crack on July 28, and the phenomenon continued until the whole surface was covered with a network of fissures. According to the latest accounts, fifty-three distinct shocks had been felt, only two or three of them being severe. Within twelve hours on August 3, thirty-five earthquakes were experienced at Kumamoto, one of which caused the ground to open in no fewer than twelve places.

THE UNITED STATES ECLIPSE EXPEDITION.

THE Navy Department in Washington is now fitting out an Expedition to Angola, on the west coast of Africa, to observe the total eclipse of the sun which will be visible there on the afternoon of December 22 next. Prof. Todd, of Amherst College, has been appointed chief of the party, a position similar to that which he held two years ago in conducting the Eclipse Expedition to Japan.

The party, which will be a large one, will leave New York about October 1, in a Government cruiser. The natural history department of the Expedition will be under the charge of Dr. Wm. J. Holland, of Pittsburg, who will make large collections and extensive investigations, especially in entomology, which is his special department. He filled a similar position in the Expedition to Japan in 1887. Work will be done in many directions, and even if the weather or any accident should render a successful observation of the eclipse impossible, the Expedition will have a great amount of valuable information and collections when it returns.

After landing at St. Paul de Loanda, 250 miles south of the mouth of the Congo, the Expedition will go about one hundred miles into the interior, in order to be on higher land, and out of the fever belt on the coast. The eclipse, which will occur on December 22, 1889, at about 3 p.m., will be total for a little over three minutes at the station south-east of Loanda. The whole length of the eclipse will be between two and three hours. In photographing its different phases, if the sky is clear, it is hoped that about 150 photographs will be taken, with the largest telescope ever used for photographing an eclipse. This will give an image of the sun about 4½ inches in diameter. Owing to the number of fine instruments which have to be carefully transported and adjusted, about two months will be spent at the observation station, and the party will be absent about five or six months altogether. The particular point where it is hoped a settlement may be made is Muxima on the Quanza River. In reply to a question as to the instruments he would take with him, Prof. Todd is reported to have said:—

"Some of them will be the same as I had in Japan, especially the great telescope, forty feet long, to get pictures of the different stages of the eclipse with. It is the same sort of a telescope that I used in photographing the transit of Venus in 1882 at the Lick Observatory. But photographing the corona is not the main thing nowadays in eclipses. All that has gone by. There are other questions of much more importance than merely to find out how the corona looks. It is a very complex phenomenon. The sources of its light are not known, and the streamers of light are in parts superposed or overlapping. The most important thing to do is to take photographs in such a way that the intensity of the light in every part can be accurately measured, and to photograph the spectrum of as many separate portions of the coronal light as possible. We are making much progress in this direction, but the old methods of eclipse photography in use ten or fifteen years ago yielded very insufficient results, and there is relatively little use in following them up if the more advanced and specialized work is not undertaken. Of course they are good as far as they go. Then I shall have several new devices, which my previous experience, particularly in Japan, has led to the invention of. Among other things I have devised a revolving plate holder, which will enable us to get the largest possible number of pictures at the critical moments."

URANIUM.

EXACTLY a century ago—namely, in 1789—Klaproth succeeded (says the *Times*) in isolating from a dark-coloured mineral known as pitchblende a yellow oxide, which, after carefully testing, he pronounced to be the oxide of a new metal. To this metallic substance he gave the name of uranium, so calling it after the planet Uranus, then recently discovered by Herschel, and it was at once classed among the rare metals, and still remains so. Its rarity is indicated by its market price, which is about £2400 per ton. There are several oxides of this metal; but the best known and most important is the sesquioxide, which forms a number of beautiful yellow salts. This oxide is largely employed for imparting delicate golden and greenish yellow tints to glass, while the protoxide is much used in producing the costly black porcelain. Uranium is also found to be useful in certain photographic processes as a substitute for the chloride of gold; but its rarity and consequent high price have hitherto caused its application to be very limited, although there are uses other than those already named to which it could be put if it were less scarce and less costly. It is found in Cornwall, Saxony, and Bohemia; but up to the present time it has only been met with in isolated pockets and patches. The centenary of its discovery by Klaproth has, however, been marked by the finding of a continuous lode at the Union Mine, Grampound Road, Cornwall, which is believed to be the only known lode in the world. This discovery is regarded as unique in the history of the metal, for the lode is what is known as a true fissure vein, and the ore is found to contain an average of 12 per cent. of the pure metal, the assays going up as high as 30 per cent. in some parts of the lode. Several tons of the ore have already been raised and sold, fetching high prices. The lode traverses the mine from north to south, and the uranium occurs in it chiefly as a sesquioxide. It is anticipated that the present discovery will enable two important applications of the metal to be followed up. The first is as a substitute for gold in electroplated ware, inasmuch as with platinum and copper it forms two beautiful alloys, each having the appearance of gold, and the former also resisting the action of acids. The second application is in connection with electric installations, where its usefulness consists in its high electrical resistance. The mineral deposits generally at the Union Mine are of an exceptional character, comprising, in addition to uranium, magnetic iron, silver lead, tin, copper, ochre, and umber.

THE BRITISH ASSOCIATION.

NEWCASTLE, *Tuesday Night.*

IT is impossible at this stage to say what will be the character of the third Newcastle meeting, so far as numbers are concerned. In one quarter I am informed it is not expected that the attendance will be above the average, while another authority, who ought to know, assures me the numbers will be greater than was the case even at the Manchester meeting. For it should be remembered that, until that meeting, Newcastle topped the record so far as numbers go. To judge from the aspect of the Reception Room, not many people have yet arrived, though doubtless they will come in by later trains, and tomorrow morning. So far as I have been able to learn, very few foreign men of science of distinction are expected. Universal regret is expressed that the serious illness of Dr. Burdon Sanderson will prevent his taking his place as President of Section D; his address, which promises to be one of much interest, will be read by one of the Vice-Presidents. The proceedings in this Section, it is expected, will be somewhat lively; more than one paper will be read on certain aspects of Darwinism, and, as vigorous controversialists of different schools will be present, some strong speaking may be looked for.

So far as the efforts of the Local Committee go, the meeting ought to be a success. It is evident that everything has been done, so far as the accommodation of Newcastle permits, for the convenience and comfort of the visitors. The Durham College of Medicine makes very excellent Reception and Reading Rooms. Smoking Rooms, Luncheon Rooms, and other conveniences that conduce to the comfort of visitors, have been provided and well equipped. The St. George's Drill Hall is large enough for the opening address and the lectures, but the quality of its acoustic properties is feared. One of the great social events of the meeting will be the banquet given by Lord Armstrong, on Thursday night, to 200 guests; while the favourite excursion is that to Durham on Saturday, when the Warden and Professors of the University will entertain 200 at lunch. Regret is expressed that the excursion to the Roman Wall has not been fixed for the Saturday instead of the Thursday. Indeed, the Thursday excursions—to Berwick, Bamburgh, Holy Island, Barnard Castle, and other places—are likely to induce many visitors to stay over that day.

Geologists are looking forward with much interest to Dr. A. Geikie's paper on his recent visit to Norway, as well as to Prof. James Geikie's address as President of the Section. Prof. Flower's address will be devoted mainly to the arrangement of Museums.

It may be worthy of note that the Economical Section will be conducted on much more scientific lines than has been hitherto the case.

INAUGURAL ADDRESS BY PROF. W. H. FLOWER, C.B., LL.D., F.R.S., F.R.C.S., PRES.Z.S., F.L.S., F.G.S., PRESIDENT.

IT is twenty-six years since this Association met in Newcastle-upon-Tyne. It had then the advantage of being presided over by one of the most distinguished and popular of your fellow-townsmen.

Considering the age usually attained by those upon whom the honour of the presidency falls, and the length of time which elapses before the Association repeats its visit, it must have rarely happened that anyone who has held the office is spared, not only to be present at another meeting in the town in which he has presided, but also to take such an active part in securing its success, and to extend such a hospitable welcome to his successor, as Lord Armstrong has done upon the present occasion.

The address which was delivered at that meeting must have been full of interest to the great majority of those present. It treated of many subjects more or less familiar and important to the dwellers in this part of the world, and it treated them with the hand of a master, a combination which always secures the attention of an audience.

When it came to my knowledge that in the selection of the President for this meeting the choice had fallen upon me, I was filled with apprehension. There was nothing in my previous occupations or studies from which I felt that I could evolve anything in special sympathy with what is universally recognized as the prevailing genius of the district. I was, however, somewhat reassured when reminded that in the regular rotation by which the equal representation in the presidential office of the different branches of science included in the Association is secured, the turn had come round for some one connected with biological subjects to occupy the chair, which during the past seven years has been filled with such distinction by engineers, chemists, physicists, mathematicians, and geologists. I was also reminded that the Association, though of necessity holding its meeting in some definite locality, was by no means local in its character, but that its sphere was co-extensive, not with the United Kingdom only, but with the whole of the British Dominions, and that our proceedings are followed with interest wherever our language is understood—I may say, throughout the civilized world. Furthermore, although its great manufacturing industries, the eminence of its citizens for their skill and intelligence in the practical application of mechanical sciences, and the interesting and important geological features of its vicinity, have conferred such fame on Newcastle as almost to have overshadowed its other claims to distinction in connection with science, this neighbourhood is also associated with Bewick, with Johnson, with Alder, Embleton, Hutton, Atthey, Norman, the two Hancocks, the two Bradys, and other names honoured in the annals of biology; it has long maintained a school of medicine of great repute; and there has lately been established here a natural history museum, which in some of its features is a model for institutions of the kind, and which, I trust, will be a means of encouraging in this town some of the objects the Association was designed to promote.

There can be no doubt that among the various methods by which the aims of the British Association (as expressed in its full title, *the advancement of science*) may be brought about, the collection and preservation of objects available for examination, study, and reference—in fact, the formation of what are now called "museums"—is one of very great practical importance; so much so, indeed, that it seems to me one to the consideration of which it is desirable to devote some time upon such an occasion as this. It is a subject still little understood, though, fortunately, beginning to attract attention. It has already been brought before the notice of the Association, both in Presidential and Sectional addresses. A committee of our members is at the present time engaged in collecting evidence upon it, and has issued some valuable reports. During the present year an association of curators and others interested in museums has been founded for the purpose of interchange of ideas upon the organization and management of these institutions. It is a subject, moreover, if I may be allowed to mention a personal reason for bringing it forward this evening, which has more than any other occupied my time and my attention almost from the earliest period of my recollection, and I think you will agree with the opinion of one of my distinguished predecessors in this chair, "that the holder of this office will generally do better by giving utterance to what has already become part of his own thought than by gathering matter outside of its habitual range for the special occasion. For," continued Mr. Spottiswoode, "the interest (if any) of an address consists not so much in the multitude of things therein brought forward as in the individuality of the mode in which they are treated."

The first recorded institution which bore the name of museum, or temple or haunt of the Muses, was that founded by Ptolemy Soter at Alexandria about 300 B.C.; but this was not a museum in our sense of the word, but rather, in accordance with its etymology, a place appropriated to the cultivation of learning, or which was frequented by a society or academy of learned men devoting themselves to philosophical studies and the improvement of knowledge.

Although certain great monarchs, as Solomon of Jerusalem and Augustus of Rome, displayed their taste and their magnificence by assembling together in their palaces curious objects brought from distant parts of the world—although it is said that the liberality of Philip and Alexander supplied Aristotle with abundant materials for his researches—of the existence of any permanent or public collections of natural objects among the ancients there is no record. Perhaps the nearest approach to such collections may be found in the preservation of remarkable specimens, sometimes associated with superstitious veneration, sometimes with strange legendary stories, in the buildings devoted to religious worship. The skins of the gorillas brought by the navigator Hanno from the West Coast of Africa, and hung up in the temple at Carthage, afford a well-known instance.

With the revival of learning in the Middle Ages, the collecting instinct, inborn in so many persons of various nations and periods of history, but so long in complete abeyance, sprang into existence with considerable vigour, and a museum, now meaning a collection of miscellaneous objects, antiquities as well as natural curiosities, often associated with a gallery of sculpture and painting, became a fashionable appendage to the establishment of many wealthy persons of superior culture.

All the earliest collections, comparable to what we call museums, were formed by and maintained at the expense of private individuals: sometimes physicians, whose studies naturally led them to a taste for biological science; often great merchant princes, whose trading connections afforded opportunities for bringing together things that were considered curious from foreign lands; or ruling monarchs in their private capacity. It every case they were maintained mainly for the gratification of the possessor or his personal friends, and rarely, if ever, associated with any systematic teaching or public benefit.

One of the earliest known printed catalogues of such a museum is that of Samuel Quickelberg, a physician of Amsterdam, published in 1565 in Munich. In the same year Conrad Gesner published a catalogue of the collection of Johann Kentmann, a physician of Torgau in Saxony, consisting of about 1600 objects, chiefly minerals, shells, and marine animals. Very soon afterwards we find the Emperor Rudolph II. of Germany busily accumulating treasures which constituted the foundations of the present magnificent museums by which the Austrian capital is distinguished.

In England the earliest important collectors of miscellaneous objects were the two John Tradescants, father and son, the latter of whom published, in 1656, a little work called "Musæum Tradescantianum; or, a Collection of Rarities preserved at South Lambeth neer London." The wonderful variety and incongruous juxtaposition of the objects contained in this collection make the catalogue very amusing reading. Under the first division, devoted to "Some Kindes of Birds, their Egges, Beaks, Feathers, Clawes and Spurres," we find "Divers sorts of Egges from Turkie, one given for a Dragon's Egge"; "Easter Egges of the Patriarch of Jerusalem"; "Two Feathers of the Phœnix Tayle"; "The Claw of the bird Rock, who, as Authors report, is able to trusse an Elephant." Among "whole birds" is the famous "Dodar from the Island Mauritius; it is not able to flie, being so big." This is the identical specimen, the head and foot of which have passed through the Ashmolean into the University Museum of Oxford; but we know not what has become of the claw of the Rock, the Phœnix tayle, and the Dragon's egg. Time does not allow me to mention the wonderful things which occur under the head of "Garments, Vestures, Habits, and Ornaments," or the "Mechanick, Artificial Workes in Carvings, Turnings, Sowings, and Paintings," from Edward the Confessor's knit gloves, and the famous "Pohatan, King of Virginia's habit, all embroidered with shells or Roanoke," also still at Oxford, and lately figured and described by Mr. E. B. Tylor, to the "Cherry-stone, upon one side S. George and the Dragon, perfectly cut, and on the other side 88 Emperours' faces," or the other "cherry-stone, holding ten dozen of tortoisshell combs made by Edward Gibbons." But before leaving these private collections I cannot forbear mentioning, as an example of the great aid they often were in advancing science, the indebtedness of Linnæus in his early studies to the valuable zoological museums, which it was one of the ruling passions of several Kings and Queens of Sweden to bring together.

Upon the association of individuals together into societies to promote the advancement of knowledge, these bodies in their corporate capacity frequently made the formation of a museum part of their function. The earliest instance of this in our country was the museum of the Royal Society in Crane Court, of which an illustrated catalogue was published by Dr. Grew in 1681.

