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# Science and Philosophy

## THE LOGICAL STRUCTURE OF PHYSICAL SCIENCE

Joseph T. Clark, S.J.

This paper undertakes to contrast for purposes of critical and constructive discussion classical[1] and modern analysis[2] of the logical structure of physical science.

Such a study seems important to professional Jesuit scientists in their twin roles as career technicians and as associate members of the academic community in presumably homogenized Jesuit colleges and universities. For a scientist who does not correctly comprehend the logical structure of his discipline, can achieve only a trial-and-error, cut-and-try success. And a scientist who misunderstands the logical structure of his enterprise, can succeed, if at all, only by a series of fortunate blunders that reverse the direction of his own researches. Moreover while contemporary specialization in scientific projects may excuse the general practitioner from knowing in detail *all* about his subject, professional justice and academic courtesy require that every scientist and science-teacher know precisely what his science is all *about*, and be prepared to explain its logical structure to all rightly curious inquirers on campus.

### CLASSICAL ANALYSIS

Classical analysis determines the logical structure of physical science by simultaneous reference to the content and implications of four presumed fundamental characteristics of its enterprise:

(1) concept formation by processes of automatic abstraction,

[1] "Classical analysis" here designates that systematic interpretation inaugurated by the taxonomist Aristotle, synthesized in part by his ancient commentators, recovered from these sources and reformulated by the Roman Boethius, recaptured independently in the original Greek and considerably realigned in translation by the Arabian philosophers from the ninth to the twelfth century, revitalized and represented to the Latin West by Aquinas, retooled and revamped in structure at the time of the origins of modern science by John of St. Thomas, and revived in contemporary circles by Jacques Maritain and his numerous neo-Scholastic associates.

[2] "Modern analysis" here refers to that alternative method of interpretation, initiated by the profound and pioneer researchers responsible for the nineteenth century reconstruction of mathematics, deepened and broadened by the creative architects of modern algebra, exploited with devastating effect against conventional philosophers by the twentieth century Logical Positivists, and currently acquiring mature philosophical and scientific status in several respectable quarters. In this connection see the quietly disturbing and therefore profitably stimulating essay of inquiry by Rudolf Allers, "On Intellectual Operations," *The New Scholasticism* 26 (1952) 1-36.

(2) subordinate location in a hierarchical classification of the theoretical sciences,

(3) syllogistic demonstration as the unique logical implement of its inferences, and

(4) subalternation as the logical link between pure and applied sciences, such as mathematics and physics in the hybrid science of mathematical physics.

## Abstraction

The systematic role of abstraction in classical analysis is authentically depicted in the relevant and representative case of mathematics in the following excerpt from Jacques Maritain's recognized exposition of the position:

> I would like to insist on this point: when I say "circle," "straight line," "the number two," evidently I am abstracting a form from a subject or matter and I am separating this form from the accidents which may belong to it in such and such of its material subjects. In reality, a circle is colored, made of wood or iron, etc. These are accidents with respect to the form *circle*, accidents which I separate from that form in order to consider it in itself. Likewise duality belongs in reality to two yards of cloth or to two soldiers in a regiment; accidental conditions with respect to the intelligible type presented by the concept *two*; I separate off this intelligible type, leaving aside the material accidents to which it is united in concrete materiality. Mathematical abstraction in which we separate the accidental form, quantity, from the subjects in which it inheres, offers us a perfectly clear example of *abstractio formalis*.[3]

It is moreover a standard tenet of classical analysis that there are exactly three such degrees of formal abstraction:[4]

(1) the first degree of formal abstraction which delivers *ens mobile* as the material object of the physical sciences,

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[3] Jacques Maritain, *Philosophy of Nature* (New York: Philosophical Library, 1951), p. 18.

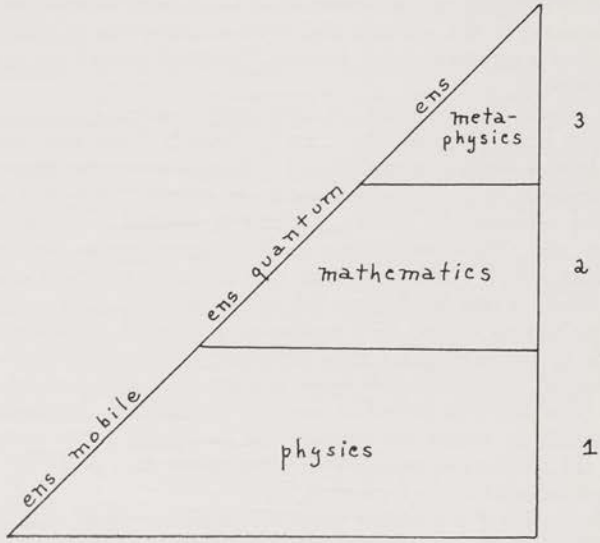
[4] But the contemporary content of classical analysis is not to be construed as the unaltered core of a consistent and homogeneous tradition. Abstraction theory has more than once been subjected to violent shifts in direction, scope, and machinery. For example: in Aristotle "abstraction" means "subtraction," in Aquinas "abstraction" means "separation," in current analysis "abstraction" ambiguously means either or both of these contrary processes. So Maritain either (a) separates the accidents from the form, or (b) separates the form from the accidents. It may just be the case that if one follows the lead of the psychological reorientation of Aristotle by Aquinas, "abstraction" may turn out to be in fact creative construction of concepts by a resourceful intelligence. For a careful study of these matters see (1) Augustin Mansion, *Introduction à la physique aristotélicienne*[2] (Paris: J. Vrin, 1946); (2) L.-M. Regis, O. P., "La philosophie de la nature: Quelques 'Apories'," *Études et Recherches* (Ottawa: Collège Dominicain, 1936), pp. 127-156; (3) Joseph Owens, *The Doctrine of Being in the Aristotelian Metaphysics: A Study in the Greek Background of Medieval Thought* (Toronto: Pontifical Institute of Medieval Studies, 1951).

(2) the second degree of formal abstraction which delivers *ens quantum* as the material object of the mathematical sciences, and

(3) the third degree of formal abstraction which delivers simply *ens* as the material object of the unique science of metaphysics.

