabilities on the part of this metal also. In appearance it differs not very much from aluminum, but it has only about once and three-quarters the density of water. It may be melted, and even distilled, without difficulty. It admits of being mechanically worked to some extent, but is more readily oxidized and acted upon by chemical

*Contrasted with gold in the same article of jewelry it sometimes produces an excellent effect.

reagents in general than aluminum. Its chief practical value has been found to depend upon the brilliant light—measurably comparable with that of the sun*—which, as you see, it produces when a thin wire or riband is burned in the air or in oxygen. This light has been brought into use for military and other signals, for the production of photographic pictures at times and in places—as at the bottom of the sea—where sunlight cannot be had, and for other purposes requiring a very pure and very intense light. The metal, purified by distillation, has also furnished chemists valuable aid in the detection of arsenic in cases of poisoning.

But the manufacture of aluminum and magnesium created a demand for sodium, to be used in reducing the former metals, and soon GREGORY's prediction was partially verified, and sodium became as cheap and abundant as before it had been rare and costly.

In 1865 an independent use was found for this metal itself. It was discovered that the addition of a very little—not more than one-half or one per cent.—of sodium to mercury increases very greatly the adhesion of the latter to other metals—a fact which I can illustrate for you with a piece of iron, a metal to which mercury in its ordinary condition will not adhere at all. This fact is taken advantage of in the extraction of native gold from the quartz with which it occurs. A solid amalgam is first formed of one part of sodium and thirty of mercury—this can be conveniently kept and transported, and is added for use to so much more mercury that there are 120—150 parts of the latter to 1 of sodium. Mercury thus treated, when agitated with the finely divided quartz and water known as "slime," takes up the minute particles of gold much more quickly and perfectly than ordinary quicksilver—and actual experiments upon the working scale have proved that the yield of gold is largely increased—in some cases to the extent of more than fifty per cent. Poorer quartz than formerly can now be worked with profit, and, at the same time, the loss of mercury itself is much diminished.

Such are the main points in the story of the "light metals"—that of the "coal-tar colors" is more simple, but not wanting in interest.

In 1826 UNVERDORBEN discovered that by distilling indigo under

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* One set of comparative experiments is said to have indicated a light-producing power equivalent to 1-225th that of the sun, while the photographic effect was found to be 1-36th of the same.

certain conditions a liquid substance is produced to which he gave the name *crystalline*, as it formed distinctly crystallizable compounds with acids—the name *aniline* was afterwards applied to it.

In 1835 RUNGE, who had obtained the same substance amongst the products of the distillation of coal-tar, noticed that it developed a violet-blue color by treatment with a solution of chloride of lime (bleaching powder).

In 1840 FRITZSCHE, in experimenting upon aniline with a mixture of chlorate of potash and hydrochloric acid, observed a blue coloration.

In 1843 HOFMANN, to whose later researches we owe much of our scientific knowledge of the aniline colors, developed a red color in treating aniline with fuming nitric acid.

All these early observations, however, were simply recorded as facts of scientific interest, the colors were not known to be dyes of permanent tinctorial value, and no practical application was made of them.

In 1856 Mr. PERKIN patented in England the first practical process for manufacturing a dyeing material from the source in question. The color which he had obtained was a violet, to which the technical name "mauve" was given—it was produced by acting upon aniline with bi-chromate of potash and sulphuric acid. This color attracted, however, no very great attention at first.

In 1858 HOFMANN, in again working upon aniline from the purely scientific point of view, again noticed the appearance of a rich crimson color, this time from the action of bi-chloride of carbon—but of this fact again no practical application was made.

In 1859 came at last, in an indirect way and from an unexpected quarter, the discovery which opened up the now important industry of aniline colors. M. M. GUINON, MARNAS and BONNET of Lyons produced a permanent and brilliant purple from *orseille* (the coloring matter of lichens), which was introduced into commerce as "French purple," and soon became widely and favorably known. This resembled so closely the tint of Mr PERKIN'S "mauve," discovered three years before, that the latter became fashionable, and attention was at once bestowed upon it and the process by which it was made; so that fresh experiments were instituted upon aniline—now with the object of technical application distinctly in view.

