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WHAT RESEARCH HAS DONE FOR YOU

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IT IS WITHIN THE MEMORY of every man of sixty that in the great Empire State of New York —and in the most intelligent of her communities, too, —the question could be seriously debated as to whether Archbishop Usher's chronology, computed by adding Adam's 930 years to Enoch's 365 years to Methuselah's 696 years, etc., gave the correct date of the creation. Today we know from radioactive measurements that the age of the earth is not less than two billion years. That is something "research has done for you."

But what has this to do with "Science and Industry?" Everything! For mankind's fundamental beliefs about the nature of the world and his place in it are, in the last analysis, the great moving forces behind all his activities. Hence the enormous **practical** importance of correct understanding as a guide to all actions.

It is man's beliefs about the nature of his world that determine whether in Africa he spends his time and his energies in beating tomtoms to drive away the evil spirits; or in Phoenicia in building a great "burning fiery furnace" to Moloch into which to throw his children as a sacrifice to his God; or in Attica in making war on his fellow Greeks because the Delphic Oracle, or the flight of birds, or the appearance of an animal's entrails bids him do so; or in medieval Europe in preparing for the millennium to the neglect of all his normal activities and duties; or in burning heretics in Flanders, or drowning witches in Salem, or making perpetual motion machines in Philadelphia, or magnetic belts in Los Angeles, or soothing syrups in New England.

The invention of the airplane and the radio are looked upon by everyone as wonderful and preeminently useful achievements, and so they are—perhaps one-tenth as useful as some of the discoveries in pure science about which I wish to speak.

Look, for a moment, at the historic background out of which these modern marvels, the airplane and the radio, have sprung. Neither of them would have been at all possible without 200 years of work in fundamental science before any bread and butter applications were dreamed of. This work started in the seventeenth century with Copernicus and Kepler and then Galileo, whose discoveries for the first time began to cause mankind to glimpse a nature and a nature's God, not of caprice and whim—as had been all the Gods of the ancient world—but instead a God who rules through law, a nature which can be counted upon, and hence is worth knowing and worth carefully studying.

This discovery, which began to be made about 1600 A. D., I call the supremely useful discovery of all the ages, for before any so-called practical application was ever dreamed of, it began to change the whole philosophical and religious outlook of the race; it began to effect a spiritual and an intellectual revolution.

The material revolution came later. The Reformation preceded the machine age. This new knowledge was what began at that early time to banish the monastic ideal which had led thousands, perhaps millions of men, to withdraw themselves from useful lives. It was this new knowledge that began to change man's conception of his duty—which is the essence of religion—to inspire man to know his universe so as to be able to live in it more rationally.

As a result of that inspiration there followed 200 years (1600-1800) of pure science involved in the development of the mathematics and of the celestial mechanics necessary merely to understand the movements of the heavenly bodies. Though this seemed useless knowledge to the unthinking, it constituted an indispensable foundation for the development of the terrestrial mechanics, the power machines, and the industrial civilization which actually followed in the nineteenth century; for the very laws of force and motion essential to the design of all power machines were completely unknown up to the time of Galileo and Newton.

Do you practical men fully realize that the airplane was only made possible by the development of the internal combustion engine—and that this in its turn was only made possible by the development of the laws governing all heat engines, the laws of thermodynamics, through the use for the hundred preceding years of the steam engine (1780-1880)—and that this was only made possible by the preceding 200 years of work in celestial mechanics—and this again was due to the discovery by Galileo and by Newton, in the first half of the seventeenth century, of the laws of force and motion, which have to be utilized in every one of the subsequent developments?

That states the relationship of pure science to industry. **The one is the child of the other.** You may apply any blood test you wish and you will at once establish the relationship. **Science begat modern industry, and the son now owes a great debt to its parent.**

In the case of the radio art, the commerical values of which now amount up to the billions of dollars, the parentage is still easier to trace. For if one's vision does not enable him to look back 300 years, even the shortest-sighted of men can scarcely fail to see back as much as forty years. For the whole structure of the radio art has been built since 1910, definitely and unquestionably upon researches carried on in the pure science laboratories for twenty years before any one dreamed that there were immediate commercial applications of these electronic discharges in high vacua.

It is precisely the same story everywhere, in all branches of human progress.

So far I have merely traced the historical steps and the researches through which the heat engine and the dynamo—which now do practically the whole of the world's physical work—came into being. Now, let me trace similarly the transition from nineteenth to twentieth century physics.

