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THE EDITOR'S PAGE

CAN SCIENCE WIN THE PEACE?

In an article entitled "Science Education and the Contemporary World",[1] published in the January, 1943, issue of the Journal of Chemical Education, Professor Gerard of the University of Chicago has the following paragraph.

> "Democracy, even what we yet have, is fighting for its life. Science will win the war—our science, I am certain, on evidence too elaborate to detail here. But science will not win the peace. For one thing, a scientific approach to the problems of reorganization will not be used—the pull and tug of realists with particular interests will resolve the direction of movements, as always before. For another, the problem of ends is still not, or barely, within the scope of science —even if idealists sit in the reconstruction councils they will be in dispute as to what ought to be done. Perhaps the peace will be lost again. But sooner or later, if democracy is to put healthy flesh on its abstract bones, the mass of people and their leaders must act scientifically. And this can be brought about only by the education they receive."

We can all concur, surely, in the belief that our science is going to win the war. We will be most anxious also to agree that science is not going to win the peace, even though our reasons for agreeing to this statement may be different. Clear thought, unprejudiced judgment, willingness to face facts and courage to live up to recognized truth are the qualities of mind needed in our peace makers. While these are part of the scientific method, they are by no means the exclusive property of science. The virtues which minds embued with these qualities must apply do not fall under the subject matter of any science, but are the simple foundation stones of two thousand year old Christianity. Perhaps, as many think at present, we are in greater danger of losing the peace than of losing the war. But, if and when that peace comes, science both as a vehicle of education and in its practical applications to every day comforts, is going to play a larger part in our lives. The end of the war will bring with it a revision of educational values. Secular educators realize now that man cannot live by science alone. The panacea has failed and leaders are insisting again on a liberal education. We, as Catholic leaders, know the only source of true peace; we know also, the marvelous part science should play in lasting peace. The tasks at hand tax everyone to the limit, yet others find time to consider these problems. They are planning the education for the peace to come. Are we?

1. Journal of Chem. Ed. 20 1 (1943)

SCIENCE AND PHILOSOPHY

THE SCIENTISTS AND FINAL CAUSALITY

Rev. Joseph P. Kelly, S. J.

In a previous article, (1), we discussed the notion of Finality in its philosophical aspects, in its relation to efficient causes and its validity in the interpretation of the material world. No attempt was made to prove it "scientifically," because we believe that no such proof exists, since teleological is essentially metaphysical. One example was proposed, that of Max Planck, (2), who asserted that the Law of Snellius "yielded a formulation of physical causality which has a distinctly teleological note." Our present discussion does not pretend to be a scientific demonstration of final causes. We will cite a few scientists who have accepted the teleological as well as the physical (efficient) view of Nature. The purpose is to show that in the mind of many scientists there is no incompatibility between the two points of view.

BACON and NEWTON

Lord Francis Bacon did not deny final causes; he did exclude them from the scope of the physical sciences. "It is rightly said that to know truly, is to know through causes. And rightly is it stated that there are four causes: material, formal, efficient and final. Of these, *final cause alone* should be omitted because it corrupts science, except in human activity." (3). After a further development of these notions, he adds: "The second part of metaphysic is the inquiry of final causes, which I am moved to report not as omitted but as misplaced . . . Not that those final causes are not true and worthy to be inquired, being kept within their own province but because their incursions into the limits of physical causes has bred a vastness and solitude in the track. For, otherwise, men are deceived if they think that there is enmity and repugnance between them," (4). "Both causes are true and compatible, the one declaring the intention and the other, the consequence only."

Bacon was distinguishing between "physical" causes and metaphysical causes. The term "physical" was much in vogue at that time, denoting the current concept of cause, as used among both

(1) Jesuit Science Bulletin. May, 1942. p. 163.
(2) Idem. p. 167.
(3) "The Works of Lord Bacon." Pub. by Bohn, London, 1854. Vol. II. p. 457.
(4) Idem. Vol. I. p. 37, sq.

scientists and philosophers. In the reaction against Aristotelian philosophy, these men were trying to avoid whatever seemed to savor of metaphysics. The "physical" cause denoted the relation between an antecedent and a consequent, and the notion of causality was equivalent to "invariable sequence." Since the final cause was not quantitative, Bacon naturally ruled it out of his attempt to formulate his methods for scientific advancement. His own words show that he did not deny the value of finality in other fields than that of the physical sciences, any more than he denied the value of metaphysics in itself. Unfortunately, he placed too much faith in his "scientific method" and the imagined progress that would result therefrom.

Newton was far more explicit in his declaration of final causes and believed that they had a proper place even in Natural Philosophy. After commenting on the fact that all bodies fall with equal velocity "in vacuo" under the force of gravity, and stating that the celestial bodies move according to the same law, he adds: "but though these bodies may continue in their orbits by mere laws of gravity, yet they could by no means have derived the regular positions of their orbits themselves from these laws." (5) This merely states what he noted elsewhere that the law of gravity could tell us how fast a body would fall but gives us no cause for it. In more modern terminology, we would say that science tells us "how a body acts" but not "why it acts." Newton recognized that the mind of man sought instinctively some knowledge that was not to be found in the natural sciences. They are deficient and must be supplemented from other sources. After describing the orbital planets about the sun and the moons that revolve about Jupiter and Saturn, he continues: "But it is not to be conceived that mere mechanical causes could give birth to so many regular motions . . . This most beautiful system of the sun, planets and comets could only proceed from the counsel and domination of an intelligent and powerful Being. And if the fixed stars are the centres of other systems, these, being formed by like wise counsel, must be subject to the domination of One." From such data Newton argues to some perfections in God and concludes: "We know Him only by His wise and excellent contrivances of things and *Final Causes.* (italics ours) . . . a god without dominion, providence and final causes is nothing else but Fate and Nature. Blind metaphysical necessity, which is certainly the same always and everywhere, could produce no such variety of things. All that diversity of natural things which we find suited to different times and places could arise from nothing but the ideas and will of a Being necessarily existing. And thus much concerning God; to discourse of Whom from the appearances of things certainly belongs to Natural Philosophy." (6).