### Hierarchical Classification

Thus within classical analysis the theory of abstraction in its systematically presumed three degrees automatically provides the structure for a hierarchical classification of the respective sciences:

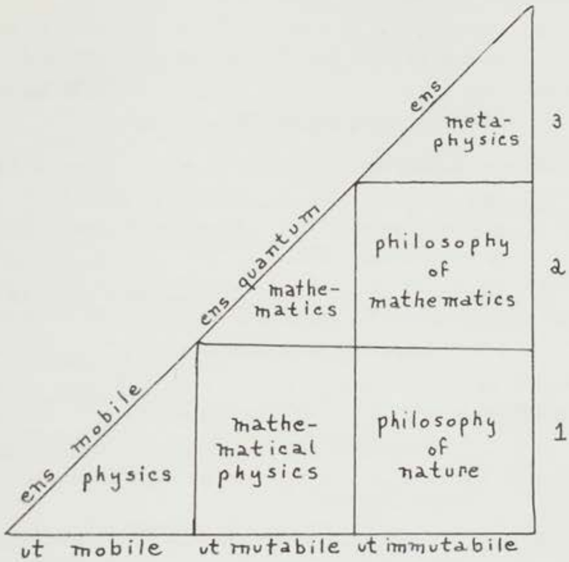



(FIGURE 1)

### Pure and Mixed Sciences

But it was clear to the architects of the classification scheme of classical analysis that not all recognizably different sciences can be categorized merely as specific subdivisions under the generic disciplines of metaphysics, mathematics, and physics. Under mathematics for example both arithmetic and geometry could be classified as specifically distinct sciences under the presumably same generic study of quantity. But such is not the case for the science for example of geometrical optics, arithmetical music, or spherical astronomy. For in each of the latter three cases the respective sciences are neither instances of pure mathematics nor pure physics but an intricate and fruitful mixture of both.

Classical analysis therefore allows three *pure* sciences: metaphysics, mathematics, and physics, and three *mixed* sciences: the philosophy of mathematics, the philosophy of nature, and mathematical physics, respectively correlated as in the following diagram:




(FIGURE 2)

To cross metaphysics with mathematics is therefore to produce a new and distinct science, the philosophy of mathematics. This science is depicted as materially mathematical and formally metaphysical and undertakes to render a metaphysical interpretation of mathematical entities. To cross the same science of metaphysics with physics is to engender a new and distinct science, the philosophy of nature. This science is materially physical and formally metaphysical and is designed to give a metaphysical explanation of the phenomena of physical change. Finally to cross a certain specific mathematical science, such as pure geometry, with a physical science, such as optics, generates a definite branch of mathematical physics, such as geometrical optics. And all such sciences, precisely as materially physical but formally mathematical, are said to render a mathematical interpretation of the physically real.

### Demonstration Technique

Classical abstraction theory not only thus determines the hierarchical classification of the three pure and the three mixed scientific *genera*, but also prescribes for each of them syllogistic demonstration as the unique instrument of inference in their logical concatenation and development. Hence to classical analysis the logical structure of physical science for example is that of a system of sentences S, such that they meet the demands of the following postulates:

(1) there is in S a finite number of terms, representative of as many abstracted concepts, and such that

(a) the meaning of these terms is so obvious to intelligence as not to need any further justification, and

(b) any other term which occurs in S may be defined by means of these canonical terms in (a);

(2) there is in S a finite number of sentences, such that

(a) the truth of these sentences is so patent to intelligence as not to require any further proof, check, examination, or explanation, and

(b) the truth of any other sentence ingredient in S may be established by deductive inference of syllogistic type from the privileged sentences in (a);

(3) each and every sentence in S must be construed as designating a specifiable domain of really existent entities,

(4) each and every sentence in S must be true in the precise epistemological sense of conformed to an objectively real state of affairs, and

(5) the logical consequences of any sentence or conjunction of sentences in S are also to be regarded as sentences in S.

The conjunction of postulates (1a) and (2a) constitutes the *evidence* postulate. The fundamental terms and the basic sentences which contain them, mentioned in postulates (1) and (2), combine to form the primary *principles* of the science in question. The postulates (3), (4), and (5) function respectively as the *reality*, the *truth*, and the *deducibility* postulates.[5]

At any cross-section therefore of the logical thought processes of a successful physics at work behind the systematic facade of its sentences classical analysis predicts the disclosure of a structure that fits the contours of the following schema:

M is P
S is M

---

S is P

Such a methodology therefore is *not* oriented toward disclosure or discovery but uniquely dedicated to a *post-factum* technique of demonstrative proof of the previously known by deductive, syllogistic in-

[5] For further and convincing detail on these important matters see (1) Heinrich Scholz, "Die Axiomatik der Alten," *Blätter für deutsche Philosophie* 4 (1930) 259-278; (2) E. W. Beth, "Critical Epochs in the Development of the Theory of Science," *The British Journal for the Philosophy of Science* 1 (1950) 27-42; (3) J. Dopp, "L'objet et les méthodes de la logique," *Revue des questions scientifiques* 10 (1949) 361-407.

ference from true, evident, immediate, and necessary premisses.[6]

## Subalternation

Classical abstraction theory which thus determines hierarchical classification and demonstrative, syllogistic development, also renders subalternation theory necessary to explain the logical link of effective connection between the elements of a pure science *A* and a pure science *B* in the constitution of a new and distinct diphthongal mixed science *AB*.

From the three main types of subalternation that are elaborated in classic analysis two are presently relevant:

(1) subalternation$_1$ of science *B* to science *A* by reason of the fact that science *B* genuinely makes use of the principles appropriate to science *A* in its science *B* demonstrations,

(2) subalternation$_2$ of science *B* to science *A* by reason of the fact that (a) science *B* shares in a significant manner the same identical subject of science *A*, and thus necessarily also (b) employs the proper principles of science *A* in its science *B* demonstrations.

Instances of subalternation$_1$ are: (i) the philosophy of mathematics, and (ii) the philosophy of nature. For although both of the latter sciences possess in their own right a set of appropriate principles into which their demonstrations are ultimately resolved, yet these principles can be maintained only by the grace and defended under challenge only by the aid of the first principles of the higher and thus subalternating$_1$ science of metaphysics.

Representative samples of subalternation$_2$ which envisions an identity of subject matter and thus also employment of identical principles, are geometrical optics and arithmetical music. Such subalternation$_2$ must be carefully distinguished in an acceptable exposition of the theory from mere subordination of one science to another in general. If for example "line" is the proper subject of a science *A*, then "straight line" and "curved line" are likewise more specific but nevertheless proper subjects of the same science *A*. There is subordination here but not technical subalternation$_2$. For the relevant characters of "straight" and "curved" are interpreted as intrinsic and germane, even though accidental and not necessary, determinations of "line." Similarly if "number" is the proper subject of science *C*, then "odd number" and "even number" are likewise more specific but proper subjects of the same generic science *C*. Here too there is subordination of a sort but not subalternation$_2$ in the technical sense. For the

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[6] And compare Ernst Kapp, *Greek Foundations of Traditional Logic* (New York: Columbia University Press, 1942), p. 74: ". . . we shall certainly not get rid of what we have to get rid of so long as we ourselves remain unconsciously dependent upon a misunderstood and a misinterpreted Aristotelian logic. Thus we have to get acquainted with the historical fact that according to Arisotle's concept of a syllogism, *the syllogism itself and the preceding mental activity run in opposite directions*".

pertinent characters of "odd" and "even" are intrinsic and appropriate, even though accidental and not necessary, specifications of number.

