SCIENCE AND MODERN CIVILISATION.[1]

WHEN Harvey was entering on his career as an investigator, in the early years of the seventeenth century, the great movement of the Renaissance had produced its full effects. Starting in Italy in the fourteenth century, it spread during the fifteenth and sixteenth centuries and permeated the rising nationalities of Western Europe. It was through the zeal engendered by this movement that the priceless literary and artistic treasures of Greece and Rome were rescued from oblivion and made the secure heritage of all time. The study of these monuments of ancient genius, and the inspiration communicated by them, saved mediæval Europe from barbarism, and created a new civilisation not inferior in polish to that of the classical ages. Upon literature and the fine arts the spirit of the Renaissance reacted with the happiest possible effects. It inspired the masterpieces of poetry, painting, architecture, and sculpture, which constitute the glory of the fifteenth and sixteenth centuries, and compel the admiration and challenge the rivalry of the nineteenth century. But, as regards natural knowledge, the influence of the Renaissance was at the first, and even for a long time, distinctly unfavourable. The writings of Hippocrates, Aristotle, Ptolemy, Galen and other masters were studied and searched, not for inspiration to new inquiry and higher development—but these great names were erected into sacrosanct authorities, beyond whose teaching it was vain, and even impious, to seek to penetrate. The result of this perversion was that the pursuit of natural knowledge degenerated into sterile disputations over the words of the masters. This numbing despotism of authority comatosed the intellect of Europe during many generations. It received the first rude shocks from the discoveries of the great anatomists of the sixteenth century; and it was finally overthrown by the force of the demonstrations of Galileo and Harvey—powerfully aided, no doubt, by the philosophical writings of Bacon and Descartes.

These four men—Galileo, Harvey, Bacon, and Descartes—were the dominating spirits of their epoch in the sphere of natural knowledge; they were contemporaries; and three of them must have had more or less personal acquaintance with each other. Harvey was Bacon's friend and physician; and we can easily believe that much talk went on between the investigator and philosopher concerning the studies in which they were mutually interested—and that Bacon imbibed his enlightened notions respecting the importance of experiments in the pursuit of knowledge from the precepts and practice of Harvey. It does not appear that Descartes was personally known to Harvey, but he was one of the earliest to accept the doctrine of the circulation, and to write in its defence. When Harvey was a student at Padua, Galileo occupied the chair of mathematics in that university. These two men take rank as the twin founders of modern science—the one in the domain of biology and the other in the domain of physics. Their lives largely overlapped; they were contemporaries for sixty-four years, and both nearly reached the patriarchal age of fourscore. Roughly speaking, their period of activity covered the first half of the seventeenth century. They were, each in his respective department, pioneers in the method of searching out the secrets of nature by observation and experiment, and in proclaiming the paramount necessity of relying on the evidence of the senses as against the dicta of authority.

The present year is the 300th anniversary of Harvey's graduation at Cambridge, and of the commencement of his career as a student and investigator of nature. That date, 1597, corresponds roughly with the birth-time of modern science. The occasion is, therefore, not inappropriate for a survey of the changes impressed upon civilised society by science—after three centuries of expansion and growth. The lapse of time is sufficiently long, and the advance made is sufficiently great, to enable us to estimate approximately the scope and strength of this new factor in our environment; and perhaps even to appreciate the influence which the cultivation of science is likely to have on the future of modern civilisation.

All the older civilisations have issued either in extinction, or in permanent stagnation. The civilisations of Egypt and Chaldæa and of Greece and Rome, after a phase of progressive decline, eventually perished by military conquest. The ancient civilisations of the Far East—those of India and China—still persist, and have a semblance of life; but it is a life of helpless torpor and immobility. Is our modern civilisation doomed to share a kindred fate? There are, I think, good reasons for believing that in this respect history will *not* repeat itself. Special features are observable, and special forces are at work, in contemporary civilisation which differentiate it profoundly from all its predecessors.

It may be said, broadly, that the older civilisations rested essentially upon art and literature (including philosophy)—and that modern civilisation rests, in addition, upon science and all that science brings in its train. This distinction is, I think, fundamental—and connotes a radical difference as regards stability and continuance between ancient and modern society. A comparison of the mode of growth of the fine arts and literature on the one hand, with the mode of growth of science and its dependent useful and industrial arts on the other, brings out this point very clearly.