(5) Newton, "Mathematical Principles of Natural Philosophy" Revised Translation by Cajori, U. of Calif. Press, 1934. p. 543.

(6) op. cit. p. 546.

The citation is rather long but we justify it because of the position of honor that Newton holds among the scientists. Perhaps it will serve to show how far the moderns have wandered from the ideal of one of their founders. Newton did not hesitate to introduce ideas of the supernatural as well as the metaphysical into Natural Philosophy. One can find nothing in Newton to justify that extreme position of many scientists, which tries to exclude from Science any notion except the observable and the measurable. But return to our problem. Cajori notes in his explanation of this famous Scholium that: "Newton used the term, *final causes* as did Aristotle and distinguished four kinds of causes: material, formal, efficient and final. Aristotle's final cause was the purpose, aim or end for which a thing is made." (7).

If we take these two as examples of the mentality of some of the early scientists, we see that there was no question of the rejection of final causes. However, Bacon pretended to give an ultimate explanation of the problem of the universe without final causes, but Newton realized that such an interpretation demanded the introduction of Finality. The Empiricists and the Positivists in the school of science held out for the rejection of all metaphysical notions. Since early times, scientists have been divided on that score. The revolt against Aristotelian Philosophy carried with it the loss of many things which would have been of much help to the scientists and might have avoided the present crisis in science. It was a "revolt against reason," not in favor of it. Newton's concept of final causes and their use in his system, as a comprehensive interpretation of Nature, was quite certainly metaphysical. It could not be proved experimentally. He offers no Mathematical formula for it. Yet, he does not hesitate to include it in his "Mathematical Principles of Natural Philosophy." At least, we can hold that he saw no incompatibility between the efficient and the final causes. He did not feel that he was guilty of an inconsistency in venturing into this field to complete his vision of natural phenomena.

Modern Scientists

In more recent times, Meyerson asks the question: "Can causality, (efficient) exist side by side with Finality." (8). In human activity, he sees no problem. Men have a free will and may or not do the bidding of another. They have a choice and can determine themselves. From one point of view, Meyerson sees the impossibility among inorganic beings. It is due, in part, to a misconception of the problem. "In the case of inorganic agents, whose actions are under the direction of inflexible laws, there exists no choice, all is determined. Finality has no part. It cannot withdraw the phenomena from the domination of

(7) op. cit. p. 670.

(8) Meyerson. "Realite et Identite." p. 363.

law and it cannot rule directly except that which seems not to be governed by law, that is to say that it is outside of science." (9). Two comments should be made on this citation. First, as we have explained in the previous article, efficient cause even in the scientific sense, does not preclude finality. A man may perform an action in the sense that he is the efficient cause of this action and at the same time may act for a purpose. Secondly, we agree that in the inorganic order, finality does not exist in its *formal* sense of the term. We can predicate only an *analogous finality* of beings that do not possess rationality. On the other hand, Meyerson admits that there is a legitimate interpretation of finality even in the inorganic world. For he says: "On the contrary, nothing prevents the laws themselves from being explained by finality. Every empirical law, from the fact that it appears to us as contingent, may be conceived as emanating from a will visioning an end." (10). He cites the case of water reaching its maximum density at 4° C., which is open to a teleological interpretation. This was discussed sufficiently in our previous article. In this opinion, Meyerson is following the same lines as Newton. The origin of things finds no explanation in scientific laws. Lest we read too much into the opinions of Meyerson, let us add that he always safeguards the scientific point of view, maintaining that if we can find a satisfactory interpretation in physical, efficient causality, the teleological interpretation must yield place. The physical cause holds the primacy in science. Lacking this, finality may serve. All of which we readily concede, if one holds strictly to scientific principles and scientific methods. But these, we believe, are definitely insufficient.

In a work, entitled: "The Great Design," (11) published a few years ago, one may read citations from various scientific men on this problem. The purpose of the book seems to be to gather together the attitude of these authorities on purpose in the universe. True, none of these writers make any attempt to prove finality in the world from a scientific point of view. Their opinions are extra-scientific. For example, Sir J. Arthur Thompson says: "That the world is orderly, that events and phenomena have a relation one with another, that there is a definite disposition of physical bodies and all the elements from which flow what we commonly call Order and the Course of Nature, none will deny. Not only is it being demonstrated by the scientists but its very existence, independently of ourselves, must be supposed as a guarantee of science and the basis of all physical laws. Science does not create order, nature and truth; it seeks to discover what actually is . . . In our daily life, purpose counts for much and thoughtful men have continued for many centuries asking whether there is purpose in Evolution. This is one of the questions that Science neither asks nor answers. What Science seems to show is that

Meyerson, op. cit. p. 364.

(11) "The Great Design." Ed. by Frances Mason.

we cannot make sense of the universe nor our place in it unless we believe in the reality of Purpose and Divine Plan that has counted throughout the past and will continue to count in the future." (12). Purpose or final causality is one of those problems that can find no answer in science. Thompson, as a scientist would very probably agree with Meyerson in holding that the final explanation should give way to the physical, efficient in science. As Wolf asserts: "in the case of the purely physical sciences teleological explanation has no place." (13). Speaking outside the strictly scientific realm, all of them would seem to leave room for a finalistic conception.

One might multiply instances indefinitely, in fact, several volumes have been written on this subject. The more deeply the scientist probes the real, the more certain does he find the rule of law and determination, either under the strict form of the law of Classical Physics or along the lines of Statistical interpretation. The "fortuitous concurrence of atoms" has lost favor as an explanation of the material order. Chance can no longer be accepted as a basic factor. We realize fully that there are many scientists who do not accept finality and probably one might cite as many against this concept as those in favor of it. Eddington prefers to call it an "anti-chance" factor, rather than use the term, "purpose." Be that as it may, we believe that these citations indicate a definite trend of thought among men of science. Those who maintain an out and out Positivism and refuse to admit metaphysical concept in any way connected with the physical sciences, have the merit of consistency with their fundamental principles. As scientists, their position differs in no way from other scientists who accept the notion of teleology. The latter, however, seem to recognize that the strictly scientific interpretation of the universe is not sufficiently comprehensive and does not satisfy the legitimate tendency of the human mind to seek further explanations. Mechanism cannot touch the real. It deals with the phenomenal and our sensations regarding the real. From the laws of nature, we may derive many excellent descriptions of the behavior of things but there is no law of science which will tell us that the purpose of a clock is to denote time. The law describes the uniform motion of the hands of the clock. As Newton says, although the heavenly bodies move according to physical laws, these same physical laws tell us nothing about the origin and variety of the motions of planets. Something more is needed.