But if "line" be the proper subject of a pure science *A*, and "visual line" be the subject of a pure science *B*, then because "visual", unlike "straight" or "curved," is interpreted as a character *both accidental and extrinsic to* "line," science *B* is eligible for subalternation$_2$ to science *A* in the strict and technical sense. For here science *B* would examine an object common to science *A* and according to the principles proper to science *A*. Similarly if "number" be the appropriate subject of a pure science *C*, and "sounding number" the subject of a pure science *D*, then since "sounding," unlike "odd" or "even," is a character *both accidental and extrinsic to* "number," science *D* may be instituted as subalternate$_2$ to science *C* in the strict and technical sense. For science *D* here studies an object common to science *C* and in accordance with the principles proper to science *C*. In a generalized formula therefore it is the case in classical theory that one science *B* may be subalternate$_2$ to another science *A* if and only if the subject of science *B* is the same as the subject of science *A*, plus an extrinsic, accidental, and *significant* difference, such as "visual" for "line" and "sounding" for "number." For classic theory recognizes that not all contraction of the subject of science *A* by any arbitrary extrinsic and accidental factor is itself sufficient to constitute a pair of subalternating-subalternated$_2$ sciences. There is for example no such subalternate$_2$ science of "sounding lines" or of "visual numbers."[7]

## This Is All That There Is

It is important at this point to acknowledge that the above sketch and summary of classical analysis, although admittedly condensed and designedly succinct, is comprehensively complete. For abstraction and its associated hierarchical classification scheme, demonstrative syllologistic technique, and subalternation$_2$ theory together constitute the *total and unique* resources of classical analysis in its systematic attempt to understand, diagnose, and interpret the logical structure of physical science. That is all that there is. There is no more. The issue is therefore definite and decisive. Either this apparatus of analysis fits the facts or it does not. If it does, the problem is solved. If it does not, then the problem remains open for an acceptable solution. There is no other responsible alternative.

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[7] The traditional literature on this subject is immense. But because the available material is limited, the conventional treatments are largely repetitive. The list runs from Aristotle to Aquinas and John of St. Thomas to Maritain and the neo-Scholastics. A convenient and handy introduction to the material and the classical sources may be found in Bernard Mullahy, C.S.C., "Subalternation and Mathematical Physics," *Laval théologique et philosophique* 2 (1946) 89-107. I commend the reference even though it will be obvious that I do not share the author's optimistic interpretation and appraisal of the relevance of subalternation$_2$ theory to contemporary mathematical physics.

## Does Classical Analysis Work?

The relevant question is therefore this: does classical analysis fit the logical structure of contemporary physical science? The answer which sober examination gives is: No. For abstraction fails to render an adequate and acceptable account of the process of concept formation in mathematics and of the operative conceptual schemes in current mathematical physics. The traditional hierarchical classification scheme misrepresents as subordination the intellectual cooperation of independent and autonomous sciences. The restriction uniquely to syllogistic demonstrative techniques is a caricature of the hypothetico-deductive methodology characteristic of mathematics and contemporary physical science. Finally subalternation$_2$ theory as an analysis of the logical linkage between mathematics and physics is a mistake, natural and inevitable perhaps, but nevertheless a mistake.

## Abstraction Fails

The fact of the matter is that classical abstraction theory fails utterly to account for even the most primitive concepts of mathematics. Maritain's report has already revealed in classical terminology that

> I would like to insist on this point: when I say "circle," "straight line," "the number two," evidently I am abstracting a form from a subject or matter and I am separating this form from the accidents which may belong to it in such and such of its material subjects. In reality, a circle is colored, made of wood or iron, etc. These are accidents with respect to the form *circle,* accidents which I separate from that form in order to consider it in itself. Likewise duality belongs in reality to two yards of cloth or to two soldiers in a regiment; accidental conditions with respect to the intelligible type presented by the concept *two*; I separate off this intelligible type, leaving aside the material accidents to which it is united in concrete materiality. Mathematical abstraction in which we separate the accidental form, quantity, from the subjects in which it inheres, offers us a perfectly clear example of *abstractio formalis.*[8]

Now it just so happens, and a low-power microscope will provide evidence sufficient to establish the statement, that among the recognizable furniture of our world there are exactly *no* perceptible objects that are perfect circles or precisely straight lines. And if a circle is not a perfect circle, then it is not a circle at all. There may indeed exist wooden wagon wheels, painted red, and fitted with iron rims. But the wheel is not a circle nor is its rim a circle. Nor is either of them a satisfactory approximation to a circle *unless the idea of circle is already presupposed in intelligence as a standard of comparison.*

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[8] Jacques Maritain, *Philosophy of Nature* (New York: Philosophical Library, 1951), p. 18.

And if so, then abstraction cannot possibly explain the genesis of that which it presupposes as part of its operative machinery. It is not only the case that such approximations are uncontrolled. They are altogether meaningless. And if the idea of circle be lacking in intelligence from what chosen instances or collection of physical objects shall the presumed process of abstraction begin? For cabbages, pineapples, Niagara Falls, and Jones Beach are each and every one of them "approximately circular". And if one wishes to assert that the rimmed wheel surely *looks like* what one imagines a circle to be, no one would dissent. But it should be recognized that the entire issue is now being significantly shifted to the analysis of the world of phenomenal appearances and optical illusions, and away from the world of real objects in which classical analysis has explicitly located and exploited it. Finally if traditional abstraction is thinned out to mean (1) abstraction of something nearly circular from objects that are approximately circular, and then (2) *idealization* of these elements into the formally constructed notion of a precisely mathematical circle, then the process is patently *not* abstraction of classic type and cannot properly be so named without disastrous confusion.

So much for the moment concerning the abstraction of circle in classic analysis. With respect to the cognate matter of straight lines and other elements of geometry in general it is important, if not profound, to observe that the extremities of a solid are faces, *not* geometrical surfaces; the extremities of a face are edges, *not* geometrical lines; and the extremities of an edge are vertices, *not* geometrical points. It is unfortunately the case that loose usage condones, as synonymous, employment of face and surface, edge and line, vertex and point. But such equivocal terminology is to be deplored and avoided at all costs. For if one abstracts from the third dimension, one gets a concept of two dimensions, not geometrical surface and certainly not area. If one abstracts from two dimensions, one contrives a concept of one dimensional extension, not geometrical line and certainly not length. For length arises deliberately from a highly elaborate construction of a two-to-one relation whose two antecedents are points and whose one consequent is one number. To pursue the structure of all relations of this kind is to enter upon the intricate details of comparative metrical geometry. But it is sure and fundamental that length and area are not mysterious entities awaiting a scheme of measurement. The number which the metrical geometer assigns to two points comes from without and does not measure anything already there. If furthermore one abstracts from none but includes all three dimensions, one produces a concept of three dimensional extent, not a region of precisely geometrical space and certainly not volume. If finally one performs the prodigious feat of abstracting from all three dimensions simultaneously, either one does not generate a conceptual content at all, or at least not one worthy or able to bear a significant name. But it is sure that such a triple-ply abstractive process does *not* deliver the geometrical conception of a point. For in the latter notion a positive and essentially correlative element is indispensable: specifiable position with respect to a field. And it is uniquely on account of this positive and positional element that geometry mentions points at all. In fact the notion of point adds nothing to geometrical position. And geometrical position adds nothing to the notion of point. For as elements of geometry both are synonymous. An assembly of mere negations may be one thing, if it is a thing at all; an assembly of positions is quite another. Abstraction may be qualified to produce the former. But it is completely incompetent to generate the latter.

