take extensive prehistoric studies in Asia Minor and in the region of the Caucasus. His studies in prehistoric archeology, which apparently are so remote from his original anatomical work, are in reality closely connected with his researches on the early history of the races of Europe. Anatomical data alone cannot solve these intricate problems, and Virchow's extensive activity in the field of prehistoric archeology is another proof of his thorough and comprehensive method which utilizes all the available avenues toward the solution of a scientific problem.

Physical anthropology and prehistoric archeology in Germany have become what they are largely through Virchow's influence and activity. His method, views and ideas have been and are the leading ones. His greatness as a scientist is due to the rare combination of a critical judgment of greatest clearness and thoroughness with encyclopedic knowledge and a genius for grasping the causal relation of phenomena. His critical judgment was so strong that, in an address delivered in the summer of 1900, he was even led to doubt the desirability of the strong preponderance of his influence upon current opinion. With profound admiration and gratitude we regard his life's work which has determined the course of a new science.

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SCIENTIFIC RESEARCH: THE ART OF REVELATION AND OF PROPHECY, II.

XI.

Collaboration of all sciences, physical and metaphysical, must ultimately be the task of the investigator and the end of research. The several sciences are the formulated expressions of nature's law of a universe, and all are functions of force, movement, energy, of life and its material foundations. To discover the relations of the sciences and to reduce them all to departments of one all-comprehending system will prove, if it can be achieved, the highest result of research. Already, the thermal, luminiferous, electrical, mechanical, chemical, and to a certain extent the biological, sciences are known to be divisions of the more comprehensive science of energetics; all treat of manifestations of energy and its conversion from form to form and its transfer from point to point. Already it is known that other manifestations of force and energy, if not still-disguised illustrations of familiar forms, are existent in the animal machine, and it is suspected by some, believed by others, admitted to be possible by yet others, that those energies which pervade the more ethereal atmospheres, the vital and perhaps other energies, are transformations of the familiar kinds. The question has even been seriously and honestly asked whether spiritual life and energies may not have definite relations of quantity, and even of transformability, with those characterizing the physical world. Vital energy, moral force, the efforts of genius, exhibit themselves in the individual in larger or lesser degree as his supply of potential energy in form of food varies from excess to deficiency and as his physical powers fluctuate.

Are there two universes, the seen and the unseen? How is the seen related to the unseen? Are there definite quantitative equivalences among the forces and the energies of the one and of the other? What are these equivalences among the energies of the unseen, if they exist, and what the facts and laws, the algebraic statements of law, and the values of the constants representing facts at the points, the surfaces, of junction?

These and other questions constitute problems for the coming investigator, familiar with the phenomena of the seen and

the unseen. Their solution will, if proved possible and practicable, furnish the elements of the Universal Science of Energetics for all these worlds.

Over ten years ago, addressing the Alpha Chapter of Sigma Xi, I took occasion to refer to the still unsolved problems of this nature.* These problems have been solved, here and there, and occasionally a great step has been made, as when the divisibility of the so-called atom of the chemist was shown to be possible, or where wireless telegraphy has become practicable; but the impression made during these ten years upon the great body of the unknown has been comparatively small, and the opportunities for further revelation and the scientific use of the imagination, of scientific prophecy, are larger than ever.

Unquestionably there exist energy relations amongst all phenomena of motion, relations of potential energy amongst all groupings of atoms, molecules and masses. The fundamental law of energetics is already known, as is the law of the quantivalence of all the energies, and as is the fact of the persistence of energies and of matter. It needs but the discovery of the mechanism of matter and of motion, and of its action in production and transfer of energy-effects, to furnish the essentials for the establishment of a complete and universal science of the material universe as we know it. We may even perhaps hope to enter at least the borders of the unseen universe, now apparently closed to us. But we have studied and weighed and measured the unseen atom and molecule; we have discovered the movement of unseen particles as ions; we have even determined the size, form and orbit of an unseen stellar world: why should we despair of ultimately finding ways of tracing the laws and the phenomena of the grander Unseen? Cicero's declaration becomes more convincing as the years go by and as science becomes more easy of comprehension and more nearly all-comprehending.

* 'The Man of Science, his Methods and his Work,' address before the Alpha Chapter of Sigma Xi, Cornell University, June 14, 1891. *Scientific American Supplement*, January 2, 1892, No. 835.

XII.