The Physical Sciences pretend to offer us an interpretation of the world. For some three centuries, the scientists have gone along developing their fields through the experimental methods and such principles as Physical Determinism and mechanical, efficient causality. The history of Science gives us ample testimony of their success.

(12) "The Great Design." p. 15.

(13). Wolf. "Essentials of the Scientific Method." p. 124.

But even here, there has been a noticeable lack of totality in their explanations. Methods and principles have been found wanting, especially in the region of sub-atomic phenomena. We need but mention the conflict, today, between the Determinists and the Indeterminists or the divergence of opinion on the relation between Causality and Statistics. To the credit of the scientists, be it said that they are formulating new concepts and new methods to meet these crises. But in view of the failure of the Materialistic Philosophy, so prevalent in the past, many scientists are inclined to reject this philosophy and are attempting to work out a new philosophy for science. Perhaps it is in hope of finding some solution for these problems that a few have taken up the idea of purpose and goal. That this is a new type of inquiry, we readily admit. Further, we recognize that any results that come from this investigation will be in an order, outside that of the ordinary lines of inquiry. Strictly speaking, these results will not enlarge the scientific knowledge, as we ordinarily understand it.

In the last analysis of this problem, we are dealing with the universe and our understanding of it. It is a complex world, many-sided and containing more aspects than can be comprehended by any one branch of knowledge. Witness the various divisions of the Physical Sciences, each treating a particular phase of Nature. If we use the term, "science" to embrace all the Natural Sciences, and hold that Science is *one* pathway to knowledge but not the *only* pathway to knowledge, how much more limited will be any particular science. Beyond the sciences are many wide fields for the investigation of Nature's hidden truths. One does not necessarily exclude the other.

The joining of the "causa efficiens" and the "causa finalis" may seem rather novel to many. Yet it is simply a reversion to the practise of the early scientists, e. g., Newton. Planck's teleological interpretation of a ray of light moving through the shortest path appears to be a bold stroke. It is not often that a scientist makes such a striking departure from the traditions of scientific interpretation.

The introduction of finality would seem to demand a sort of "complementarity" doctrine—to borrow a term from the scientists. In the case of the electron, the scientist observes that at times it manifests the properties of a wave phenomenon and at other times, those of a corpuscular phenomenon. A reasonably sufficient explanation requires both aspects. One completes the other. Efficiency and finality are likewise complementary, when the mind demands a satisfactory knowledge of natural events. The Laws of Nature may show how physical bodies act, they reveal nothing of the reason why they act in a particular manner nor why there are laws. This "why" may be beyond the scope of the physical sciences but it is not outside the province of the human intellect. The Law of Snellius does express the fact that a ray of light takes the shortest path but gives no reason for this shortest path. Why should it not take the middle path? Would not the empirical law be equally valid in this case? It is true that we may not be able to solve the eternal "why" in all cases, but that merely indicates the limitations of the mind. There are still a large number of unsolved problems in the sciences. Who has yet understood the force of gravity? In the course of investigations, explorers will sometimes come upon the remnants of an ancient civilization. They discover ruins of dwellings, war and domestic implements, etc. From these, they conclude to the existence of a form of civilized life. There must have been a purpose and design behind these. Otherwise, how explain their existence. The universe about us manifests undeniable signs of this same purpose and design. By the same argument we are justified in using the notions of teleology, in addition to efficiency, for an adequate interpretation of the world.

CHEMISTRY

HISTORY OF ATOMIC WEIGHT DETERMINATIONS[1]

By Gerald F. Hutchinson, S. J.

MODERN WORK. Theodore W. Richards

In this section of our history we will confine ourselves to the work of Theodore W. Richards and his associates at the Harvard laboratories; not because this is the only worth while work of the kind done in modern times, but because we think an appreciation of the work done at Harvard provides a just survey of the advance made since the beginning of this century.

Toward the close of the nineteenth century, Josiah Elias Cooke was professor of natural philosophy at Harvard University. Theodore W. Richards was a young man, growing to all appearances, into the profession of his father who was an artist. But Cooke was a friend of the Richards' family, and made an early and lasting impression on the young son. Allured by the personality of the professor, Theodore left Hanover College without taking a degree to study under Cooke. The chemistry of the time was taught in the course of natural philosophy, and Professor Cooke really mixed his philosophy with his science. He was convinced that atomic weights were numbers freighted with mystery and that a deeper knowledge of them would provide the key to many storehouses of human knowledge. He strove to impress this conviction on the minds of his young students, and to arouse in them a desire to work in this direction. When Richards sat at the feet of Cooke the exhortation fell on fertile soil. To Cooke and his philosophic approach to atomic weights, perhaps more than to any other individual cause, we may attribute the bending of Richards' genius toward atomic weight determinations.

Cooke's own work on the atomic weight of antimony was the first work of its kind undertaken in the United States. After Richards had attained his Bachelor degree he was put to work determining the combining ratio of hydrogen and oxygen. The method previously employed was the reduction of copper oxide in an atmosphere of hydrogen. Richards used the same method but with this important change. Previously the weight of oxygen had been determined by the loss of weight of copper oxide, and the weight of hydrogen by the difference between this weight and the weight of

1. This is the second in a series of articles on the history of atomic weight determinations.

the water formed. Thus all the error of the process was accumulated on the measurement of the weight of hydrogen, the lightest substance to be measured. Richards weighed the hydrogen directly in large containers and determined the weight of the oxygen by subtraction. By this method, taking all possible precautions, he established the ratio, 8 to 1.0082, a value within 0.0004 of the value accepted today. If one were looking for the keynote to Richards' success, it could be found here in his very first work. His determination to weigh the hydrogen directly excellently exemplifies his genius for discovering points of procedure which would increase the accuracy of his final results.