So much at the moment for the classic abstractionist account of circle and straight line. There remains the explicit matter of duality and the number two. If a flair for realism induces one to agree with Maritain that "duality belongs in reality to two yards of cloth," and if one is also aware—as schoolboys put it—that three feet make one yard and that twelve inches make one foot, then one ought likewise to maintain that *sixity* and *seventy-two-ity* also belong in reality to two yards of cloth. And it is six of one and half-of-a-dozen of the other just how one maneuvers in order to justify a public preference for duality in the context. It is difficult to see how one can fail to be all at sixes and sevens in the matter. There is therefore a subtle complication of metrical elements involved in the issue of yards which is absent in the second case of "two soldiers in a regiment". And the issues are not clarified by treating both instances as if they exhibited a perfect parallelism.

But the two soldiers also create a considerable amount of bother. For M. Maritain, as responsible spokesman for the content of classic analysis, speaks without qualification of *two* and of *the number two* as if there were no appreciable difference between them. One palpable disparity, pregnant with more than mere grammatical significance, is that *two* is an adjective and *the number two* is a singular substantive, in fact a proper name, a title as unique, individual, incommunicable, and unreproducible as *the* President of the United States in August, 1952. It is then not only *not* evident but clearly impossible to abstract an individualized particular, like *the number two*, from individualized particulars, as two soldiers in a regiment on present parade. As Frege urged long ago:

> . . . In the case of 0, we have simply no object at all from which to start our process of abstracting. It is no good objecting that 0 and 1 are not numbers in the same sense as 2 or 3. What answers the question How many? is number, and if we ask for example, "How many moons has this planet?", we are quite as much prepared for the answer 0 and 1 as for 2 or 3, and that without having to understand the question differently. No doubt there is something unique about 0, and about 1 too; but the same is in principle true of every whole number, only the bigger the number the less obvious it is. To make out of this a difference in kind is utterly arbitrary. What will not work for 0 and 1

cannot be essential to the concept of number.[9]

And it is clear to conscientious examination that the classical abstractionist definition of number as *multitudo extensorum mensurata per unum* simply will not work for 0 and 1. Nor is this failure redeemed by an otherwise interesting but here irrelevant and inapplicable distinction between *numerus concretus* and *numerus abstractus*. There is no other available alternative within the framework of the systematic interpretation of classical analysis but to deny flatly that 0 and 1 are numbers at all. But this is in fact to play fast and loose in a reckless and irresponsible manner with the actual content of established and successful mathematical science, not to analyze its intellectual structure dispassionately, objectively, and without systematic prejudices. Either then 0 and 1 are not numbers as 2 and 3 are numbers, or abstraction cannot account for their origin.

The number two therefore, no matter how frequently it may be talked *about* in discourse or written *about* in the language of arabic numeral notation, is happily unique, perpetually self-identical, and under no circumstances latent and awaiting abstractional disclosure in the folds of two yards of cloth and reproduced in a brace of soldiers. It is thus not in any sense paradoxical but the simple truth to state that *two* is not a number while *the number two* is a number and there cannot possibly be two numbers two. The inviolate uniqueness of the number two remains today, as it has ever since Plato's time at least, an unanswered and unanswerable challenge to any version of classical abstraction theory proposed as an adequate analysis of the origin and nature and epistemological status of mathematical entities.

## Complete Collapse

It is unfortunate but a fact that this failure of abstraction theory in the central field of mathematics entails truly catastrophic consequences for the rest of classical analysis, and in particular for its diagnosis of the logical structure of physical science. For if the second degree of formal abstraction is unsuccessful and inadmissible, then there is need neither for the first nor for the third. Thus by the removal of mathematics from the middle panel of the structure, the entire classification scheme collapses. Moreover whenever abstraction fails to render an adequate account of the operative concepts in any science, uniquely syllogistic demonstrative techniques for its logical development instantly become dubious and highly questionable, if not impossible. Finally subalternation$_2$ theory because inextricably intertwined with the abstractionally derived elements within the system, also falls. For it is clear that subalternation$_2$ theory cannot survive the successful appearance in physical science of (1) one set of identical phenomena correlated in physics with $n$ mathematical systems, nor

[9] G. Frege, *The Foundations of Arithmetic* (1884), translated by J. L. Austin (Oxford: Basil Blackwell, 1950), p. 57ᵉ. This classic study of the subject rewards richly careful and conscientious attention.

(2) $n$ sets of physical phenomena correlated with one identical mathematical pattern. But since (1) Huyghens and respectively Newton there have existed in physics both a wave optics and a ray optics with different mathematical apparatus in each case, and since (2) Clerk Maxwell there has existed a certain set of equations, representative of both light and electricity and magnetism. In the instance of Huyghens and Newton there is one piece of physics correlated with two pieces of mathematics. In the case of Maxwell there is one piece of mathematics correlated with two pieces of physics. Classical subalternation$_2$ theory is paralyzed by these established facts. For it is impossible on systematic grounds to specify what, if anything, is subalternated$_2$ to what.

### The Task of Reconstruction

When keystones are dislodged, arches collapse. Classic analysis of the logical structure of physical science lies today in irreparable ruins. It is therefore a standing challenge to an alert and responsible Scholasticism to reconstruct on more solid terrain a more expertly designed and more tightly articulated intellectual edifice of truly adequate and acceptable analysis. Only thus will it be possible to restore to the center of the system an equally impressive monument of comparable unity and integration.

## MODERN ANALYSIS

This paramount and urgent task of reconstruction can successfully be achieved in contemporary times if and only if it proves feasible to substitute within the system

(1) creative construction of deductively fertile conceptual schemes for the photographically filtered reproduction of ideas by abstraction,

(2) hypothetico-deductive methodology for the sterile technique of demonstrative syllogisms,

(3) coordinate parallelisms at strategic points of autonomous sciences for the hierarchical classification scheme of conventional analysis, and

(4) isomorphism or an identity of relational structure amidst a diversity of relations and relata, for subalternation$_2$ with its presumed but unwarranted identity of relations and relata.