In the same year—1859—M. VERGUIN, of the firm of RÉNAUD *frères* of Lyons, discovered and patented the process for producing a splendid red color by treating aniline with bi-chloride of tin.

Attention was now at once forcibly drawn to these new dyes—their great beauty, brilliancy, power of supporting artificial light and intense colorific effect were recognized—and chemists went to work in all directions to look for new colors from the same source, and different means of obtaining those already known. In 1859, 1860 and 1861 numerous patents were taken out, chiefly in England and France, for processes connected with the new manufacture. By acting with reducing agents upon aniline red it was found that beautiful blue colors could be obtained, and subsequently fine tints of green, yellow, brown, and black were successively brought forward.

Many persons have of late years become familiar with the names of various fashionable colors—Magenta, Solferino, fuchsine, azaleine, peonine, mauve, violine, imperial violet, regina purple, bleu de Paris, bleu de Lyons, azurine, emeraldine, phosphine, couleur de mais, &c., &c.—without knowing that all these were derived from one and the same source, and that source no other than the homely, dirty, sticky and disagreeable substance—coal-tar.

As the manufacture is now carried on, the tar is subjected to fractional distillation, repeated several times upon the different products obtained. The portion boiling between about 160° and 250° F.—called in commerce *benzole*—consists mainly of the two substances benzole and toluole. These are converted into nitro-benzole (also known and used as artificial oil of bitter almonds) and nitro-toluole by treatment of the liquid with fuming nitric acid. Further treatment, now with reducing agents—generally in practice acetic acid and metallic iron—produces aniline and toluidine, which mixed together constitute the liquid known commercially as *aniline*. This is the immediate source of the various colors, which are produced by a great number of different processes—some of which have just been indicated, and which may, for the most part, be classed under the heads of oxidation, reduction, and the substitution of compound radicals for the element hydrogen.

Here are some specimens of these substances, of the colors derived from them, (in the dry state and in solution in alcohol), and of fabrics which have been dyed with some of the more prominent tints.

On the blackboard you will see the formulae which represent the more important chemical reactions referred to.

The distillation of coal-tar, for the purpose of producing the light oil or benzole to be used in making these colors, is now an important business of itself, and involves the manufacture at the same time of a number of secondary products from the same material—many of which are practically useful, and give rise in turn to independent branches of industry.

Some of the fluid products are used, as "solvent naphtha," for dissolving indian rubber and in the preparation of varnishes—others are employed to increase the illuminating power of coal gas—others for the manufacture of lubricators for machinery and railroad carriages. Naphthaline and carbolic acid have each been found to afford new colors, rivalling in brilliancy and beauty those from aniline, and carbolic acid itself has come into use as one of the most powerful antiseptics and disinfectants.

One of the fluid products of coal-tar distillation, and that by far the most abundant in quantity—the "dead oil," which comes over at higher temperatures than the benzole—still remains almost without known application. It is used for preserving timber from decay, and for making lampblack, but the supply so far exceeds the demand from these or any other sources that the oil is almost without value in the market. It offers a fine field for further investigation.

In thus reviewing some of the points as to the relation between purely scientific discoveries and their practical applications, I must not omit to notice briefly one or two errors upon this subject, which are not uncommon, and which sometimes bring undeserved contempt upon the pursuit of researches in applied science.