A study of atomic weight determinations by the chemical method may be conveniently divided into two parts, the choice and purification of the starting materials, and the decomposition and analysis of the compound. Richards' attack on these two problems may be described briefly though they involved seemingly endless, tedious and monotonous labor.

Four conditions are laid down by Richards for the choice of starting material: 1—it must be capable of preparation in a very pure state; 2—it must contain, besides the element whose atomic weight is to be determined, only elements whose atomic weights are accurately known; 3—the condition of valent must be definite, i. e., there must be only one stage of oxidation; 4—it must be capable of exact analysis or of exact synthesis from weighed quantities of the elements concerned.

Once the compound has been chosen the work of purification begins. This was carried out for the most part by the ordinary methods of quantitative analysis familiar to every student, but the pains which Richards took to insure absolute purity staggers all except those who are endowed with the patience and love of precision which were part of the very nature of Theodore Richards. One becomes weary with monotonous routine while reading in the papers of Richards of crystallization after crystallization, of evaporation after evaporation and of distillation after distillation. When the material has thus been prepared in a very pure state, the work is scarcely half done. The other process of decomposition and analysis is about to begin. There are two chief difficulties met with in this procedure, the solubility of the precipitate formed, and the tendency of each phase to carry away with it some of the phase from which it separates. The methods used by Richards to meet these difficulties will now be discussed.

The Bottling Apparatus

If the compound is to be prepared in a state of absolute purity, it is clear that the last fine traces of moisture must be excluded. Also, with certain compounds, traces of moisture will hydrolyze the substance, thus changing the chemical constitution and vitiating the results. This difficulty was first met by Richards in his work on the atomic weight of strontium, and was overcome by his invention of what is now called the "bottling apparatus." The compound, after thorough drying by fusion, had to be cooled in an atmosphere free from moisture. The apparatus consists essentially of two tubes fitted together by a ground glass joint. The first is usually made of quartz to withstand fairly high temperature, and in this is placed the substance to be dried held in a drying boat. The other tube is of ordinary glass and has a pocket in one side. The bottle in which the substance is to be weighed and stored until needed is placed in this tube and its stopper in the side arm. A steady stream of any gas desired can be circulated through the whole apparatus. In this atmosphere the whole substance is dried, and when thoroughly dry the boat is tipped into the bottle, the stopper worked into place and then by means of a rod forced tight before any moisture can diffuse into the bottle. Before opening the gas is swept out by a stream of nitrogen and finally by a stream of previously dried air. Of a substance thus dried Richards says, "The substance is really dry, and its weight has a definite meaning."

Since the determination of atomic weights in many cases involves the weighing of a silver halide, the solubility of this salt presents an interesting difficulty. It has been known since 1857 that this substance is sufficiently soluble to affect quantitative results. Silver chloride has a solubility of several milligrams per liter when freshly precipitated, but a large excess of either ion reduces the solubility. Stas thought that three times the weight of silver chloride dissolved was sufficient to effect total precipitation. Richards showed that the amount depended upon the efficiency of our methods for detecting the last faint cloud, and even then only approximately. For the purpose of such detection Richards devised the nephelometer which has since become famous in biochemical work.

The Nephelometer

Two test tubes are arranged near each other and slightly inclined toward each other, and by means of sliding shades, can be slightly or totally shielded from a bright source of light. The tubes are observed from above by means of two thin prisms, which bring together one half of the circular top of each tube, and produce an appearance resembling the half shadow apparatus of the polarimeter. The unknown substance is precipitated as an opalescence by suitable reagents in one tube, and a known amount treated in exactly the same way is placed in the other tube. Each tube reflects light and the tubes appear faintly luminous. If the shades have to be adjusted to exactly the same height in order to show like tints to the eye, the amount of precipitate in the two tubes may be assumed to be equal. If, on the other hand, the shade over the known tube must be adjusted so as to expose only half as much of the opalescent mixture as in the other tube, the former precipitate may be assumed to be twice as plentiful. Accordingly a new standard solution is made up containing only half as much precipitate as the former and a new test made. Of this apparatus Richards says, "In this way in a very short time, the amount of suspended precipitate in the unknown tube may be estimated with considerable precision, and the trace of undissolved substance estimated." The accuracy of this method is interesting. The "considerable accuracy" of which Richards speaks is 1 or 2%, which, when dealing with a suspension of two milligrams per liter, amounts to 0.04 milligrams or one part in 30,000,000 parts of water! As is seen the nephelometer depends on the opalescence of reflected light. The method of Stas depended on the opalescence of transmitted light. The latter is the less accurate.

The method used by Richards to prevent the substance from carrying some of one phase into another phase was not new though the application to the purpose was somewhat unique. His fusions, distillations, etc., were carried out in vacuo.

Standardization of Weights

Richards did not claim that his method of standardization of weights was original. Its wide application, however, was due to him, so we will review it briefly here. The method is known as substitution. One of the weights, usually the smallest, is weighed against some other object, and then another weight of the same denomination is substituted for the original weight and the proper adjustment made. A weight double the denomination is then balanced against both of them and the correction made if necessary. In this way the whole set is balanced, with the result that the whole set is consistent with itself even though it may not correspond with another set. Richards standardized his weights before each determination.

We have said that the chief contribution which Richards made to this work was the detection and correction of errors which were made by previous investigators. The application of his method will become clear by the consideration of a typical example. It may seem strange to us that until 1903 Richards never doubted the fundamental values of Stas, even though he made many technical improvements. He had based all his calculations on the atomic weight of silver as given by Stas, namely 107.66. Such was the trust of one genius in the work of another. However in this year Richards was working on the transition points of hydrated salts as a means of determining fixed points in thermometry. His results with sodium bromide were exceptionally good, so Richards decided to make an analysis of the compound in order to check the ratio of bromine to silver, and thus the atomic weight of bromine. His results were extremely illuminating, revealing an error of 0.2% when compared with the values of Stas. Such an amount was outside the limit of experimental error, so Richards set to work to find the cause of the discrepancy. Having eliminated the possibilities from his own work, he determined upon the laborious task of determining the atomic weight of silver. This involved a check of the ratio of silver to oxygen. Not only did he prove Stas in error, but he found the source of the error and performed the identical experiments and obtained results which checked his own values.