### Constructed Conceptual Schemes

For modern analysis of contemporary science discloses clearly that the logical structure of successful physics requires the license of an unlimited franchise to physical science creatively to construct its repertory of pregnant conceptual schemes. It simply is not the case that abstraction of classical type from events in sense experience deserves the credit for what the obvious and open genius of pioneers in physics has successfully devised. And here the study of the history of science is decisive. All that is necessary to be convinced on the matter is to read the original records and reports of historically vindicated scientists. They are replete with the biographical revelations of mind necessary to clinch the issue. Two simple instances of this kind, readily available to the least trained scientific layman and where, although the documentation is ample and detailed, the mathematics is relatively simple, are (1) Torricelli and the invention of the conceptual scheme of atmospheric pressure, and (2) Lavoisier and the final abandonment of phlogiston theory in chemistry.[10] These monumental advances in physical science owe absolutely nothing to the systematic contributions of classical abstraction theory. They are the result, as the records show, of alert and informed intelligence thinking things through hard and venturing educated and disciplined guesses. The complete inability of classical abstraction theory to account for the elements of contemporary physics such as general relativity and quantum physics goes without saying. The upshot of the entire issue is that (1) abstraction theory was never satisfactory anywhere,[11] and (2) is today altogether untenable everywhere in the field of mathematics and in that of physical science.

## Hypothetico-Deductive Method

As abstraction which supplied the class concepts, entails the demonstrative syllogism which exhibited their overlap, as the unique implement of logical development in science, so does the creative construction of deductively fertile conceptual schemes imply hypothetico-deductive methodology as operative procedure for advancement in science. At any cross-section of successful thinking in physics modern analysis predicts and actually discloses that the logical structure of physical thought conforms to the following paradigm:

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[10] One of the better books on this important matter is James B. Conant, *Science and Common Sense* (New Haven: Yale University Press, 1951). See particularly Chapters 4 and 7. An excellent companion volume is Herbert Butterfield, *The Origins of Modern Science* (London: G. Bell and Sons, 1949). For college use I recommend pertinent items in the growing series of *Harvard Case Histories in Experimental Science* (Cambridge: Harvard University Press, 1950 —). Certain relevant points are also emphasized by Joseph T. Clark, S.J., "Contemporary Science and Deductive Methodo!ogy," *Proceedings of the American Catholic Philosophical Association* (Washington: Catholic University of America, 1952), pp. 94-131.

[11] Not even in Aristotle for the mathematics of his ancient age. For it is clear to the informed historian that Aristotle's meagre acquaintance with mathematics is completely unrepresentative of the interests and achievements of his contemporaries. Greek mathematics of his time teemed with problems of impressive scientific potential. And it is a just complaint against Aristotle that he never once is on record either as reporting an important mathematical discovery or asking an original and fruitful question. There are trivial classifications here and there but no reflections of the intense and successful mathematical research of his peers. If Aristotle had also learned in the Seminars of the Academy about the unbounded sequence of primes, unique prime factorization, and the relations between various classes of quadratic and biquadratic irrationalities, then he might have refrained—and Scholasticism after him—from regarding mathematics and physics as the abstract and the concrete versions of the same thing.

$$p \supset . q_1 \cdot q_2 \cdot q_3 \ldots q_n : q_1 \cdot q_2 \cdot q_3 \ldots q_n : \supset p$$

wherein $p$ stands as surrogate for all the complex suppositions of a specimen theory, and $q_1, q_2, q_3, \ldots q_n$ represent respectively its implied and predicted, and then tested and confirmed consequences. The schema may be read in this context as follows: if it is the case that if $p$ then $q_1$ and $q_2$ and $q_3$ on to $q_n$, and it is the case that $q_1$ and $q_2$ and $q_3$ on to $q_n$, then $p$.

This is indeed how physics has successfully thought since Galileo at least and continues so to think. A theory $p$ is a pure invention, guided of course by past successes and relevant to experience, but it is a creatively designed *reconstruction* of experienced events and not a photographic *reproduction* of the real. It is in short quite literally a guess but an educated and severely disciplined one. To test impartially its relevance to matters of fact, one selects as many *strategic* consequences of the deductively fertile conceptual scheme of $p$ as are considered *logically* pertinent and revealing. Hence the $n$ of $q_n$ may be very large or very small, contingent upon specific circumstances. Such logically significant predictions, if countermanded by recalcitrant experience through a sufficient series of unequivocal $\bar{q}$ results, relentlessly require the constructive revision of $p$ into a new form $p'$ that may or may not resemble the original $p$. If however a sufficient set of successful predictions confirms the relevance of $p$ more and more, then $p$ gradually attains the respectable status of physical fact and the honorable position of serving as confident point of departure for the construction of a newer and wider $p_2$.

At this point the classical analyst turns critic and long familiar with the aspirations and techniques of demonstrative syllogisms, protests that the logical structure of contemporary physics is patently illogical. For it is argued that the entire enterprise of experimental science is nothing but a gigantic fallacy: the affirmation of the consequent. For even if it be the case that if it rained then the streets are wet, still it is not necessarily the case that wet streets proclaim infallibly that it rained. Some other cause may account for the phenomenon. Hence it is charged against modern analysis that the empirical confirmation of theoretical predictions can never prove that the theory in question is the true one and therefore the uniquely right and correct one.

Adequate rejoinder here requires two preliminary remarks: (1) the classical analyst here makes the questionable supposition that there is a uniquely right and correct theory for every range of phenomena, and (2) there is the matter of the relevance to physical science of the specific charge of logical fallacy itself. In reply to (1) there are two correlated points to establish: (a) it simply cannot be shown to be the case that for each and every range of phenomena there exists exactly one theory that is uniquely *true-to* it and such that all other alternative theories are false and fraudulent; (b) it surely is the case that for any given range of phenomena there exists at least some one or other hypothetico-deductive theory that is *true-enough-of* it to allow for effective prediction and successful control.

For given a thought and a thing, it is fantastic to suppose that the thought can be *true-to* the thing, as a portrait for example may be *true-to* a face. For the face and the portrait are each a thing and can thus be respectively *true-to* each other. But a thought and a thing are altogether incomparable because one is a thing and not a thought and the other is a thought and not a thing. But given a thought and a thing, it makes significant sense to assert that the thought may or may not be *true-of* the thing. Similarly theories which can never be *true-to* the objects of their reference, may yet nevertheless be *true-enough-of* them. For formal truth, as Scholasticism has consistently seen since Aristotle and never completely abandoned the insight, is *not* a property of isolated ideas or concepts. Formal truth attaches or not *exclusively* to the judgment and its semantical counterpart in a statement. And a statement is thus designated as true if and only if there exists a relation of identity between what the statement asserts and the state of affairs to which it refers.