A later Newton, Galileo, Bacon or Compte, with learning sufficient to perceive the relations of the fundamental facts and laws of allied sciences, possibly comprehending the common features of all natural science, will find here the greatest of opportunities for the greatest of all great minds. The progress of the sciences, individually, is continuing to exhibit gain in rate of gain; the boundary between chemistry and physics, between both, and applied mechanics, between all phases of nature and all movement, is constantly becoming more and more obscured. The time is evidently steadily approaching when chemistry and physics will have a common and smoothly shaded, if not obliterated, junction, when energetics will comprehend all phenomena, and all laws of mass and molecular and atomic motion, alike. Mighty minds will certainly come forward, in due time, each familiar with the learning of each of a pair of divisions having thus adjacent limits, to join the two sections together with a perfect and indistinguishable weld. With our present knowledge of the tendency toward the simplification and the union of the sciences, it is even possible to imagine the appearance, at some future day, of minds capable of thus reducing to continuity and unity the whole area. There is the more reason for conviction that such a result may be sometime attained as we realize the fact that it is through such unity and conspiring of the forces and the laws of the universe that nature accomplishes her great purposes and that man must, by similar extension and union of his codes of

scientific law and his use of forces and energies, attain the solution of the greatest of the problems now confronting him.

Scientific research is only just beginning to be appreciated and to be understood, even by those engaged in the great work. The 'scientific method of advancement of sciences,' as I have elsewhere called it,* is hardly yet beginning to be fully recognized as a method to be developed and formally and systematically promoted. The organization of the Smithsonian, the later foundation of the Carnegie Institution, and the administrations of the scientific associations generally, are hardly yet beginning their real work—that of placing this fundamental basis of all scientific research on its proper and only correct footing. The organization of laboratories for research is only just beginning to be recognized as the real economic foundation of all human progress in scientific and industrial fields. Here and there a great mind is now coming to see the opportunity that thus offers for investment of capital in a manner most fruitful and productive of return to the world. Hereafter this revelation of the scientific method of the promotion of science will find many Carnegies to promote the work thus pioneered.

The perfected pantology, seen from afar by a few great souls, known already in some details by men of genius, will take form, as time passes, by the gradual collaboration of science with science and of congeries of sciences with other aggregations, indefinitely. The trend is already definite and the progress made, during the nineteenth century alone, has been enormous. Its rate has been and still remains an acceleration.

XIII.

The progress of a nation, the progress of the world of civilization, is coming to be seen to be dependent upon the advancement of science by deliberate, scientific, wise planning of investigation by learned men, each in his chosen department. The study of 'Curves of Progress'* of all the various departments of human knowledge and of all the material movements of modern life, can now be seen to promise the revelation of new facts, their groupings to illustrate, graphically, usually, the underlying law, and to permit the prophecy of future progress and its essential and controlling conditions. The comparison of the trend of the various curves of progress of intelligence, of production of trained and cultured men, of the steel and the iron manufactures, of accumulation of wealth, of advances in earning power of producers, of the development of a material civilization and of the highest civilizations, shows very clearly the fact of a correspondence amongst them all in method and rate, and of acceleration of advance, and reveals the law that all progress must be traced to the more or less scientific development of universal application of scientific methods of advancement of science.

The graphical representation of the statistics of Mulhall, which I employed in the first illustrations, the similar exhibition of the constant growth of production, as, for example, in the copper industry,† may be used to exhibit the universal fact that all real progress, materially, involves the extension of a market and the steady and accelerated growth of production, with synchronous increase in the efficiency of methods of production through invention and improved methods, the equally steady rise in wages of producers availing themselves of such improvements in the art, and the steady decrease of costs and prices as meas-

* Vice-President's address before the American Association for the Advancement of Science, 1878, St. Louis meeting.

* 'The Trend of National Progress,' *North American Review*, September, 1895.—R. H. T.

† 'The Modern Law of Supply and Demand,' SCIENCE, December 4, 1896.—R. H. T.

ured by the buying power of the wage of the worker. As I have somewhere said:

"The world has made greater progress in the last century than in all the earlier ages. This progress it owes to the inventor, the mechanic and the engineer. Modern material advancement practically dates from the time of the general recognition of the inventor's rights, and the formulation of the first rough outlines of our modern system of patent law, at the commencement of the seventeenth century. But all progress is an acceleration, and, slow at first, it becomes increasingly rapid, until, after a time, all the world is astounded by its mighty rush."

