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CONTENTS

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MICHELSON'S ECONOMIC VALUE[1]

IN the year 1896 Albert A. Michelson took a new egg into the nest over which he brooded—or the department on which he sat—at the University of Chicago, and after an incubation period of twenty-five years—so long a time did it take to prove that the egg had ever been fertilized at all—he at last had it hatched and sufficiently feathered to justify pushing it out of the nest and bidding it go scratch up its own worms.

To-night, Mr. Chairman, you, representing the public which is obliged to supply the corn-meal required to keep both Michelson and Millikan scratching, have brought us here to exhibit our worms and to let you see whether they are worth the price paid to get them. And as you will presently see that leaves me no choice but to take for the subject of my speech the length of Mr. Michelson's worm, or the economic value of Michelson. For if you ask him to explain, in terms that you can understand, the value of his work I think that you will be told to go to the interior of a star where the temperature is estimated to be 50,000,000° C., or even to a hotter place, if such there be, described by a familiar monosyllable especially beloved by men like Michelson trained for the sea. For Mr. Michelson is wont to say that the sole reason, and the good and sufficient reason, why he spends so much time trying to measure the velocity of light to one part in three hundred thousand is simply that he likes to do it.

But I am going to make bold, now that I have left the nest and am where he can no longer reduce my rations, to contradict him and to tell you, and to tell him, that that is not the sole reason, nor is it the good and sufficient reason. (You see, Mr. Michelson, the young rooster, after the immemorial manner of young roosters, is questioning the old cock's right to do just exactly as he "damn-pleases" in the hen-yard.) To prove my point I have only to call your attention to the fact that if Mr. Michelson had "chosen" to spend his days and his nights sitting on a log pounding it with the butt end of a hatchet he would soon have found himself in a straight-jacket in the nearest institution especially provided by the state for the care of the deranged.

[1] Address delivered at the dinner of the Society of Arts and Sciences held in New York on February 22, 1929, upon the occasion of the presentation of the gold medal of the society to Messrs. Michelson and Millikan.

In a word, the reason you, the public, support Michelson's work on ether drift and the velocity of light, and the reason he sticks at those measurements like a burr to a collie-dog, is that both you and he *have faith in the worth-while-ness* of those measurements. And the real reason that he tells the reporters that he does it merely because he likes to is that he knows that if the reporter hasn't already "got religion" it can't be pumped into him in two minutes. There are some things that one can not explain for the next edition of the tabloid newspaper.

But the matter goes still deeper. It is rarely that a scientist himself knows just where his particular increment to the sum total of human knowledge is going to fit into "the whole," or find its relations to other increments. Galileo was not looking for useful applications when he was rolling his marbles down the inclined plane to discover the laws of force and motion, nor Kepler when he tried to understand the orbits of the planets, nor Newton when he deduced the law of gravity from observations on the moon, nor Volta when, merely toying with contact electrical effects, he laid the foundations for an understanding of electrical potentials; but all of them undoubtedly *had confidence in the value of knowledge* in enabling man to live more wisely in his world, not perhaps so much in enabling him to raise more cabbages to the acre, but, much more important than that, *in preventing him from wasting his time and his energies in chasing illusions,* in enabling him *to direct his thinking and his acting toward realities* instead of toward will-o'-the-wisps. It is only in looking back from our vantage point of centuries that we see that these men by their researches were actually *ushering in a new civilization.*

Has the time yet come when we can look back upon the particular type of activities, exceedingly precise physical measurements, which Mr. Michelson has followed, and say that from the standpoint of the hard-boiled business man who has had to pay the bills they have justified themselves? It is much too early now to balance the books, and will probably be too early for centuries to come, for the inspiring thing about work in the field of science is that *every bit of new knowledge becomes from the moment of its discovery the heritage of all future ages,* enabling coming man, as long as mankind endures, to live just so much more wisely than past man has known how to live. But in the case of Michelson's work I think we can even now get an inkling—a mere suggestion—of some of its economic values or at least its economic possibilities. Of course these may be either positive or negative—there are always some entries on both sides of a ledger—and since Mr. Michelson always inspired me by example to be strictly honest whatever happens, I am going to begin by presenting one of the liabilities instead of the assets. This one has to do with that particular nearly-bad-egg that he had to incubate for twenty-five years before it hatched and matured sufficiently to justify him in pushing it out of the nest.