The evolution of literature and art displays the following well-marked characteristics. Starting from some rude beginnings, each branch of literature and each branch of the fine arts grows by a succession of improved ideals until a certain culminating level of excellence (or phase of maturity) is attained. When this level is reached no further growth takes place, nor even seems possible. The level of excellence attainable by any nation depends presumably upon the measure of the original endowment of the race with artistic and literary faculty. When and after this summit level of excellence is achieved, all subsequent expansion, if any, is quantitative rather than qualitative—and consists in modifications, variations, repetitions and imitations—but without any real advance in artistic and literary excellence. It may be further noted that there is observable in the past annals of literature and the fine arts a fatal tendency to a downward movement. The variations are apt to show meretricious qualities—which indicate, in the judgment of critics, a degradation from the high standard of the earlier masters. The life of each of the fine arts seems, as Prof. Courthope has expressed it, to resemble the life of an individual in having periods of infancy, maturity and decline. The witness of history bears out this view.

It is almost startling to consider how long ago it is since most branches of art and literature had already reached their highest known pitch of excellence. The Homeric poems are supposed to have been composed a thousand years before the Christian Era—and no one doubts that as examples of epic poetry they still stand in the front rank. In the fourth and fifth centuries B.C. there occurred in Greece an extraordinary outburst of artistic and literary genius—such perhaps as the world has never seen before nor since. During this epoch sculpture was represented by Phidias and Praxiteles—architecture by the builders of the Parthenon—painting by Apelles and Zeuxis—dramatic poetry by Sophocles, Euripides, and Aristophanes—and speculative philosophy by Plato and Aristotle. Greece maintained her political independence for two centuries after this period; but she did not produce anything superior, nor apparently even equal, to the masterpieces of this golden age.

A parallel sequence is observable in the history of Ancient Rome. Art, literature, and philosophy—and all studies that may be grouped under these headings—attained their culmination in the Augustan age; and no advance thereupon took place, but rather a falling off, during the subsequent centuries of imperial Rome's political existence.

If we turn our eyes to the Far East we see that the masterpieces of architecture and ornamental metal work, and of poetic and philosophical literature are all old—many of them very old. Neither in India nor China nor in any other Far Eastern country are there any indications of advance for many centuries in the domain of artistic and literary culture.

The history of Western Europe tells a similar tale. The finest examples of Gothic and Norman architecture date from the twelfth and thirteenth centuries. Painting culminated in Italy during the fifteenth and sixteenth centuries with Raphael, Da Vinci, Correggio, Titian, and Paul Veronese. The same art reached its highest level in the Low Countries with Rembrandt and Rubens—in Spain with Velasquez and Murillo—in France with Claude Lorraine and Poussin—all artists who flourished in the seventeenth century. In England nothing greater than the works of Reynolds, Gainsborough, and Turner has been produced by later artists. Similarly with literature: most of the masterpieces belong to a past age. Italy can show no higher examples of poetry than the creations of Dante,

[1] Extract from the Harveian Oration, delivered before the Royal College of Physicians, October 18, by Sir William Roberts, M.D., F.R.S., Fellow of the College.

Petrarch, Tasso, and Ariosto. The most ardent admirers of the Victorian poets would scarcely contend that any of them stand on a higher pedestal than Shakespeare and Milton; nor would any German critic claim equality for any recent poet of the Fatherland with Goethe and Schiller. In the delightful art of music, the masterpieces of Haydn, Handel, and Mozart, judging by their popularity at the present day, are not surpassed by the works of any of the later musical composers.

I need not pursue the subject in greater detail. Wherever we look—in all ages, among all peoples—we encounter the same story with regard to that large and varied and most precious outcome of the human mind which may be grouped under the categories of the fine arts and literature. There is a history of improvement and growth up to a certain culmination, or phase of maturity. Beyond that point no further growth seems possible—but rather, instead, a tendency to decline and decadence.[1]

The evolution of science differs fundamentally from that of literature and the fine arts. Science advances by a succession of discoveries. Each discovery constitutes a permanent addition to natural knowledge—and furnishes a post of vantage for, and a suggestion to, further discoveries. This mode of advance has no assignable limits; for the phenomena of nature—the material upon which science works—are practically infinite in extent and complexity. Moreover, science creates while it investigates; it creates new chemical compounds, new combinations of forces, new conditions of substances, and strange new environments—such as do not exist at all on the earth's surface in primitive nature. These "new natures," as Bacon would have called them, open out endless vistas of lines of future research. The prospects of the scientific inquirer are therefore bounded by no horizon—and no man can tell, nor even in the least conjecture, what ultimate issues he may reach.