It is important therefore to understand exactly what it is that a scientific statement asserts. Careful analysis of representative samples shows that any acceptable and accepted scientific statement S advertises to the interested and literate public that some one or other relation $R$, usually mathematically formulated, holds between two or more *named* arguments, $a, b, c, \ldots$, such as $aRb$, under explicit or contextually implied conditions $u$, $v$, $w$, etc. Such a statement is successful if it is shown by reason of sufficient confirmation in fact to be consistently reliable. Hence to accept in the sense of a personal commitment a representative scientific statement S, such as: $aRb$, as factually true of the physical world entails that there exists in the non-linguistic universe of experience at least some one element $x$ and some one element $y$, such that $xRy$. But such acceptance does *not* entail that the relational identity of $aRb$ (in the linguistic structure which is the science of physics) and $xRy$ (which is the structure of a segment of the physical world) warrants and guarantees the identity of $a$ with $x$ and of $b$ with $y$.[12] Empirical confirmation therefore of individual scientific statements does not and cannot canonize the conceptual schemes within which $a$ and $b$ happen to be the names of $x$ and $y$. For if $x$ as a physical entity does not have a proper name, then it is otiose to try to determine whether $a$ is it. But $x$ and $y$ both have a structure and it is important to ascertain whether $aRb$ represents accurately enough $xRy$. Similar remarks pertain with equal relevance to the content of entire physical theories, severally and jointly. It is therefore, classical analysts please note, *not* the objective of hypothetico-deductive methodology in physics to prove that $p$ is uniquely *true-to* the facts. It is rather content to disclose that $p$ is *true-enough-of*

[12] And is this what Aquinas really meant when he wrote the significant passages in *De Coelo* 2. 1. 17, and *S.T.* 1. 32. 1. 2?

them. Hence the charge in (2) of a logically fallacious affirmation of the consequent misses its mark.

Moreover in a finite world, already successfully mapped in large part by established compeers of *p*, the number of logically possible and physically relevant alternatives to *p* decreases to the vanishing point. In the abstract never-never land of pure logic it may be possible that gremlins sometimes water down the highways without the implied presence of rain. Hence in abstract logic the precipitous affirmation of the consequent is seriously fallacious. But in the concrete and largely explored universe of physics the chances are negligible that gremlins sometimes do the work of electrons in an experimental laboratory. It thus happens that increasing and accumulative knowledge eliminates possible alternatives and thus renders unfulfilled the necessary conditions for the commission of the fallacy. Classical analysts should recognize that it is entirely a matter of admissible alternatives. For if there are *no* relevant alternatives to *p*, then it follows that if it is the case that if *p*, then *q*; and *q*, then *p*. If it is the case that the streets are wet *if and only if* it rained, then the phenomenon of wet streets proclaims infallibly that it rained. In the hypothetico-deductive method, as expertly manipulated in physical science, implication approximates such strict equivalence.[13]

## Isomorphism and Mathematical Physics

Just as classical abstraction theory ultimately entails subalternation$_2$ as the rational link between mathematics and mathematical physics, so too in modern analysis creative concept formation in mathematics and physics entails isomorphism as the logical structure of mathematical physics. By the formal notion of isomorphism is here meant a one-to-one correspondence $C$ between the objects and relations of a mathematical structure $M$ and the objects and relations of a physical structure $M'$, where relations of order $n$ correspond to relations of order $n$, and such that whenever a relation $R$ holds between the objects of $M$, the corresponding relation $R'$ under $C$ holds between the corresponding objects of $M'$ and conversely.

In arithmetic for example which is the science of number and not the art of computation, the study of relational characters and not the identification of relational terms, there exists the *additive* relation whereby, let us say, $c = a + b$. In the physics of length, to choose the simplest case as paradigm, there is the *juxtapositive* relation whereby, let us say, $C = A \ (+) \ B$, where the plus sign is enclosed in parentheses to avoid the solecism of employing a single symbol to indicate two different relations at the same time. The physicist has reasons of his own which he sometimes revises in the face of recalcitrant experience, for believing that numbers *a*, *b*, *c*,

[13] For a recent restatement of the above charge of logical fallacy in hypothetico-deductive method see Pierre Conway, O.P. and George Q. Friel, O.P., "Farewell Philosophy," *The New Scholasticism* 24 (1950) 363-397, especially pp. 385-386.

are not only unambiguously assignable to lengths *A, B, C,* but even so assignable that A (+) B = C exactly when a + b = c. In a word he believes until contrary evidence requires that he revise this belief, that his real and physical *juxtapositive* relation between lengths is isomorph to the ideal and mathematical and *additive* relation between numbers. But he does *not* on that account believe that numbers are long or short or addition juxtaposition or conversely. It is therefore technically economical but semantically *elliptical* to say that one "adds" lengths or to write in strictly mathematical notation: A + B = C.

More elaborate applicabilities of more complex mathematical physics are simply more elaborate isomorphisms between real and physical relations and ideal and prefabricated mathematical relations. It is not the case however that all kinds of physical entities enter into all kinds of mathematical relationships. Densities for example do not enter into relations of the additive type. And it is often enough the case that more refined experiences require revision in previously established isomorphisms. The superposition of velocities for example was once considered isomorph to the simple addition of the numbers that measured them. But under special relativity theory they came to be considered isomorph to the addition theorem of a certain hyperbolic function. But the fact endures that throughout the entire range of contemporary mathematical physics the logical structure remains the same as depicted in the previous paradigm. The fundamental mistake therefore of subalternation$_2$ theory in classical analysis, and it is a mistake and it is fundamental, was to misconstrue an identity of relational structure amidst a diversity of relations and relata as if it were an identity of relations and relata. Hence the bizarre expressions of '*visual* line' and '*sounding* number' in classical analysis.[14]

## Coordination of Sciences

Just as abstraction theory entailed the triply hierarchical classification scheme of conventional analysis for the theoretical sciences, so too isomorphism in modern analysis implies in turn a coordinate map of antonomous sciences which may however cooperate through fruitful parallelisms at strategic points. This reconstructed scheme of all the speculative sciences that are open to the insights of natural human reason, may conveniently be sketched and exhibited in the accompanying diagram, preferably printed in the primary colors and their mixtures in appropriate places:

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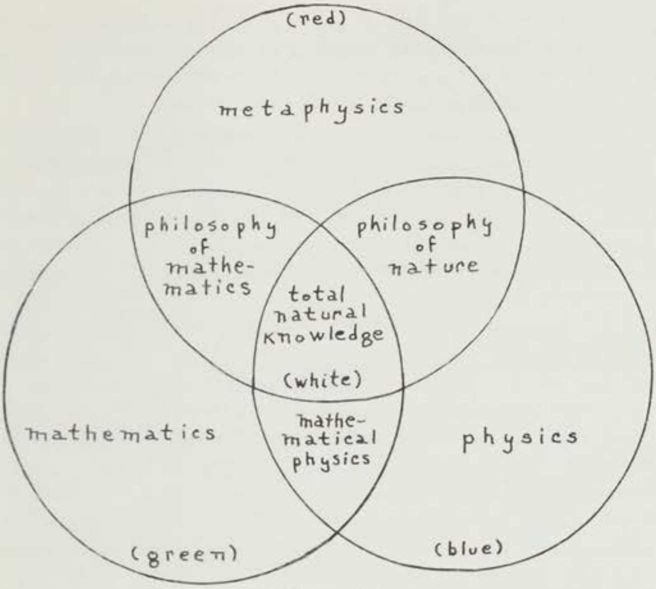
[14] Two good books of uneven value and increasing difficulty on the logical structure of mathematics and its correlation with physics are respectively (1) William L. Schaaf [Editor], *Mathematics: Our Great Heritage* (New York: Harper and Brothers, 1948), and (2) R. B. Kershner and L. R. Wilcox, *The Anatomy of Mathematics* (New York: The Ronald Press Company, 1950).