The idea that the maintenance of a museum was a portion of the public duty of the State or of any municipal institution had, however, nowhere entered into the mind of man at the beginning of the last century. Even the great teaching bodies, the Universities, were slow in acquiring collections; but it must be recollected that the subjects considered most essential to the education they then professed to give were not those which needed illustration from the objects which can be brought together in a museum. The Italian Universities, where anatomy was taught as a science earlier and more thoroughly than anywhere else in Europe, soon found the desirability of keeping collections of preserved specimens, and the art of preparing them attained a high degree of excellence at Padua and Bologna two centuries ago. But these were generally the private property of the professors, as were nearly all the collections used to illustrate the teaching of anatomy and pathology in our country within the memory of many now living.

Notwithstanding the multiplication of public museums during the present century, and the greater resources and advantages which many of these possess, which private collectors cannot command, the spirit of accumulation in individuals has happily not passed away, although generally directed into rather different channels than formerly. The general museums or miscellaneous collections of old are now left to Governments and institutions which afford greater guarantee of their permanence and public utility, while admirable service is done to science by those private persons with leisure and means who, devoting themselves to some special subject, amass the materials by which its study can be pursued in detail either by themselves or by those they know to be qualified to do so; which collections, if they fulfil their most appropriate destiny, ultimately become incorporated, by gift or purchase, in one or other of the public museums, and then serve as permanent factors in the education of the nation, or rather of the world.

It would be passing beyond the limits of time allotted to this address, indeed going beyond the scope of this Association, if I were to speak of many of the subjects which have pre-eminently exercised the faculties of the collector and formed the materials of which museums are constructed. The various methods by which the mind of man has been able to reproduce the forms of natural objects or to give expression to the images created by his own fancy, from the rudest scratchings of a savage on a bone, or the simplest arrangement of lines employed in ornamenting the roughest piece of pottery, up to the most lovely combinations of form and colour hitherto attained in sculpture or in painting, or in works in metal or in clay, depend altogether on museums for their preservation, for our knowledge of their condition and history in the past, and for the lessons which they can convey for the future.

Apart from the delight which the contemplation of the noblest expressions of art must produce in all cultivated minds, apart also from the curiosity and interest that must be excited by all the less successfully executed attempts to produce similar results, as materials for constructing the true history of the life of man, at different stages of civilization, in different circumstances of living, and in divers regions of the earth, such collections are absolutely invaluable.

But I must pass them by in order to dwell a little more in detail upon those which specially concern the advancement of the subjects which come under the notice of this Association—museums devoted to the so-called "natural history" sciences, although much which will be said of them will doubtless be more or less applicable to museums in general.

The terms "*natural history*" and "*naturalist*" have become deeply rooted in our language, but without any very definite conception of their meaning or the scope of their application. Originally applied to the study of all the phenomena of the universe which are independent of the agency of man, natural history has gradually narrowed down in most people's minds, in consequence of the invention of convenient and generally understood and accepted terms for some of its various subdivisions, as astronomy, chemistry, geology, &c., into that portion of the subject which treats of the history of creatures endowed with life, for which, until lately, no special name had been invented. Even from this limitation botany was gradually disassociating itself in many quarters, and a "naturalist" and a "zoologist" have nearly become, however irrationally, synonymous terms. The happy introduction and general acceptance of the word "biology," notwithstanding the objections raised to its etymological signification, has reunited the study of organisms distinguished by the possession of the living principle, and practically eliminated the now vague and indefinite term "natural history" from scientific terminology. As, however, it is certain to maintain its hold in popular language, I would venture to suggest the desirability of restoring it to its original and really definite signification, contrasting it with the history of man and of his works, and of the changes which have been wrought in the universe by his intervention.

It was in this sense that, when the rapid growth of the miscellaneous collections in the British Museum at Bloomsbury (the expansion of Sir Hans Sloane's accumulation in the old Manor House at Chelsea) was thought to render a division necessary, the line of severance was effected at the junction of what was natural and what was artificial; the former including the products of what are commonly called "natural" forces, unaffected by man's handiwork, or the impress of his mind. The departments which took cognizance of these were termed the "Natural History Departments," and the new building to which they were removed the "Natural History Museum."

It may be worth while to spend a few moments upon the consideration of the value of this division, as it is one which concerns the arrangement and administration of the majority of museums.

Though there is very much to be said for it, the objection has been raised that it cuts man himself in two. The illustrations of man's bodily structure are undoubtedly subjects for the zoologist. The subtile gradations of form, proportion, and colour which distinguish the different races of men, can only be appreciated by one with the education of an anatomist, and whose eye has been trained to estimate the value of such characters in discriminating the variations of animal forms. The subjects for comparison required for this branch of research must therefore be looked for in the zoological collections.

But the comparatively new science of "anthropology" embraces not only man's physical structure: it includes his mental development, his manners, customs, traditions, and languages. The illustrations of his works of art, domestic utensils, and weapons of war are essential parts of its study. In fact it is impossible to say where it ends. It includes all that man is or ever has been, all that he has ever done. No definite line can be drawn between the rudest flint weapon and the most exquisitely finished instrument of destruction which has ever been turned out from the manufactory at Elswick, between the rough representation of a mammoth, carved by one of its contemporary men on a portion of its own tusk, and the most admirable production of a Landseer. An anthropological collection, to be logical, must include all that is in not only the old British Museum but the South Kensington Museum and the National Gallery. The notion of an anthropology which considers savages and prehistoric people as apart from the rest of mankind may, in the limitations of human powers, have certain conveniences, but it is utterly unscientific, and loses sight of the great value of the study in tracing the gradual growth of our complex systems and customs from the primitive ways of our progenitors.

On the other hand, the division first indicated is as perfectly definite, logical, and scientific as any such division can be. That there are many inconveniences attending wide local disjunctions of the collections containing subjects so distinct yet so nearly allied as physical and psychical anthropology must be fully admitted; but these could only have been overcome by embracing in one grand institution the various national collections illustrating the different branches of science and art, placed in such order and juxtaposition that their mutual relations might be apparent, and the resources of each might be brought to bear upon the elucidation of all the others—an ideal institution, such as the world has not yet seen, but into which the old British Museum might at one time have been developed.

A purely "Natural History Museum" will then embrace a collection of objects illustrating the natural productions of the earth, and in its widest and truest sense should include, as far as they can be illustrated by museum specimens, all the sciences which deal with natural phenomena. It has only been the difficulties, real or imaginary, in illustrating them which have excluded such subjects as astronomy, physics, chemistry, and physiology from occupying departments in our National Natural History Museum, while allowing the introduction of their sister sciences, mineralogy, geology, botany, and zoology.

Though the experimental sciences and those which deal with the laws which govern the universe, rather than with the materials of which it is composed, have not hitherto greatly called forth the collector's instinct, or depended upon museums for their illustration, yet the great advantages of collections of the various instruments by means of which these sciences are pursued, and of examples of the methods by which they are taught, are yearly becoming more manifest. Museums of scientific apparatus now form portions of every well-equipped educational establishment, and under the auspices of the Science and Art Department at South Kensington a national collection illustrating those branches of natural history science which have escaped recognition in the British Museum is assuming a magnitude and importance which brings the question of properly housing and displaying it urgently to the front.

Anomalies such as these are certain to occur in the present almost infantile though rapidly progressive state of science. It may be taken for granted that no scientific institution of any complexity of organization can be, except at the moment of its birth, abreast of the most modern views of the subject, especially in the dividing lines between, and the proportional representation of, the various branches of knowledge which it includes.

The necessity for subdivisions in the study of science is continually becoming more apparent as the knowledge of the details of each subject multiplies without corresponding increase in the power of the human mind to grasp and deal with them, and the dividing lines not only become sharper, but as knowledge advances they frequently require revision. It might be supposed that such revision would adjust itself to the direction taken by the natural development of the relations of the different branches of science, and the truer conceptions entertained of such relations. But this is not always so. Artificial barriers are continually being raised to keep these dividing lines in the direction in which they have once started. Difficulties of readjustment arise not only from the mechanical obstacles caused by the size and arrangements of the buildings and facilities for the allocation of various kinds of collections, but still more from the numerous personal interests which grow up and wind their meshes around such institutions. Professors and curatorships of this or that division of science are founded and endowed, and their holders are usually tenacious either of encroachment upon or of any wide enlargement of the boundaries of the subject they have undertaken to teach or to illustrate; and in this way, more than any other, passing phases of scientific knowledge have become crystallized or fossilized in institutions where they might least have been expected. I may instance many European Universities and great museums in which zoology and comparative anatomy are still held to be distinct subjects taught by different professors, and where, in consequence of the division of the collections under their charge, the skin of an animal, illustrating its zoology, and its skeleton and teeth, illustrating its anatomy, must be looked for in different and perhaps remotely placed buildings.

For the perpetuation of the unfortunate separation of palæontology from biology, which is so clearly a survival of an ancient condition of scientific culture, and for the maintenance in its integrity of the heterogeneous compound of sciences which we now call "geology," the faulty organization of our museums is in a great measure responsible. The more their rearrangement can be made to overstep and break down the abrupt line of demarcation which is still almost universally drawn between beings which live now and those which have lived in past times, so deeply rooted in the popular mind and so hard to eradicate even from that of the scientific student, the better it will be for the progress of sound biological knowledge.

But it is not of the removal of such great anomalies and inconsistencies which, when they have once grown up, require heroic methods to set them right, but rather of certain minor defects in the organization of almost all existing museums which are well within the capacity of comparatively modest administrative means to remedy, that I have now to speak.

That great improvements have been lately effected in many respects in some of the museums in this country, on the Continent, and especially in America, no one can deny. The subject, as I have already indicated, is, happily, exciting the attention of those who have the direction of them, and even awakening interest in the mind of the general public. It is in the hope of in some measure helping on or guiding this movement that I have ventured on the remarks which follow.

The first consideration in establishing a museum, large or small, either in a town, institution, society, or school, is that it should have some definite object or purpose to fulfil; and the next is that means should be forthcoming not only to establish but also to maintain the museum in a suitable manner to fulfil that purpose. Some persons are enthusiastic enough to think that a museum is in itself so good an object that they have only to provide a building and cases and a certain number of specimens, no matter exactly what, to fill them, and then the thing is done; whereas the truth is the work is only then begun. What a museum really depends upon for its success and usefulness is not its building, not its cases, not even its specimens, but its curator. He and his staff are the life and soul of the institution, upon whom its whole value depends; and yet in many—I may say most—of our museums they are the last to be thought of. The care, the preservation, the naming of the specimens are either left to voluntary effort—excellent often for special collections and for a limited time, but never to be depended on as a permanent arrangement—or a grievously under-salaried and consequently uneducated official is expected to keep in order, to clean, dust, arrange, name, and display in a manner which will contribute to the advancement of scientific knowledge, collections ranging in extent over almost every branch of human learning, from the contents of an ancient British barrow to the last discovered bird of paradise from New Guinea.

Valuable specimens not unfrequently find their way into museums thus managed. Their public-spirited owners fondly imagine that they will be preserved and made of use to the world if once given to such an institution. Their fate is, unfortunately, far otherwise. Dirty, neglected, without label, their identity lost, they are often finally devoured by insects or cleared away to make room on the crowded shelves for the new donation of some fresh patron of the institution. It would be far better that such museums should never be founded. They are traps into which precious—sometimes priceless—objects fall only to be destroyed; and, what is still worse, they bring discredit on all similar institutions, make the very name of museum a byword and a reproach, hindering instead of advancing the recognition of their value as agents in the great educational movement of the age.

A museum is like a living organism—it requires continual and tender care. It must grow, or it will perish; and the cost and labour required to maintain it in a state of vitality is not yet by any means fully realized or provided for, either in our great national establishments or in our smaller local institutions.

Often as it has been said, it cannot be too often repeated, that the real objects of forming collections, of whatever kind (apart, of course, from the mere pleasure of acquisition—sometimes the only motive of private collectors), and which, although in very different degrees, and often without being recognized, underlie the organization of all museums, are two, which are quite distinct, and sometimes even conflicting. The first is to advance or increase the knowledge of some given subject. This is generally the motive of the individual collector, whose experience shows him the vast assistance in forming definite ideas in any line of research in which he may be occupied that may be derived from having the materials for its study at his own command, to hold and to handle, to examine and compare, to take up and lay aside whenever the favourable moment to do so occurs. But unless his subject is a very limited one, or his means the reverse, he soon finds the necessity of consulting collections based on a larger scale than his own. Very few people have any idea of the multiplicity of specimens required for the purpose of working out many of the simplest problems concerning the life-history of animals or plants. The naturalist has frequently to ransack all the museums, both public and private, of Europe and America in the endeavour to compose a monograph of a single common genus, or even species, that shall include all questions of its variation, changes in different seasons, and under different climates and conditions of existence, and the distribution in space and time of all its modifications. He often has to confess at the end that he has been baffled in his research for want of the requisite materials for such an undertaking. Of course this ought not to be, and the time will come when it will not be, but that time is very far off yet.

We all know the old saying that the craving for riches grows as the wealth itself increases. Something similar is true of scientific collections brought together for the purpose of advancing knowledge. The larger they are the more their deficiencies seem to become conspicuous; the more desirous we are to fill up the gaps which provokingly interfere with our extracting from them the complete story they have to tell.

Such collections are, however, only for the advanced student, the man who has already become acquainted with the elements of his science, and is in a position, by his knowledge, by his training, and by his observing and reasoning capacity, to take advantage of such material to carry on the subject to a point beyond that at which he takes it up.

But there is another and a far larger class to whom museums are or should be a powerful means of aid in acquiring knowledge. Among such those who are commencing more serious studies may be included; but I especially refer to the much more numerous class, and one which it may be hoped will year by year bear a greater relative proportion to the general population of the country, who, without having the time, the opportunities, or the abilities to make a profound study of any branch of science, yet take a general interest in its progress, and wish to possess some knowledge of the world around them and of the principal facts ascertained with regard to it, or at least some portions of it. For such persons museums may be, when well organized and arranged, of benefit to a degree that at present can scarcely be realized.

To diffuse knowledge among persons of this class is the second of the two purposes of museums of which I have spoken.

I believe that the main cause of what may be fairly termed the failure of the majority of museums—especially museums of natural history—to perform the functions that might be legitimately expected of them is that they nearly always confound together the two distinct objects which they may fulfil, and by attempting to combine both in the same exhibition practically accomplish neither.

In accordance with which of those two objects, which may be briefly called *research* and *instruction*, is the main end of the museum, so should the whole be primarily arranged; and in accordance with the object for which each specimen is required, so should it be treated.

The specimens kept for research, for advancement of knowledge, for careful investigations in structure and development, or for showing the minute distinctions which must be studied in working out the problems connected with variations of species according to age, sex, season, or locality; for fixing the limits of geographical distribution, or determining the range in geological time, must be not only exceedingly numerous (so numerous, indeed, that it is almost impossible to put a limit on what may be required for such purposes), but they must also be kept under such conditions as to admit of ready and close examination and comparison.