The difference here indicated between the growth of art and literature and the growth of science is, of course, inherent in the subjects; and is not difficult to explain. The creation of an artist, whether in art or literature, is the expression and embodiment of the artist's own mind—and remains always, in some mystic fashion, part and parcel of his personality. But a scientific discovery stands detached; and has only an historical relation to the investigator. The work of an artist is mainly subjective—the work of a scientific inquirer is mainly objective. When and after a branch of art has reached its period of maturity, the pupil of a master in that art cannot start where his master ended, and make advances upon his work; he is fortunate if at the end of his career he can reach his level. But the pupil of a scientific discoverer starts where his master left off; and, even though of inferior capacity, can build upon his foundations and pass beyond him. It would seem as if no real advance in art and literature were possible except on the assumption that there shall occur an enlargement of the artistic and literary faculty of the human mind. No such assumption is required to explain and render possible the continuous advance of science. The discoverer of to-day need not be more highly endowed than the discoverer of a hundred years ago; but he is able to reach further and higher because he stands on a more advanced and elevated platform built up by his predecessors.

The fatal weakness of previous civilisations lay in the absence of any element which had inherent in it the potentiality of continuous growth and unlimited expansion—and this is precisely what exact science supplies to modern civilisation. A sharp distinction must be drawn between the so-called science of antiquity and the science of to-day. The ancients had a large acquaintance with the phenomena of nature, and were the masters of many inventions. They knew how to extract the common metals from their ores; they made glass; they were skilled agriculturists; they could bake, brew, and make wine, manufacture butter and cheese, spin, weave, and dye cloth; they had marked the motions of the heavenly bodies, and kept accurate record of time and seasons; they used the wheel, pulley and lever; and knew a good deal of the natural history of plants and animals, and of anatomy and practical medicine. This store of information had been slowly acquired in the course of ages—mostly through haphazard discovery and chance observation—and formed a body of knowledge of inestimable value for the necessities, conveniences, and embellishments of life. But it was not science in the modern sense of the word.[1] None of this knowledge was systematised and interpreted by coordinating principles; nor illuminated by generalisations which might serve as incentives and guides to further acquisitions. Such knowledge had no innate spring of growth; it could only increase, if at all, by casual additions—as a loose heap of stones might increase—and much of it was liable at any time to be swept away into oblivion by the flood of barbaric conquest.

[1] If we take a wider view of the constituent elements of organised society —and embrace in our consideration the religious systems, the political and civil institutions, the military organisations, the commerce and the miscellaneous disconnected mass of natural knowledge existing in the older civilisations—we look in vain for any constituent which had more than a limited scope of expansion, and was not subject to decay.

It is quite obvious, from the subsequent course of events, that there came into the world of natural knowledge about three centuries ago, in the time of Galileo and Harvey, a something—a movement, an impulse, a spirit—which was distinctly new—which Bacon, with prophetic insight, termed a "new birth of time."

This remarkable movement did not originate with any startling revelation; it consisted rather in an altered mental attitude, and a method. There arose a distrust in the dicta of authority, and an increasing reliance on ascertained facts. These latter came to be regarded as the true and only data upon which natural knowledge could be securely founded and built up. Doubt and question took the place of false certainty. The hidden meaning of phenomena was sought out by observing them under artificially varied conditions—or, to use the words of Harvey, "the secrets of nature were searched out and studied by way of experiment." *À priori* reasoning from mere assumptions, or from a few loosely observed facts, fell into discredit. Observations were repeated and made more numerous and more exact. These were linked together with more rigid reasoning to stringent inductions. Hypotheses (or generalisations) were subjected to verification by experiment; and their validity was further tested by their efficacy in interpreting cognate problems, and by their power to serve as guides to the acquisition of fresh knowledge. Instruments of precision were devised for more accurate observation of facts and phenomena —for weighing and measuring, for estimating degrees of temperature, the pressure of gases, the weight of the atmosphere, and for recording time. The sense of sight was aided by means of the telescope and microscope. The invention of instruments and appliances for assisting research was an essential and invaluable feature of the "new philosophy." It is singular that so little progress in this direction was made by the quick-witted Greeks of the classical period; and their neglect or incapacity in this respect largely accounts for their conspicuous failure in science as contrasted with their brilliant success in art and literature.[2]