(Figure 3.)

## Systematic Postscript

It is my impression that classical analysts of the robustly realist type are afraid that to assimilate the assured results of modern analysis of the logical structure of physical science would be to begin to dissolve the integral and precious synthesis of Scholastic thought. It is for example vaguely felt that to allow the creative construction of deductively fertile conceptual schemes would mean to import into the system an irresponsible subjectivism, not amenable to the systematic and presumably infallible checks of abstraction through automatic processes. This fear is vain. For it is experience, implacable and relentless, that checks effectively the speculations of physics at every turn. From an unsuccessful prediction there is no appeal. And every physicist knows it. In no other enterprise of intelligence do the verdicts of sense enjoy comparable epistemological prestige. Modern physical science, despite its proliferation of conceptual schemes and hypothetico-deductive methodology, is the very antithesis of irresponsible subjectivism. It is in fact the paragon of realism.

It is furthermore generally assumed without adequate critical examination that the introduction of hypothetico-deductive methodology would paralyze the Scholastic sense of certitude and truth, characteristic of ideally formulated syllogistic demonstration, and spread the virus of an apathetic, spineless, and irresolute scepticism. This anxiety is likewise groundless. For it is one thing to say "if *p* then *q*" and to stop there. It is quite another to say "if *p* then *q*, and

$q$," or "if $p$ then $q$, and not $q$". For in either case the issue of $p$ is decided and as decisively as possible at the moment. It is just as certain and clear and true in physics that phlogiston does not exist as it is true that man is mortal if all animals are.

It is also vaguely and uncritically surmised that to accept even after examination and careful tests the illuminating analogue of isomorphism from professional mathematics would be to sell the system's birthright to absolutes for the mess of pottage known as relativism. This surmise is likewise inaccurate and equally vain. For if isomorphism is *relational*, it is not on that account *relativistic* in a pejorative sense.

Finally the fear is predominant that if one were to allow any tampering whatever with the impressive synthesis of the hierarchical classification of the sciences on the basis of the three degrees of abstraction, then Scholasticism would also fall victim to the deplorable chaos and disarray so characteristic of a certain noisy segment of contemporary intellectuals. But this anxiety is likewise groundless and unreasoned. For it is possible to reconstitute a unified map of the speculative sciences, both pure and mixed, and to exhibit thus that although *no one science needs another* in the execution of its selected tasks, *humanistic man needs all the sciences* if he is ever to attain to the total natural knowledge of the total natural reality accessible to him.

It is the opinion of this paper that (1) there is no problem more urgent than the reconstruction along the lines of modern analysis of the Scholastic interpretation and appraisal of the logical structure of physical science, and (2) no problem of comparable magnitude more promising of successful solution in contemporary times through informed and cooperative effort between philosopher-scientists and scientist-philosophers.

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## FORMATION OF THE JESUIT SCIENCE COLLOQUIUM AT WESTON COLLEGE

At the beginning of the present school year, a Science Colloquium was organized at Weston College for the purpose of fostering and stimulating interest in the branches of the physical and mathematical sciences. In addition to the Faculty members of Weston College and the Scholastics who are or have been engaged in the teaching or study of the natural sciences, membership has been extended to the Directors and Members of the various science faculties of Jesuit Colleges and High Schools in the area.

Fr. Francis C. Buck was named by Rev. Fr. Rector to serve as Moderator; Mr. Martin F. McCarthy is the first Chairman and Mr. Richard D. Fahey is the first Secretary of the Science Colloquium.

The present plans call for a monthly meeting to be held on Sunday afternoon. We are indebted to Fr. Daniel Linehan for offering us the facilities of the Lecture Hall of the Seismology Building for our Colloquia.

On Sunday, October 19, 1952, the first Science Colloquium was conducted. We were very happy to welcome several members from the science faculties of Holy Cross College and Boston College, together with a large number of Fathers, Theologians, and Philosophers from Weston. Rev. Fr. Rector delivered the Inaugural Address and discussed the pronouncements of the recent Holy Fathers and of Rev. Fr. General concerning the apostolic value of scientific studies in the work of the Society of Jesus. The topic for the first Colloquium was *The Geology of New England*. Mr. John E. Brooks gave a brief exposition of the role of the Society of Jesus in the development of the Earth Sciences, and introduced Mr. James W. Skehan; Mr. Skehan presented an illustrated lecture on the mountain-building processes which are responsible for the geological development and the present appearance of New England. This was followed by a period for questions and an informal discussion which proved most pleasant and, we hope, profitable for all.

## SCIENTIFIC APOSTOLATE OF THE SOCIETY OF JESUS*

JAMES E. COLERAN, S.J.

I am somewhat abashed in facing a group of scientists, whether fledgling or full-fledged. I am not now, and never have been, a scientist.

But I could not be a Catholic and a Jesuit if I did not respect science and want to encourage its study. My reasons? Not to go too far back in Church History, Pius XI and Pius XII, by many statements and acts, have made clear to the whole world their desires of seeing science, true science, advancing under the aegis and with the aid of the Church; and they wanted Catholics, even priests, to have their part in this work.

Pius XI pointed out, in his Motu Proprio, *In Multis Solatiis*, founding the Pontifical Academy of the Sciences, that divinely revealed truth could not suffer but only be helped by the serious development of the natural sciences.[1] He founded his Academy to promote such development.

That he wished those in the priesthood to have their part in this work is clear from his Encyclical *Ad Catholici Sacerdotii*.[2] In this Encyclical he devotes much space to urging priestly interest and training in the sciences. He says, in general, that priests who feel a call

* The following paper is the Inaugural Address delivered by Very Reverend James E. Coleran, S.J., Rector of Weston College on the occasion of the first Science Colloquium at Weston College, Sunday, October 19, 1952.

[1] *AAS*, 28 (1936), 421-424.

[2] *Ibid*., pp. 5-53, especially pp. 35-36. (In the NCWC English translation published by America Press on pp. 24-25.)

to such study should be encouraged, for such study redounds to the honor and prestige of the Church herself and to the glory of Jesus Christ, her Head.

And he lays it down as a rule for all priests that they should not be content to equip themselves with such learning and culture as seemed adequate in the past, but they should honestly strive to acquire that higher and fuller knowledge at which our time by diligent effort has arrived; which knowledge, due to diligent scientific investigation, far surpasses that of preceding ages.

Note that here the Holy Father speaks to all priests!