If the whole of the specimens really required for enlarging the boundaries of zoological or botanical science were to be displayed in such a manner that each one could be distinctly seen by any visitor sauntering through the public galleries of a museum, the vastness and expense of the institution would be quite out of all proportion to its utility; the specimens themselves would be quite inaccessible to the examination of all those capable of deriving instruction from them, and, owing to the injurious effects of continued exposure to light upon the greater number of preserved natural objects, would ultimately lose a large part of their permanent value. Collections of this kind must, in fact, be treated as the books in a library, and be used only for consultation and reference by those who are able to read and appreciate their contents. To demand, as has been ignorantly done, that all the specimens belonging to our national museums, for instance, should be displayed in cases in the public galleries, would be equivalent to asking that every book in a library, instead of being shut up and arranged on shelves for consultation when required, should have every single page framed and glazed and hung on the walls, so that the humblest visitor as he passes along the galleries has only to open his eyes and revel in the wealth of literature of all ages and all countries, without so much as applying to a custodian to open a case. Such an arrangement is perfectly conceivable. The idea from some points of view is magnificent, almost sublime. But imagine the space required for such an arrangement of the national library of books, or, indeed, of any of the smallest local libraries; imagine the inconvenience to the real student, the disadvantages which he would be under in reading the pages of any work fixed in an immovable position beneath a glass case; think of the enormous distances he would often have to traverse to compare a reference or verify a quotation, and the idea of sublimity soon gives place to its usual antithesis. The attempt to display every bird, every insect, shell, or plant, which is or ought to be in any of our great museums of reference would produce an exactly similar result.

In the arrangement of collections designed for research, which, of course, will contain all those precious specimens called "types," which must be appealed to through all time to determine the species to which a name was originally given, the principal points to be aimed at are—the preservation of the objects from all influences deleterious to them, especially dust, light, and damp; their absolutely correct identification, and record of every circumstance that need be known of their history; their classification and storage in such a manner that each one can be found without difficulty or loss of time; and, both on account of expense as well as convenience of access, they should be made to occupy as small a space as is compatible with these requirements. They should be kept in rooms provided with suitable tables and good light for their examination, and within reach of the necessary books of reference on the particular subjects which the specimens illustrate. Furthermore, the rooms should be so situated that the officers of the museum, without too great hindrance to their own work, can be at hand for occasional assistance and supervision of the student, and if collections of research and exhibited specimens are contained in one building, it is obvious that the closer the contiguity in which those of any particular group are placed the greater will be the convenience both of students and curators, for in very few establishments will it be possible to form each series on such a scale as to be entirely independent of the other.

On the other hand, in a collection arranged for the instruction of the general visitor, the conditions under which the specimens are kept should be totally different. In the first place, their numbers must be strictly limited, according to the nature of the subject to be illustrated and the space available. None must be placed too high or too low for ready examination. There must be no crowding of specimens one behind the other, every one being perfectly and distinctly seen, and with a clear space around it. Imagine a picture gallery with half the pictures on the walls partially or entirely concealed by others hung in front of them: the idea seems preposterous, and yet this is the approved arrangement of specimens in most public museums. If an object is worth putting into a gallery at all it is worth such a position as will enable it to be seen. Every specimen exhibited should be good of its kind, and all available skill and care should be spent upon its preservation and rendering it capable of teaching the lesson it is intended to convey. And here I cannot refrain from saying a word upon the sadly neglected art of taxidermy, which continues to fill the cases of most of our museums with wretched and repulsive caricatures of mammals and birds, out of all natural proportions, shrunken here and bloated there, and in attitudes absolutely impossible for the creature to have assumed while alive. Happily there may be seen occasionally, especially where amateurs of artistic taste and good knowledge of natural history have devoted themselves to the subject, examples enough—and you are fortunate in possessing them in Newcastle—to show that an animal can be converted after death, by a proper application of taxidermy, into a real life-like representation of the original, perfect in form, proportions, and attitude, and almost, if not quite, as valuable for conveying information on these points as the living creature itself. The fact is that taxidermy is an art resembling that of the painter, or rather the sculptor; it requires natural genius as well as great cultivation, and it can never be permanently improved until we have abandoned the present conventional low standard and low payment for "bird-stuffing," which is utterly inadequate to induce any man of capacity to devote himself to it as a profession.

To return from this digression, every specimen exhibited should have its definite purpose, and no absolute duplicate should on any account be permitted. Above all, the purpose for which each specimen is exhibited, and the main lesson to be derived from it, must be distinctly indicated by the labels affixed, both as headings of the various divisions of the series, and to the individual specimens. A well-arranged educational museum has been defined as a collection of instructive labels illustrated by well-selected specimens.

What is, or should be, the order of events in arranging a portion of a public museum? Not certainly, as too often happens now, bringing a number of specimens together almost by haphazard, and cramming them as closely as possible in a case far too small to hold them, and with little reference to their order or to the possibility of their being distinctly seen. First, as I said before, you must have your curator. He must carefully consider the object of the museum, the class and capacities of the persons for whose instruction it is founded, and the space available to carry out this object. He will then divide the subject to be illustrated into groups, and consider their relative proportions, according to which he will plan out the space. Large labels will next be prepared for the principal headings, as the chapters of a book, and smaller ones for the various subdivisions. Certain propositions to be illustrated, either in the structure, classification, geographical distribution, geological position, habits, or evolution of the subjects dealt with, will be laid down and reduced to definite and concise language. Lastly will come the illustrative specimens, each of which as procured and prepared will fall into its appropriate place. As it is not always easy to obtain these at the time that they are wanted, gaps will often have to be left, but these, if properly utilized by drawings or labels, may be made nearly as useful as if occupied by the actual specimens.

A public exhibition which is intended to be instructive and interesting must never be crowded. There is, indeed, no reason why it ever should be. Every such exhibition, whether on a large or small scale, can only contain a representative series of specimens, selected with a view to the needs of the particular class of persons who are likely to visit the gallery, and the number of specimens exhibited should be adapted to the space available. There is, therefore, rarely any excuse for filling it up in such a manner as to interfere with the full view of every specimen shown. A crowded gallery, except in some very exceptional circumstances, at once condemns the curator, as the remedy is generally in his own hands. In order to avoid it he has nothing to do but sternly to eliminate all the less important specimens. If any of these possess features of historical or scientific interest demanding their permanent preservation, they should be kept in the reserve collections; if otherwise, they should not be kept at all.

The ideal public museums of the future will, however, require far more exhibition space than has hitherto been allowed; for though the number of specimens shown may be fewer than is often thought necessary now, each will require more room if the conditions above described are carried out, and especially if it is thought desirable to show it in such a manner as to enable the visitor to realize something of the wonderful complexity of the adaptations which bring each species into harmonious relation with its surrounding conditions. Artistic reproductions of natural environments, illustrations of protective resemblances, or of special modes of life, all require much room for their display. This method of exhibition, wherever faithfully carried out, is, however, proving both instructive and attractive, and will doubtless be greatly extended.

Guide-books and catalogues are useful adjuncts, as being adapted to convey fuller information than labels, and as they can be taken away for study during the intervals of visits to the museum, but they can never supersede the use of labels. Anyone who is in the habit of visiting picture galleries where the names of the artists and the subject are affixed to the frame, and others in which the information has in each case to be sought by reference to a catalogue, must appreciate the vast superiority in comfort and time-saving of the former plan.

Acting upon such principles as these, every public gallery of a museum, whether the splendid saloon of a national institution or the humble room containing the local collection of a village club, can be made a centre of instruction, and will offer interests and attractions which will be looked for in vain in the majority of such institutions at the present time.

One of the best illustrations of the different treatment of collections intended for research or advancement of knowledge, and for popular instruction or diffusion of knowledge, is now to be seen in Kew Gardens, where the admirably constructed and arranged herbarium answers the first purpose, and the public museums of economic botany the second. A similar distinction is carried out in the collections of systematic botany in the natural history branch of the British Museum, with the additional advantage of close contiguity; indeed, as an example of a scheme of good museum arrangement (although not perfect yet in details), I cannot do better than refer to the upper story in the east wing of that institution. The same principles, little regarded in former times in this country, and still unknown in some of the largest Continental museums, are gradually pervading every department of the institution, which, from its national character, its metropolitan position, and exceptional resources, ought to illustrate in perfection the ideal of a natural history museum. In fact, it is only in a national institution that an exhaustive research collection in all branches of natural history, in which the specialist of every group can find his own subject fully illustrated, can or ought to be attempted.

As the actual comparison of specimen with specimen is the basis of zoological and botanical research, and as work done with imperfect materials is necessarily imperfect in itself, it is far the wisest policy to concentrate in a few great central institutions, the number and situation of which must be determined by the population and the resources of the country, all the collections, especially those containing specimens already alluded to as so dear to the systematic naturalist, known as authors' "types," required for original investigations. It is far more advantageous to the investigator to go to such a collection and take up his temporary abode there, while his research is being carried out, with all the material required at his hand at once, than to travel from place to place and pick up piecemeal the information he requires, without opportunity of direct comparison of specimens.

I do not say that collections for special study, and even original research, should not, under particular circumstances and limitations, be formed at museums other than central national institutions, or that nothing should be retained in provincial museums but what is of a directly educational or elementary nature. A local collection, illustrating the fauna and flora of the district, should be part of every such museum; and this may be carried to almost any amount of detail, and therefore in many cases it would be very unadvisable to exhibit the whole of it. A selection of the most important objects may be shown under the conditions described above, and the remainder carefully preserved in cabinets for the study of specialists.

It is also very desirable in all museums, in order that the exhibited series should be as little disturbed as possible in arrangement, and be always available for the purpose for which it is intended, that there should be, for the use of teachers and students, a supplementary set of common objects, which, if injured, could be easily replaced. It must not be forgotten that the zealous investigator and the conscientious curator are often the direst antagonists: the one endeavours to get all the knowledge he can out of a specimen, regardless of its ultimate fate, and even if his own eyes alone have the advantage of it; the other is content if a limited portion only is seen, provided that can be seen by everyone both now and hereafter.

Such, then, is the primary principle which ought to underlie the arrangement of all museums—the distinct separation of the two objects for which collections are made; the publicly exhibited collection being never a store-room or magazine, but only such as the ordinary visitor can understand and profit by, and the collection for students being so arranged as to afford every facility for examination and research. The improvements that can be made in detail in both departments are endless, and to enter further into their consideration would lead me far beyond the limits of this address. Happily, as I said before, the subject is receiving much attention.

I would willingly dwell longer upon it—indeed I feel that I have only been able to touch slightly and superficially upon many questions of practical interest, well worthy of more detailed consideration—but time warns me that I must be bringing this discourse to a close, and I have still said nothing in reference to subjects upon which you may expect some words on this occasion. I mean those great problems concerning the laws which regulate the evolution of organic beings, problems which agitate the minds of all biologists of the present day, and the solution of which is watched with keen interest by a far wider circle—a circle, in fact, coincident with the intelligence and education of the world. Several communications connected with these problems will be brought before the Sectional meetings during the next few days, and we shall have the advantage of hearing them discussed by some of those who by virtue of their special attention to and full knowledge of these subjects are most competent to speak with authority. It is therefore for me rather delicate ground to tread upon, especially at the close of a discourse mainly devoted to another question. I will, however, briefly point out the nature of the problems and the lines which the endeavour to solve them will probably take, without attempting to anticipate the details which you will doubtless hear most fully and ably stated elsewhere.

I think I may safely premise that few, if any, original workers at any branch of biology appear now to entertain serious doubt about the general truth of the doctrine that all existing forms of life have been derived from other forms by a natural process of descent with modification, and it is generally acknowledged that to the records of the past history of life upon the earth we must look for the actual confirmation of the truth of a doctrine which accords so strongly with all we know of the present history of living beings.

Prof. Huxley wrote in 1875:—"The only perfectly safe foundation for the doctrine of evolution lies in the historical, or rather archæological, evidence that particular organisms have arisen by the gradual modification of their predecessors, which is furnished by fossil remains. That evidence is daily increasing in amount and in weight, and it is to be hoped that the comparisons of the actual pedigree of these organisms with the phenomena of their development may furnish some criterion by which the validity of phylogenic conclusions deduced from the facts of embryology alone may be satisfactorily tested."

Palæontology, however, as we all know, reveals her secrets with no open hand. How can we be reminded of this more forcibly than by the discovery announced scarcely three months ago by Prof. Marsh of numerous mammalian remains from formations of the Cretaceous period, the absence of which had so long been a source of difficulty to all zoologists? What vistas does this discovery open of future possibilities, and what thorough discredit, if any were needed, does it throw on the value of negative evidence in such matters! Bearing fully in mind the necessary imperfection of the record we have to deal with, I think that no one taking an impartial survey of the recent progress of palæontological discovery can doubt that the evidence in favour of a gradual modification of living forms is still steadily increasing. Any regular progressive series of changes of structure coinciding with changes in time can of course only be expected to be preserved and to come again before our eyes under such a favourable combination of circumstances as must be of most rare occurrence; but the links, more or less perfect, of many such series are continually being revealed, and the discovery of a single intermediate form is often of immense interest as indicating the path along which the modification from one apparently distinct form to another may have taken place.

Though palæontology may be appealed to in support of the conclusion that modifications have taken place as time advanced, it can scarcely afford any help in solving the more difficult problems which still remain as to the methods by which the changes have been brought about.

Ever since the publication of what has been truly described as the "creation of modern natural history," Darwin's work on the "Origin of Species," there has been no little controversy as to how far all the modifications of living forms can be accounted for by the principle of natural selection or preservation of variations best adapted for their surrounding conditions, or whether any, and if so what, other factors have taken part in the process of organic evolution.

It certainly cannot be said that in these later times the controversy has ended. Indeed those who are acquainted with scientific literature must know that notes struck at the last annual meeting of this Association produced a series of reverberations, the echoes of which have hardly yet died away.

Within the last few months also, two important works have appeared in our country, which have placed in an accessible and popular form many of the data upon which the most prevalent views on the subject are based.

The first is, "Darwinism: an Exposition of the Theory of Natural Selection, with some of its Applications," by Alfred Russel Wallace. No one could be found so competent to give such an exposition of the theory as one who was, simultaneously with Darwin, its independent originator, but who, by the title he has chosen no less than by the contents of the book, has, with rare modesty and self-abnegation, transferred to his fellow-labourer all the merit of the discovery of what he evidently looks upon as a principle of overwhelming importance in the economy of Nature; "supreme," indeed, he says, "to an extent which even Darwin himself hesitated to claim for it."

The other work I refer to is the English translation of the remarkable "Essays upon Heredity and Kindred Biological Problems," by Dr. August Weismann, published at the Oxford Clarendon Press, in which is fully discussed the very important but still open question—a question which was brought into prominence at our meeting at Manchester two years ago—of the transmission or non-transmission to the offspring of characters acquired during the lifetime of the parent.