Morals, manners, culture, develop with the progress of the age and the progress of the age depends upon the advancement of science and the promotion of a material civilization with its concomitants of intelligence, leisure and opportunity, by the development of methods of useful employment of every department of the applied science. The progress which has been made, for example, during the two centuries just past, has been due in large part to general progress in intelligence; progress in intelligence has been due to advancement in education and to that splendid contagion of civilization which comes with increasing contact of class with class and general distribution of the privileges of enlightened civil life. Such forward and upward movements come of the growth of production and that increase in wealth and leisure which allow of the more general distribution of opportunity and of education and of the comforts of civilized life. The foundation of all progress, spiritual, intellectual and material, alike, for the nation always, for the individual usually, is material. Only with aggregation of property and increase in comfort with decreasing hours of labor can liberty be secured for thought and for care of others, for education and for aspiration, and for either moral or material gain. Wealth will demoralize individuals; it may even, with a rude people, stimulate crime and vice; it is yet the fundamentally essential element of human progress, and the nation or the individual taking full advantage of its opportunities and privileges gains in maximum degree in morals, manners and culture.

Among the ancients, a high degree of civilization and a corresponding lofty plane of morals, manners and culture were possible to the few and an aristocracy of intelligence, as of the limited wealth of time, was a natural consequence; but it was not possible to have a satisfactory condition of the people as a whole until they were emancipated by advancing material civilization from the bondage of continuous toil.

Many problems still loom up in the immediate future, and some of them, outside the domain of scientific research as commonly restricted to a definite field and scope, of vastly greater importance than any known unsolved question in scientific departments of physical work. The greatest of problems for civilization, that of an efficient and profitable and generous education of all people upon whom is fixed the responsibility, in however small degree, of self government, and in such manner that the risk to people and to government shall be least, while the opportunities of the youth of the nation shall be the greatest possible in acquirement of wisdom and learning, of knowledge and culture, and of the fundamental principles underlying the best practice in the arts in which they are engaged.

'The modern educations,' as I have called them,* are many in detail, but all are underlaid by the fundamental, scientific, princi-

* 'The Mechanic Arts and Modern Educations.' An address before the Virginia Mechanics' Institute, Richmond, Va., May 18, 1894. *Scientific American Supplement*, November 3, 1894, p. 15,705.

ples which are the essential elements, also, of successful scientific research; the efficient revelation to the growing and maturing mind of the great facts and the principal data of all branches of knowledge or of philosophy proposed to be taught, and this discovery, to the youth of sufficient capacity, of the great laws of nature which relate those facts to one another and to the great scheme of the universe. Finally comes the deduction, from the trend of movements controlled by those laws, of the most direct line of present and future progress and the best methods of promoting, of profiting by, scientific progress in later times. There may be hardly a less exact science of education than of astronomy or geometry or mechanics, and there is but a mathematical line of ideal, perfect advance. Our grandest problem is to find and to follow that line and to show the way to later generations.

We are not called upon simply to ascertain what, for our time, is the most desirable system of school and college work, or even what is the most 'complete and generous,' the most truly Miltonian, education; but rather to discover and reveal the best system of teaching a people what a people should know, effectively and with certainty. This problem being solved, we may reveal the principles and all their corollaries and show the way to 'educate a people for the life and work of the people.' Prophecy then will become simple and certain respecting the ideal educations, and the results of their formulation and introduction by great minds devoted to the greatest of all human tasks in the fields of human knowledge.

XIV.

Revelation and prophecy are thus the characteristics of the work of the scientific investigator and the outcome of research. The revelation of the facts and the laws of the phenomena witnessed in the various kingdoms of nature, their mutual relations, the control of the movements of all cycles, and all progress in the orderly evolution of the natural world, by law, the motions of atoms, changes of compounds, growth and life-histories of creation and its worlds, giving the human mind the power to look back upon the centuries and the ages, is but the first part of the task of science. A prophecy of a future of progress in the infinite evolution, discovering the trend of every continuous movement up to date and indicating the direction of further development, is the second and consequent task. In science, more than in any other department of knowledge, is it possible to judge the future by the past and, as the movements of sun, stars, planets and all satellites may be now predicted by the astronomer, so the evolutions of geology, of botany, of biology, of the races themselves, man and animals, are coming more and more within the purview of the seer. The life-histories of worlds and systems and perhaps of universes are to steadily reveal themselves in coming time. Already it is possible that the long uncertain question of the method of restoration of kinetic energy and all life, within a universe, run down, apparently dead and cold, and whose energies of motion have been converted into potential forms, is beginning to find answer; the significant hint of the new star and the new nebula in Perseus may prove the first of the revelations throwing light upon this immense enigma.