The new method soon began to yield fruit—at first slowly, then more and more rapidly as the workers increased in number, and the method was more fully understood. Discoveries were no longer solely stumbled on accidentally, but were gathered in as the fruit of systematic observation and purposive research. It is not necessary for me, even if I had the time and ability, to trace the history of scientific discovery from the time of Harvey onward. I will only mention a few particulars by way of illustration. You all know how, as time passed on and knowledge

[1] "It is not a collection of miscellaneous, unconnected, unarranged knowledge that can be considered as constituting science."—*Whewell.*

[2] Whewell observes ("History of the Inductive Sciences," vol. i. book 1, chap. iii.): "The Aristotelian physics cannot be considered as otherwise than a complete failure. It collected no general laws from facts; and consequently, when it tried to explain facts, it had no principles which were of any avail." Whewell argues that this failure was not due to the neglect of facts. He goes on to say: "It may excite surprise to find that Aristotle, and other ancient philosophers, not only asserted in the most pointed manner that all our knowledge must begin from experience, but also stated in language much resembling the habitual phraseology of the most modern schools of philosophising, that particular facts must be *collected;* that from these general principles must be obtained by *induction;* and that these principles, when of the most general kind, are *axioms.*" Then he quotes passages in proof from Aristotle's writings. It is, however, pretty evident that Aristotle's reverence for facts was no more than a pious opinion, which he habitually ignored in the actual handling of questions of natural knowledge. His treatise "On the Parts of Animals" bristles with errors of observation which a very moderate amount of painstaking would have rectified. Had the ancient Greeks, and their successors in the middle ages, been more accurate observers of facts, and had they sought for and invented instruments for the more exact observation of facts, they would not have so conspicuously failed to establish at least the foundations of exact science. The historian of the inductive sciences, however, will have it otherwise. He sums up his argument thus: "The defect was that, although they had in their possession *Facts and Ideas, the Ideas were not distinct and appropriate to the Facts.*" Is it not rather the case that the "Ideas were not distinct and appropriate to the Facts," precisely because the "Facts" were indistinctly seen and imperfectly apprehended?

expanded, the primary sciences became divided into separate departments for more minute study—how new sciences have arisen, some of which have now grown to vast proportions—how improved instruments and appliances of infinite delicacy have been invented to aid research—and how, in the present age, the gains of pure science have been turned to innumerable channels of practical utility.

The advances made in physics and mechanics during the seventeenth and eighteenth cenuturies prepared the way for the invention and perfection of the steam-engine in the nineteenth century. The introduction of the steam-engine increased at a bound the power of the human arm many-fold.[1] Through its instrumentality the land has been covered with railways, and the sea with ocean steamers. Electrical science has given us the telegraph and telephone, a new illuminant, and a new motor. The steam printing press, the telegraph, and the railway together, have made it possible to produce that perhaps most wonderful of all the indirect outcomes of the growth of science—the modern newspaper. The great science of chemistry has revealed the composition of the material world; has originated vast industries, which give work and wages to millions of the population; and has placed all kinds of manufacturing processes upon a basis of scientific precision. Under cover of chemistry have sprung up the sub-sciences of photography and spectroscopy, which have given a new and unexpected development to our knowledge of the heavenly bodies. The revelations of palæontology and embryology have led to the establishment on a firm basis of the theory of organic evolution. This theory—by far the most penetrating generalisation of our time—has not only thrown a flood of light upon the deepest problems of natural history, but has also revolutionised the whole domain of speculative thought. Physiology and practical medicine have profited immensely by the general advance of the sister sciences, and by the adoption of scientific methods in the prosecution of research. Optical science gave birth to the achromatic microscope. The microscope has laid bare the minute structure of plants and animals, and introduced zoologists and botanists to a vast sub-kingdom of minute forms of life, previously undreamt of. The microscope also, in conjunction with chemistry, founded the new science of bacteriology. Bacteriology has inspired the beneficent practice of antiseptic surgery; it has also discovered to us the parasitic nature of zymotic diseases—and opened out a fair prospect of ultimate deliverance from their ravages.