Men are not unfrequently to be heard speaking of themselves or of their neighbors as having made some business experiment—in agriculture, in mining, in manufactures, or the like—with all the aids of modern science—aids derived either from their own study of the subject or from consultation with those professionally acquainted with it; the result is declared to be disastrous, and the "good old practical way" is praised as far safer than the pursuit of any "new-fangled" and "theoretical" notions. Such men very often fail to see that several conditions were necessary to the attainment of their object, every one of which had to be fulfilled in order to success in the final result—that they fulfilled, perhaps intelligently and completely, the greater number of such conditions, but failed in some one, or possibly overlooked it altogether. We have seen that some such conditions are of a purely scientific—others of a commercial—character. The former involve the facts and laws of nature—the latter the principles and present state of trade. If either be neglected, or their bearing upon each other be overlooked, failure need not be wondered at

The man who would apply scientific knowledge to some special purpose must be certain that he really *has* the knowledge in the first instance—must make sure of his facts, and fully understand the principles involved. If he submit the scientific aspect of a question to a professedly scientific man for advice, he must have some guarantee that the adviser is well informed and, above all, honest enough not to pretend to know more than he really does—and, in laying the case before such an adviser, care must be taken that all material facts upon which an opinion is to be based are fully and fairly stated. The same degree of attention must then be given to the commercial side of the question—the common-place considerations of cost and price, profit and loss, interest and insurance, present condition and future fluctuations of markets, must be looked into with the aid of the fullest information and best judgment possessed by oneself or those upon whom reliance may be placed; and, finally, the bearing upon each other of the scientific and commercial conclusions arrived at must be carefully taken into account in deciding to make or not to make the experiment in view, and in choosing the form, time, and manner of making it.

So-called "practical" men often regard with ridicule what they suppose to be the failure of scientifically conducted experiments, in consequence of their own failure to distinguish between experiments made with a view to obtaining information and those which are made in order to achieve a particular concrete result—the "*experimenta lucifera*" and "*experimenta fructifera*" so admirably contrasted by the father of modern Inductive Philosophy. An excellent illustration of this may be drawn from the history of the cultivation for four years, by the celebrated German chemist LIEBIG, of a piece of land in the neighborhood of Giessen.* The land in question—about

*LIEBIG—Principles of Agricultural Chemistry, etc., 1855, pp. 30–35.

ten acres in extent—was in 1845 a perfectly barren tract of sand, upon which there did not grow in a whole year grass or anything else in quantity to support a single sheep. Mineral manure of particular kinds was applied to this soil—it improved in character year by year—and in 1849 it "excited the admiration and wonder of all who had known the original state and quality of the land." The tract had now acquired value, and was sold. An account of the total expenditure upon the place, as set against the price received for it, shewed that the former exceeded the latter by about 8,000 florins —or, say $3,200. A "practical" man, in the sense in which the term is often erroneously used, might say (and such reflections were actually made) that this was a glaring example of the absurd results following the application of science to matters of business—that the land had, indeed, been enriched, and such result was very well as a matter of scientific interest or amusement, but that the consequence to the pocket of the experimenter was not profit, but the loss of no small sum of money.

The object of the experiment was not immediate profit, but information—information which might at a later day be rendered profitable, and which could only be obtained by means of this present outlay. In order to render distinctly observable the effects of certain manures, the scientific conditions were simplified by working upon a piece of land so barren that it would not of itself support vegetation at all. A distinct question was put to nature, and a distinct answer was received. The knowledge thus gained was valuable, and—like all valuable things—had to be paid for. The sum of 8.000 florins just spoken of was the price paid for this knowledge, not the loss upon an unsuccessful speculation. The knowledge once gained, the experiment was not proposed as a model for imitation. The use to be made afterwards of the knowledge itself was an entirely different affair—the true application was to be made in the cultivation of ordinary land, poor enough to need manure, yet not so poor as entirely to preclude financially successful cultivation.

One other popular error in connection with our general subject consists in demanding more of science than she can at present give, requiring full information upon subjects of which our real knowledge is confessedly very incomplete. This is perhaps a more common mistake in the present day than that just alluded to—men have become so accustomed to hear of the wonderful achievements of this scientific age, and the rate at which the frontier line that divides the known from the unknown is being pushed forward, that they almost forget the existence of such a line, and fancy that they have but to call for whatever information they may need for their individual purposes in order at once to receive it.