Wherever the path of time may be traced and represented by its 'curve of progress' its terminal in the present may be with certainty projected forward into a future, and prophecy becomes as accurate, approximately, as the line of the immediate past.

It is science only that can read the oracle of the future.

Knowing, from an experience extending far back into the past, that all the phenom-

ena of nature are simply parts of one great movement, each event a consequence of an earlier trend and a natural, necessary and obvious sequence of a next preceding event, it becomes easy to understand that every coming event might be foreseen by an all-comprehending mind, and that even the least learned and the most commonplace among scientific men may predict with certainty within its limits, the man of genius and learning simply having a more extensive range within individual bounds than his fellow.

Certainty and accuracy of these oracles thus are approximated as the conditions are the more simple, the phenomenon the less involved with other sequences, the trend the more definite and the period over which the curve of progress must be extended into the future the shorter. The rise and fall of the tides, the instant of an eclipse, the motions of the companion of Sirius, the form of every definite cycle, may be determined and their future predicted accurately. The growth of a great population, the progress of civilization as measured by growth of manufactures, or by advances in education, or by the gifts of philanthropy, may be traced along a curve of the immediate future, at least approximately. The coming events of the seismic period just reached in the West Indian seas cannot be even approximately predicted. The trend of progress of our own country may be perfectly determined and the future may be as clearly indicated—*provided* no change, catastrophic or other, in the controlling forces which determine its path, meantime, occurs. The astronomer deals with positive and exact prophecy; the economist and statistician must content himself with approximations and probabilities of varying values.

Yet, even the economist and the student of history may declare assent to the following code and, in this general way, reduce economics and history to the form of a science with capacity for prophecy.

1. The laws of social and economic phenomena and movement control all human progress and determine the advance of all nations, and give form to their 'curves of progress' in wealth, education and culture and morals.

2. These laws are found to insure steady progress with acceleration and without much regard to so-called 'crises' or good or bad times.

3. The 'trend of progress' in past decades, for example, in our own country, and this acceleration, constitute a guide in predicting the immediate future of our industrial and social system.

4. This 'curve of progress' being drawn for the past history of the nation, its direction at the moment indicates the certain trend for the immediate future, its probable trend for later dates, and its progress in future decades with a degree of probable approximation which lessens as the remoteness of the time of fulfilment of the prophecy increases.

5. The means and methods of progress are through the steady improvement of the arts and sciences and the constant reduction of the proportion of the working power of the world which is wasted, or at least employed with no permanent effect, with as constant increase in the proportion applied to the increase of our stores of desirable and permanent forms of wealth.

6. Culture, and all desirable things, will come to the nation, in the future, in increasing proportion, so long as the present conditions of production are maintained and a whole nation is kept employed in increasing proportion and with increasing productiveness and with constant gain in the proportion of labor which is applied to the supply of other products than those of immediately perishable character. The less the labor required for production of food-

stuffs, for example, the more becomes applicable to the manufacture of the comforts of life.*

The same simple principles apply to the industries generally and individually, to the advances observed in the economic progress of the arts, to the development of every science. The thermodynamist traces the history of the heat-engines and finds that he may plot a curve of their gain in efficiency, in that of increasing steam-pressures, expansion ratios, speeds of piston and of rotation, 'duties' and even financial returns. He predicts the approximate values of these quantities for the engineer, and the engine-designer and builder know practically what to anticipate in the immediate future and how to modify their designs in the direction of further improvement. The spinning of cotton and the weaving of cloth, even, follow similar general laws and the expert traces the curve of their progress and knows that increasing speeds of rotation of spindle, a more rapid beat of the loom, simplification of mechanism, all tending to make the day's work of the expert operator more productive, will carry out the curve of progress with further and constant tendency to elevation. The superposition of the two curves insures still more rapid rise, and the gain of the Olympia Mill in the South over the most ancient in operation in the North comes thus largely of the fruition of a visible and measurable and steady past progress.

The resultant of all the curves of modern progress in superposition is seen in those of the nation and, studying these, we may assert that given, in the immediate future as in the immediate past, that quiet and peace essential to maximum efficiency of industry, to the maintenance of production on the part of the whole working population, through unintermitted labor with highest skill, through maximum time consistent with a wholesome and healthful life, the trend of national progress will continue onward and upward with further acceleration, even though already far ahead of anything ever before seen in any part of the world. Unimpeded by folly, demagogism or international troubles, our total wealth should at least double each generation; the earnings of the average worker should nominally double each forty years or less, and, measured in buying power, at a much higher rate. The next generation, all going smoothly, will see the average skilled workman enjoying as much of comfort and luxury as the average member of the college faculty to-day, and probably more.

