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PHYSICS AND THE FUTURE[1]

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As the conversation turned to the problems faced by our children, my table companion was confident of the future. "During their generation," she asserted, "life can not change as it has for us. Experience will once more be usable as a reliable guide."

If advances in our mode of life are to cease, will it not be the result of a stagnation of our knowledge and techniques? Let us see what present trends indicate with regard to the direction and extent of such future changes.

No better guide can be found to the future than a review of what has happened in the past. Let us accordingly examine the trend of physics through history. Taking the broad view that the science of physics is concerned with the applications as well as the principles of mechanics, heat, electricity, etc., it will be seen that such a review must consider also the growth of techniques and inventions, for these embody some of the most important scientific advances.

In his recent book, "Science and the New Humanism," George Sarton has emphasized the fact that science is almost the only aspect of human activity which shows a definite and continuous growth throughout history. Though advances in other fields have occurred, they have come for the most part as a result of development of techniques based on growing science.

We are accustomed to speak of the stone age, the bronze age, the iron age and the machine age. This sequence reviews in quick outline the growth of man with regard to the tools with which he has done his work. Each stage has been ushered in as some inquirer, more persistent or more fortunate than his

[1] Based on a paper read at Ottawa, June 29, before the American Association for the Advancement of Science.

predecessors and building on the foundation of their techniques, has learned some new facts regarding the properties of matter, the chemistry of metals or the laws of mechanics. Such mechanical inventions are not the only ones. Language and writing are among the most significant inventions of all, giving as they do means of communicating ideas, carrying on abstract thoughts and remembering happenings with definiteness. When the invention of printing, telegraphy, the telephone, radio and moving pictures are added, it becomes possible for people to share thoughts widely, to become quickly aware of what is happening to all mankind and to "remember" what has happened to men in the past. Thus the world becomes almost a conscious unit, very similar to a living organism. So even the non-mechanical inventions have found their most effective application through the aid of scientific developments.

Hand in hand with this development of invention has gone the increase in our knowledge of nature. The properties of matter had to be learned before tools could be fashioned. Knowledge of the forest to the hunter, of soil and weather, grains and animals to the farmer, these formed the science of primitive life. Then, as now, new discoveries, that wood could be set on fire, that a moving magnet would produce an electric current, made possible improved conditions of life. Likewise, improved techniques opened the door for new knowledge. Skilfully made lenses made possible a telescope, and Jupiter was found to be a miniature solar system. As high vacuum pumps were developed, x-rays were discovered, and with them came new knowledge of the structure of matter. "If I saw farther, 'twas because I stood on giant shoulders," is the statement ascribed to Isaac Newton, who clearly recognized the way in which one advance makes possible another.

The result has been an increase in the rate of growth of knowledge and of the control of nature which is one of the most striking phenomena of man's history. When old knowledge was passed on by tradition and new knowledge came by accident, progress was slow. The ancient thought he did things as they had always been done, for the changes during one's lifetime were imperceptible. With the modern era came a fundamentally new concept. Now we search for new knowledge, and use it for "enlarging the bounds of human empire." The knowledge of nature which from the beginning had been man's gradually but accidentally increasing heritage has now become the conscious objective of alert minds. Three centuries ago the hobby of a few amateurs, this enterprise of science has gradually become the most significant intellectual quest of man. As a result, changes for the better in our mode of living are the order of the day. Our life differs from that of two generations ago much more than did that from the life of two thousand years before.

To see the cumulative effect of this advancing knowledge, it is instructive to use the historian's device of compressing the time scale, shall we say by a million fold. We may then think of the first men as learning a year or two ago to use certain odd-shaped sticks and stones as tools and weapons. Sounds took on meaning, and speech appeared. Last week some one developed the art of skilfully shaping stones to meet his needs. Man became an artist, and by day before yesterday he had learned to use simplified pictures as symbolic writing. Yesterday the alphabet was introduced. Bronze was the metal that was most used. Yesterday afternoon the Greeks were developing their brilliant art and science. Last midnight Rome fell, hiding for several hours the values of civilized life. Galileo observed his falling bodies at 8:15 this morning. By ten o'clock the first practical steam engine was being built. At eleven the laws of electromagnetism were developed, which by eleven thirty had given us the telegraph, electric power, the telephone and incandescent electric light. At twenty minutes to twelve, x-rays were discovered, followed quickly by radium and wireless telegraphy. Only fifteen minutes ago the automobile came into general use. Air mail has been carried for hardly five minutes. Not until the last minute have world-wide programs broadcast by short wave radio become popular. Now at noon we find mankind in a wholly new sense unified by science.