Thus have the several sciences advanced, and are still advancing, in concert, step on step, by mutual help, at an ever-increasing speed—pushed on by that irrepressible forward impulse which has characterised the scientific movement from its inception. This movement has now become the dominant factor in civilisation.

There is no doubt that, under the reign of science, a striking amelioration in the state of society has taken place. The mass of the people are better housed and fed—and, above all, better educated. Their sanitary surroundings are improved, and the death-rate has fallen. Crime and pauperism have diminished, and there is greater security for person and property. The amenities and enjoyments of life are on the increase, and the average scale of comfort is markedly raised. Moreover, this amendment is not confined to the material and physical well-being of the population. There is some evidence that the complex of conditions we term "modern civilisation" is acting favourably in the direction of making people more reasonable and better conducted. Peace is now the normal condition between civilised states; and there is a growing trend of opinion in favour of settling international differences by the more rational method of arbitration, rather than by war. Political morality approximates more nearly to that recognised as proper in private life. The duel has almost been laughed out of court. Industrial quarrels are conducted with more order; there is an appeal to facts and reason on both sides, and more readiness to adjustment by compromise.

The whole environment of modern life seems in several ways calculated to foster habits of correct thinking and acting. The inclusion of science in the scope of general education is a very important innovation. This extends the range of subjects in regard to which precise reasoning is possible; and tends to promote the application of scientific modes of thinking and reasoning to all the problems of life. We may be quite sure that exact thinking leads in the main to correct conduct; an evil deed is not only a crime, but also a blunder. The periodical press must, one would think, be a good training-school for thinking and reasoning. The discussion of all sorts of questions in its columns can scarcely fail to have an educating effect. The disputants must perforce read one another's arguments, and be, consciously or unconsciously, influenced thereby. It may be assumed, or at least hoped, that there is in arguments, as in organic forms, a tendency to the survival of the fittest—and that in the long run the better argument carries the day. The blaze of publicity amid which we live, through the ubiquitous newspaper, lends an additional motive to right-doing. The "fierce light which beats upon a throne" beats nowadays also upon the citizens, and doubtless helps to keep them in the straight path.

But, say the prophets of evil: "This will not endure; modern civilisation, based on science, will in time go the way of all its predecessors, and end in extinction or in decay and stagnation." It is proverbially unsafe to dogmatise about the future; and in all human affairs, even those termed scientific, there is nothing so certain as the unexpected. This, however, may be affirmed: that if modern civilisation is to come to an end, it will not perish in the same way, nor from the same causes, as previous civilisations.

One of the standing perils of civilised communities in ancient times was the risk of being subjugated by less civilised neighbours, or of being overwhelmed by hordes of barbarian invaders. This danger no longer threatens us. Power has passed for ever into the hands of the nations which cultivate science, and invent. The appliances of war are now placed on a scientific basis; and the issue of battle is decided in the laboratories of the engineer and the chemist. The late C. H. Pearson argued that the dark and yellow races, in virtue of their greater number and fecundity, might in time come to dispute the supremacy of the white races—that they would learn the drill and copy the armaments of European armies, and thus equipped would be able, by their superior mass, to hem in and curb, if not to subjugate, the Western nations. But the march of science and invention never stops; and it is inconceivable that the scientific nations shall not always be many stages in advance of the unscientific nations in the destructiveness of their weapons and the perfection of their military equipments—and this would give them an advantage which scarcely any disparity of numbers could neutralise. The "yellow terror" can never be more than a phantom until these races begin to show capacity for scientific discovery, and the further (and somewhat different) capacity for turning their discoveries to practical uses.