This transition was probably made as dramatically in my case as in that of anyone in the world, for I was in the fortunate position of having entered the field just three years before the end of the complete dominance of nineteenth-century modes of thought. In those three years, 1893-1896, I had the privilege of personally meeting and hearing lectures by the most outstanding creators of nineteenth-century physics—the giants Kelvin, Helmholtz, Boltzmann, Poincaré, Rayleigh, Van't Hoff, Michelson, Ostwald and Lorentz. In one of these lectures I listened with rapt attention to the expression of a point of view which was undoubtedly held by most of them—indeed by practically all physicists of that epoch.

The speaker had reviewed, first, the establishment and definite proof of the principles of mechanics during the seventeenth and eighteenth centuries, culminating in Laplace's great "Mecanique Celeste" (Celestial Mechanics). Then he had turned to the wonderfully complete verification of the wave theory of light by Young, Fresnel, and others between 1800 and 1850—experiments which laid secure foundations for the later structure known as "the physics of the ether," one of the most beautiful products of nineteenth century thinking and experimenting. Then he had traced the development, in the middle of the century, of the greatest and most fundamental generalization of all science—the principle of the conservation of energy. Finally he covered the development by Maxwell (1867-83) of the electromagnetic theory, and its experimental verification by Hertz in 1888—only six years earlier than the date (1894) of the lecture in question. This theory abolished, in all particulars except wave length, the distinction between light, radiant heat, and long electromagnetic waves—all these phenomena being included under the general head of the physics of the ether, or the physics of radiant energy.

Then, summarizing this wonderfully complete, well-verified, and apparently all-inclusive set of laws and principles—into which it seemed that all physical phenomena must forever fit—the speaker concluded that it was probable that all the great discoveries in physics had already been made. Future progress was to be looked for, not in bringing to light qualitatively new phenomena, but rather in making more exact quantitative measurements upon old phenomena.

Just a little more than one year later, and before I had ceased pondering over the aforementioned lecture, I was present in Berlin on January 4, 1896, when Roentgen presented to the German Physical Society his first X-ray photographs. These clearly demonstrated that he had found some strange new rays which had the amazing property of penetrating as opaque an object as the human body, and revealing on a photographic plate the skeleton of a living person.

Here was a completely new phenomenon—a qualitatively new discovery, and one having nothing to do with the principles of exact measurement. As I listened, and as the world listened, we all began to see that the nineteenth century physicists had taken themselves a little too seriously, that we had not come quite as near sounding the depths of the universe, even in the matter of fundamental physical principles, as we thought we had.

This was the dramatic introduction, from the standpoint of one of the very young stage assistants in the play, to the new period in physics. Nobody at that time dreamed, however, what an amazing number of completely new phenomena would come to light within the next ten years.

The discovery of X-rays in December, 1895, had revealed a whole new domain of ether physics—phenomena that travel with the speed of light. The discovery of **radio-activity**—discovery No. 2— which came in 1896, now revealed an entirely **new property of matter,** and quite as important a property—so far as its influence upon our conceptions of our world are concerned—as any which had ever been discovered. For it forced us, for the first time, to begin to think in terms of **a universe which is changing, living, growing, even in its atomic elements**—a dynamic instead of a static universe, such as the nineteenth century had assumed. It has exerted the most profound influence not only upon physics, which gave it birth, but also upon chemistry, upon geology, upon biology, upon philosophy and religion, changing our ideas in all of them. For radioactivity not only revealed for the first time a world changing, transforming itself continually even in its chemical elements, but it also began to show the futility of the gross mechanical pictures upon which we had set such store in the nineteenth century.

Again, one had to wait only another year for the appearance of another stupendous discovery—discovery No. 3. Roentgen's discovery furnished an instrument and a technique which made possible the rapid development of the **electron theory of matter** by J. J. Thomson of England in 1897. This was one of the grandest, because the simplest, of all the great physical generalizations. It pictured the electron not only as a constituent of all the atoms of matter, but also as the binding element that held the atoms together. What that discovery has done for industry is immeasurable. Radio, radar, motion pictures—there is scarcely an industry that does not use that electronic discovery. One now asks, what hasn't **that** "research done for you?"