We shall now consider a comparative example of the work of these two men. The determination of the ratio of lithium chloride to silver chloride and silver and the atomic weight of lithium.

The Starting Materials

Stas started with lithium chlorate. The reason for this choice is that lithium has the lowest atomic weight of any metal, the compound contains three times as much oxygen as lithium which is a larger percentage of oxygen, the compound is quite stable and can be purified to a high degree.

Richards, since he was checking the results of Stas, neglected nothing which would improve his results. His starting point was, therefore, a search for a better beginning material. Two important considerations directed his reaearch,

1—Several atoms of oxygen must be involved.
2—The salts must be of such nature that the following ratios may be accurately determined.

$$\frac{MXO}{MX}y \quad \text{and} \quad \frac{MX}{Ag}$$

Lithium perchlorate was finally chosen, after deep consideration, because it was the only salt which combined the following advantages.

1—It was easily purified by crystallization without attendant impurities.

2.—It can be dried by fusion without decomposition. It fuses at 236°C., and loses no oxygen at 300°C.

3—It is not deliquescent or hydroscopic in fairly dry air.

4—It may be synthesized from the chloride merely by the evaporation of this salt from a slight excess of HCl. The less volatile perchloric acid expells the more volatile HCl.

5—It contains 60% oxygen, which is more available oxygen than any other substance including anhydrous hydrogen peroxide. 10 cc., equal to about 24 grams, when changed to the chloride under normal conditions, furnishes about 10 liters of oxygen.

The tabulation of these advantages is a simple matter, but a moment's reflection will reveal the tremendous amount of work required to check these properties, and eliminate other compounds because they fail to meet these requirements.

The Purification of Silver

The methods of Stas and Richards were both electrolytic. Silver was first precipitated from silver nitrate, and finally deposed by electrolysis. To this point they agreed, and Richards believed they had silver of equal purity. The next point was to free the silver from the mother liquor, and here the roads parted.

Stas fused it and cast it into ingots under an oxidizing flux, or granulated it by dropping it into water. In all cases it was reddened in a silver crucible before weighing. Richards pointed out that this method permitted the occlusion of some oxygen which was prevented from escape by the method of cooling.

Richards resolved the difficulty into a two fold question. 1—the container in which the silver was to be fused, 2—the atmosphere in which the fusion was to take place. Stas had used a cupel of basic calcium phosphate, but this showed that a trace of silver phosphate was prepared in this way. After investigating every possible material, lime was found so satisfactory that, after fusion, the silver showed no calcium band in the spectrum. At first glance it would appear that a vacuum would be the best "atmosphere" in which the fusion could take place, but Richards found otherwise. He found, as a result of much experimentation, that the best method was first to fuse it, "in vacuo," and then refuse it in hydrogen. In this way it was possible to keep the amount of hydrogen occluded outside the limit of weighability.

The Purification of Lithium Chloride

Stas attempted to purify his lithium chloride by the ordinary chemical method, but found it practically impossible to remove the last traces of sodium and potassium, which elements are closely allied chemically to lithium. After much labor he still found his product alkaline to litmus, and apparently gave up the attempt as chemically impossible. This, of course, represented an impurity and affected his final results.

RICHARDS found exactly the same trouble, and quickly convinced himself that he wasn't going to get much farther by the ordinary chemical means. He refused, though, to proceed with an impure compound and set to work in the laboratory and library to solve the problem. Eventually he discovered that the fluoride of potassium was sixteen times as soluble as the fluoride of sodium, three hundred and forty times as soluble as the fluoride of lithium. By converting the chloride to the fluoride, precipitation and reconversion to the chloride, he obtained his compound free from sodium and potassium. Finally with his drying apparatus he excluded moisture.

Richards writings are filled with examples of such ingenuity, and it is his ability to meet the type of difficulty discussed above that has given him his greatest title to distinction in atomic weight determination.

The results of Stas and the corrections applied by Richards are interesting. Stas' value for the atomic weight of Lithium was 7.003, and the correction of Richards brought it down to 6.940, a difference of 0.064. This correction is very small, one may say, compared with the work involved. If we consider the work from the purely scientific aspect, it can scarcely escape the highest commendation. The existence of atoms has been a part of our knowledge for less than a century and a half, yet today, due in large part to the men we have considered in this discussion, their relative weights are known with an accuracy to the third decimal place.

What is the practical advantage of these results? We will let Richards answer this question for himself. The answer mirrors Professor Cooke, the philosophical chemist, who started Richards on his brilliant career.

> "Who can tell? What is the meaning of the periodic system connecting these mysterious numbers? No one who has thought about the matter at all, can doubt that a real understanding of the periodic system would take us very far into the understanding of some of the deepest laws of the universe. We have here a cosmic riddle, the answer to which would put into the hands of humanity knowledge heretofore undreamed of."

When Mr. Gladstone was unable to understand some discovery of Michael Faraday, and asked, "But after all, what use is it?" the famous scientist is supposed to have answered, "Why, sir, there is every probability that you will soon be able to tax it!"

How much closer to the truth are both of these leaders of science today than in the days when they uttered these statements!

MATHEMATICS

A SOLUTION OF THE DIFFERENTIAL EQUATIONS OF GEODESIC LINES OF EUCLIDEAN SPACE

JOHN F. CAULFIELD, S. J.

The geodesic lines of Euclidean space (paths of shortest distance between two points in the space) are known from Geometry to be straight lines. The Calculus of Variations provides a method of obtaining the differential equations of the geodesic lines. The Integration of these equations is in almost all cases quite difficult. A method of solving the equations of the geodesic lines of Euclidean space was outlined in an abstract published previously in this BULLETIN for Oct. 1941, Vol. XIX, p. 33. In the present article a detailed solution of a particular case will be given, followed by a generalization for the case of n-dimensional space.