Against the more insidious peril of decay and stagnation the scientific movement seems also to offer effective safeguards. We sometimes hear complaints of the hurry and bustle—the stress and strain—of modern life; this unrest may incommode individuals—but it is the antiseptic of society. Probably the deadliest predisposing factor in the decline of former civilisations was the mental inanition arising from deficiency of fresh and varied intellectual pabulum. Physiological analogies lead us to the inference that an idle brain, like an idle muscle or an idle gland or nerve, would deteriorate in function; and, conversely, that a well-exercised brain would tend to reach its possible best. I conceive that our forefathers and the ancients, for the most part, led somewhat monotonous lives. They had but little fresh and varied food for thought. The generality could not, for lack of "news," take a sustained interest in the course of public events. The world of science was an unopened book. Intercommunication was slow and difficult; and the whole current of existence flowed sluggishly. Contrast this with the vivid abounding life of the present day. Veins of interest are greatly multiplied—to meet and satisfy the infinitely varied individual aptitudes of men and women. A considerable number of persons of both sexes now busy themselves, either as amateurs or something more, with the study of some branch of science or natural history. Those whose bent is to politics, art, letters, sport, or fashion, find in the daily newspaper and the periodical press an unfailing fresh supply of the mental food they love. Business and pleasure are carried on with a briskness formerly unknown, and the pulse of national life is quickened through every part. It seems impossible that decay should invade the body politic while such conditions of all-pervading activity prevail—and there is no valid reason why these conditions should not continue to prevail. It has often been remarked that

1 Mr. Mulhall calculates that "our steam-power in the United Kingdom is equal to the force of 169,000,000 able-bodied men, a number greater than the whole population of Europe could supply."—*National Progress during the Queen's Reign*, p. 22.

periods of national upheaval, when men's minds are deeply stirred—like the rise of Islam, the Protestant Reformation, and the French Revolution—were exceptionally prolific of able men. It does not appear altogether unreasonable to suppose that the stir and movement of modern life may be similarly favourable to the production of "men of light and leading" for the service of the community. The proximate cause of the downfall of states seems always to have been a defective supply of strong and capable men at the head of affairs, and in positions of trust. The *dolce far niente* is not conducive to the formation of strong characters; and those who sigh and yearn for social quietism may find comfort in the reflection that the hum and buzz which disturbs them is a sure token of the health and strength of the common hive.

THE BEHAVIOUR OF ARGON IN X-RAY TUBES.[1]

IN continuation of some experiments made by Prof. Callendar in the early part of 1896, the authors have studied the behaviour of argon in X-ray tubes of various types. The phenomena presented by a tube filled with carefully dried and purified argon, are in many respects peculiar, as compared with those presented by other gases under similar conditions.

In the early experiments above mentioned it had been our custom to keep the X-ray tube connected with the pump, which was used as a reservoir of dry air during long exposures. The gas, which was absorbed by the working of the tube at a high vacuum and a long equivalent spark-gap, was restored from time to time, as the vacuum became too high, by letting a little air in from the pump by means of a convenient tap. In this manner it was possible to operate the tube at a very high rate of efficiency for two hours or more at a time. These long exposures were required for some experiments on the velocity of the X-rays, which have been described in a communication to the Canadian Royal Society, May 1896.

It was noticed on several occasions, after one of these long exposures, that there was considerable blackening and sputtering of the electrodes, and also that the pressure of the air in the tube had increased considerably above the degree of vacuum required for the production of X-rays when the tube was first exhausted. After allowing the tube to rest for a few hours, although there was very little increase in the pressure, it was also observed that no kathode rays were produced until the discharge had been passed for some time. It appeared probable that some of these effects, which are recorded in the paper above mentioned, were due to the accumulation of argon in the tube. The spectral lines of that gas were on some occasions faintly discernible in parts of the tube, but no systematic spectroscopic observations were taken.

In making further investigations on the behaviour of argon, we hoped to find that, owing to its natural inertness, the vacuum would be of a very permanent type as compared with other gases. We also hoped that its monatomic character would afford features of interest.

For the preparation and purification of the argon used in these experiments, the Cavendish spark method was adopted, as described by Rayleigh and Ramsay. For this purpose a special transformer was constructed, the primary and secondary of which were wound on different parts of the core. The primary was connected to the 100-volt lighting circuit. The secondary gave 10,000 volts on open circuit, available for starting the arc, but the voltage on the arc when running was only 2,000. The secondary could be short-circuited, owing to the arrangement of the winding, without materially increasing the current, or running any risk of burning up the coil. The apparatus could thus be left running safely by itself day and night without wasting any power on resistances. After concentrating the argon to about 60 or 70 per cent. in the flask, it was further purified in a test-tube apparatus, constructed so as to contain the minimum of liquid. The excess of oxygen was sparked off with hydrogen, and the residue removed by absorption with alkaline pyrogallate. The argon thus purified was kept in a bulb containing P_2O_5.