When in 1917 I made the best determination I could of the value of the electron I had to use in getting the final quantity the best value then available of the velocity of light, I went to Mr. Michelson and asked him within what limits I might count upon his determination of the velocity of light. He replied, "To one part in ten thousand." So I chose for my computations the value $c = 2.999 \times 10^{10}$ cm./sec., the nearest value, to four places of accuracy, to his mean, and since my accuracy in the determination of e could not be more than one part in a thousand I thought I should never have to bother about changing e because of anything that might happen to the velocity of light. But last year, unfortunately for me, Mr. Michelson made a new and most accurate determination of c, which is one part in 3,000 instead of one part in 10,000 lower than my chosen value. Also, because of two new determinations of the absolute value of the ohm—experiments of quite the Michelsonian type though made by others—I find that my value of e is probably affected because of the change in this last constant by one part in two thousand, and these two changes being in the same direction, I am obliged to change my value of e by about one part in a thousand so that it becomes 4.770×10^{-10} instead of 4.774×10^{-10}.[2] This is such a wound to my pride

[2] The reason I have not heretofore made the foregoing readjustment in my value of e is, first, that it is of no particular significance anyway (see below); and, second, that I have until recently doubted its legitimacy.

In the presentation of the best values of widely used physical constants I have heretofore questioned the wisdom, or even the correctness, of making a differentiation between so-called international units and absolute units before a suitably authorized international commission had recognized that difference, since otherwise such differentiation would rest merely upon some individual's *estimate* of the superior reliability of some particular new determination or determinations over the weighted mean of the whole series of determinations used by the international commission which in 1908 and 1911 fixed upon the international units. However, Professor Raymond T. Birge has called my attention to the fact that in view primarily of the close agreement between new determinations of the absolute value of the ohm by F. E. Smith (*Phil. Trans.*, 1914) and Grüneisen and Giebe (*Annal. Physik.*, 1920), the compilers of tables have actually recently begun to make the foregoing differentiation. It is because of this fact and because of Michelson's undoubted new precision in the measurement of the velocity of light that I have thought it worth while to begin herewith to recognize the effect of these changes upon the value of e.

But this change is actually only of academic interest, since it is in any case within the limits of my estimated uncertainty. The limit of accuracy of the oil-drop method is fixed by the uncertainty in the measurement that I am thinking of trying to obtain heart-balm by instituting a breach-of-promise suit against Mr. Michelson. If I succeed, the economic value of Michelson will be about a hundred thousand dollars less than it is now. So much for the debit side of the account.

Let us now glance at an item or two on the other side of the ledger. The special theory of relativity may be regarded as merely a generalization of the famous Michelson and Morley experiment, another typical Michelsonian attempt to measure with great precision a quantity of fundamental importance, namely, the speed of the earth through the ether. As everybody knows, it came out negative, that is, no such speed, nor any trace of it, could be found, and after forty years of most painstaking repetitions, capped by Michelson last year, it still seems to be impossible to find any speed whatever of the earth with respect to the ether.