The trend of production of the industrial arts, and especially of those which contribute most to the comfort and pleasure and moral and intellectual profit of the people, will be found to exhibit the most impressive advances, and already the wealth of the country in this form is equal to the total of all our houses and lands—and is increasing at a double rate; which, 'being interpreted,' means that, our necessities being practically fully supplied, our people are now accumulating the comforts of life and all its good things by application to the production of new wealth in these forms an already large and a rapidly increasing proportion of the productive energy and ability of their ablest minds and most highly skilled artisans. Ability, capital and mechanical energy and brute forces are conspiring as never before to give the great body of the people of the United States and, in less degree, of other civilized nations, a large and increasing proportion of the growing product of these three factors of progress. We are fifty per cent. more comfortable than were our people in 1880, sixteen times as comfortable as were our

* 'The Trend of National Progress,' R. H. Thurston, *North American Review*, September, 1895.

parents in 1850, and our children in the rising generation will have twice as many luxuries and live twice as easy and comfortable lives, if they so choose, in their later time as do we to-day.* The oracle may sometimes be in error; but it remains the fact that "science, and science only, often can and frequently does, by a perfectly accurate and correct method, give us clairvoyant views of the immediate, if not of the remote, future. Of the trend of modern progress, in the direction and in rate of movement, there is no reasonable doubt."

XV.

Finally, *en résumé,* to our time,† all life and movement, whether of man, animals, vegetation, seasons, suns and planets, arts, commerce, civilization, intellectual, moral or physical worlds, depend upon transformations of preëxisting energy. All studies, all work in the domain of the physical, the natural sciences, relate to transformations of energies and their mutual interactions and modifications. We have learned to compute the velocity, to determine the methods of refraction and reflection of light; but we still know little of its exact character as motion of molecules. We know the related form, heat-energy, in its sensible effects; but we are still unable to differentiate the one from the other. We can produce and utilize electricity in many ways, but we, as yet, do not even know what it is or how its transformations from other energies are effected. We work with these three forms of power, they are the amusement of the ignorant, the wonder of the sage, the slaves of humanity; but we do not even know what is the nature of the substance through which they act to produce their beautiful, their marvelous, their world-impelling effects. The ether is still to us an enigma, unsolved by the wisest, a riddle to the most expert investigator.

The chemist knows much of the composition of 'compounds,' but he has never seen, felt or identified an 'atom' and still vaguely dreams of a single first element into which all shall be resolved. He counts with unseeing eyes the number of atoms in a 'molecule,' but has never yet learned their form or grouping. Even with the aid of the physicist he loses track of their transformations in the furnace of the sun and the stars, and finds in the spectroscopic lines a strange language of which he lacks the key. He can isolate and weigh the phosphorus in a gram of steel, but he cannot give us the phosphorescent fuel, the source of light, of the fire-fly. He can reduce the muscle, fat, and nerve matter of the human system into their elements, but he cannot produce the storage batteries of brain and spine, or the gymnotus' cells.

The astronomer weighs and measures the sun, the moon, the planets, and the nearer stars; but he stands aghast and amazed by that flying sphinx, '1830 Goombridge,' the 'runaway star,' flying 200 miles a second, faster than it could fall from infinite space, and its origin, course, destiny are to him questions of the oracles. He has, as yet, no solution. He is lost amid the depths of space, he knows not where to look for a limit, or how to prove its non-existence. He asks, with the believing and the unbelieving among the simple, How and when shall the 'Heavens melt with fervent heat'? and, How long shall this wandering handful of worlds traverse the infinite safely and without that conflagrating collision with other systems or other worlds that, as it seems possible, now and then, at intervals of years or of centuries, causes a star to blaze out in the midst of darkness with a brilliancy greater than that of the

* 'The Trend of National Progress,' Conclusions.

† This section is abstracted from the earlier address already referred to.

sun? His little span of life is too short to permit him to follow the evolution of the worlds from their initial nebulæ, too brief to give him access to the secrets of their Maker.

The geologist tells us of the past history of all that lives, and of this spinning globe on which it has found foothold, falling into life from unknown space, and time, and depths; but he cannot tell us whence came all life, whence all spirits, all human and divine souls now constituting its living freight, as it wanders with unguessed destiny through an unmeasured universe. He roughly traces its superficial changes from the day of mist, through the ages of creation and growth of all that has come into life; but he and the physicist and the astronomer are alike uncertain whether it shall endure a thousand million of years or a single day. The physicist predicts a limit of a few million years, the geologist believes many millions, but no man knows when life shall perish from the face of the earth.