But, further, these three great discoveries were soon followed by Planck's even more fundamental one—discovery No. 4—**the discovery of discontinuous, jump-like, or "quantum" energy and momentum changes.** The reason this discovery had not been made earlier is that man was here entering an almost completely unexplored domain—namely, the domain of subatomic or microscopic, as distinguished from ordinary or macroscopic, energy and momentum exchanges. This field is most simply entered through photo-electric research, already found industrially very useful, especially in television. These last three discoveries, 2) radioactivity, 3) electronics, 4) quanta, actually determined the direction of my own study and research for the next fifty years.

But the greatest discovery of all—discovery No. 5—came in 1905. It may have been something of a blow to the nineteenth century to learn of the general transmutability of the elements, but how much more of a shock to find that **the principle of the conservation of matter itself is definitely invalid.**

Beginning in 1901, the mass of an electron was shown by direct experiment to grow measurably larger and larger as its speed is pushed closer and closer to the speed of light, i.e., energy is here being transformed into mass, or inertia. But of much greater interest than that is the reverse process found through the fact that Einstein worked out of the relativity formula a general relation between the two quantities, energy and mass, of the form $mc^2 = E$. Here, m means mass in grams, c^2 is the velocity of light squared, or the enormous number 9×10^{20}, and E is energy in ergs.

This equation seems now to have the best of experimental credentials. The atomic bomb at least has convinced the world of that. If it is a correct one, it means that matter itself in the Newtonian sense, the quantitative measure of which is mass or inertia, has entirely disappeared as a distinct and separate entity, i.e., as an invariant property of any system. In other words, **matter may be annihilated, the equivalent radiant energy appearing in its place.** And in view of the enormous value of the factor 9×10^{20}, a very small number of grams of matter may transform themselves into a stupendous number of ergs of energy. Thus, according to Einstein's equation, one gram of mass transferring itself into heat or radiant energy per second means the development of 90 billion kilowatts of power.

It is well known with what joy the astronomers have seized upon this fact to enable them to explain why the sun, for example, can not possibly have been pouring out heat as long as it is now known to have been doing if it is merely a hot body cooling off. Or again, if it were pure carbon and oxygen in their proper combining ratio, the sun would burn itself out in only 2,500 years. If, however, it has the capacity at the tremendous temperatures existing in its interior — say 40,000,000° C.—of transforming its very mass into radiant energy, then the great mystery of its enormous lifetime is solved.

Further, we now think we know the process by which this transformation takes place. It is the process of the building up of the heavier elements out of the lightest primordial element, hydrogen, which still constitutes a considerable part of the sun's mass. We now estimate that 80 per cent of the sun's atoms are hydrogen atoms. Here is the key to the evolution of heat by the sun. Accurate measurement actually shows that the four uncombined hydrogen atoms weigh more in the uncombined state than in the combined state. The difference—called the "packing fraction energy"—is what feeds the furnaces of the sun, which generously sends our share down to earth for storage in coal or oil, or for direct use in wind-mills, solar heaters and the like. Mother Earth has stored away in coal alone enough solar atomic energy to keep us going for 4,000 years, at the present rate of use of heat and power.

According to my calculations, there may be 1 per cent as much packing fraction energy available to us through the fission of uranium as through the burning of coal. Therefore, if I am right, those of you who are in the power industry don't need to fear ever being put out of business by fission energy. This has already shown great biological usefulness, but uranium's practical utility is limited by its rarity, by its commercial availability—and if man has got any intelligence at all he will conserve his uranium and not burn it up in heat or power plants. **There is no atomic packing energy to be got out of the common abundant elements.** That, again, is something that "research has done for you."

Now, let me close by telling you what I think industry should do in its own interests and at the same time—though only incidentally—to pay back a little bit of the debt it owes to both fundamental and applied research. (I treat them here as one since all research that increases our knowledge of nature, or our control over her processes, is useful research, as I have attempted through the foregoing history to show.) What such research, then—whether you call it pure or applied—has done in the past for you, it can assuredly do even more fully in the future, if you act with wisdom and intelligence. The key to the whole problem lies in the careful selection and training of young research men.

Within the last forty years, the United States has helped mightily to save world civilization twice when it was threatened by the spirit of the wild beast. What is happening now in international affairs shows clearly that that spirit is not yet dead, and that therefore we must provide the most effective defense against it of which we are capable.

I think that the most obvious teaching of the last two wars in both England and America is that the most effective defense consists in having an adequate supply of able, well trained scientific men.