Such men bring a pound or two of soil from one of their fields to a chemist, and expect that, after he has looked at it, poured a little acid upon a portion of it in a test-tube, or submitted it to some to them unknown process of analysis, he shall inform them of something, of moderate cost, peculiarly adapted to that field, that shall at once remedy all its defects, and magically increase its fertility. Our real knowledge of chemistry is almost as imperfect in reference to its applications to agriculture as to medicine, and specific recipes for specific diseases are about as imaginary in the one case as in the other. No sensible man refuses to send for a doctor when he is sick because pathology is a very imperfect science, and the physician must often feel doubt about his diagnosis and hesitation as to the remedies he ought to use. Yet the most extravagant expectations are often formed of the precision and completeness with which questions can be answered as to the applications of science to agriculture and the arts—the greatest disappointment is expressed when these expectations fail to be realized—and that which science *can* do at present is pronounced to be valueless because she cannot yet do *everything*.

I have already occupied your attention so long that I can devote but little time to the consideration of the last topic which I proposed to bring before you—namely, the practical form which it seems desirable to give to the teaching of Applied Chemistry in this University.

To place a student abreast of the present condition of such an eminently progressive and practical department of science as this, and to qualify him to keep up with its progress hereafter, two things appear to be chiefly needed; first, such didactic instruction as shall fairly place before him the most important results of investigation on the part of technical chemists in the past, our stock of knowledge accumulated up to the present date; in the second place, such practical instruction of the faculties of his mind and physical senses as shall enable him hereafter to test for himself the results of others, and to do his part in adding to our store of knowledge, and in applying it to practical questions as they arise.

Hence the principal features in the systematic teaching proposed are—a course of lectures upon the Applications of Chemistry to the Arts, and a course of laboratory instruction in Practical and Analytical Chemistry.

In the former of these the leading principles of Agriculture, Metallurgy, and the more important Arts and Manufactures, so far as these are dependent upon Chemistry, should be taken up in order and discussed, with suitable illustration by specimens, models, diagrams, and experiments. The order should be that of the arts themselves, classified in relation to the nature and uses of their products, the materials and processes involved—not that of the laws and elementary substances of pure Chemistry, which are already fully treated of in the able hands to which they have so long been committed in the University. There is great want of suitable text-books—at any rate in English—to be used in connection with such a course; and this is to be regretted, as a good, clearly written text-book—not too large—embracing the topics of a lecture within a a moderate compass—and following in the main the same order with that pursued by the lecturer—undoubtedly affords valuable assistance to the student. Books of reference, however, which may be profitably consulted on particular subjects, exist in abundance—in English, as well as in French and German.

The practical course in the laboratory should include the construction and use of the apparatus employed in chemical research, the manipulation connected with the various processes of operative chemistry, the methods of analysis—both qualitative and quantitative—, and especially the modifications of these most conveniently applicable to the purposes of technical investigation.

Such a course is likely to be looked upon by most students as intrinsically attractive—even amusing. The actual performance of chemical experiments and observation of chemical phenomena have always a certain charm. Even two hundred years ago BECHER *, though he speaks of chemists as a strange class of mortals impelled by an almost insane impulse to seek their pleasures among smoke and vapour, soot and flame, poisons and poverty, adds as regards himself "yet among all these evils I seem to myself to live so sweetly, that may I die if I would change places with the Persian King."

* The author of *Physica Subterranea*.

It is, however, scarcely possible to over-estimate the real advantages of laboratory practice, to the student of general chemistry, but still more to him who would learn how its teachings may be applied to the purposes of daily life. By means of such practice he learns to look directly at nature—to see natural objects and natural phenomena with his own eyes, not simply in the reflection of what he supposes to be the appearance they present to others. The teacher or the book may, and ought to, tell him what to look at, and how to observe it—but he must not rest satisfied with having been so told—he must look at it, observe it, familiarize himself with it, and retain in his mind a distinct picture of the thing itself, instead of the description merely which others have given of it. It is possible to have the longest Latin and Greek names and the most mysterious looking symbols firmly impressed upon the memory, while the things which these names and symbols signify remain utterly unfamiliar. Scientific terms are extremely valuable from their precision and convenience—but, like all words, they are merely the representatives of things, of facts, of principles, of ideas—and with these themselves we must become familiar if we would really understand their mutual relations and the applications which may be made of them.