Science has thus become the basis of civilization, and is the primary factor in promoting its growth. During recent years it has been the science of physics whose activity seems to have been most significant in this regard. Just as earlier society was based upon agriculture and local trade, so modern communities are built upon the scientific foundation which makes possible rapid transportation and communication, the preservation and distribution of food and adequate sanitation. With only primitive knowledge of metallurgy, mechanics, electricity, chemistry and hygiene, our cities could not exist; and with them gone, country life also could have only a primitive form. It is on this basis that the president of the Massachusetts Institute of Technology has made the claim that in the last fifty years physics has exerted a more profound influence in changing all aspects of life than has been exerted in a comparable period by any other agency. The development of previous ages has grown to a mighty crescendo, within which we are living.

The growth of this scientific activity may be thought of as an aspect of social evolution. It supplies the knowledge which enables men to use the materials of nature for supplying their wants. The process involves specialization of function, which enables certain men to acquire extraordinary knowledge and skill in special fields. One important aspect of this process is the recent establishment of research laboratories. We have noted how the growth of knowledge, which had been mostly of an accidental nature, became with the modern era of science a primary objective of professional research men. Astronomical observatories and industrial research laboratories have pointed the way. In no field have these investigators proved their value more conclusively than in physics and the allied techniques. We may thus state with assurance that during the coming generation research in physics will continue with more and better trained investigators, with better organization and equipment, than during the past generation. We should accordingly expect an increasingly rapid growth of physical science, except in so far as the law of diminishing returns may make research effort less productive than during the past generation.

Present Trends in Physics

By surveying one after the other the various fields of physics, we may gain some idea of the new advances that may be expected. In its fundamentals, physics is concerned with the relations between time, space and matter. During the past thirty years, remarkable advance has been made with regard to our understanding of our own position in space and time.

Two generations ago we had just become aware that the earth and life on it had existed for a very long time as measured in terms of the human life span. Since the development of radioactive methods of time measurement, we have been able to date the formation of rocks with precision and to assign a reliable though rough estimate of some billions of years to the age of the earth. In fact, the age of the universe itself, as shown by the stars and galaxies studied by powerful telescopes, has been put under searching scrutiny. Theoretical estimates have varied from an eternal universe to one whose duration has hardly exceeded that of the earth. There is little doubt but that within the next thirty years our information on this point will have been made much more reliable and precise. That is, we may hope to find out when the world was made.

In tracing man's origin to the Miocene age of more than a million years ago, and the origins of civilization to some five thousand years B.C., the geologists and archeologists have made important contributions to the physicist's problem of measuring time and enabling man to understand his own position with relation to the time scale. It thus becomes clear that an adequate consideration of "science and the future" must include a consideration of a future extending not only into thousands but possibly into millions of years.

One of the major technical achievements of the past century has been the great reduction of time required to communicate ideas and to accomplish desired ends. Fast mail, the telegraph, telephone and radio—these have enabled people for the first time to act and think in unison. At last it is possible for men the world over to act as a social unit if they so desire.

Not the least significant in this direction is our increasingly accurate control of time. Galileo's invention of the pendulum clock was an important step in this direction. The recent wide-spread introduction of electric clocks using accurately synchronized alternating current and of precise time signals broadcast by radio at frequent intervals have made practicable the planning of our daily lives according to more definite schedules. Precision electric and pendulum clocks are now timing the earth's rotation to study its irregularities. In ultra-short wave radio, time intervals are measurable in trillionths of a second. In atomic physics we are concerned with processes whose duration varies from more than a billion years down to less than a billion trillionth of a second.