Einstein, in 1905, generalized the foregoing result by postulating that it is in the nature of the universe impossible to find the speed of the earth with respect to ether. This postulate rests most conspicuously upon, and historically grew chiefly out of, the negative result of the Michelson-Morley experiment. Now one of the most important consequences that Einstein drew from the special theory of relativity is that mass and energy are interconvertible terms—that radiant energy, for example, can not appear without the corresponding disappearance of mass. This startling conclusion, which amounts to the denial of the ancient doctrine of the conservation of mass as distinct from the conservation of energy, has in recent years met with three new and powerful experimental supports. The first is that the assumption that the sun is stoking his own mass into his furnaces, and thereby reducing his waist-band at a rate measured by the scales of 250,000,000 tons a minute, furnishes the only means the astronomer can now find of accounting for the enormous lifetime of the sun and the stars, as attested by both astronomical and geological evidence. The second is that the interconvertibility of mass and energy seems to be an established experimental fact in the special case of an electron moving with a speed close to that of light. The third is that the facts of radiation-pressure, discovered by Lebedew in Russia, and Nichols and Hull in America, about 1898, mean that ethereal radiation has the only distinguishing property of mass, namely, inertia. Further, the quantitative equation of relationship, namely, $mc^2 = E$, in which m is mass in grams, c the velocity of light, and E energy in ergs, follows inevitably from the theory of relativity, and three different quantitative tests of this theory, all involving very painstaking and very precise measurements of the Michelsonian type, have all now yielded results *in quantitative agreement* with the predictions, so that I think that all physicists and astronomers will now agree that the foregoing equation is a safe guide for the theorist of the present and the future. *Historically, it is hard to see how it could ever have been arrived at without both Michelson's own very exact measurements, and others of the kind he has led the way in showing how to make.*

of the viscosity of air, which enters into it in the 3/2 power. In my determination of e I estimated the viscosity of air to be known to 1/20 per cent. If this is an overestimate e would be affected 1½ times as much, so that if Eddington's recent theoretical deduction of e, which is ½ per cent. higher than my value, is correct, the viscosity of air must be about .3 per cent. higher than I have estimated it to be. I do not think this can be the case.

Now, whether that conception has any immediate commercial importance or not, if it is true, as we think it is, it is one of such stupendous significance for man's understanding of the universe in which he lives that its importance transcends all assignable money value, and Michelson's part in bringing it to light makes him a bigger world-asset than any billion dollar corporation in the United States, or than all of them put together.

But I am not through yet with the rôle played recently in human progress by refined physical measurements of the Michelsonian type. While Michelson has been driving ether-drift and speed-of-light experiments to the limit of accuracy in America, Aston in England has been setting himself a precisely similar task in determining, by the so-called isotope technique, the atomic weights of the elements.

The first result was the beautiful discovery that the weights of all the elements are exact multiples of a fundamental unit which is close to the weight of the hydrogen atom. I use the word beautiful in describing this discovery because of the amazing simplicity and orderliness with which it endows nature, inevitably suggesting that all the elements have been built out of hydrogen.

But while we are admiring the beauty and simplicity of this generalization, let me call attention to the interesting circumstance that even some of us physicists overlooked for years the result that everybody can now easily see, namely, that the foregoing exact-multiple law, first stated in 1913 and 1914, is in irreconcilable conflict with the preceding generalization, the Einstein equation. For if mass and energy are interconvertible, and if the masses of all atoms are exact multiples of a mass-unit, then there can be no emission or absorption of energy when these units go out of one atom, or into another. In other words, there can be no forces holding atoms together and preventing transmutations, and there can be no evolution of energy when such transmutations spontaneously occur, as they do in radioactive processes. These conclusions are obviously contrary to all experience so there must be something wrong with the isotope law unless we are willing to throw overboard Einstein's equation.

Just what was wrong was brought to light a year ago last summer, for the case of all elements except hydrogen, solely because of Aston's skill in *adding another decimal point to the accuracy with which he could measure the masses of the various atoms*—a typical Michelsonian accomplishment.

And these new measurements, along with Einstein's equation, enabled Dr. Cameron and myself to get about a year ago what seems to me to be the inevitable interpretation of the so-called "cosmic rays"—strange super-gamma rays which bombard the earth incessantly day and night, apparently without any measurable change in intensity with either direction or time. They are best observed and measured by sinking electroscopes in deep, high altitude, snow-fed lakes. Their easily observable ionizing effects are found to decrease rapidly with depth but, according to our as yet unpublished measurements of last summer, not to disappear entirely until depths of much more than three hundred feet have been reached.