From books and lectures may be obtained a general or panoramic view of the field of study of which we are speaking—from them may be derived a knowledge of the natural order, arrangement and connection of the facts which have been observed by others, and which the student is afterwards as far as possible to observe for himself—upon these he may have to depend for some facts the opportunity of observing which is practically out of his reach—but the more he regards them as simply drawing his attention to and placing under his own observation the unveiled face of nature herself, the sounder, the more valuable, and the more practically available will be the knowledge which he obtains.*

* "That a system of teaching the physical sciences should not remain barren of application to useful purposes, and indeed that it should exercise any beneficial influence whatever on the mind, it ought to be such as to ensure to the student an immediate, familiar, and, as it were, personal acquaintance with the facts and laws of nature, and with the manner in which they arise under our hands and eyes in scientific processes."—*Report (above quoted) of the Cambridge University Commission—p. 116. (under the head of " Laboratories and apparatus :")*

"He" (the chemist) "must learn to interpret the effects of mixture, heat, and other chemical agencies, so as to see in them those facts which chemistry makes the basis of her doctrines. And, in learning to interpret this language, he must also learn to call it forth;—to place bodies under the requisite conditions, by the apparatus of his own laboratory and the operations of his own fingers.—WHEWELL—*Philosophy of the Inductive Sciences—Vol. 2. p. 501.*

Even as regards long known facts, the experiments in illustration of which he merely repeats, he finds that no impressions equal in clearness and accuracy those which he acquires with the blow-pipe and the test-tube in his own hands—and he soon perceives that the use of such apparatus, and the performance of such experiments, constitute in themselves an art which must be practically mastered in order to be made available.

But it is only by coming into direct contact with natural phenomena that anything like original investigation can be attempted, and every student of applied chemistry, or indeed of any branch of natural science, ought to be, in however humble and limited a way, an original investigator. Our knowledge of nature is necessarily progressive—the more we learn the more we find there remains to be learned—each question solved suggests other and new questions, and new methods of attacking them.

It may be objected that we can only look to intellects of unusual power for new discoveries, and that ordinary minds must be content with merely receiving their novel teachings and endeavoring to understand and remember them.

But in building up the stately edifice of scientific truth workmen are employed of every grade—great master masons, who far excel their fellows in comprehension of the designs of the creative mind—active builders, who can lay stone upon stone, each in its proper place, as the mighty plan becomes gradually revealed—and simple laborers, who can do nothing more than hew out of the rock and bring to the builders the material destined for the structure. In their appointed sphere of service the last are as important and as useful as the first. The main thing that is required of them is that they shall offer nought but sound material to be incorporated in the pile—that no spurious and valueless stones be permitted to fill positions from which they must presently be rejected.

At intervals of centuries there appear the wonderful intellects—the BACONS and the NEWTONS—by whom (themselves sometimes accomplishing much—sometimes very little—in the details of scientific research) the whole course of scientific progress is changed, and the direction of successful intellectual effort pointed out to their fellow-men. Then we have at all times, and more especially in these modern days, many strong and active minds busily devoting themselves to the establishment of new—that is, unrecognized—laws of nature, determining and putting together in the form of principles the mutual relations of the facts which they find for the most part already known, but which have hitherto been more or less isolated and without order. And, lastly, we have a far greater number of thinkers, observers, and experimenters who occupy themselves with simply ascertaining and recording facts themselves. These last do good and honorable service.

No fact, however apparently trivial and insignificant, is destitute of value, provided only it *be really* a fact—really a fragment, however small, of the eternal truth of nature. And in the study of nature, it matters not in what direction, no man can acquire the power and the habit of accurate, original, practical observation without now and then coming across facts that are new, that should be recorded and preserved, and that may—in the future, if not immediately—turn out to be of the utmost interest, importance, and practical value.