The biologist can give microscopic measures and microphotographic pictures of the tissues, and can trace a nerve to its minutest ramifications; but we have yet to learn the secrets of the source of life, of method of production and application of energies, of those transformations that give form, structure, life, and power to the organism of monad or of man. He exhibits the mechanism of the fish, but finds not the secret of separation of oxygen from the medium in which he lives, and cannot produce a submarine vessel. He knows the shape and movement of the bird, but flight remains to him a mystery. He measures the heat of the animal body, but biologist, chemist, physicist and engineer, all together, give us no hint of the method of its production. They know, to an ounce, the power per cubic inch or per pound of the muscle, but neither one nor all can say how that power is originated, how transferred or how exerted by the transmitting threads of working muscle.

The engineer has, for a century, made steady progress in the adaptation of machinery to every purpose of modern life. He converts the potential energy of the vegetable life of a myriad earlier ages into steam power, and applies it to the impulsion of railway carriage, of steamship, and of mill; but, in the process, he wastes four-fifths or nine-tenths of it, and pays out principal where he might, perhaps, pay only interest. He turns the elastic force of expanding steam into an electric current and sends it out to relieve the burden of the overworked horse; but he allows as much to slip from his grasp, often, as he usefully applies to his proposed work. He diverts the energy of combustion or of falling water into the new form, and the electric light, through his genius, gives illumination to street, and dwelling, and hall; but every light ray goes forth to its task carrying with it a sheaf of heat rays; and the glow-worm shames the man, producing light without heat, and heat apart from light, and all researches exhibit only our ignorance and comparative inefficiency. He measures the speed and power of the albatross, the eagle, and the swallow; but he only marvels the more at their beautiful movements and rapid flight. He captures the dolphin and overcomes the whale when they traverse the surface of the ocean, but he knows not how to follow them into the depths of the sea. He crowds his fellows into mills and factories, but sees no way of giving each an individual life and work, comfort and health in equal and fair quantity. The man of science, whatever his chosen task, whatever his field of labor, however high his attainments and whatever the magnitude of his accomplishments, finds that acquisition of learning, gain in knowledge of the ways of nature, increas-

ing appreciation of, and familiarity with, God's ways, only bring to his dazed eyes greater and more novel marvels, grander and wider sweep of opportunity, mightier and mightier mysteries, all challenging him to nobler aspirations, more earnest labor, higher aims. Every step towards higher, better, brighter life gives him reason for greater humility, larger faith, and stronger sense of the infinitude of duty and opportunity.

The work of the man of science is present still, and is never-ending. But, glancing at the past, he sees that he has no reason for discouragement, every reason for enthusiastic ambition. He sees a wonderful, a glorious, a fruitful work just begun, and his the privilege of taking part in it. His work is the basis of present highest human existence, the potential foundation of still nobler life. Great problems have been solved; greater and grander remain, which shall certainly be solved by him. His is the task of showing the way to make all the powers of nature genii aiding man; of giving comforts of every kind to his fellow, and powers of accomplishment of great work for public good; pointing out the way to give widely distributed enjoyment of life, leisure for moral development, for intellectual growth, opportunity for study of the universes, the attainment of highest physical, intellectual, moral ideals. He will yet penetrate the secrets of the living machine, learn how to evade the law of Carnot, to produce and apply the energies of chemical combination to the generation of heat without light, light without heat, power without waste; to transform thermal from chemical energy, without combustion at high temperature, as does the meanest animal; to convert it into mechanical power without the thermodynamic loss inherent in our heat engines, as does beast, bird, and worm; to obtain its equivalent of electric energy, as does the nervous system of every living creature; to intelligently select and sort out the radiant energies into luminous, thermal, or other etheric forms, at his will, as does the unconscious bit of hardly living jelly floating in the spume of the wave crest of every tropical sea.

XVI.

Our anticipations for scientific research, and for the future of its noble band of men of genius, may confidently be affirmed to be justified, however sanguine, by the history of the past and by the reasonable prophecy, in the light of the past, of its greatest seers. It may well be doubted if any living soul can realize, in full, the tremendous portent of that prophecy, and it is likely that its fulfillment will transcend the most ambitious and vigorous imaginings of our day. As the advances of the nineteenth century have inconceivably transcended the most enthusiastic prediction of the eighteenth, the revelations of the twentieth century may be expected to still further exceed the anticipations of the most far-seeing and sanguine prophets among men of science of our own time.