It is generally recognized that it is one of the main elements of Darwin's, as well as of every other theory of evolution, that there is in every individual organic being an innate tendency to vary from the standard of its predecessors, but that this tendency is usually kept under the sternest control by the opposite tendency to resemble them, a force to which the terms "heredity" and "atavism" are applied. The causes of this initial tendency to vary, as well as those of its limits and prevailing direction, and the circumstances which favour its occasional bursting through the constraining principle of heredity offer an endless field for speculation. Though several theories of variation have been suggested, I think that no one would venture to say we have passed beyond the threshold of knowledge of the subject at present.

Taking for granted, however, as we all do, that this tendency to individual variation exists, then comes the question, What are the agents by which, when it has asserted itself, it is controlled or directed in such a manner as to produce the permanent or apparently permanent modifications of organic structures which we see around us? Is "survival of the fittest" or preservation by natural selection of those variations best adapted for their surrounding conditions (the essentially Darwinian or still more essentially Wallacian doctrine) the sole or even the chief of these agents? Can isolation, or the revived Lamarckian view of the direct action of the environment, or the effects of use or disuse accumulating through generations, either singly or combined, account for all? or is it necessary to invoke the aid of any of the numerous subsidiary methods of selection which have been suggested as factors in bringing about the great result?

Anyone who has closely followed these discussions, especially those bearing most directly upon what is generally regarded as the most important factor of evolution—natural selection, or "survival of the fittest"—cannot fail to have noticed the appeal constantly made to the advantage, the utility, or otherwise of special organs, or modifications of organs or structures to their possessors. Those who have convinced themselves of the universal application of the doctrine of natural selection hold that every particular structure or modification of structure must be of utility to the animal or plant in which it occurs, or to some ancestor of that animal or plant, otherwise it could not have come into existence; the only reservation being for cases which are explained by the principle which Darwin called "correlation of growth." Thus the extreme natural selectionists and the old-fashioned school of teleologists are so far in agreement.

On the other hand, it is held by some that numerous structures and modifications of structures are met with in Nature which are manifestly useless; it is even confidently stated that there are many which are positively injurious to their possessor, and therefore could not possibly have resulted from the action of natural selection of favourable variations. Organs or modifications when in an incipient condition are especially quoted as bearing upon this difficulty. But here, it seems to me, we are continually appealing to a criterion by which to test our theories of which we know far too little, and this (though often relied upon as the strongest) is, in reality, the weakest point of the whole discussion.

Of the variations of the form and structure of organic bodies we are beginning to know something. Our museums, when more complete and better organized, will teach us much on this branch of the subject. They will show us the infinite and wonderful and apparently capricious modifications of form, colour, and of texture to which every most minute portion of the organization of the innumerable creatures which people the earth is subject. They will show us examples of marvellously complicated and delicate arrangements of organs and tissues in many of what we consider as almost the lowest and most imperfectly organized groups of beings with which we are acquainted. But as to the use of all these structures and modifications in the economy of the creatures that possess them, we know, I may almost say, nothing, and our museums will never teach us these things. If time permitted I might give numerous examples in the most familiar of all animals, whose habits and actions are matters of daily observation, with whose life-history we are as well acquainted almost as we are with our own, of structures the purposes of which are still most doubtful. There are many such even in the composition of our own bodies. How, then, can we expect to answer such questions when they relate to animals known to us only by dead specimens, or by the most transient glimpses of the living in a state of nature, or when kept under the most unnatural conditions in confinement? And yet this is actually the state of our knowledge of the vast majority of the myriads of living beings which inhabit the earth. How can we, with our limited powers of observation and limited capacity of imagination, venture to pronounce an opinion as to the fitness or unfitness for its complex surroundings of some peculiar modification of structure found in some strange animal dredged up from the abysses of the ocean, or which passes its life in the dim seclusion of some tropical forest, and into the essential conditions of whose existence we have at present no possible means of putting ourselves in any sort of relation?

How true it is that, as Sir John Lubbock says, "we find in animals complex organs of sense richly supplied with nerves, but the functions of which we are as yet powerless to explain. There may be fifty other senses as different from ours as sound is from sight; and even within the boundaries of our own senses there may be endless sounds which we cannot hear, and colours as different as red from green of which we have no conception. These and a thousand other questions remain for solution. The familiar world which surrounds us may be a totally different place to other animals. To them it may be full of music which we cannot hear, of colour which we cannot see, of sensations which we cannot conceive."

The fact is that nearly all attempts to assign purposes to the varied structures of animals are the merest guesses and assumptions. The writers on natural history of the early part of the present century, who "for every why must have a wherefore," abound in these guesses, which wider knowledge shows to be untenable. Many of the arguments for or against natural selection, based upon the assumed utility or equally assumed uselessness of animal and vegetable structures, have nothing more to recommend them. In fact, to say that any part of the organization of an animal or plant, or any habit or instinct with which it is endowed, is useless, or still more injurious, seems to me an assumption which, in our present state of knowledge, we are not warranted in making. The time may come when we shall have more light, but infinite patience and infinite labour are required before we shall be in a position to speak dogmatically on these mysteries of Nature—labour not only in museums, laboratories, and dissecting-rooms, but in the homes and haunts of the animals themselves, watching and noting their ways amid their natural surroundings, by which means alone we can endeavour to penetrate the secrets of their life-history. But until that time comes, though we may not be quite tempted to echo the despairing cry of the poet, "Behold, we know not anything," a frank confession of ignorance is the most straightforward, indeed the only honest position we can assume when questioned on these subjects.

However much we may be convinced of the supreme value of scientific methods of observation and of reasoning, both as mental training of the individual and in the elucidation of truth and advancement of knowledge generally, it is impossible to be blind to the fact that we who are engaged with the investigation of those subjects which are commonly accepted as belonging to the domain of physical science are unfortunately not always, by virtue of being so occupied, possessed of that most precious gift, "a right judgment in all things."

No one intimately acquainted with the laborious and wavering steps of scientific progress (I can answer at least for one branch of it) can look upon that progress with a perfect feeling of satisfaction.

Can it be said of any of us that our observations are always accurate, the materials on which they are based always sufficient, our reasoning always sound, our conclusions always legitimate? Is there any subject, however limited, of which our knowledge can be said to have reached finality?

Or if it happens to any of us as to

A man who looks at glass
On it may stay his eye,
Or if he pleases through it pass
And then the heavens espy,

are not those heavens which are beyond the immediate objects of our observation coloured by our prejudices, prepossessions, emotions, or imagination, as often as they are defined by any profound insight into the depth of Nature's laws? In most of these questions an open mind and a suspended judgment appear to me the true scientific position, whichever way our inclinations may lead us.

For myself, I must own that when I endeavour to look beyond the glass, and frame some idea of the plan upon which all the diversity in the organic world has been brought about, I see the strongest grounds for the belief, difficult as it sometimes is in the face of the strange, incomprehensible, apparent defects in structure, and the far stranger, weird, ruthless savagery of habit, often brought to light by the study of the ways of living creatures, that natural selection, or survival of the fittest, has, among other agencies, played a most important part in the production of the present condition of the organic world, and that it is a universally acting and beneficent force continually tending towards the perfection of the individual, of the race, and of the whole living world.

I can even go further and allow my dream still thus to run:—

Oh yet we trust that somehow good
Will be the final goal of ill,—

That nothing walks with aimless feet,
That not one life shall be destroyed
Or cast as rubbish to the void
When God hath made the pile complete.

SECTION A.

MATHEMATICS AND PHYSICS.

Opening Address by Captain W. de W. Abney, C.B., R.E., F.R.S., F.R.A.S., President of the Section.

The occupant of this chair has a difficult task to perform, should he attempt to address himself to all the various subjects with which this Section is supposed to deal. I find that it has very often been the custom that some one branch of science should be touched upon by the President, and I shall, as far as in me lies, follow this procedure.

This year is the jubilee of the practical introduction of photography by Daguerre and Fox Talbot, and I have thought I might venture to take up your time with a few remarks on the effect of light on matter. I am not going into the history of photography, nor to record the rivalries that have existed in regard to the various discoveries that have been made in it. A brand-new history of photography, I dare say, would be interesting, but I am not the person to write one; and I would refer those who desire information as to facts and dates to histories which already exist. In foreign histories perhaps we English suffer from speaking and writing in a language which is not understanded of the foreign people; and the credit of several discoveries is sometimes allotted to nationalities who have no claim to them. Be that as it may, I do not propose to correct these errors or to make any reclamations. I leave that to those whose leisure is greater than mine.

I have often asserted, and I again assert, that there should be no stimulus for the study of science to be compared to photography. Step by step, as it is pursued, there will be formed a desire for a knowledge of all physical science. Physics, chemistry, optics, and mathematics are all required to enable it to be studied as it should be studied; and it has the great advantage that experimental work is the very foundation of it, and results of some kind are always visible. I perhaps am taking an optimist view of the matter, seeing there are at least 25,000 living facts against my theory, and perhaps not 1 per cent. of them in its favour. I mean that there are at least 25,000 persons who take photographs, and scarcely 1 per cent. who know or care anything of the "why or wherefore" of the processes, so far as theory is concerned. If we call photography an applied science, it certainly has a larger number who practise it, and probably fewer theorists, than any other.

He would be a very hardy man who would claim for Niépce, Daguerre, or Fox Talbot the discovery of photographic action on matter. The knowledge that such an action existed is probably as old as the fair-skinned races of mankind, who must have recognized the fact that light, and particularly sunlight, had a tanning action on the epidermis, and the women then, as now, no doubt took their precautions against it. As to what change the body acted upon by light underwent it need scarcely be said that nothing was known, and perhaps the first scientific experiment in this direction was made rather more than a hundred years ago by Scheele, the Swedish chemist, who found that when chloride of silver was exposed to light chlorine was given off. It was not till well in the forties that any special attention was given to the action that light had on a variety of different bodies; and then Sir John Herschel, Robert Hunt, Becquerel, Draper, and some few others carried out experiments which may be termed classical. Looking at the papers which Herschel published in the Philosophical Transactions and elsewhere, it is not too much to say that they teem with facts which support the grand principle that without the absorption of radiation no chemical action can take place on a body; in other words, we have in them experimental proofs of the law of the conservation of energy. Hunt's work, "Researches on Light," is still a text-book to which scientific photographers refer, and one is sometimes amazed at the amount of experimental data which is placed at our disposal. The conclusions that Hunt drew from his experiments, however, must be taken with caution in the light of our present knowledge, for they are often vitiated by the idea which he firmly held, that radiant heat, light, and chemical action, or actinism, were each of them properties, instead of the effects, of radiation. Again, we have to be careful in taking seriously the experiments carried out with light of various colours when such colours were produced by absorbing media. It must be remembered that an appeal to a moderately pure spectrum is the only appeal which can be legitimately made as to the action of the various components of radiation, and even then the results must be carefully weighed before any definite conclusion can be drawn. No photographic result can be considered as final unless the experiments be varied under all the conditions which may possibly arise. Coloured media are dangerous as enabling trustworthy conclusions to be drawn, unless the characters of such media have been thoroughly well tested and the light they transmit has been measured. An impure spectrum is even more dangerous to rely upon, since the access of white light would be sure to vitiate the results.

Perhaps one of the most puzzling phenomena to be met with in photography is the fact that the range of photographic action is spread over so large a portion of the spectrum. The same difficulty of course is felt in the matter of absorption, since the one is dependent on the other. Absorption by a body we are accustomed, and indeed obliged by the law of the conservation of energy, to consider as due to the transference of the energy of the ether wave-motion to the molecules and atoms comprising the body by increasing the vibrations of one or both.

In the case where chemical action takes place we can scarcely doubt that it is the atoms which in a great measure take up the energy of the radiation falling on them, as chemical action is dependent on the liberation of one or more atoms from the molecule, whilst, when the swings of the molecules are increased in amplitude, we have a rise in temperature of the body. I shall confine the few remarks I shall make on this subject to the case of chemical action. The molecule of a silver salt, such as bromide of silver, chemists are wont to look upon as composed of a limited and equal number of atoms to form the molecule. When we place a thin slab of this material before the slit of the spectroscope we find a total absorption in the violet and ultra-violet of the spectrum, and a partial absorption in the blue and green, and a diminishing absorption in the yellow and red. A photographic plate containing this same salt is acted upon in exactly the same localities and in the same relative degree as where the absorption takes place. Here, then, we have an example of, it may be, the vibrations of four atoms, one of which at least is isochronous, or partially so, with the waves composing a large part of the visible spectrum. The explanation of this is somewhat obscure. A mental picture, however, may help us. If we consider that, owing to the body acted upon being a solid, the oscillations of the molecules and atoms are confined to a limited space, it probably happens that between the times in which the atoms occupy, in regard to one another, the same relative positions, the component vibrations of, say, two of the atoms vary considerably in period. An example of what I mean is found in a pendulum formed of a bob and an elastic rod. If the bob be made to vibrate in the usual manner, and at the same time the elastic rod be elongated, it is manifest that we have a pendulum of ever-varying length. At each instant of time the period of vibration would differ from that at the next instant, if the oscillations were completed. It is manifest that increased amplitude would be given to the pendulum swings by a series of well-timed blows differing very largely in period; at the same time there would be positions of the pendulum in which some one series of well-timed blows would produce the greatest effect. In a somewhat similar manner we should imagine that the ethereal waves should produce increased amplitude in the swing of the atoms between very wide limits of period, and, further, that there should be one or more positions in the spectrum when a maximum effect is produced.[1] I would here remark that the shape of the curves of sensitiveness, when plotted graphically, of the different salts of silver to the spectrum have a marked resemblance to the graphically drawn curves of the three colour-sensations of the normal eye, as determined by Clerk Maxwell. May not the reason for the form of the one be equally applicable for the other? I only throw this out as evidence, not conclusive indeed, that the colour-sensitiveness of the eye is more probably due to a photographic action on the sensitive retina than to a merely mechanical action. That this is the case I need scarcely say has several times been propounded before.

The ease with which a silver salt is decomposed is largely, if not quite, dependent on the presence of some body which will take up some of the atoms which are thrown off from it. For instance, in chloride of silver we have a beautiful example of the necessity of such a body. In the ordinary atmosphere the chloride is, of course, coloured by the action of light; but if it be carefully dried and purified, and placed in a good vacuum, it will remain uncoloured for years in the strongest sunlight. In this case the absence of air and moisture is sufficient to prevent it discolouring.

If in the vacuum, however, a drop of mercury be introduced, the coloration by light is set up. We have the chlorine liberated from the silver and combining with the mercury vapour, and a minute film of calomel formed on the sides of the vessel.