The problem of solving these equations arose in testing a sufficient condition for Euclidean space; namely, in the vanishing of the Riemann Christoffel Tensor. For, the vanishing of this tensor is a necessary and sufficient condition that the differentials:

$$dt^i = -\binom{i}{r\ s}\, t^r\, dx^s, \qquad (i = 1, \ldots, n)$$

be exact differentials and completely integrable.[1] When the components t^i are replaced by dx^i/ds, and the resulting expressions are divided by ds, one obtains precisely the differential equations of the geodesic lines as given by the Calculus of Variations:

$$d^2x^i/ds^2 + \binom{i}{r\ s}\, dx^r/ds\, dx^s/ds = 0, \quad (i = 1, \ldots, n) \qquad (1)$$

so that these equations are integrable under the same conditions.

Attempts to solve equations (1) by quadrature for the case of Euclidean space are difficult. It is possible to show, however, that the equations of straight lines are the primitives corresponding to these differential equations, not by integrating the differential equations directly, but by taking the equations of straight lines as primitives differentiating them twice, and showing that they give the differential equations (1).

1. A proof of this theorem may be found in the Writer's Thesis on Investigating a Necessary and Sufficient Condition for Euclidean Space, Boston College, 1941, p. 11.

First, the solution for the particular case of three dimensions will be given in detail. Then, since the primitives as well as the differential equations are of tensor form, the solution of the particular case will be generalized for the case of n-dimensions.

PARTICULAR CASE: The differential equations (1) for the case of a Euclidean space of three dimensions defined by the spherical coordinates (r, u, v) become:

$$\begin{aligned} d^2r/ds^2 - r(du/ds)^2 - r\sin^2 u\,(dv/ds)^2 &= 0, \\ d^2u/ds^2 + 2/r\; du/ds\; dr/ds - \sin u \cos u\,(dv/ds)^2 &= 0, \qquad (2) \\ d^2v/ds^2 + 2/r\; dr/ds\; dv/ds + 2\cot u\; du/ds\; dv/ds &= 0. \end{aligned}$$

That the equations of straight lines are the primitives corresponding to this set of differential equations (2) is shown as follows:

The equations of straight lines expressed by the Euclidean coordinates (x,y,z) are:

$$x = ks + a, \qquad y = ms + b, \qquad z = ns + c. \qquad (3)$$

Transforming these equations into the spherical coordinates (r,u,v) by the transformations:

$$x = r\sin u\cos v, \quad y = r \sin u \sin v, \quad z = r\cos u, \qquad (4)$$

gives:

$$\begin{aligned} r\sin u\cos v &= ks + a \\ r\sin u \sin v &= ms + b \qquad (5) \\ r\cos u &= ns + c \end{aligned}$$

The first derivatives of equations (5) are then found with respect to the arc length s:

$$\begin{aligned} \sin u\cos v\; r' + r\cos u\cos v\; u' - r\sin u\sin v\; v' &= k, \\ \sin u \sin v\; r' + r\cos u\sin v\; u' + r\sin u\cos v\; v' &= m, \qquad (6) \\ \cos u\; r' - r\sin u\; u' &= n. \end{aligned}$$

Consider these equations as three simultaneous equations in the three variables (r',u',v'), and solve for the variables. A solution by determinants gives: (The determinant of the coefficients reduces to $r^2 \sin u$.)

$$\begin{aligned} r' &= k\sin u\cos v + m\sin u\sin v + n\cos u, \\ u' &= (k\cos u\cos v + m\cos u\sin v - n\sin u)\; 1/r \qquad (7) \\ v' &= (-k\sin u + m\cos v)\; 1/r\sin u. \end{aligned}$$

The second derivatives of equations (7) are then taken with respect to the arc length s:

$$\begin{aligned} r'' = {} & u'\,(k\cos u\cos v + m\cos u\sin v - n\sin u) \\ & + v'\,(-k\sin u\sin v + m\sin u\cos v), \\ u'' = {} & r'\,(k\cos u\cos v + m\cos u\sin v - n\sin u)\,(-1/r^2) \\ & + u'\,(-k\sin u\cos v - m\sin u\sin v - n\cos u)\,(1/r) \qquad (8) \\ & + v'(-k\cos u\sin v + m\cos u\cos v)\,(1/r), \\ v'' = {} & r'\,(-k\sin u + m\cos v)\,(-1/r^2\sin u) \\ & - u'\,(-k\sin v + m\cos v)\,(\cos u/r\sin^2 u) \\ & + v'\,(-k\cos v - m\sin v)\,(1/r\sin u). \end{aligned}$$

The coefficients on the right hand side of these equations may be replaced by substitutions from equations (7). Thus:

$$\begin{aligned} &k \sin u \cos v + m \sin u \sin v + n \cos u = r', \\ &k \cos u \cos v + m \cos u \sin v - n \sin u = ru', \\ &k \cos v + m \sin v = u'r \cos u + r' \sin u. \end{aligned}$$

Equations (8) now become:

$$\begin{aligned} r'' &= r(u')^2 + r \sin^2 u \, (v')^2, \\ u'' &= -(2/r)\, r' u' + \sin u \cos v \, (v')^2, \\ v'' &= -(2/r)\, r' v' - 2 \cot u \, u' v'. \end{aligned} \qquad (9)$$

Yielding precisely the differential equations (2). Hence, equations (3) are the corresponding primitives and their solutions.

GENERAL CASE: The equations of straight lines in a Euclidean space of n-dimensions are:

$$y^i = a^i s + b^i, \qquad (i = 1, \ldots, n) \qquad (10)$$

Generalizing the method used for the particular case, it will be shown that these are the primitives corresponding to the differential equations of the geodesic lines of n-dimensional Euclidean space. As it was pointed out in the beginning of this article, the condition for this solution is that the Riemann Christoffel Tensor vanish. For, in that case the differential equations are exact and completely integrable. The method of showing that equations (10) are the solutions of (1) is as follows:

First, introduce a transformation, transforming the Euclidean variables y^i to any other set of coordinates x^j. The transformations may be written $y^i = y^i(x^j)$, $(i = 1, \ldots, n)$

Substituting the latter in (10):

$$y^i(x^j) = a^i s + b^i, \quad (i = 1, \ldots, n) \qquad (11)$$

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2. L. P. Eisenhart, *Riemannian Geometry*, Princeton: Princeton University Press, 1926, p. 2.