Genius and learning may be expected to persist in the coming times and courage is never lacking. The later Newtons will exhibit as great prescience as the earlier, the coming Davys and Faradays will accumulate no less learning than the great minds of the past, and the nerve of Heilprin, standing amidst lightnings, fire and smoke, and falling rains, mud, and lava, studying the processes of volcanic action from the edge of the roaring crater of Mt. Pelée, is as characteristic of the modern scientific investigator as was that of a Pliny, in a similar adventure, two thousand years earlier. 'With intelligence to guard his life against every needless risk, and yet with constancy and professional zeal to make him face cheerfully all inevitable danger,' such a man will always illustrate the 'un-

conscious courage and heroism of the scientific spirit.'* The true scientific spirit, however, is quite as often and as impressively shown by the investigator who publishes conclusions at variance with the beliefs of the world or of his own colleagues, and the physical suffering of a Galileo and the moral crucifixion of the promoters of almost every new discovery or new philosophy afford illustrations of this fact. But courage best appears in toleration.

The past, the present and the future have their special interests to the student of the trend of human progress, and it is easy, in a general way, to follow the line of the curve. Compare what is known of the older civilizations with the present of our own and the promise of the future for coming generations of civilized men!

In the days of the prehistoric races, whose only records are now found in the few relics here and there discovered by the geologist and the antiquarian, centuries passed without important changes, and progress was inconceivably slow as measured by the movement of the later days. Progress in the most enlightened countries was comparable to that of China during recent centuries and the barbarian stood absolutely still and remains, even to-day, as with his ancestors and forefathers of a thousand generations before science or civilization had a home or a name. The 'curve of progress' was practically rectilinear and horizontal through centuries and millenniums.

With the appearance of manufactures, trade and widening commerce and exchange, a rise became observable and the trend of progress during the periods of the history of the East Indian, the Babylonian, the Assyrian, and the old Greek was slowly but steadily upward. The discoveries and philosophies of Aristotle and his contemporaries and successors, the introduction of the Aristotelian methods of study of nature and of the sciences generally, the inventions of Hero and the other Alexandrians, of the mechanicians of the Museum and the Serapion, the revelations of the Ptolemys and the Euclids, the alchemists and the naturalists of the Egyptian period and of Greek mastery of the Nile: these events and these inventors in science, philosophy and mechanics produced the first observable acceleration and upward curvature. The Saracens, driving out the Greeks, substituting their own for the older civilization, but yet seizing and carrying forward the torch of knowledge and preserving every spark of the older light, promoting all the sciences, cherishing, learning all and caring for men of science, brought about a still more marked acceleration, and the upward trend of the curve continually became more observable until, by transfer into Italy, and in the hands of Leonardo, by importation into Spain through Moorish enterprise and wisdom, learning and the modern arts, so far as then known, all the sciences found safe and permanent home in Europe, despite the later opposition and persecution of the pioneers in science by the all too human elements of the dominant church.

But it was not until about the beginning of the seventeenth century, at a time when all the arts and all the sciences took a sudden start upward like the flowers of spring, that any rapid progress commenced. Then astronomy and physics and chemistry and all the applied sciences began to contribute to the advancement of learning, and Bacon's aspiration and Milton's cheerful leading, gradually bringing about a systematization of knowledge and a scientific method of advancement of science, began to illustrate the wonderful power of systematic work in well determined courses in accelerating all human progress. From the introduction of the inventions which gave firm foundation to the iron and steel manu-

* *The Nation*, June 5, 1902, p. 437.

facture, supplied the world with a reliable, powerful and cheap prime mover, made the factory system practicable and modern systems of manufacture feasible, the curve of progress has been rapidly, and more and more rapidly, mounting upward. Its coordinates may, from that date, be accurately measured and its locus precisely followed by collating the statistics of iron or the textile or the educational progress of the world's leading nations. They all follow a similar course and one is a gauge quite as much as another. The output of our colleges and especially of our colleges of engineering now follows the trend of progress of the nation and the output of men learned in applied science and that of our blast furnaces alike afford us a measure and a gauge of the advancement of the nation toward a still higher civilization.

A study of the curve of progress to date, and especially of the trend of progress at date, thus shows that we may find, in this revelation the rise and the advance of civilization into our own times, evidence which is convincing to the extent of proof that we are entered upon a stage in which the characteristic features are intelligent and systematic development of every department of human knowledge and of human skill, a stage in which scientific investigation is assuming constantly a more and more controlling share in the perfection of the sciences, the applied sciences and the arts of life. It is becoming constantly more and more productive of results favoring the progress of the race in its every department of life and growth.