Delicate experiments show that not only is this absorbent almost necessary when the action of light is so strong or

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[1] The effect of perfect and nearly perfect synchronism of one oscillation upon another is also to be found exemplified in my "Treatise on Photography" ("Text-book of Science Series").

so prolonged that its effect is visible, but also when the exposure or intensity is so small that the effect is invisible and only to be found by development. The reason for this absorbent is not far to seek. If, for instance, silver chloride be exposed to light *in vacuo*, although the chlorine atoms may be swung off from the original molecule, yet they may only be swung off to a neighbouring molecule which has lost one of its chlorine atoms, and an interchange of atoms merely takes place. If, however, a chlorine absorbent be present which has a greater affinity for chlorine than has the silver chloride which has lost one of its atoms, then we may consider that the chlorine atoms will be on the average more absorbed by the absorbent than by the subchloride molecules. The distribution of the swung-off atoms between the absorbent and the subchloride will doubtless be directly proportional to their respective affinities for chlorine, and so for the other salts of silver. If this be so, then it will be seen that the greater the affinity of the absorbent for the halogen the more rapid will be the decomposition of the silver salt. This, then, points to the fact that if any increase in the sensitiveness of a silver salt is desired it will probably be brought about by mixing with it some stronger halogen absorbent than has yet been done.

The question as to what is the exact product of the decomposition of a silver salt by the action of light is one which has not as yet been fully answered. For my own part, I have my strong beliefs and my disbeliefs. I fully believe the first action of light to be a very simple one, though this simple action is masked by other actions taking place, due to the surroundings in which it takes place. The elimination of one atom from a molecule of a silver salt leaves the molecule in an unsatisfied condition, and capable of taking up some fresh atom. It is this capacity which seemingly shrouds the first action of light, since when exposure is prolonged the molecules take up atoms of oxygen from the air or from the moisture in it. Carey Lea, of Philadelphia, has within the last three years given some interesting experiments on the composition of what he calls the photochloride of silver, which is the chloride coloured by light, and Prof. Hodgkinson has also taken up the matter. The conclusions the former has drawn are, to my mind, scarcely yet to be accepted. According to the latter experimentalist the action of light on silver chloride is to form an oxidized subsalt. This can hardly be the case, except under certain conditions, since a coloured compound is obtained when the silver chloride is exposed in a liquid in which there is no oxygen present.

This coloration by light of the chloride of silver naturally leads our thoughts to the subject of photography in natural colours. The question is often asked when photography in natural colours will be discovered. Photography in natural colours not only has been discovered, but pictures in natural colours have been produced. I am not alluding to the pictures produced by manual work, and which have from time to time been foisted on a credulous public as being produced by the action of light itself, much to the damage of photography and usually of the so-called inventors. Roughly speaking, the method of producing the spectrum in its natural colours is to chlorinize a silver plate, expose it to white light till it assumes a violet colour, heat till it becomes rather ruddy, and expose it to a bright spectrum. The spectrum colours are then impressed in their natural tints. Experiment has shown that these colours are due to an oxidized product being formed at the red end of the spectrum and a reduced product at the violet end. Photography in natural colours, however, is only interesting from a scientific point of view, and, so far as I can see, can never have a commercial value. A process to be useful must be one by which reproductions are quickly made ; in other words, it must be a developing and not a printing process, and it must be taken in the camera, for any printing process requires not only a bright light but also a prolonged exposure. Now it can be conceived that in a substance which absorbs all the visible spectrum the molecules can be so shaken and sifted by the different rays that eventually they sort themselves into masses which reflect the particular rays by which they are shaken ; but it is almost—I might say, quite—impossible to believe that when this sifting has only been commenced, as it would be in the short exposure to which a camera picture is submitted, the substance deposited to build up the image by purely chemical means would be so obliging as to deposit in that the particular size of particle which should give to the image the colour of the nucleus on which it was depositing. I am aware that in the early days of photography we heard a good deal about curious results that had been obtained in negatives, where red brick houses were shown as red and the blue sky as bluish. The cause of these few coincidences is not hard to explain, and would be exactly the same as when the red brick houses were shown as bluish and the sky as red in a negative. The records of the production of the latter negatives are naturally not abundant, since they would not attract much attention. I may repeat, then, that photography in natural colours by a printing-out process—by which I mean by the action of light alone—is not only possible but has been done, but that the production of a negative in natural colours from which prints in natural colours might be produced appears, in the present state of our knowledge, to be impossible. Supposing it were not impracticable, it would be unsatisfactory, as the light with which the picture was impressed would be very different from that in which it would be viewed. Artists are fully aware of this difficulty in painting, and take their precautions against it.

The nearest approach to success in producing coloured pictures by light alone is the method of taking three negatives of the same subject through different-coloured glasses, complementary to the three colour-sensations which together give to the eye the sensations of white light. The method is open to objection on account of the impure colour of the glasses used. If a device could be adopted whereby only those three parts of the spectrum could be severally used which form the colour-sensations, the method would be more perfect than it is at present. Even then perfection could not be attained, owing to a defect which is inherent in photography, and which cannot be eliminated. This defect is the imperfect representation of gradation of tone. For instance, if we have a strip graduated from what we call black to white (it must be recollected that no tone can scientifically be called black, and none white) and photograph it, we shall find that in a print from the negative the darkness which is supposed to represent a grey of equal mixtures of black and white by no means does so unless the black is not as black nor the white as white as the original. The cause of this untruthfulness in photography has occupied my attention for several years, and it has been my endeavour to find out some law which will give us the density of a silver deposit on a negative corresponding with the intensity of the light acting. I am glad to say that at the beginning of this year a law disclosed itself, and I find that the transparency of a silver deposit caused by development can be put into the form of the law of error.

This law can be scarcely empiric, though at first sight it appears that the manipulations in photography are so loose that it should be so. It is this very looseness, however, which shows that the law is applicable, since in all cases I have tried it is obeyed. That there are theoretical difficulties cannot be denied, but it is believed that strictly theoretical reasoning will eventually reconcile theory with observation.

This want of truth in photography in rendering gradation, then, puts it out of the range of possibility that photography in natural colours can ever be exact, or that the three negatives system can ever get over the difficulty.

One of the reproaches that in early days was cast at photography was its inability to render colour in its proper monochromatic luminosity. Thus whilst a dark blue was rendered as white in a print—that is, gave a dense deposit in a negative—bright yellow was rendered as black in a print, or nearly so—that is, as transparent or nearly transparent glass in the negative. To the eye the yellow might be far more luminous than the blue, but the luminosity was in the photograph reversed. I need scarcely say that the reason of this want of truth in the photograph is due to the want of sensitiveness of the ordinarily used silver salts to the least refrangible end of the spectrum. Some fifteen years ago Dr. H. W. Vogel announced the fact that when silver salts were stained with certain dyes they became sensitive to the colour of the spectrum, which the dyes absorbed. This at once opened up possibilities, which, however, were not at once realized, owing perhaps to the length of exposure required when the collodion process was employed. Shortly after the gelatine process was perfected, the same dyes were applied to plates prepared by this method, which, although they contained the same silver salts as the old collodion process, yet *per se* were very much more sensitive. A new era then dawned for what has been termed isochromatic and orthochromatic photography. The dyes principally used are those belonging to the eosin group and cyanine—not the ordinary cyanine dye of commerce, but that discovered by Greville Williams. For a dye to be of use in this manner it may be taken as an axiom—first propounded by the speaker, it is believed—that it must be fugitive, or that it must be capable of forming a silver compound. The more stable a dye is the less effective it is. If we take as an example cyanine, we find that it absorbs in the orange and slightly in the red. If paper or collodion stained with this colouring-matter be exposed to the action of the spectrum, it will be found that the dye bleaches in exactly the same part of the spectrum as that in which it absorbs, following, indeed, the universal law I have already alluded to. If a film containing a silver salt be dyed with the same, it will be found that, whilst the spectrum acts on it in the usual manner—viz. darkening it in the blue, violet, and ultra-violet—the colour is discharged where the dye absorbs, showing that in one part of the spectrum it is the silver salt which is sensitive, and that in the other it is the colouring-matter. If such a plate, after exposure to the spectrum, be developed, it will be found that at both parts a deposit of silver takes place; and further, when the experiment is carefully conducted, if a plate with merely cyanine-coloured collodion be exposed to the spectrum and bleached in the orange, and after removal to the dark room another film containing a silver salt be applied and then a developer, a deposit of silver will take place where the bleaching has occurred. This points to the fact that the molecules of a fugitive dye, when altered by light, are unsatisfied, and are ready to take up an atom or atoms of silver, and other molecules of silver will deposit on such nuclei by an action which has various names in physical science, but which I do not care to mention. This is the theory which I have always advocated, viz. that the dye by its reduction acts as a nucleus on which a deposit of silver can take place. It met with opposition; a rival theory which makes the dye an "optical sensitizer"—an expression which is capable of a meaning which I conceive contrary to physical laws—being run against it. The objection to what I may call the nucleus theory is less vigorous than it has been, and its diminution is due perhaps to the more perfect understanding of the meaning of each other by those engaged in the controversy. To my mind, the action of light on fugitive dyes is one of the most interesting in the whole realm of photography, as eventually it must teach us something as to the structure of molecules, and add to the methods by which their coarseness may be ascertained. Be the theory what it may, however, a definite result has been attained, and it is now possible to obtain a *fair* representation of the luminosity of colours by means of dyed films. At present the employment of coloured screens in front of the lens, or on the lens itself, is almost an essential in the method when daylight is employed, but not till some dye is discovered which shall make a film equally sensitive for the same luminosity to the whole visible spectrum will it be possible to make orthochromatic photography as perfect as it can be made. The very fact that no photograph of even a black and white gradation will render the latter correctly must of necessity render any process imperfect, and hence in the above sentence I have used the expression "as perfect as it can be made."

The delineation of the spectrum is one of the chief scientific applications to which photography has been put. From very early days the violet and ultra-violet end of the spectrum have been favourite objects for the photographic plate. To secure the yellow and red of the spectrum was, however, till of late years, a matter of apparently insurmountable difficulty; whilst a knowledge of that part of the spectrum which lies below the red was only to be gained by its heating effect. The introduction of the gelatine process enabled the green portion of the spectrum to impress itself on the sensitive surface; whilst the addition of various dyes, as before mentioned, allowed the yellow, the orange, and a portion of the red rays to become photographic rays. Some eight years ago it was my own good fortune to make the dark infra-red rays impress themselves on a plate. This last has been too much a specialty of my own, although full explanations have been given of the methods employed. By preparing a bromide of silver salt in a peculiar manner one is able so to modify the molecular arrangement of the atoms that they answer to the swings of those waves which give rise to these radiations. By employing this salt of silver in a film of collodion or gelatine the invisible part of the spectrum can be photographed and the images of bodies which are heated to less than red heat may be caused to impress themselves upon the sensitive plate. The greatest wave-length of the spectrum to which this salt is sensitive so far is 22,000 λ, or five times the length of the visible spectrum. The exposure for such a wave-length is very prolonged, but down to a wave-length of 12,000 it is comparatively short, though not so short as that required for the blue rays to impress themselves on a collodion plate. The colour of the sensitive salt is a green blue by transmitted light; it has yet to be determined whether this colour is all due to the coarseness of the particles or to the absorption by the molecules. The fact that a film can be prepared which by transmitted light is yellow, and which may be indicative of colour due to fine particles, together with an absorption of the red and orange, points to the green colour being probably due to absorption by the molecules. We have thus in photography a means of recording phenomena in the spectrum from the ultra-violet to a very large wave-length in the infra-red—a power which physicists may some day turn to account. It would, for instance, be a research worth pursuing to photograph the heavens on a plate prepared with such a salt, and search for stars which are nearly dead or newly born, for in both cases the temperature at which they are may be such as to render them below red heat, and therefore invisible to the eye in the telescope. It would be a supplementary work to that being carried out by the brothers Henri, Common, Roberts, Gill, and others, who are busy securing photographic charts of the heavens in a manner which is beyond praise.

There is one other recent advance which has been made in scientific photography to which I may be permitted to allude, viz. that from being merely a qualitative recorder of the action of light it can now be used for quantitative measurement. I am not now alluding to photographic actinometers, such as have been brought to such a state of perfection by Roscoe; but what I allude to is the measurement and interpretation of the density of deposit in a negative. By making exposures of different lengths to a standard light, or to different known intensities of light, on the same plate on which a negative has to be taken, the photographic values of the light acting to produce the densities on the different parts of the developed image can be readily found. Indeed, by making only two different exposures to the same light, or two exposures to two different intensities of light, and applying the law of density of deposit in regard to them, a curve is readily made from which the intensities of light necessary to give the different densities of deposit in the image impressed on the same plate can be read off. The application of such scales of density to astronomical photographs, for example, cannot but be of the highest interest, and will render the records so made many times more valuable than they have hitherto been. I am informed that the United States astronomers have already adopted the use of such scales, which for the last three years I have advocated, and it may be expected that we shall have results from such scaled photographs which will give us information which would before have been scarcely hoped for.

One word as to a problem which we may say is as yet only qualitatively and not quantitatively solved. I refer to the interchangeability of length of exposure for intensity of light. Put it in this way. Suppose that with a strong light, L, a short exposure, E, be given, a chemical change, C, is obtained: will the same change, C, be obtained if the time is only an *n*th of the light L, but *n* times the exposure? Now this is a very important point, more particularly when the body acted upon is fairly stable, as, for instance, some of the water-colour pigments, which are known to fade in sunshine, but might not be supposed to do so in the light of an ordinary room, even with prolonged exposure. Many experiments have been made at South Kensington as regards this, more especially with the salts of silver, and it is found that, for any ordinary light, intensity and exposure are interchangeable, but that when the intensity of light is very feeble, say the $\frac{1}{1000000}$ of ordinary daylight, the exposure has to be rather more prolonged than it should be, supposing the exact interchangeability always held good; but it has never been found that a light was so feeble that no action could take place. Of course it must be borne in mind that the stability of the substance acted upon may have some effect; but the same results were obtained with matter which is vastly more stable than the ordinary silver salts. It may be said in truth that almost all matter which is not elemental is, in time and to some degree, acted upon by light.

I should like to have said something regarding the action of light on the iron and chromium salts, and so introduced the subject of platinotype and carbon printing, the former of which is creating a revolution in the production of artistic prints. I have, however, refrained from so doing, as I felt that the President of

Section A should not be mistaken as the President of Section B. Photogravure and the kindred processes were also inviting subjects on which to dwell, more especially as at least one of them is based on the use of the same material as that on which the first camera picture was taken by Niēpce. Again, a dread of trenching on the domains of art restrains me.

Indeed, it would have been almost impossible, and certainly impolitic, in the time which an address should occupy, to have entered into the many branches of science and art which photography covers. I have tried to confine myself to some few advances that have been made in its theory and practice.