In a similar way we may trace man's increasing understanding and control of space. Perhaps nothing has had more influence on man's attitude toward nature than the gradual unfolding of the immensity of the world. Starting with Galileo's discovery of the moons of Jupiter, which gave the first convincing evidence of the truth of the theory that the earth revolves about the sun, our known universe has now been extended to hundreds of millions of light years. Because of a change in the energy of the light from these far spaces it would seem that our knowledge will be forever limited to distances not much greater than are now known. In this sense at least we may consider our universe as finite, and in spite of telescopes of increasing size we need not expect the future to open to us much vaster vistas. Here, on the side of the very large, is thus placed a natural limit to future scientific advance.

Similarly in the field of the very small, though size alone gives no insuperable limit to our knowledge, both experiment and theory agree in indicating that the measurement of motion of objects must become less precise as their size becomes smaller. This means that we do not hope to be able to predict exactly what will happen to particular atoms. Statistical predictions of the average of many trials is all that can be hoped for. It is possible that this limitation may be of importance in the application of physics to certain problems concerned with the action of living organisms.

These examples suggest that there are fields of knowledge which may be forever beyond our ken. It would not be surprising to find other similar limits presenting themselves, as researches in other directions become more far-reaching. Thus there has been, in the last thirty years, no significant advance in the precision of ordinary distance measurement since Michelson's calibration of the standard meter in terms of light waves to one part in several million.

It is unnecessary to consider the manner in which rapid transportation is giving us increasing control of distance. Nor need we emphasize the increasingly accurate construction and measurement of manufactured articles. These important trends have shown such value that there is no doubt of their continuation and extension.

We may properly include as a major trend in physics the increasing control of large and small masses in manufacturing operations. The building of gigantic ships and bridges with reliably calculated strengths represents one extreme. Milady's miniature watch or the biologist's micromanipulator for dissecting individual cells is the other. Though these trends will doubtless continue, it is not to be expected that along this line the next century will show an advance comparable with that of the last. When objects are of dimensions of the order of a thousand feet, gravitational forces become of such importance as compared with cohesive forces that further increase in size becomes rapidly more difficult. By using steel of the highest tensile strength, such spans as the Golden Gate bridge become possible. Light alloys should extend the limiting size somewhat; but nature has set a limit to the distance between supports of objects, which at best is roughly five or ten miles, and for most forms of objects is much less.

Similarly, we are already working with things so small that their molecular motions are appreciable. Molecular bombardment is now a limiting factor in the precision of electrometers and galvanometers, so that further decrease in size is of little value. For scientific work, including living cells, metallurgy, atomic studies, etc., there is, however, much to be gained by further emphasis on observing and handling microscopic masses.

Corresponding to the extension of our knowledge of distances, there is a similar extension in our knowledge of masses. It was almost two centuries ago that Cavendish weighed the earth and thus made possible the measurement of the masses of the sun and planets. Only within the last generation has it become possible to estimate reliably the amount of matter in our galaxy. We can even begin to guess with some confidence the mass of the knowable universe. Similarly since 1900 precision methods have been developed for weighing molecules, atoms and sub-atomic particles, even including that most elusive of objects, a single ray of light. Having thus weighed the largest and smallest of things, further extension of this art must be in the direction of refinement and simplicity of measurement.

These developments in our knowledge and control of time, space and matter constitute the growth of the fundamentals of physics. Only a brief mention can be made of modern trends in the more detailed aspects of the science.

Both physics and chemistry are concerned with developing materials with desirable properties. The recent great advances in this direction will doubtless be discussed by Professor Urey. The dynamics of moving bodies, which from the time of Galileo to the present century had been primarily of academic interest, has with the use of the automobile become an essential part of everyday knowledge. With the development of aerodynamics, hydrodynamics has likewise received new impetus.

Perhaps the most significant mechanical advance of the last century, however, was the development of sources of power, steam and gas engines and water turbines. The efficiency of conversion of potential and chemical energy into useful work by these engines has increased from an original few per cent. to a value so high that though further advances are possible they can not greatly alter the power situation. We are favored for the time being with plentiful supplies of fuel in coal and oil. Within a century petroleum will have to be extensively supplemented by artificial liquid fuel, a procedure already followed in Europe. Within a thousand years the more readily available coal will be approaching exhaustion. New sources of power will thus gradually become of importance. Sources now available include agricultural products, such as wood and alcohol, water power, wind power and direct solar heat. Of these, perhaps that of agricultural products has the greatest promise of becoming a major power source. It is apparent, however, that unless fundamentally new developments occur, future generations will not be as favored as we are with regard to available power.