Organized investigation of the problems of the industries is thus becoming as obviously useful and as generally employed in those fields as in pure science itself. 'The scientific method of science-advancement' is the method of every worker in every direction. The universities give large attention to research; it is cultivated by the colleges; it is the object of professional and industrial associations and of great endowed institutions founded for this special purpose.

The beginning of the twentieth century will probably become marked in history as that also of the organized industry of investigation, in all the departments of nature, of industry and of life, as that of the commencement of a rapid rate of acceleration of fruitful production, and as that of the firm establishment of science and of the scientific method as recognized elements of human progress.

In the promotion of this movement, no influence should be more potent and more general than that of Sigma Xi. This organization of the most brilliant minds devoted to science for science's sake—minds selected with care from among the choicest intellects coming forth from all schools, educated, learned, enthusiastic and capable, trained and expert—must, if it is maintained at its original and its present high standard, prove a mighty force for good in every field of most intelligent human activity, of highest scientific achievement.

Charles Sumner once said: "This is our talisman: Give us Peace! And population will increase above all experience, resources of all kinds will embellish the land with immortal beauty; the name of the Republic will be exalted until every neighbor, yielding to irresistible attraction, seeks new life in becoming part of the great whole and the national example will be more puissant than army or navy for the conquest of the world."*

"Give us Peace!" And science, art, industry and ability, conspiring, shall insure growth of population in numbers, wealth, comfort and intelligence and the revelation of nature's secrets, the utilization of na-

* 'Prophetic Voices concerning America,' Lee and Shepard, 1874.

ture's energies; and the inventions of a new century shall justify every one of Charles Sumner's 'prophetic voices,' from those of Seneca to those of Cobden, De Tocqueville and that orator, seer and prophet, Sumner himself. Seneca's continent has appeared and there are no more geographical worlds to conquer; but there are greater worlds still accessible to the scientific explorer. The prophecy of the 'bought servant,' George Webb, became true with the birth of a new nation:

Rome shall lament her ancient fame declined
And Philadelphia be the Athens of mankind.

Meantime, the nation, as prophesied by Sheridan, shall thus maintain a 'name and government rising above the nations of Europe with a simple but commanding dignity that wins at once the respect, the confidence and the affection of the world.'

And, in all this, the man of science, seer, revealer and prophet, shall play the noblest part.

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*ATTENUATION AND DISTORTION ON LONG-DISTANCE TELEPHONE AND POWER TRANSMISSION LINES REGARDED AS HYDRODYNAMIC PHENOMENA.**

THE analogy between a steady flow of water in a long pipe under the action of the constant head and a continuous current of electricity under some constant pressure such as is furnished by one or more cells of a battery, has often been employed to give a clear elementary physical conception of the mathematical relations expressed by Ohm's law. In this case the applied pressure is gradually consumed by the resistance experienced by the current, and in strict analogy with the flow of water, the loss per unit of length is proportional to the product of the square of the current and the first power of the resistance. So far as the mathematical relations are concerned the two problems are identical.

It is the object of this paper to extend this hydrodynamic analogy to the more complicated case of long-distance transmission by alternating currents in general.

Telephone transmission has been specifically mentioned in the title in order to include the general case of variable frequency. The importance of thus extending and enlarging this analogy will be evident when we reflect that all the complicated phenomena of long-distance electrical power transmission, by any combination of land lines and cables with their sending and receiving apparatus, may be completely reproduced in all its details of operation by simple pumping machinery with its transmission pipes and air chambers, whose manner of operation may be made clear to any one without the aid of higher analysis. Let us first take the case of a double-acting pump cylinder and piston in which the two ends of the cylinder are connected by a simple pipe or by-pass without valves. When this apparatus is filled with water and the piston is moved back and forth by a uniformly rotating crank, the water is forced through the by-pass alternately from one end of the cylinder to the other. If the by-pass is short, the resistance to motion may be taken as due to fluid friction only, since the inertia of the water may then be disregarded. This is in every particular analogous in the manner of its operation to a sinusoidal electromotive force acting in a circuit whose induction and capacity may be disregarded in comparison with its ohmic resistance.

But in case the pipe connecting the ends of the pump cylinder be made very long and the size sufficient to greatly reduce the friction, we may disregard this in com-

* Abstract of paper read before the American Association for the Advancement of Science by Professor Henry T. Eddy, University of Minnesota, Pittsburgh meeting, June, 1902.