With the aid of Einstein's equation and Aston's atomic weights Dr. Cameron and I have computed the energy that should be released in a radioactive change—a process which transforms one atom of accurately measured mass into another atom of accurately measured mass. The difference in the measured masses before and after the change should give, when multiplied by c^2, the energy evolved, also accurately known, and *the results are found to check with the computation,* thus giving credentials to the method.

The interesting result of this mode of approach is that it shows that *no radioactive or disintegrating process can occur which, according to Aston's measurements, can possibly produce a radiation more than one fourth as energetic,* i.e., *as penetrating, as our softest observed cosmic rays nor more than one thirtieth as energetic as our most penetrating observed cosmic rays.* On the other hand, the creation of the common elements out of hydrogen should, according to Aston's atomic mass measurements and Einstein's equation, release energies of just about the observed penetrating power—quite accurately the observed penetrating power according to Dirac's formula. But the exactness of the fit is not at this stage very important. The illuminating facts are, first, that only the *atom-building process* can produce cosmic-ray *bands* of anything like high enough energies, and, second, that the *sequence* of observed cosmic ray frequencies fits quite nicely the sequence of the atomic weights of *the abundant* elements, which are very few in number, for probably more than 95 per cent. of all matter consists of oxygen, magnesium, silicon and iron. Our conclusion is that *the evidence is very strong that the cosmic rays are the subatomic radio signals broadcasting the continuous creation of these elements somewhere.*

But where? Apparently not in the sun or in the stars, since all observers agree that the sun, the great hot mass just off our bows, affects by his presence *not in the slightest* the stream of cosmic rays flowing into the earth. Further, Dr. Cameron and I can find no effect of the Milky Way, nor of the nearest extragalactic system, the spiral nebula of Andromeda. We think, therefore, that the high temperatures of the stars are inimical to the clustering processes required for the building of the common elements out of hydrogen, and we conclude that *the intensely cold regions of interstellar space probably furnish the essential conditions for such atom building.*

Whether or not the foregoing conclusion is correct, Einstein's equation and Aston's curve alone, the former due partially to Mr. Michelson, the latter representing superrefinement in physical measurement of just the sort that Mr. Michelson is famous for, enable us to draw one definite and very important conclusion, namely, that *there is no energy available to man through the disintegration of any of the common elements.* Man will presumably some day learn to disintegrate the elements, but he will have to expend energy upon them to do it. *There is no appreciable energy available to man through atomic disintegration.* Radium, it is true, releases about a million times as much energy per gram in disintegrating as carbon does in burning, but there isn't enough of it, nor of any radioactive substance, to more than keep a few corner pop-corn men continuously going.

On the other hand, a practically unlimited supply of energy would be available to man if the hydrogen in water and elsewhere on the earth could unite, here on earth, to form helium, nitrogen, oxygen and the other common elements. This, we think, is just what is happening in interstellar space and thereby producing the observed cosmic rays, but the foregoing cosmic-ray facts seem to indicate *that this process can not take place on earth,* and if this is true, then man will, in the future as in the past, depend entirely upon the sun for his supply of available energy. To bring us up against such *realities* is the mission of men like Michelson. Inspiring realities they are, too, and their economic values are well-nigh unlimited, for we can direct our own efforts and our energies to better advantage with that knowledge. We have not yet begun to utilize the solar energy that is available to us, and we shall do it better with the knowledge that it is probably all we have.