One of the major problems of the physics of the future is thus to investigate all sources of energy which show promise of being important. A hopeful lead is the inexhaustible flow of energy from the sun and stars in the form of radiant heat. Geological records indicate that for a billion years the sun has poured heat upon the earth at about the same rate as it now comes to us. Chemical energy, such as coal burning in oxygen, could not supply this power for more than a thousand years before the sun would cool. Within the last twenty years several theories of stellar heat have been put forward, the most promising of them based upon atomic nuclear reactions similar to radioactivity. In the laboratory, it has been found that such nuclear reactions can be produced and are capable of supplying heat in the necessary amounts. We do not yet know, however, how these nuclear reactions are made to occur efficiently on the sun, nor have we any assurance that they can be brought about on earth in such a way as to act as a source of energy.

Our situation in this regard is similar to that of the primitive man who felt the pleasant warmth of a forest fire, but had not learned how to keep the fire alight, much less how to kindle it. We know the desired energy is present on the earth. We hope to learn how to make it available to man.

There is thus no reason to be pessimistic with regard to power supply. It may require a decade, a century or a thousand years, but there appears no reason to fear man's inability to find an adequate new supply before the failure of power sources now developed limits the advance of society.

It is evident that we have only begun to appreciate the many uses of power. Heat, artificial light and running water have become almost universal in this country. Refrigeration, including air conditioning, is rapidly expanding its usefulness. Electric power and heat in the home, power for transportation and for industry—here is a trend that is upward, with no limit now in sight. The trend in the electrical distribution of power seems to be toward placing power plants near sources of fuel or water power, and transmitting the energy by high tension. Here physical problems of electrical insulation and electrical resonance are involved. Great improvements in high voltage insulation and very possibly use of direct current will make possible much farther transmission at much higher voltages.

The efficiency of electrical motors, generators, transformers and heaters is already so nearly perfect that further improvements in this direction are unimportant. There is considerable room, however, for improvement in the efficiency of electric lighting. Though notable advances have been made within the last generation, it remains theoretically possible to produce more than ten times as much white light for a given expenditure of power than is now given in ordinary house lighting. The fluorescent lighting now being introduced marks another important step toward high efficiency lighting; but more remains to be accomplished.

Special mention should be made of the physicist's studies of low temperatures, using liquid helium at fractions of a degree above absolute zero. Here the ordinary physical properties of elasticity, heat capacity and electrical conductivity are greatly altered. Recent developments have made this extreme cold accessible without great difficulty. We have not yet found important industrial uses for such low temperatures, but there is good reason to anticipate significant scientific advances from studies in this field.

It would appear that optical instruments have approached close to the limit of their technical development. The wave structure of light prohibits appreciably higher optical resolution than is attained by present instruments. Rapid development is, however, in progress in the understanding and use of rays of other wave-lengths. Within the past fifteen years the complete spectrum of electromagnetic waves, from the longest wireless waves, through heat rays to light, and on from ultraviolet to x-rays, gamma rays and cosmic rays, has been explored. In the short-wave regions of ultraviolet and x-rays, and in the long-wave regions of infra-red and radio waves, efficient radiators are available, and the properties and possibilities of the rays are well understood. There remain, however, intermediate regions, especially that of waves from a millimeter to a centimeter in length, which hold significant scientific and practical possibilities, which have not been developed.

Closely associated is the question of communication. Every stage of this advance has followed upon some fundamental discovery in physics. The work of Oersted, Ampere and Henry on the magnetic effect of the electric current led directly to the telegraph. The electric waves of Maxwell and Herz made possible Marconi's wireless. Radio broadcasting had to await the electron tube of Richardson and de Forest. The photoelectric cell is essential to television. There remains great room for advance in this field, using the physical laws and techniques now understood. One can not predict what new principles may appear which will bring about further epochal changes.

There are many professional physicists who are not at all concerned with the practical applications, but solely with the fundamental principles of their science. The understanding of the physical world is their objective. Within the last half century they have found the atoms postulated by Democritus two thousand years ago and have learned much regarding their structure and properties. Sub-atomic particles have also been found and investigated, electrons, positrons, neutrons, photons, barytrons and neutrinos, the building blocks of which the world is made. Some of these particles are known only as visitors, coming to us as cosmic rays from remote space. Their masses and electrical charges are known. When these particles approach each other at very short distances, new kinds of forces have been found, which overpower the ordinary electrical and gravitational forces.