The discovery of the action of light on silver salts is one of the marvels of this century, and it is difficult to overrate the bearing it has had on the progress of science, more especially physical science. The discovery of telegraphy took place in the present reign, and two years later photography was practically introduced; and no two discoveries have had a more marked influence on mankind. Telegraphy, however, has had an advantage over photography in the scientific progress that it has made, in that electrical currents are subject to exact measurement, and that empiricism has no place with it. Photography, on the other hand, has laboured under the disadvantage that, though it is subject to measurement, the factors of exactitude have been hitherto absent. In photography we have to deal with molecules the equilibrium of whose components is more or less indifferent according to the process used; again, the light employed is such a varying factor that it is difficult to compare results. Perhaps more than any other disadvantage it labours under is that due to quackery of the worst description at the hands of some of its followers, who not only are self-asserting, but often ignorant of the very first principles of scientific investigation. Photography deserves to have followers of the highest scientific calibre; and if only some few more real physicists and chemists could be induced to unbend their minds and study the theory of an applied science which they often use for record or for pleasure, we might hope for some greater advance than has hitherto been possible.

Photography has been called the handmaid of Art; I venture to think it is even more so the handmaid of Science, and each step taken in perfecting it will render it more worthy of such a title.

SECTION B.

CHEMISTRY.

OPENING ADDRESS BY SIR LOWTHIAN BELL, BART., F.R.S., F.C.S., D.C.L., M.INST.C.E., PRESIDENT OF THE SECTION.

IT has occasionally been the practice of former occupants of this chair to devote a considerable portion of the Presidential address to the more recent discoveries in chemical science. This branch of learning advances now with such rapid strides and covers so wide a field, that no one who has not made it the business of his life can hope to discharge this duty with even a moderate share of success.

My immediate predecessor, indeed, discouraged any further attempts in this direction on the ground of the impossibility of doing it justice within the limits of a short discourse, and his remarks were consequently directed to the best methods of teaching the science with which Section B is more directly concerned. I propose this morning to add my testimony to the importance of Dr. Tilden's recommendation by comparing the rate of progress of one of our great national industries as it has been advanced with and without the aid which chemistry is capable of affording. For this purpose I have selected the metallurgy of iron, not only from my greater familiarity with its details, but because, in my judgment, it affords a suitable example for the object I have in view.

It is needless to insist on the disadvantage attending the application of a science to practical work, without a fair knowledge of the principles which regulate its action. At the same time it would be unfair to those who were engaged in the manufacture of iron during the first half of the present century to deny the value of the services rendered to their art, without giving much thought to the laws of Nature upon which their processes depended. The work so performed sufficed nevertheless to place the world in possession of the metal in such abundance and at so low a cost, that no engineering works have been delayed on account of the high price of or absence of the required quality in the produce of our ironworks during the period in question. On the other hand, it is not to be denied that since the ironmasters have allied themselves with the chemist, they have made more progress in thirty years than their predecessors did in three centuries.

No one unacquainted with the archæology of the iron trade could suppose that the colossal furnaces pouring forth their streams of molten metal, followed by the rapid action of the Bessemer converter, were the modern representatives of the iron-making appliances of former days. Out of the latter, in a low hearth not larger than a domestic fire-place, often dependent on the wind for their blast, a few pounds of ore were, at a considerable cost for labour, fuel, and waste of metal, converted into malleable iron. By means of a modern furnace in an hour and a half a ten-ton converter can be filled with liquid cast iron, which in twenty minutes may be run into ingots cheaper, stronger, and more malleable than the best wrought iron of our ancestors, or indeed of our own manufacture.

How out of the small fire of the ancient ironworks the German *Stück-Ofen* was evolved is a matter of conjecture. In both, owing to the conditions under which the fuel was burnt, carbon dioxide was largely the product of its combustion. The oxidizing property of this gas was in each the cause of the waste of metal just spoken of. Probably, and for other reasons than avoiding this loss of iron, attempts were made to increase the dimensions of the *Stück-Ofen.* If this addition were one of limited extent, the smelter would find to his cost that a substance was obtained which no longer possessed the malleable property of that obtained from the lesser furnace. This change would be due to the absorption of carbon, but not in sufficient quantity to constitute that valuable form of the metal known as cast iron. With a material useless for the smith and incapable from its difficult fusibility of being run into moulds, we can understand the delay which took place in the introduction of the blast furnace, which about the middle of the sixteenth century gave to cast iron a recognized and valuable position in the arts.

In those days there was no very exact science to appeal to, for two hundred and fifty years after the "high furnace" of the Germans and French had been set to work, Fourcroy, in his "General System of Chemical Knowledge and its Application to the Phenomena of Science and Art," arrived at the conclusion that cast metal was erroneously supposed to be a mixture of slag and iron or a compound of arsenic or manganese and iron. This was written in 1804, in a work of 5000 pages, when he leant to the opinion that Monge and Berthollet were more correct in considering the product of the blast furnace as consisting of iron, oxygen, and carbon.

When the malleable iron-maker had placed in his hands a material containing, as the pig did, more than 90 per cent. of metal, he found it greatly to his advantage to avoid having to deal with all the earthy matter contained in the ores, for it was the presence of silica and alumina which helped to add to the waste incurred in the old hearths. The object sought for in the old Catalan fires, as they were called, in treating ore was one of a reducing or deoxidizing character, whereas the reverse of this was required when ore was replaced by pig-iron. In the first oxygen had to be removed from the oxide of iron, in the latter oxygen had to be united with the metalloids found in the pig. These were distinctions unknown in the days we are considering, and therefore did not trouble the minds of the ironmasters. In both cases there was a large formation of oxide of iron, and when pig-iron was handed over to the Catalan furnace man, it was the oxide of iron so generated which performed the desired duty, and thus this simple mode of procuring malleable iron remained undisturbed for upwards of two hundred years.

The discovery which led to the discontinuance of the low blast furnace as a means of procuring iron in its malleable form was that of puddling made by Cort in 1784. In point of fact Cort's process was merely doing in a reverberatory furnace that which was previously effected by means of compressed air. In an economic point of view, however, the difference is great, and its consequences were of immense importance, for to the puddling furnace we were first indebted for an ample supply of cheap iron by which, in a variety of well-known ways, the interests of the human race have been so largely promoted. As an indication of the indifference of those formerly engaged in industrial pursuits to the scientific aspect of their calling, may be mentioned the fact that puddling had been largely followed for upwards of half a century before it occurred to anyone to examine the chemistry of the process.

Down to the beginning of the seventeenth century the only fuel used in the blast furnace, and, indeed, in the manufacture of iron generally, was charcoal. In 1620, Dudley made several attempts to substitute mineral coal for vegetable fuel in his smelting works, which, by the exhaustion of timber, had become very expensive. He failed in this, and in consequence the British iron trade gradually fell until it was not equal to the production of one modern blast furnace. This happened in 1740, when Darby, by treating pit coal in the same fashion as the charcoal burners had done with wood, *i.e.* by charring it, restored vitality to an expiring industry. It is true the restoration must have been of a languid character, for in half a century afterwards it is said the weekly produce of a furnace did not exceed fifteen or sixteen tons.

Various changes were introduced into the manufacture of iron in the first quarter of the present century, but these were rather of a mechanical than of a chemical nature. They chiefly owed their origin to the lessons taught by the chemist Black to James Watt, who profited by them in the application of steam as a motive power. This brings us to the year 1828, a year which will always be distinguished in the annals of the iron trade by the discovery of Neilson of the value of heated air in smelting the ores of this metal. I never heard it pretended that the inventor had any pretensions to be considered a man of sciencee Had it been otherwise, the knowledge of the virtues of the hot blast might have been indefinitely postponed, and this opinion is founded on the fact that for many a long year no satisfactory explanation was given why heat obtained by burning coal in the hot air apparatus was capable of saving three or four times its weight in the fuel consumed in the furnace itself. I propose, with your permission, to consider this subject with more attention than I shall devote to other portions of this address, and I am led to do this, not only because it is one of some scientific interest, but because its study seems to afford a solution to some questions in respect to which great differences of opinion prevailed among those whose daily work led them to pay much attention to their details. These questions have all a reference to the quantity of fuel consumed in smelting the ore, as this may be affected by the temperature of the blast and the dimensions of the furnaces employed for this purpose.

As is well understood, the heat excited in an iron furnace may be classified under three heads:—

First, that derived from the combustion of the coke at the point where the blast enters the furnace, the ultimate product being carbonic oxide.

Second, the conversion of a portion of this carbonic oxide into carbon dioxide.

Third, the heat carried into the furnace by the blast.

For the better illustration of the relations which the heat derived from these sources bear to each other, a table (No. I.) has been prepared in which the quantities of each are given in Centigrade calories, and reckoned upon 20 units of iron to correspond with English weights. The information upon which the calculations are based is derived from actual observation gathered from furnaces of different sizes and fed with air at different temperatures.

TABLE I.

—	A	—	—	—
Height of furnace in feet	48	48	80	80
Calories—per unit of coke burnt to CO	2078	2028	2018	2045
,, from portion of this CO burnt to CO_2	560	1059	1636	1463
Total calories from coke	2638	3087	3654	3508
Calories in blast	—	508	534	732
Total heat per unit of coke	2638	3595	4188	4240
Temperature of blast C	0°	485°	485°	695°
Cwts. blast per ton of metal	228	128	103	94
,, escaping gases per ton of metal	285	170	138	126
,, slag per ton of metal	34	31	29	28

A second table contains statements showing the manner in which the heat so generated is appropriated in the various divisions of the duty the furnaces had to perform, and for facility of comparison, alongside the quantities of heat so required, their equivalents in the coke used have been added.

In the table No. II. the appropriation of the heat is separated into *Constants* and *Variables*. The first consists of items where the quantity of heat in making a particular quality of iron is only liable to alterations of trifling amount. On the other hand, the variables exhibit in A and B differences so considerable that work which in the furnace blown with cold air absorbed 73,388 calories per 20 cwts. of pig-iron, was done with 58,645 calories by merely raising the blast to 485°.

The cause of this great variation in the amount of heat required for a given weight of pig-iron, produced under different circumstances as to temperature of blast and size of furnace, depends on changes in the actual amount of work to be performed. How this arises will be best seen in the description of the four examples set forth in the two tables.

Beginning with A, which is a furnace 48 feet in height, blown with cold air and consuming 45 cwts. of coke and 18 cwts. of limestone per ton of metal, the volume of gas produced may be taken at 14,460 cubic yards at ordinary temperatures and pressures. At the temperature at which they escape we may assume the volume per ton of iron to be about 36,000 cubic yards, passing out of the furnace at the rate of 357 cubic yards per minute.

In comparing the consumption of coal formerly burnt in the hot-air stoves with the saving of coke in the furnace, account must be taken of the different conditions of the combustion. In Table I., owing to the small quantity of carbon dioxide formed, the heat evolved is only 2638 calories per unit of coke, whereas each unit of the coal consumed in heating the air afforded three times this quantity of heat. Doubtless there was a great loss in the operation of heating the air, for it would not appear that much above one-fourth of the theoretical quantity of heat capable of being generated by the coal reached the furnace through the *tuyères*.

We have now to consider the nature of the change which is effected in a furnace where, for every 2638 calories generated by the combustion of the coke, 508 calories are carried in by the blast. It will be readily understood that with the velocity at which the gases are passing out of the cold-blast furnace they have but little time to impart their heat to the incoming solids, or to have the carbonic oxide they contain converted into carbon dioxide. The withdrawal of so much coke, and its place taken by heat contained in the blast, means that the 14,460 cubic yards of escaping gases are reduced to about 12,120 cubic yards. The effect of this is not only to alter the speed at which the gases are passing through the materials, but to alter the relation in point of quantity which the ironstone present in the furnace bears to the coke, so that, in point of fact, a larger space is occupied by the ore than was before, and a lesser one by the fuel. We have thus the carbonic oxide passing more slowly over the oxide of iron at the same time that there is a greater quantity of the oxide exposed to the influence of the reducing gas. To illustrate how this operates, a table has been prepared, showing how each 1000 cubic feet of furnace space is occupied in the four cases we are considering:—

	A 48-feet cold blast.	B 48-feet hot blast.	C 80-feet blast.	D 80-feet blast.
Coke cubic feet ...	736	686	590	590
Limestone ,, ...	63	75	86	77
Ironstone ,, ...	201	239	324	333
	1000	1000	1000	1000

The immediate effect of the introduction of the hot blast is to alter the spaces filled by the three minerals from those given in

Column A to coke 686, limestone 75, and ore 239 cubic feet. This is followed by a twofold advantage. Volume for volume, ore and limestone possess double the heat-intercepting power of coke, and there is 19 per cent. more ore ready to oxidize the carbonic oxide passing over it at a reduced speed of 16 per cent. than there was when using cold air. The increased efficiency of the coke, due to a more perfect cooling of the gases and higher oxidation of the carbonic oxide, permits its further suppression until the relative spaces filled by the materials are those shown under Column B. These advantages would not of themselves suffice to save 16 cwts. of coke or thereabouts out of 45 cwts., but the reduction in the coke consumed is followed by a diminution in the quantity of air used and in the weight of gases and slag produced. A reference to the appropriation of heat classified under the head of "Variables" will show in consequence diminution from 73,338 to 54,643 calories.

It may be asked whether this prolonged exposure of the ore to the reducing gases could not be secured by driving the furnace at a slower speed. There is, however, a point which may be regarded as one of equilibrium, in which the quantity of cold materials charged at the top just suffices to reduce the temperature of the gases, leaving it as far as is possible consistent with the dimensions of the furnace. If the volume of blast entering at the *tuyères* is lowered one-half, it would mean that the materials would be exposed for twice the time to the hot gases that they were previous to the alteration in the rate of driving. The elevation in the temperature of the coke would enable its carbon to act on the carbon dioxide, so that there would ensue as great a loss under the second head of heat evolution in Table I. as there is gained by a more perfect interception of the heat contained in the gases.

There is, however, another way of securing this prolonged exposure of the ore to the action of the reducing gas without incurring the inconvenience just referred to, viz. by increasing the dimensions of the furnace blown with cold air. When this was done by raising the height from 48 to 71 feet, it was found that the duty performed by the coke, apart from the heat contained in the blast, was just about the same as that in the hot-blast furnace.