If you belong to the group represented by the Bishop of Ripon which fears the too rapid advance of science and lives in dread of the day when some unscrupulous, or careless, Dr. Faust may touch off the stupendous subatomic powder magazine and blow this comfortable world of ours into star dust, you may henceforth banish your hobgoblin and sleep in peace in the consciousness that the creator has realized the wisdom of introducing some fool-proof features into his machine. If, on the other hand, you belong to the group represented by Lord Birkenhead which anticipates that one fine day the scientist will transform this earth into a Lotus Land in which the atoms will do all our work for us while we lie in bed and keep our digestions good by ordering two atoms worth of massage between meals, then you may wake up, banish your idle Utopian dream, and get back to your job, reflecting that the best of life is in the striving, and that there is infinitely more fun in learning how to smash a resistant atom than there could be in lying on your back and watching it explode.

Michelson's economic value! In the last analysis there is nothing that is practically important at all except our *ideas,* our group of concepts about the nature of the world and our place in it, for out of these springs all our conduct. There is not an idea that I have advanced to-night, a conclusion that I have drawn from Einstein's equation, from Aston's curve, from cosmic ray data, that would have been possible had not somebody driven to the limit the precision of physical measurement, and much of it became possible because of Michelson's own super-refined experiments—so true has it been proven to be that human progress "grows out of measurements made in the sixth place of decimals." Not he, nor anybody else, saw at the time what bearings the results would have. He merely felt in his bones, or knew in his soul, or *had faith to believe* that accurate knowledge was important. But some of the bearings have already appeared and others will continue to be found for ages yet to be.

I personally owe *everything* to the fact that thirty-two years ago Mr. Michelson took me into his nest at the University of Chicago, and I personally believe that the United States has not had in this generation a greater economic asset than Albert A. Michelson.

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METEOR CRATER EXPLORATION

IN its genesis, characters and relations the Arizona meteoric bowl is unique, unless the pittings in Siberia made by a meteor fall in 1908 are comparable. The Meteor Crater with its association of iron meteorites is one of the scientific marvels of the world, but not yet properly appreciated by the public or by the scientific fraternity. Unfortunately the subject is involved in unhappy personalities.

A recent article (June, 1928) in the *National Geographic Magazine* gives a popular description of the crater, but is faulty in omission and in implication. It fails to give the proofs of meteor-impact origin; it omits the very interesting story of its exploration and study, and, most important, fails to give proper credit for discovering and publishing the evidence of its impact origin. On the contrary, the article by implication and by the photographs appears to give the credit for discovery to G. K. Gilbert and the U. S. Geological Survey. Naturally any account of the crater exploration and the discovered evidence would have required the name of Daniel Moreau Barringer, which was entirely suppressed.

Naturally and properly the implication in the article has been resented by Barringer, who at great cost in time, effort and money explored and probed the crater, marshaled and first published the facts, and so proved beyond any reasonable doubt the meteor-impact genesis. A very spirited correspondence, involving a number of friends of Barringer, has not yet obtained the *amende honorable.* There is here a question of scientific and journalistic ethics. The purpose of this writing is to tell the true story of the crater study and to establish the credit for the discovery and publication of the truth.

The masses of nickeliferous iron, known as Canyon Diablo siderites, have been found in great numbers, and of size up to 1,400 pounds, scattered over the Arizona desert a few miles south of Sunshine station on the A. T. and Santa Fe Railroad. During the late eighties or early nineties of the last century two parties, F. W. Voltz, at Canyon Diablo, and the Williams Brothers, at Winslow, made a business of collecting the meteorites, with the aid of Mexicans, and of selling them to institutions and collectors all over the world. In consequence the Canyon Diablo siderites are the most widely distributed of all meteorites. They were also the first to yield minute diamonds, described by A. E. Foote in the *Proceedings* of the American Association for the Advancement of Science, Vol. 40, 1892, pp. 279–283.

In the midst of the desert area over which the irons were distributed is the great crateriform pit, four fifths of a mile across at the top and about 450 feet deep below the surrounding plain. With the elevated rim of quartz dust and rock fragment it has, from the inside of the bowl, a vertical relief of 570 feet.

This association of the crater, then bearing the absurd name of Coon Mountain or Coon Butte, with the