I have tried—Gentlemen—to place before your minds some ideas with regard to a particular department of natural science—to point out some of the motives which invite our attention to it—to define to some extent its proper limits—to indicate in general terms the method of its study—and to suggest some of the errors and misapprehensions which occasionally prevail with regard to it.

In conclusion, I would not, by altogether failing to notice the noblest light in which it may be viewed, be guilty of what, in the memorable words of BACON,* is "the greatest error of all the rest—the mistaking or misplacing of the last or farthest end of knowledge—for" says he:

"Men have entered into a desire of learning and knowledge, sometimes upon a natural curiosity, and inquisitive appetite; sometimes to entertain their minds with variety and delight; sometimes for ornament and reputation; and sometimes to enable them to victory of wit and contradiction; and most times for lucre and profession; and seldom sincerely to give a true account of their gift of reason, to the benefit and use of men: as if there were sought in knowledge a couch, whereupon to rest a searching and restless spirit; or a terras, for a wandering and variable mind to walk up and down with a fair prospect; or a tower of state, for a proud mind to raise itself upon; or a fort or commanding ground, for strife and contention; or a shop, for profit or sale; and not a rich store-house, for the glory of the Creator, and the relief of man's estate."

* Of the Advancement of Learning—Book I.

If the department of knowledge which we have been discussing is peculiarly concerned with the "relief of man's estate," it is also peculiarly well fitted to raise up in our minds the remembrance, with gratitude and reverence, of Him who has bestowed upon us all the good gifts of nature, with the highest gift of all—reason, wherewith to discern their uses and avail ourselves of their benefits—who has committed into our hand the beasts of the field, the trees of the forest, the treasures of the dark mine and the fruitful soil, all that we need to surround ourselves with comfort and with beauty—and who, at the same time, teaching us humility, has himself so clothed the lilies of the field as that SOLOMON in all his glory was not like them arrayed.

ADDENDUM.

Since the above lecture was delivered the attention of the writer has been drawn to the following recently published statements with regard to the *École Centrale des Arts et Manufactures* of Paris, which are interesting as placing in a distinct and positive light the practical results of technical education in France:

"The École Centrale . . . . . . is now, perhaps, the most celebrated school of applied sciences in the world, and so great have been the services it has rendered that M. Michel Chevalier once said:—'If the École Centrale were not in existence, it would be necessary to create it as the complement of the treaties of commerce.'

It has 500 pupils, and the number of applications for admission is always twice as large as the actual vacancies. The period of study occupies three years, and the pupils are obliged to take up all the subjects comprised in the course. It is thoroughly adapted to industrial science, the first year being on theoretical subjects, and the second and third on theory and application to practice. The heads of the subjects of these two years are:—applied mechanics; the construction and erection of machinery; analytical, industrial, and agricultural chemistry; civil engineering; natural philosophy in its application to the arts; metallurgy; mineralogy; geology; and mining. Amongst 2,000 young men who have left this school, the career of 1,394 has been recently traced, and the issue was this:—247 had died, while of the others 480 were engineers or superior officers of railways; 54 were mechanical engineers; 124 iron masters; 280 manufacturers of considerable eminence; 55 were architects; 35 contractors for public works; and 42 professors of the applied sciences. The rest filled honourable posts in trade or in the service of the French and foreign governments. The names of some of the engineers and manufacturers are widely known. It would be impossible in any country to account more satisfactorily for any 2,000 pupils of any school or college. . . . .

. . . Throughout France there is but one opinion of the value of the diploma of the École Centrale. Whether those who hold it become chemists, or metallurgists, or contractors, they are everywhere found to be thoroughly well-prepared men, intelligent as draughtsmen, and ready in the application of their theoretical knowledge."

Article on "Technical and Scientific Education" in the Edinburgh Review for April, 1868. (Am. ed,) pp. 227–228.