TABLE II.—*Showing the appropriation of Heat and its equivalent per ton Iron.*

Appropriation of Heat per 20 of Pig-Iron.	A—Blast 0° C.		B—Blast 485° C.		C—Blast 485° C.		D—Blast 695° C.	
	Calories.	Cwts. coke	Calories.	Cwts. coke	Calories.	Cwts. coke	Calories.	Cwts. coke
CONSTANTS:—								
Reduction of Fe_2O_3 in ore	33,108	12·550	33,108	9·209	33,108	7·905	33,108	7·808
Reduction of metalloids in pig	4,174	1·582	4,174	1·161	4,174	0·996	4,174	0·984
Dissociation of CO($2CO = C + CO_2$)	1,440	0·546	1,440	0·400	1,440	0·344	1,440	0·340
Fusion of pig-iron	6,600	2·501	6,600	1·836	6,600	1·576	6,600	1·557
Constant calories per 20 of pig	45,322	—	45,322	—	45,322	—	45,322	—
Coke consumed per 20 of pig... ... ... cwts.	—	17·179	—	12·606	—	10·821	—	10·689
VARIABLES:—								
Evaporation of water in coke	630	0·239	411	0·114	312	0·074	298	0·070
Decomposition of water in blast	5,420	2·055	3,348	0·931	2,720	0·649	2,408	0·568
Expulsion of CO_2 in limestone	6,660	2·526	5,920	1·647	5,054	1·207	4,070	0·961
Reduction of CO_2 in limestone to CO	6,912	2·620	6,144	1·709	5,248	1·254	4,099	0·962
Fusion of slag	18,590	7·045	17,325	4·819	16,720	3·993	15,565	3·673
Carried off in escaping gases	29,482	11·178	18,486	5·144	11,043	2·636	8,906	2·101
Heat in *tuyère* water at hot-blast furnaces, loss from walls, &c.	5,694	2·158	7,011	1·950	7,057	1·686	9,389	2·616
Variables for 20 of pig	73,388	—	58,645	—	48,154	—	44,735	—
Variables for coke for 20 of pig ... ... cwts.	—	27·821	—	16·314	—	11·499	—	10·551
SUM OF CONSTANTS AND VARIABLES:—								
Calories for 20 of pig-iron	118,710	—	103,967	—	93,476	—	90,057	—
Cwts. of coke for 20 of pig-iron	—	45·000	—	28·92	—	22·32	—	21·24

With regard to the position of equilibrium above referred to, it is worthy of remark that, while this was reached when a furnace of 48 feet ran 100 tons per week when driven with cold air, it was not arrived at in one of similar dimensions using heated air until the make was increased to about 220 tons.

When we proceed to examine the composition and weight of the gases given off by a 48-feet furnace blown with air at 485° C., it will be found that about 20 per cent. of the carbon as dioxide has disappeared, due no doubt to the still excessive temperature of the upper zone and too rapid a current of the reducing agent. An obvious way to remedy this evil would be by an addition to the capacity of the furnaces. This was done by raising them to a height of 80 feet, with a cubical space three or four times greater than those of 48 feet. In such a furnace, almost the full theoretical quantity of carbon as dioxide has been obtained, but, while the larger furnace held three or four times as much ore, &c., the production was only about double that of the lesser. On referring to Table II., it will be seen that a further economy of 6·6 cwts. of coke has been effected in Furnace C as compared with B, due solely to an enlargement of space, for the temperature of the blast was exactly the same in both. This improvement, it will also be perceived, is due to an extension of those causes which acted so beneficially when hot air was applied to B.

If 6·6 cwts. of carbon or thereabouts is the full quantity per ton of iron which can be found in the gases as dioxide, and if, in a furnace working under the conditions of C, it requires 22·32 of coke to furnish this carbon and that in the carbonic oxide, it is clear we cannot withdraw any coke without disturbing the position of equilibrium supposed to have been established in the case of the furnace in question. Suppose into such a furnace the blast, instead of 485°, is admitted at 695°, as happened under Column D. The additional heat, 732 calories, instead of 534 as in C, will make itself felt throughout the entire height of the furnace, including, of course, the upper zone. Immediately this happens, the carbon dioxide generated by the reduction of the ore attacks the coke and escapes as carbonic oxide. If Table I. is examined, it will be seen that almost the whole of the additional heat carried into the furnace D, as compared with C, has been absorbed by the disappearance of carbon dioxide, so that the net power of the coke unit in both cases is practically the same. Nevertheless it will be remarked that there is still a small saving of coke due to a reduced amount of blast, escaping gases, &c.

From what has preceded, it has been concluded that a furnace of 80 feet affords sufficient opportunity for the gases being as fully saturated with oxygen as the nature of the process of deoxidizing the ore will permit. The sensible heat in the escaping gases, however, still represents a considerable loss, reduced as they have been from 29,482 to 11,043 calories.

According to estimate, it was believed that the reduction of oxide of iron ought to be attended by an increase of temperature—in other words, the conversion of carbonic oxide into carbonic dioxide produced more heat than that absorbed by splitting up oxide of iron into its constituent parts. The estimated difference not being a large one, an experiment was made by substituting in the furnace inert substances having about the same specific heat as the ore. The results confirmed the correctness of the calculation—the temperature of the escaping gases fell, and rose to their normal point when the use of ore was recommenced. A more expensive experiment was subsequently made in the same direction by building, at Ferry Hill, a pair of furnaces having a height of 103 feet, without any substantial benefit being derived from the large additional expenditure incurred.

It was Scheerer, I think, who first divided the blast furnace into zones. The first division, beginning at the top and extending twelve feet downwards, was designated the preheating zone, the following eighteen feet downwards was distinguished as the reducing zone, the next eight feet the carburizing zone, followed by four feet which constituted the zone of fusion. The lowest of all, having a depth of about six feet, was named the zone of combustion. The author of this mapping out, as it were, of the interior of the furnace, does not wish to be understood as confining its various functions within the respective spaces assigned to them; on the contrary, he admits the existence of considerable variations of position. My own observations, however, have led me to conclusions varying considerably from those adopted by Scheerer.

The fundamental cause of these differences seems to depend on the temperature considered as being required for a commencement of the reduction of the ore. By Scheerer the reducing zone is considered to require a temperature of 1000° to 1200° C. This change undoubtedly is not the same with all kinds of ores, but my experiments were conducted when using almost every variety of the mineral. According to the trials made, a mixture of one volume of carbon dioxide and two volumes of carbonic oxide at a temperature of 410°, removed 10 per cent. only of the oxygen in Cleveland ore, and 37·8 per cent. from an artificially prepared oxide. The composition of the gases at the different depths, however, indicates in an unmistakable manner the nature of the action which is going on at any particular point. A table has been prepared from actual analyses of the gases which gives the quantity of oxygen present for every 1000 parts of metal produced; and to this is added the weight of carbon they contained. The results vary, but the general inference to be drawn from the observations made on furnaces of 80 feet, is that by the time the minerals have passed through a space of eight feet of the depth they have to travel, all the oxygen susceptible of removal from the ore in the upper region is found in the gases, the remainder being retained until it reaches the zone of fusion. The same is the order of action in a somewhat modified form which was found to prevail in the case of furnaces 48 feet in height.

TABLE III.—*Showing the quantity of Oxygen and Carbon in gases per* 1000 *parts of pig-iron produced. The* 8 *feet immediately below charging plates is occupied by charging apparatus.*

Distance below top of minerals.	0 feet.		8½ feet.		18 feet.		31 feet.		44¼ feet.		57 feet.		62½ feet.		68 feet.	
	O.	C.	O.	C.	O.	C.	O.	C.	O.	C.	O.	C.	O.	C.	O.	C.
No. 1. Oxygen ...	1843	—	1250	—	1235	—	1234	—	1236	—	1207	—	1137	—	1348	—
Carbon ...	—	1101	—	864	—	816	—	871	—	904	—	899	—	890	—	967
No. 2. Oxygen ...	1843	—	—	—	1410	—	1482	—	1190	—	1207	—	1255	—	1366	—
Carbon ...	—	1104	—	—	—	914	—	1046	—	894	—	887	—	—	—	927
No. 3. Oxygen ...	1670	—	1309	—	1206	—	1312	—	1256	—	1253	—	1253	—	1378	—
Carbon ...	—	1048	—	926	—	907	—	918	—	946	—	931	—	939	—	1013
No. 4. Oxygen ...	1670	—	1271	—	1224	—	1300	—	—	—	1261	—	1285	—	1387	—
Carbon ...	—	1048	—	897	—	898	—	917	—	—	—	926	—	977	—	1021

NOTE.—Nos. 3 and 4 were using partially calcined limestone, hence the deficiency of O and C until the lower depths are reached.

On casting the eye along the lines of figures a somewhat remarkable circumstance is apparent, viz. that the quantity of oxygen per 1000 of pig-iron gradually decreases as the gases ascend, until they approach the upper region, when it commences to increase. This had been the subject of observation for many years without any complete explanation being given of its cause. Dr. Percy, among others, bestowed some attention to the circumstance without arriving at any opinion satisfactory to himself. It is a little extraordinary that, so far as I have seen, no notice has ever been taken of the fact that the carbon in the gases followed the same law. While engaged in investigating the action of furnace gases on the ore a peculiarity was observed previously unknown to me, viz. that large quantities of carbon were deposited by the dissociation of the reducing gas, the action being $2CO = CO_2 + C$. Experimentally I ascertained that spongy iron, as well as oxide of iron, was capable of producing the change, and that 30 per cent. of carbon dioxide, mixed with the carbonic oxide, arrested the reaction, the temperature at the time being 420°. Dr. C. A. Wright, who subsequently became chief chemist of our laboratory, was asked to continue the examination. The conclusion arrived at was the impossibility of effecting the complete reduction of E_2O_3, or of any oxide by CO. On the contrary, when metallic iron known to contain no oxygen was exposed to a current of this gas, carbon was deposited and oxygen absorbed. It would seem, therefore, that this absorption of oxygen by the iron and precipitation of carbon suffice to explain the disappearance of these two elements from the gases, and that they remain in this condition until the fusion of the iron, in contact with intensely heated carbon, liberates the oxygen as well as that portion of the carbon which is not absorbed by the metal in order to produce pig-iron.

So far, then, as the analyses given in Table III. enable us to judge, instead of the upper two-thirds of a furnace being required for the purposes of reduction, no material change is effected after passing through eighteen feet in a modern furnace of 80 feet in height. After this the composition of the gases, and, therefore, of the minerals, remains pretty steady until the vicinity of the *tuyères* is reached, with the consequences already referred to.

Of the excess of oxygen at the zone of combustion it is highly probable that a portion is due to the reduction of P_2O_5, S_1O_2, SO_3, and CaO. In the case of Cleveland iron I have estimated this at 54 parts per 1000 of pig-iron produced, but the average total oxygen beyond that furnished by the blast in the first two instances given was 130 parts. At this rate there must have been 76 parts of oxygen liberated from the oxide of iron, which is equal to 19 per cent. of that originally combined with the iron in the ore.

It may be appropriate here to refer to what may be taken as a typical expression of the working of a blast furnace in respect to the presence of carbon dioxide. An analysis of the gases is therefore inserted, drawn from an 80-feet furnace at various levels, with the simple remark that it is improbable that carbon dioxide can exist for any length of time when exposed to incandescent coke at the temperature which prevails at the depths mentioned in the last two columns.

TABLE IV.—*Showing what may be regarded as a typical instance of the absence of Carbon Dioxide in the gases taken from a furnace of* 80 *feet. Measurements taken from the highest level of the minerals*, i.e. 8 *feet below charging plates.*

Depth below charge	Escape pipe.	3½ feet.	9¾ feet.	16 feet.	22½ feet.	28¾ feet.	35 feet.	41¾ feet.	66 feet.
Carbonic acid ...	16·07	11·71	10·03	8·17	6·12	—	—	0·72	3·01
Carbonic oxide	27·34	29·71	31·39	31·40	32·79	35·27	36·00	36·02	39·47
Hydrogen ...	0·11	0·10	0·07	0·14	0·28	0·10	0·11	0·08	0·14
Nitrogen ...	56·48	58·48	58·51	60·29	60·81	64·63	63·89	63·18	57·38
Total ...	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Something like forty years ago the escaping gases from the blast furnaces, rich as they were in carbonic oxide, were permitted to burn wastefully on the surface of the minerals charged at the throat. This meant a loss of about 54 per cent. of the heating power of the coke. For reasons already given it was of course impossible to utilize much of this heat in the actual smelting of the ore because of the necessity of preserving a large excess of carbonic oxide in the gases. This, however, constituted no reason why, apart from the furnace work itself, this vast quantity of gaseous fuel should not have been utilized, as it no doubt would earlier have been, had the ironmakers known, as they now do, its full value. To-day all the blast and other engines are driven and the air is heated at our blast furnaces by fuel formerly wasted, and this without any labour for stoking being required. In Great Britain alone the annual saving is fully equal to four million tons of coal.

In connection with the other volatile products which accompany the iron smelters' work I will only mention ammonia. Some qualities of coal admit of being used in the raw state. In this case, as in distilling coal for illuminating purposes, ammonia is generated and may be collected. Instead, however, of the ammoniacal vapour being all contained in the hydrocarbons as in gas-making, it is diluted in addition with all the fixed carbon as oxides and all the nitrogen of the atmospheric air used in its combustion. Nevertheless, Messrs. Bairds, of the Gartsherrie Works, and others, are manufacturing large quantities of ammonia sulphate from the ammonia so obtained. A similar object is achieved by attaching the necessary condensers to the apparatus for coking coal. The process of distillation is then carried on in hermetically closed ovens heated by the combustion of the gases evolved. These, before reaching the fireplace where they are burnt, are deprived of their ammoniacal vapours by passing through condensers provided for the purpose. Previous, however, to this being done, the waste heat from the coking process had been applied for generating steam, so that at certain collieries in the county of Durham all the mechanical power is obtained without any coal being specially burnt for this purpose.

Before speaking of the next and last great improvements in connection with my subject, I should like to say a few words, and a few words only, respecting steel, a well-known and most valuable compound of iron and carbon. Let me first observe that it seems improbable that this substance was not earlier known to the ancients, as was at one time supposed. The facility with which the metal combines with carbon renders it very unlikely that acieration would not occasionally take place when iron itself was the object of the manufacturer. Certain it is that Agricola, who wrote in 1556, describes in Latin a mode, apparently as well known as that of making iron itself, of making *Acie.* The engraving in his "De re metallica" shows bars of malleable iron placed upright in a charcoal fire resembling that of a Catalan hearth. These, after an exposure of several hours to the incandescent charcoal and hot carbonic oxide, were found changed to steel and employed as such.

After the invention of the blast furnace, pig-iron was placed in a similar hearth, and while in a melted state a blast of air was directed upon the molten metal, until just as much carbon remained with the iron as constituted steel. This mode of procedure continued to be practised long within my own recollection, and may, for what I know, still be followed in some districts. The subject of steel-making occupied the attention of Hassenfratz, of Réaumur, and others, but practically the only process followed until 1865 was the well-known one of cementation.