But that is not only the key to our **defense. It is also the key to all our future progress as a nation.** The Rockefeller Foundation saw this thirty years ago, and in collaboration with some of us officers of the National Research Council set up the National Research Council Fellowship Board to meet that need. I can give you statistical evidence that since the date at which this step was taken the United States has risen from a place well down the line among the nations in productivity, in both pure and applied science (certainly in physics, chemistry, biology and medicine) to a place of world leadership in all these fields.

I attribute that change largely to the National Research Fellowship plan. Not only that, but those National Research Council fellows also were found in key positions in World War II. They certainly did their full share in the winning of that war. Though specifically trained in so-called fundamental science, they actually came strikingly into leadership in the practical problems of the war—that is, in radar, in rockets and other phases of jet propulsion, in atomic energy developments, in meteorology, etc.—problems which the exigencies of war brought forth.

This well-tested National Research Council Fellowship plan could be and should be greatly expanded **now,** and without essential change. It is a highly competitive plan of proved effectiveness for picking and training the ablest research material among the nation's coming leadership in science and its applications. In my judgment, this is a responsibility that should be assumed by **industry** in the interests of its own progress, but the results would be available for national defense as well, as was the case in World War II.

If the foregoing move is made in a large way by industry—in the interests of picking and training its most effective personnel for its own use—the movement will be entirely removed from the corrupting influence of politics, and from all the trends toward totalitarianism or stateism, in which lies the greatest menace to the future of a free America. The need is great and the time is critical—no less critical than when the immortal Lincoln raised the question whether this nation or any nation conceived in liberty and so dedicated could long endure. Never in our history have the forces tending to destroy the free American way of life bequeathed to us by the founding fathers, been so strong the world over as at this moment. Here is, I think, one of the most effective ways of preserving our freedom.

COMET 1948 l

by EDISON PETTIT

COMET l (l for the twelfth letter of the alphabet; this being the twelfth comet seen this year) is reported to have been first seen and photographed in Africa during the solar eclipse of November 1. It was first reported by Dr. Harley Wood in Australia on November 6, and by Dr. John Paraskevopoulos in Africa on the 7th. It was then south and somewhat east of the star Spica (Alpha Virginis), rising just before the sun. When first seen in the northern hemisphere in the morning of November 9 it was 12° south of Spica and 12° east of Corvus. The head was of about the brightness of the pole star, 2nd magnitude, with a tail extending westward some 20°.

The orbit of this comet passes the sun within one eighth the earth's distance, or 12 million miles. The comet reached this nearest solar distance (perihelion) on October 27, coming toward the earth from behind the sun, so that its approach could not be observed. In fact, it has been inside the earth's orbit since the last days of September, but the sun has always been in the way. By the end of November it was leaving the earth's orbit and, already faded to magnitude 5, with a tail only 6° long, would soon become a telescopic object.

Whether a comet is a remarkable object depends on (1) the amount of matter in it, (2) the closeness of its approach to the sun, (3) the position of the orbit with relation to the earth's, and (4) the relative places of the earth and comet during its appearance.

Brilliant comets with long tails streaming across the sky are rather rare. One of the finest comets of the last century was that of 1882, discovered in broad daylight on September 3. It was one of the "Sun Grazers" and actually passed through the solar corona. Seen in the autumn sky, this comet exhibited a brilliant tail and sheath at the head extending toward the sun.

In the present century the comet of 1907, visible in the morning sky, was a bright object—much better situated and brighter than the present comet. Comet 1910 a, in the winter evening sky, had a tail more than 30°long, and Halley's comet of that year was a wonderful sight. No comet can be compared with Halley's. It passed through all the phases of comet formation, from a faint fuzzy spot to its appearance on that spring morning when the earth actually passed through its tail—which could be seen streaming from horizon to horizon. The great comet of 1914, which passed over the northern sky, was the last of the great brilliant comets which everyone in the northern hemisphere could see. Compared with these, the present comet is second rate, and about the same as comet 1947 n, another southern comet.

Comets are probably a dense cluster of small meteorites mixed with gaseous material, which is driven away by the action of the sun—we suppose, by light pressure—to form the tail. The sheath of the head in great comets cannot be explained by light pressure. The light of the tail and head consists of reflected sunlight and light emitted by the gases **per se.** This emitted light consists largely of the hydro-carbon and cyanogin bands. A study of the intensities in the spectral lines of these bands by Dr. Pol Swings has shown that this light is emitted by a process of fluorescence. The nuclei of the heads of great comets sometimes also show light emitted by sodium and other metals near the time of perihelion passage.