Similarly, the physicist looks outward. He finds with Einstein that for rapidly moving planets a slight modification of Newton's law of gravitation is necessary. At distances greater than the diameter of our galaxy there apparently appears a repulsive force which becomes greater than gravity and makes galaxies fly apart.

He suspects his laws of electrodynamics and of the conservation of energy, and subjects them to more searching tests. For this work no laboratory particle has sufficient energy. He must use a cosmic ray with a thousand times the energy that he can develop by electrical methods.

THE GROWING INFLUENCE OF PHYSICAL DISCOVERIES

If such a physicist can appreciate more adequately his place in the world and why things are as they are, he has a sufficient reward for his effort. This knowledge forms an essential part of man's cultural heritage. Yet its importance is also great in shaping men's lives. Its significance in this regard can perhaps be best indicated by citing examples. Consider the discovery of electromagnetic induction by Faraday and the discovery of x-rays by Roentgen.

Faraday's discovery was considered a century ago as a purely scientific curiosity. It was recognized that here was a means of producing an electric current, and laboratory generators were made. But why should the public be interested in electric current? It was fifty years later, when Edison showed the value of electricity in lighting houses, that the importance of Faraday's discovery began to be evident. With regard to the effect it has had upon the lives of men, it is, I believe, demonstrable that the discovery of electromagnetic induction was the most important event of the nineteenth century. Empires would fall apart, society would become disorganized, if the electrical machines based upon Faraday's discovery were put out of commission.

Roentgen's discovery was made within the lifetime of most of those listening to this address. What could be of more purely academic interest than extending the spectrum of electromagnetic radiation to a thousand-fold shorter wave-length? That was Roentgen's achievement. I have tried to think of the most important event that has happened in my lifetime. Perhaps it was the world war. Let us then compare the consequences of Roentgen's quiet announcement of x-rays in 1895 with those of the dramatic events which in 1914 plunged the world into war. Let us speak in terms of human values, life and death, attitudes, means of living, the organization of society.

First consider death. Such data are hard to find. The war lords do not want them advertised. I have, however, recently looked up the figures. In the world war there were about 8½ million soldiers killed in all the armies, one fourth of the able-bodied men now living in the United States and Canada—a tremendous slaughter. Yet of the 450 million people then living in the countries at war, some 50 million will have died of cancer. The lives of some three million others will have been saved from cancer by the use of x-rays and the radium which was discovered as a result of x-rays. If you add to these the considerably greater number whose lives have been saved by the x-ray diagnosis of tuberculosis, a broken bone or an infected tooth, it becomes evident that even in the warring countries x-rays will have saved as many lives as were taken in battle.

"But," I hear you saying, "what of the vast political and economic disturbance caused by the war?" X-rays have also had their great economic and political effects, not so dramatic, but perhaps even more far-reaching. What does it mean to the economic and political life of the United States to be integrated by radio? For one thing it means that we are a unit of governable size, with no apparent tendency toward disintegration. It means nation-wide markets for centrally produced and advertised goods. Yet without x-rays, no radio. For the radio is the child of the electron, and the electron owes its recognition to the ionization of air by x-rays. Similarly, were it not for x-rays we should not now have sound movies or long-distance telephony or radio beacons to guide air mail or a multitude of other devices that rely upon electrons for their operation.

But the real significance of such a discovery as x-rays is much deeper. Physics lay stagnant. "The future lies in the next decimal place," was the current phrase of the day. With it inactive, other fields of science were also developing but slowly. For twenty years the idea of ions had been making poor headway in chemistry and physics. The announcement of x-rays kindled a tinder box. Never perhaps has history shown such an outburst of scientific activity. Thousands of investigators set themselves to study the newly opened possibilities. Within a few months came the announcement that x-rays dissociate air and other gases into charged ions, and chemistry had the impulse that was needed to start it on its phenomenal modern growth. Another few months, and radioactivity was discovered, leading to radium and all its consequences. Another year or two and electrons became known. The atomic theory was now on a firm basis, but the atom itself was found to have a structure. Not an important field of science but was stimulated by these developments. The geologist had placed in his hands a radioactive clock for measuring the ages of his rocks. The biologist was given an artificial method of producing mutations, changing species at will. The psychologist received electron tubes for measuring nerve currents. The scientific world was set aflame. While many advances would have occurred without Roentgen's discovery, its appearance greatly stimulated these advances. One may say that the modern scientific era was ushered in by x-rays.