In the first set of trials of this argon in X-ray tubes, a Fleuss mechanical pump was used, which permitted very rapid exhaustion of the tubes, but had no arrangement for measuring the high vacua. The vacuum was estimated in these cases by the appearance of the tube and the width of the dark space.

The first tube tried had two aluminium electrodes, and had been lying open to the air for some time previously. It was exhausted and washed out two or three times with dry argon, and then sealed off at a good X-ray vacuum. Each operation occupied only two or three minutes, and the vacuum has since that date deteriorated slightly, probably owing to insufficient removal of residual gas from the electrodes, but it still gives sufficient light to see the bones of the hand. The tube during exhaustion presented exactly the same appearances, except in colour and spectrum, as if it had been filled with air.

The second tube had been worked up to a sparkless vacuum some weeks previously, and had been frequently renovated by heating. It had an aluminium kathode and a platinum anode. It was connected to the pump and exhausted as soon as possible after opening. It was then filled with dry argon up to a pressure of one-fifth millimetre, and exhausted to an X-ray vacuum five times in succession. The glow on the kathode inside the dark space showed the F line of hydrogen, and also the C line more faintly. These lines probably indicated the elimination of hydrogen from the electrodes, especially the kathode, as they became fainter with each repetition of the process of washing out.

At the sixth filling of the tube, the pump was worked for ten strokes only. The kathode then began to sputter and blacken the tube, and the argon was apparently absorbed, as the discharge refused to pass in three minutes. Fresh argon was again admitted, the coil was left running, but *the pump was not worked at all*. The spectroscope this time showed only blue argon without any trace of hydrogen. The concave aluminium kathode sputtered violently and partly melted down. In less than two minutes the discharge refused to pass through the tube, which was then sealed off.

The coil used in these experiments was a very small one, which gave a two-inch spark with difficulty when running on a large 8-volt battery.

The next tube upon which we experimented was a double focus tube, containing two aluminium kathodes and a platinum antikathode. This was washed out with argon and exhausted eight times with the two-inch spark coil running all the time. The direction of the discharge was frequently reversed, but no trace of absorption could be observed. The argon lines always disappeared, and the hydrogen lines, especially F, became faintly visible inside the kathode, as the tube approached an X-ray vacuum. The tube at each exhaustion gave fairly bright X-rays, and showed no blackening or sputtering. The hydrogen lines showed more brightly close to the kathode than in the body of the tube, where the argon lines were most conspicuous. The hydrogen appeared in fact to be coming out of the metal. The glass walls of the tube were in a very dry state, as it had been previously heated and exhausted.

Finding that we could not get rid of the residual hydrogen with the coil, we had resort to the alternating current, which we had previously found very effective in tubes with double electrodes. It appears that the elimination of hydrogen takes place chiefly, if not entirely, at the kathode. With the first application of the alternating current, the hydrogen lines showed extremely bright. The tube was then exhausted. In fifty strokes, the discharge refused to pass. On refilling with argon to a pressure of one-tenth of a millimetre, the blue glow inside the dark space showed only argon and no hydrogen. The pump on this occasion was not worked at all, but the gas apparently was absorbed, and the discharge refused to pass in about three minutes. There was some sputtering of the electrodes and blackening of the tube, but the aluminium, though blistered, was not melted. The experiment was repeated twice with the same results. On reconnecting the tube to the two-inch spark coil, the same absorption was observable but less rapid. The electrodes were larger, and were less heated than in the case of the first tube.

We concluded from these and similar observations, of which the above may be taken as a sample: (1) that the hydrogen occluded in the kathode played the part of carrier of the discharge from the metal to the gas. (2) That if there were sufficient occluded hydrogen, there would be little or no sputtering of the aluminium. (3) That when no hydrogen was present, the discharge was conveyed from the kathode by particles of the metal itself, which were capable of exciting fluorescence of the glass, and of gener-

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