Since the days of Fourcroy it was ascertained that in addition to the iron, carbon was an essential ingredient in cast metal, bu invariably accompanied by more or less silicon, and wheneve the minerals contained sulphur or phosphorus these metalloid were also present. The nature of the actions employed fo ridding the product of the blast furnace of these substances so a to render it malleable had also been carefully examined and explained by the light of scientific investigation. The manufacturer had, it is true, learnt by experience and observation how to produce an article of excellence without much knowledge of the science of his art. Among other things he ascertained that to obtain a ton of wrought iron he required the heat of an equal weight of coal in the puddling furnace; but he did not know, nor did even men of science, I think, ever dream, that the oxidation of the metalloids in the pig-iron, and that of a small portion of the metal itself, would afford heat enough to enable the workmen to dispense with the use of all coal in the process of conversion. When, therefore, the iron trade was informed, in a paper read before the British Association in 1856, entitled "A Mode of making Iron without the use of Fuel," its author, Henry Bessemer, was set down by the iron trade as a deluded enthusiast. At that period I doubt whether ten pounds of wrought iron had ever been seen in a state of fusion at one time. Bessemer, in his description, however, spoke of melting tons of it with no more heat than that afforded by the rapid oxidation of about 5 or 6 per cent. of the weight of the pig-iron used. Not only, therefore, was the subject one of economic but also of high scientific interest. Nevertheless, a mere statement of the title of the paper was all the notice bestowed by our predecessors in their Transactions on a discovery which has revolutionized the art of making iron. It is quite true that for some time it appeared as if the scientific aspect of the question were to constitute its only recommendation, for the malleable iron made in a Bessemer converter proved unmanageable when hot, and destitute of strength when cold. Finally it was ascertained that phosphorus was the source of the evil, and, further, that while carbon and silicon could be almost entirely removed from the molten metal, this third metalloid remained unaffected by the treatment. The extent to which the hurtful influence of phosphorus makes itself felt in the wrought iron obtained by the Bessemer process is somewhat remarkable, because while two- to three-tenths per cent. is often present in puddled bars of fair quality, probably no consumer would accept Bessemer steel when it contains half of this amount. The first success was obtained in Sweden, where by using pig-iron containing a mere trace of the objectionable substance a product was obtained which was satisfactory. For many years the beneficial effect produced by manganese on steel had been well known, and it occurred to R. F. Mushet, son of David Mushet, one of, if not the earliest scientific metallurgist in the United Kingdom, to try its influence in the converter on iron made from the hæmatite iron of the west of England which contained from 0·05 to 0·1 per cent. of phosphorus. This addition, apparently by its removing occluded or combined oxygen in the molten iron, afforded the necessary relief, and the operation being one of extreme simplicity enables steel or wrought iron to be produced at a greatly reduced cost. To such an extent has this been carried, that ore is brought by sea over a distance of 1000 miles to Middlesbrough, and from it steel rails are made more cheaply than a greatly inferior article of iron can be produced from the abundant and economically wrought bed of ironstone found within a couple of miles of that town. As an example of the facility of conversion may be adduced the fact that the molten metal is brought direct from the blast furnace, turned into steel or ingot iron as the case may be, and the heat evolved by the operation is sufficient to enable the product in many cases, without further use of fuel, to be taken direct to the mill and rolled into a finished bar.

We have just seen that 0·1 per cent., or thereabouts, of phosphorus renders steel or ingot iron valueless; in like manner very insignificant variations in the quantities of carbon or silicon materially affect their quality. Now the blow, as it is termed, in a Bessemer converter may be accomplished in from twelve to fifteen minutes. It is clear, therefore, the opportunity of ascertaining the precise quality of the steel is one of very short duration. It is, I think, not disputed that a product can be obtained by this process possessed of very high, if indeed not of the highest excellence; but it is also pretended that the quality is not sufficiently uniform for certain purposes. The ordinary reverberatory furnace is incapable of affording the necessary temperature for melting steel or wrought iron, but by employing the fuel in a gaseous state, and by heating the air and gas before they are brought together, as is done in the valuable furnace suggested by the Messrs. Siemens, the heat is so intensified that wrought iron in it is rapidly fused. Steel is now largely made in such furnaces, either by mixing wrought and cast iron, as proposed by M. Pierre Martin, or by means of cast iron alone, when the carbon is removed by the addition of iron ore and some limestone, in which case, by the agency of the ore, the metalloids are oxidized and removed from the bath of iron. Some hours being required for this, sufficient opportunity is afforded for ascertaining the progress of the operation.

The cause of the iron in the Siemens furnace as well as in the Bessemer converter retaining its associated phosphorus, in time began to attract the attention of chemists. In each case the expulsion of the metalloids is effected by oxidation. The carbon is gasified, and the silicium on being acidified is absorbed, and forms a slag containing usually 40 to 50 per cent. of silicic acid. In the presence of such an excess of this substance, any phosphoric acid, if formed, could not be absorbed by the slag. It was the late M. Grüner, of Paris, who, in 1867, first pointed out this fact, and he it was who first recommended the use of lime in order to render the slag basic instead of acid. Further, in order to avoid the presence of silica, he recommended at the same time that the converter should be lined with lime instead of with fire-clay.

The same subject engaged my own attention, when guided by the fact that, as oxide of iron in the puddling furnace was capable of acidifying and removing a large quantity of the phosphorus as iron phosphate, it might be possible by keeping the temperature of the metal below that required for the process of puddling to make this removal more complete. The result of these experiments was communicated to the Iron and Steel Institute in March 1877, when it was shown that pig-iron containing 1·75 per cent. of P could in a few minutes have this reduced to 0·2 per cent.

The rapid destruction of the ordinary Bessemer converter led Mr. G. I. Snelus to consider the practicability of using a lime lining, and on experimenting with this on a working scale he confirmed the opinions previously enunciated by Grüner, by observing that the presence of lime had removed a considerable quantity of the phosphorus. These discoveries constitute the foundation of the very important basic process of Messrs. Thomas and Gilchrist, which consists in adding lime to the molten steel in a converter constructed on the principle described by Mr. Snelus. Considerable difficulty had, however, been experienced by this metallurgist in the attachment of the lime lining to the walls of the converter. This important question was solved by Mr. Edw. Riley by exposing dolomite to a very high temperature in order to prevent further shrinking, and then grinding and mixing the powder with coal tar. This formed a species of cement which is applied to the sides and bottom of the converter in the form of bricks or as cement.

The acidification and subsequent transference to the slag of the phosphorus by the basic treatment has led to its application to agriculture. For this purpose the slag is ground to a fine powder, and sprinkled over the land without any further preparation. By this operation an indispensable element of animal life is derived from the remains of living creatures which, ages ago, found a grave in the ferruginous mud destined to become the great Cleveland bed of ironstone.

Before closing this portion of my official duty, I cannot refrain from tendering to chemists an assurance of the great advantage the manufacturers of iron feel they have derived from the lessons taught them by chemical science. I am the more anxious to do this because we, among others, have been reminded that we are losing the supremacy among industrial nations we once enjoyed for want of that knowledge of chemistry which is more assiduously cultivated abroad than it is in our own country. I am not prepared to deny that the opportunities for acquiring a scientific education are less generally spread here than is the case in France, Germany, or Belgium, but for this the nation, and not the iron trade in particular, is responsible. It must also be admitted that as manufacturers we no longer stand so far above other lands as we formerly did. In this result any differences of education are in no way concerned, for if I were to classify the nationalities of the various inventions enumerated in the course of my remarks, the fears of those who are alarmed at the appearance of a Belgian girder or a German steam-engine on our shores would, I think, be allayed. Perhaps I might be allowed to offer a very few words on the technical side of this important question of education. Much I shall not be able to say, because I have not yet been able to learn the precise position the subject occupies in the minds of its most earnest advocates. If it means, as is sometimes alleged, a system by which, along with scientific instruction, manual dexterity in the use of tools, or a practical knowledge of various manufacturing processes has to be acquired, I confess I am not sanguine as to the results. Certain I am that if foreign workmen are more skilful in their trades, which, as a rule, I doubt, and which in the iron trade I deny, this superiority is not due to scientific training in the manner proposed, for in this they possess, so far as I have seen, no advantage over our own workmen. My objection to the whole system is the impossibility of anything approaching a general application being practicable. I have not a word to say against the rudiments of science being taught wherever this is possible. The knowledge so obtained may often give the future workman a more intelligent interest in his employment than he at present possesses; but I think they who expect much good to attend such a thin veneer of chemistry or physics do not take sufficient account of the extent of the knowledge already possessed by more highly educated men who are now directing the great workshops of the world. It is by extending and enlarging this that substantial aid has to be afforded to industry and science, and not by teaching a mere smattering in our primary or any other schools. In the case of young people who from necessity must leave the school-room at an early age, my own leaning is towards the present system, with the addition of drawing and some natural science. By it certain important lessons are taught, which, if not followed under the discipline of the schoolmaster, run some risk of being entirely neglected. After this, probably, the playground will be found more useful and much more popular with school-boys than trying to learn a trade by means of tools which, before he has to use them in earnest, may be thrown into the scrap heap.

As a national question the attention of the Government, Imperial or municipal, ought to be directed to the importance of establishing in all great manufacturing centres institutions resembling that of the Physical College of this city. These should consist of appropriate and even handsome buildings, properly furnished with all the instruments and appliances required for teaching the sciences in their practical bearings on industrial pursuits. In Newcastle, as well as in other places, this has been done on a fairly ample scale, and the advantages the College of Science in this city are capable of affording are offered on such terms that no one can plead expense being a barrier to mental improvement.

Bearing in mind the importance of the subject, and remembering, as my colleagues and myself do, the difficulties we have had to encounter and those we have still before us, I am strongly of opinion that the erection and maintenance of colleges of science should not be left to the accidental liberality of the few, but should be taken in hand by the nation at large.

NOTES.

AMONGST the recent scientific missions undertaken by order of the French Government are: one by Prof. Viault, of Bordeaux, in the table-lands of Peru, Ecuador, and Bolivia, to continue the investigations of the late M. Paul Bert into rarefied air; one by M. de Coubertin, Secretary of the Committee for the Encouragement of Physical Exercises in Education in the United States and Canada, to visit the Universities and Colleges, to study the working of the various athletic associations frequented by the young people of these countries; one by M. Jacques de Morgan, mining engineer, to explore those parts of Asia Minor lying between the south of the Caspian Sea, Armenia, the Gulf of Alexandria, and Anti-Taurus (this mission will occupy two years and three months); and one by M. Candelier, to Columbia, to make ethnographical researches and collections for the State.

MESSRS. LONGMANS have made arrangements with Dr. Nansen for the publication, both in London and New York, of an account of his recent expedition across Greenland. The book will be fully illustrated, and will probably be published in the spring of next year.

THE twenty-sixth annual meeting of the British Pharmaceutical Conference was opened at the Durham University College of Science, Newcastle, on the 10th inst., when the President, Mr. C. Umney, delivered the annual address.

THE Department of Botany, British Museum, has acquired the collection of microscopic slides made by the late Prof. de Bary.

A CORRESPONDENT of the *Daily Chronicle* states that particulars have reached Constantinople, of a volcanic eruption which occurred some days ago in the province of Erzeroum, destroying the village of Kantzorik, and the majority of its inhabitants. Kantzorik was a little village of 215 inhabitants, situated in the Caza of Tortoum, about 60 kilometres north of the city of Erzeroum. The village nestled in a narrow fertile valley about 1600 metres above the level of the sea, on the slope of the eastern mountains. Before the eruption the inhabitants were startled by subterranean noises, and they noticed at the same time that the springs on a mountain which stands at the eastern end of the valley were dried up. Alarmed at these phenomena they appealed to the nearest local authorities, and were advised at once to evacuate the village. The warning for the majority was too late. Towards midday, whilst the terrified peasants were preparing for flight, the eruption came. The torrent rushed down, bearing on its molten surface boulders and masses of earth torn from the surface or belched from the heart of the mountain. The whole village, with 136 persons, was engulfed in the stream.

IT is reported from Japan that Viscount Ennomoto, the new Minister of Education, is devoting special attention upon the introduction of technical education into the primary schools of the Empire, and that he has turned to Italy as a model. His scheme is to include technical education in the curriculum of the preparatory schools, and to give children technical training from the outset.

MR. BOTHAMLEY, Assistant Lecturer and Demonstrator in the Chemical Department of the Yorkshire College, has been unanimously elected President of the Photographic Convention of the United Kingdom for the meeting in 1890, which is to be held at Chester.

THE "Hand-book of Newcastle and District," compiled in view of the meeting of the British Association there this year, consists of three parts, a third being on the geology of the district. The volumes are very neatly got up and well printed. The general hand-book is by the Rev. Dr. Collingwood Bruce, the greatest living authority on the antiquities and history of the district, who has succeeded in making a highly readable and instructive volume. In a short introduction he shows the immense progress made by Newcastle since the last two visits of the Association, and especially since the introduction of railways. Dr. Bruce gives many reminiscences of the old life of Newcastle, and interesting details as to its historical buildings, as well as its modern institutions. In an appendix, brief descriptions are given of the places of interest in the vicinity of Newcastle arranged in alphabetical order. The second volume is devoted to the industries of Newcastle and the north-east coast, and is edited by Mr. Wigham Richardson. Each section is written by a specialist, and the whole is well illustrated by a fine series of maps and diagrams. We have chapters on agriculture, by Mr. Thomas Bell; railways from the Tweed to the Tees, by Mr. W. G. Laws; the harbours of the north-east coast, by Mr. P. J. Messent; mining and quarrying, by Mr. J. Boland Anderson; engineering, by Mr. W. Boyd; shipbuilding, by Mr. J. A. Rowe; electricity, by the Hon. C. A. Parsons; manufacture of iron and steel, by Mr. C. Lowthian Bell; lead, by Mr. N. C. Cookson; copper, by Mr. George Gatherall; antimony, by Mr. N. C. Cookson; zinc, by Mr. John Pattison; aluminium, by Mr. Curt Netto; chemical manufactures, by Mr. T. W. Stuart; gasworks, by Mr. W. Hardie; printing, by Mr. Sidney Reid; manufacture of paper, by Mr. W. H. Richardson; flour milling, by Mr. Edmund Procter; leather manufacture, by Mr. D. Richardson; tanning, by Mr. G. Angus; coachbuilding, by Mr. J. Philipson; earthenware, by Mr. H. Heath and Mr. C. T. Maling; photography, by Mr. Edwin Dodds; carpeting, by Mr. A. Henderson; cement, by Mr. J. Watson; the development of the Portland cement industry, by Mr. J. L. Spoor; ropemaking, by Mr. R. Dixon; the brewing trade, by Mr. T. W. Lovibond; tobacco, by Mr. J. Harvey; with a concluding section by the editor. The geology section is by Prof. Lebour, and is much above the average of similar hand-books.

DR. RUDOLPH KOENIG, the well-known constructor of standard acoustical apparatus in Paris, has just made a discovery of extreme importance in the theory of music, the details of which he will expound at the forthcoming meeting of the Naturforscher at Heidelberg. This is an extension of Helmholtz's theory of *timbre* to certain cases not represented in the elementary mathematical theory, and corresponding to the actual case of the *timbres* of certain musical instruments. The paper is certain to give rise to discussion, and will be of interest to musicians, who have never, as is notorious, taken kindly to Helmholtz's theory in its original form.

FROM an official summary of the proceedings at the German Anthropological Congress, which met at Vienna last month, it appears that after Prof. Ranke had read the year's report, in which the establishment of chairs of anthropology at German Universities was specially mentioned, Prof. Virchow read a paper on the progress of anthropology in the last twenty years. He thought in the next twenty years anthropologists would be able to explain the connection of the various races and peoples of Europe. Prof. Schaafhausen dealt with the present condition of the study of crania for anthropological purposes, and Prof. Ranke with the position of the ears in different races. Dr. Waldeyer described certain investigations of his into the placenta in the human species and in apes, while Prof. Zuckerkandl spoke