If science has come to have a determining place in our economic, social and intellectual life, it is because of such discoveries as this. Strictly speaking, one such achievement should not thus be singled out as if it alone had caused these transformations; for the whole body of science is closely interrelated. Roentgen's discovery is rather to be compared with a declaration of war which initiates a whole series of world-shaking events. On this basis, as seen after forty-three years, the discovery of x-rays is thus quite comparable with the starting of the world war.

But here is a vast difference. The scars of the great war are rapidly healing. New alliances are being formed. Future wars are being planned and old ones forgotten. Science's achievements, on the contrary, are of growing significance. Recent discoveries have not yet shown their human worth. Had we used Faraday's discovery of electromagnetic induction instead of the much later one of Roentgen, our comparison with the world war would have been too one-sided. Electrical machinery is vital to the world's existence. Industrially, politically or socially, it is now far more significant than the result of any past war. We have seen the growing value of the discovery of x-rays. A century from now, when the world war means no more than the pages of history describing Napoleon's conquests mean to us now, x-rays and the developments consequent upon it will have become of a significance comparable with that of electricity to-day. Physics and the future! All history demonstrates the growing value of scientific discoveries. Fire, the wheel, handling of iron and steel, the laws of motion and electricity, never have they meant as much to man as to-day. By the same token we can be confident of the permanent value of the scientific achievements of our own age.

In the past there have been alternating periods of rapid scientific advance and relative stagnation. There are now definite signs of a decline of physics research in central Europe; but the increasing interest in both fundamental and applied physics in other parts of the world indicates that this decline is a local rather than a world trend. The Orient has joined the Occident in physics research. India contributes to our knowledge of scattered light and of stellar atmospheres; China interprets atoms by scattered x-rays; Japan develops iron with new magnetic properties. British research is carried on throughout the empire. Mexico joins effectively in the study of cosmic rays. With physics research now truly world-wide, the future advances can hardly be greatly affected by local political disorders. On the other hand, we may continue to expect periods of relative stagnation following the solution of problems that occupy the attention of leaders of the science. This was the situation in physics toward the close of the nineteenth century after classical mechanics and electrodynamics had been developed, and again in 1930 for a brief period, following the development of quantum mechanics. Very probably similar quiescent stages will follow the solution of the major problems of nuclear physics and cosmic rays. As before, however, these quiescent stages should be only temporary, for many physics problems remain to be solved and the rewards for their solution are great.

PHYSICS AND A STABILIZED SOCIETY

The growth of physics is thus intimately bound to the future of civilization. Advances in science and techniques go hand in hand, and both become easier in a well-organized society where specialists can develop highly specialized skills. It is thus impossible to conclude an adequate statement about physics and the future without some consideration of the mutual relation between physics and the organization of society.

It has become clear to all who have their eyes open that the great power given to man by his new knowledge of the world may be used either to his good or to his harm. Without cooperation, we have seen that this knowledge can not be made fully effective. If men divide into antagonistic groups it may become terribly destructive. When it becomes sufficiently evident that the welfare of the more powerful communities depends upon cooperation rather than upon strife with others, we may expect such cooperation to be not far distant. The growth of physics, through its great advances in communication, its highly specialized and interdependent industries, and the great power given to industrially organized communities, is rapidly bringing about just this condition, where strife endangers every one and cooperation gives rich rewards to all. Thus, not only does physics need well-organized civilization for its own development, but it is in itself a powerful factor in stabilizing such a cooperative society.

OBITUARY

FRANK BURSLEY TAYLOR

FRANK BURSLEY TAYLOR was born in Fort Wayne, Ind., on November 23, 1860, the only child of Judge Robert S. and Fannie Wright Taylor. His father was nationally known as a master of law in cases involving electrical sciences and a man of superior talent and broad interests. Taylor was graduated from the Fort Wayne High School in 1881, but because of poor health