3. C. E. Weatherburn, *Riemannian Geometry and the Tensor Calculus*, Cambridge: The University Press, 1938, p. 58.

Differentiating with respect to the arc length s:

$$\delta y^i / \delta x^j \;\; dx^j / ds_k = a^i_i , \quad (i = 1, \ldots, n) \qquad (12)$$

Multiplying both sides by $\delta x / \delta y$,and summing on the index i, will enable us to solve for dx^j/ds:

$$\delta x^k / \delta y^i \;\; \delta y^i / \delta x^j \;\; dx^j / ds_k = a^i_i \;\; \delta x^k_i / \delta y^i_j , \qquad (13)$$

In the summation indicated by i in $\delta x / \delta y \;\; \delta y / \delta x$, the only non-zero components will be when $k = j$. In that case they are equal to unity, leaving as the result:

$$dx^k / ds = a^i \;\; \delta x^k / \delta y^i . \qquad (14)$$

At this point it is instructive to notice the process of solving for dx^k/ds. The expression $\delta x^k / \delta y^i$ is equal to the cofactor of $\delta y^i / \delta x^k$ in the determinant whose elements are $\delta y^i / \delta x^j$, (i stands for the column and j for the row), divided by the same determinant.[2] When we multiply $\delta y^i / \delta x^j$ by $\delta x^k / \delta y^i$, and sum on the index i, we are multiplying $\delta y^i / \delta x^j$ times the cofactor of $\delta y^i / \delta x^k$ in the determinant whose elements are $\delta y^i / \delta x^j$. When k is not equal to j, the result is zero. When k is equal to j, the result is the determinant itself with elements $\delta y^i / \delta x^j$. In the latter case the numerator and denominator of $\delta y^i / \delta x^j \;\; \delta x^j / \delta y^i$ is one and the same determinant, so that the result is unity. This process of evaluating $\delta y^i / \delta x^j \;\; \delta x^k / \delta y^i$ is usually expressed by means of the Kronecker delta.

Continuing, then, from equations (14), the next step is to take the second derivatives of dx^k/ds with respect to the arc length s. Thus:

$$d^2x^k / ds^2 = a^i \;\; \delta^2 x^k / \delta y^i \, \delta y^h \;\; \delta y^h / \delta x^k \;\; dx^k / ds \qquad (15)$$

From equations (12), introduce the following substitutions:

$$a^i = \delta y^i / \delta x^j \; dx^j / ds$$

Thus: $d^2x^k / ds^2 = \delta^2 x^k / \delta y^i \, \delta y^h \;\; \delta y^h / \delta x^k \;\; \delta y^i / \delta x^j \;\; dx^j / ds \; dx^k / ds$ (16)

The Christoffel symbols of the second kind can now be introduced by making a substitution from their law of transformation. This law contains two terms involving Christoffel symbols of the second kind.[3] In one of the terms the Christoffel symbol is a function of the transformed variables x^j, while in the other term it is a function of the original variables y^i. But the latter variables are Euclidean, so that the corresponding Christoffel symbols are zero. From the remaining terms of the law, the following substitution can be introduced into equations (16):

$$\delta^2 x^k / \delta y^i \, \delta y^h = - \overset{k}{(a\ b)} \; \delta x^a / \delta y^i \;\; \delta x^b / \delta y^h \, .$$

Substituting the latter in (16):

$$d^2x^k / ds^2 = - \overset{k}{(a\ b)} \; \delta x^a / \delta y^i \;\; \delta x^b / \delta y^h \;\; \delta y^h / \delta x^k \;\; \delta y^i / \delta x^j$$
$$dx^j / ds \; dx^k / ds \qquad (17)$$

The components $\delta x^a / \delta y^i \;\; \delta y^i / \delta x^j$, with summation indicated by i, and the components $\delta x^b / \delta y^h \;\; \delta y^h / \delta x^g$, with summation indicated by h, are equal to the Kronecker delta, so that the components $\delta x^a / \delta y^i \, \delta y^i / \delta x^j$ are equal to zero unless a is equal to j, and in that case they are equal to unity; while the components $\delta x^b / \delta y^h \, \delta y^h / \delta x^g$ are equal to zero unless b is equal to g, and in that case are likewise equal to unity.

Equations (17) now become:

$$d^2x^k / ds^2 = - \overset{k}{(j\ g)} \; dx^j / ds \; dx^g / ds,$$

yielding the differential equations (1). Hence, their solutions are of the form of equations (10).

(Note: To facilitate the printing, two symbols have been introduced with the following meanings: The symbol $\overset{i}{(r\ s)}$ is used to represent the Christoffel symbol of the second kind; while the italicized δ is used to denote a partial derivative).

NEWS ITEMS

CANISIUS COLLEGE CHEMISTRY DEPARTMENT

The Western New York Section of the American Chemical Society held their January meeting at Canisius College on Thursday, January 21, 1943.

A "get-together" for all the members of the various committees of the Western New York Section, arranged by Rev. T. Joseph Brown, S. J., Chairman of the Department of Chemistry, was held in the Chemistry Library previous to the dinner at 6:45 P. M.

The dinner speaker was Lieutenant James R. Barrett, ballistics expert of the Buffalo Police Department, who received his Master of Science degree in chemistry from Canisius College in June, 1942. Lieutenant Barrett's topic was "Scientific Crime Detection in the City of Buffalo."

At the public meeting held in the College auditorium, Major John Cummings of the Chemical Warfare Service of the United States Army spoke on "The Chemist's Role in Civilian Defense." Major Cummings, who is lecturing in civilian defense courses at Amherst College, Amherst, Mass., gave an excellent talk on protection from chemical agents which will be of great aid to chemists who have charge of the gas defense civilian groups.

HOLY CROSS COLLEGE CHEMISTRY DEPARTMENT

For the new year beginning on February 15, 1943, the chemistry department has appointed four graduate assistants. They will start the second term in cycle with the graduate appointees of September, 1942, and hope to contince on through the summer.

A number of alumni from the chemistry courses have gone into meteorological work through its earlier organization and through the latest Pre-meteorological training courses given at M. I. T., N. Y. U. and other universities. Although the requirements are taken largely from physics and mathematics, our chemistry students are fortunate in having a sufficient background in these sciences. Their training in thermo-dynamics, either through physical chemistry or in added formal courses, seems to enhance their acceptance for the work and their progress in it. Outstanding alumnus is Captain Roland J. Bourke, U. S. A., who graduated in chemistry, bachelor '39, master '40. He has advanced rapidly; has written the technical manual for one of the courses in the service; and has been sometime instructor at M. I. T. Meteorology seems to be an expanding field. It is a "Jesuit Science."

HOLY CROSS COLLEGE PHYSICS DEPARTMENT

Mr. John K. Chenis and Mr. Bernard H. Moran, formerly members of our staff, are now commissioned officers in the U. S. Naval Reserve with the rank of Lieutenant.

Dr. Alfred Basch is a member of the Physics staff of the College of the City of New York.

On August 11, 1942, Father William F. Burns, S. J., took part in the WGY Science Forum Program (General Electric Company, Schenectady, N. Y.) dealing with the theme: "Roman Numbers versus Decimals."

Dr. William F. Radle, graduate of St. Thomas' College (now Scranton University), joined our faculty last Fall. He had been a member of the Physics Department of Purdue University. Interspersed with his course in advanced studies (A. B. St. Thomas' College, 1927; A. M. Catholic University, 1929; Ph.D. Catholic University, 1940) there have been many years of teaching experience, fitting him in a special way for the present emergency.

ST. PETER'S COLLEGE ALUMNI CHEMISTS CLUB, 1942-1943

October 15—Business Meeting. Election of Officers.

November 12—Lecture. Dr. C. M. Gooding, Director of Research. The Best Foods Incorporated. "The Chemistry of the Vegetable Oil Industry."

December 10—Illustrated Lecture. Rev. Richard B. Schmitt, D. Sc. Chairman of Chemistry Department. St. Peter's College. "Fingerprints of Chrystals."

January 21—Lecture. Mr. H. G. Walker, Manufacturing Engineer, Western Electric Company, Inc. "Three Decades of Chemistry in the Telephone Field."

February 18—Lecture. Mr. R. J. Carey, Research Chemist, General Foods Corporation. "Dehydration of Foods."

March 18—Lecture. Mr. W. H. Stevens, Director of Resin Research, Roxalin Flexible Finishes Company. "Organic Finishing in the Present Emergency."

April 22—Illustrated Lecture. Joseph B. Niederl, Ph.D., Director of Micro Organic Research, New York University. "Tit-bits of Synthetics."

May 20—Business Meeting. Business and Social Session. Informal Entertainment. Nomination of Officers.

ST. PETER'S COLLEGE. CHEMISTRY DEPARTMENT

On Friday, January 15th, Dr. Carlton Fredericks, Consulting Nutritionist, of the U. S. Vitamin Corporation, 250 East 43rd St., New York City, delivered a most interesting and instructive lecture to the Students Chemists' Club. The subject of his talk: "Vitamins for Victory."

Mr. H. G. Walker, Western Electric Co. Inc., lectured to the St. Peter's Alumni Chemists' Club on Thursday, January 21, 1943. The speaker is the Manufacturing Engineer and has received high honors for his successful work in Western Electric Telephone Co. The topic of his talk was: "Three Decades of Chemistry in the Telephone Field."

Dr. F. Eldred, Ph.D., director of research for Reede & Carnrich, Pharmaceutical Chemists, will conduct a research problem at St. Peter's College chemical laboratory. The main work will be to obtain the "phenol Co-efficient" of a new product discovered by Dr. Joseph Niedoerl of New York University, Washington Square, New York.

FAIRFIELD COLLEGE PREPARATORY SCHOOL

Fairfield Prep with an enrollment of 300 boys in this its first year is functioning normally even though under war conditions. The classroom building, a huge mansion, is well adapted to school purposes. The kitchen is now a chemistry classroom with kitchen sinks, cabinets, and storerooms serving scientific purposes. The laboratory adjoins the classroom. It is a spacious room with windows on three sides and a skylight overhead. The laboratory furniture was constructed by a local milling company. Three hardwood laboratory tables without lockers are plain but sturdy. A cast iron sink with two water faucets is centered in each half of each table, and four double gas cocks for propane gas serve each table. By this relatively inexpensive arrangement three tables accommodate twenty-four boys per laboratory period. A laboratory wall blackboard and a shelf for triple beam balances are arranged on the non-window side of the room. Tables for trip scales and accessories are at opposite ends of the room. The wall sinks in the classroom are located next to the door to the laboratory and are readily accessible. At present forty-eight boys, in two sections of twenty-four boys each, are in the Chemistry course, a Third Year subject. The class text is that of Black & Conant. Black's manual is used in the laboratory.

Physics is not being offered this year since the Senior Class is very small, but plans are in progress for a complete Physics course next year.

FORDHAM PREPARATORY SCHOOL

In a recent assembly, Mr. Juffey, S. J., ran a "double feature" in which some members of the Camera Club explained the chemistry of photographic materials. They had an exhibition in Collins Auditorium with all the different elements used in the making of film and the development, in separate test-tubes. Lantern slides, made by the club members themselves, were then projected, showing diagrams loaned by Eastman Company, of the whole process of making photographic film. A fourth year group from the Chemists Club gave a series of short papers on the explosives used in modern warfare, with some general statements about the super-explosives that government research workers are perfecting in the laboratories. The Camera Club is under the direction of Rev. Alfred A. Purcell, S. J.