But he had already made his mind clear in the Apostolic Constitution *Deus Scientiarum Dominus* (1931), in which he laid the norms for courses of studies for Ecclesiastical degrees.[3] In this remarkable document Pius XI begins by insisting, with the Vatican Council, that faith and human reason cannot be at odds.[4] Rather, he assures us, that once we come to see their agreement they can bring to each other mutual aid. Then, after tracing the concern of the Church for all branches of learning through every age—especially during the so-called dark ages—he makes this glorious assertion:

> The Catholic Church does not fear persecutors which bring the reward of the glory of martyrdom; nor heresies which force her to focus more accurate light on her deposit of sacred doctrine; this one thing she fears: ignorance of the truth—for her enemies are moved by misunderstanding and prejudice. For Tertullian truly said, "Desinunt odisse qui desinunt ignorare."[5]

Hence against the errors of today he calls for training in learning of those of the faithful who are capable. And, with a special force, he insists that from candidates for the priesthood some should be chosen who will be completely dedicated not only to the sacred sciences but also to those which are in any way related to them.[6]

Such men should be trained not merely to teach the doctrine of the Church but to defend Her from all fallacious ideas. In the implementation of this Constitution he demands, as a pre-requisite for ecclesiastical studies, a foundation in the natural sciences,[7] and he even allows in the philosophical curriculum special courses in these sciences.[8] He does not, then, consider them alien to ecclesiastical studies.

Pius XII, addressing the Italian Society for the Advancement of Science, on October 3, 1942, had this to say:

> We rejoice to salute in you the lofty subject of science . . . and especially that in your Congress you have made your scope

[3] *AAS*, 23 (1931), 241-262.

[4] *Ibid.*, p. 241.

[5] *Ibid.*, pp. 244-245. The quotation from Tertullian is from *Ad Nationes*, I, 1.

[6] *Ibid.*, pp. 245-246.

[7] *Ibid.*, p. 252, in Tit. II, art. 25 as interpreted in the *Ordinationes* of the Congregation of Studies, Tit. II, art. 13, (*Ibid.*, p. 266).

[8] *Ibid.*, p. 282 (In the Appendix to the *Ordinationes*).

also research and knowledge beyond time which passes and the moment which is fleeting, by that spiritual impulse which spurs you on to new horizons beyond visible things.[9]

His challenging call to these scientists is found in this powerful sentence:

> The assiduous realization of the maxim "vitam impendere vero",[10] ("to devote one's life to truth"), the untiring dedication to the service of science, the fight for the conquest of even more perfect knowledge, no less than its systematic application to the constantly increasing exigencies of life—all this constitutes a mission from which the leaders in the scientific field can not withdraw themselves without irreparable loss for country and people.

The same Pius XII, in his Allocution to the Congress of Mathematicians, (November 12, 1942), said:

> Sacred science . . . and profane science (that tireless struggle for a more vast knowledge of created things) are not enemies but sisters. The higher nobility of the one . . . does not lessen the greatness, the importance, the necessity, the merit of the other, which studies and masters in the universe the work of the Creator.[11]

And again, coming closer to home, the same Pius XII, speaking directly to the Fathers of the XXIX General Congregation said:

> It is your duty, in name and in reality, to be not only religious men, but also men of great learning . . . and if they ought especially to cultivate the Faith, they ought also to acquire exact and complete knowledge, and, following in the glorious footsteps of their Institute, to pursue the advancement of the sciences as much as they can and in whatsoever way they can, being convinced that along this path, rugged though it be, they can make a great contribution to the greater glory of God and the up-building of His Church.[12]

So Father Janssens was but speaking the mind of the Church and trying, in the Jesuit spirit, to fulfill the expectations of the Holy See when he spoke so vigorously of the sciences in his letter of 1947, *On Our Ministries*.[13] He places scientific work, properly so called, among the works of the Society which are of prime importance and of the greatest necessity in our own day. He means both sacred and profane

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[9] *AAS*, 34 (1942), 343-345. The whole address merits reading. The two passages quoted are found on p. 344.

[10] The quotation is from Juvenal *Sat.*, IV, 91.

[11] *AAS*, 34 (1942), 370-371.

[12] *AR*, 11 (1946-50), 57.

[13] *Ibid.*, pp. 299-336. The pertinent passage is on pp. 318-319. (In the English translation, pp. 8-10.)

sciences. Both, he says, redound to the glory of the Church and the building up of the Mystical Body.

Then, more than has been done in any of the previous documents quoted, Father General indicates the apostolic value of scientific labors. These studies can repair the ravages of false scientific presentations or of true sciences falsely used, and thus protects the Church. They provide positive material to aid the student of philosophy and even of the sacred sciences. They dispel ignorance in the Church and silence the derision of unbelievers, and save the faithful from false ideas to the benefit of their souls. They assure us that the facts of science are being handled and proposed to the world by men with faith and with a knowledge of the true philosophy and theology.

There is hope, moreover, that a priest who would not be acceptable to scientific men merely because he knows theology and philosophy will be acceptable if he comes to them ready to speak their language on their own subject. For every apostle must first learn the language and mentality of those whom he would approach.

Father Janssens underlines a very practical point when he declares[14] that the life of a true scientist is one of "self-abnegation, toil, and often of small consolation". This is true absolutely speaking. To be a solid scientist, a scholar, requires much hidden work, with little fanfare. We all long for the plaudit: "Well done!" We all like to be assured that we are at every moment doing something of great importance. But often the hidden work in the laboratory and the library, or at the desk, the painful search of careful observation, of critical appraisal, of accurate presentation tries the patience.

More people would smile on us if we worked in the more popular apostolates. But Father General calls[15] this tendency in the Jesuit student of science an illusion, even when the attraction is to work that is in itself more priestly and apostolic. To lay the foundations is more useful, he tells us, than putting on the finishing touches.

Father Janssens urges the Provinces to dedicate men for this work, but he warns the Scholastics who will be chosen for this work that they must have fortitude and self-abnegation. In fact, they should enter this work with the idea that to undertake it is to pledge themselves to a life long holocaust.[16]

These words of Father General are true. We hail his inspiration and encouragement to pursue scientific studies. But we would be foolish if we did not soberly consider that such work, blessed by the Church and the Society as apostolic, requires an apostle's self dedication. To discipline one's self to scholarly study for the attainment of knowledge which even the unbeliever will respect, is a program which demands of the Jesuit long years of study of his philosophy,

[14] *Ibid.*, p. 317.
[15] *Ibid.*, p. 317.
[16] *Ibid.*, p. 318.

his theology and his science. He can neglect none of these and still fulfill his mission. He must be humble and docile, receptive of learning, enthusiastic and eager, anxious for learning, single minded and self denying to remove the hidden impediments to learning. There is no spectacular, jet-propelled route to pre-eminence in science. What the Church and the Society ask of you is that you rank with the best. For Jesuits to do this means greater sacrifice than is demanded of laymen. But real Jesuits and real Jesuit scientists are capable of it.

In conclusion, I take the liberty of making my own the words of Pope Pius XI in his *Motu Proprio* founding the Pontifical Academy of Science (October 1936). For they apply, if only in a humble way to me and to you.

> We have high hopes that the members of this Pontifical Academy will, through this Institute of studies, Ours and theirs, advance ever further and higher in fostering the progress of science. And we do not ask anything more, since that dedication which we ask of those who serve the truth has as its foundation this noble purpose, this excellent task.[17]

# Chemistry

## A SYLLABUS OF LECTURE DEMONSTRATIONS IN CHEMISTRY

Bernard A. Fiekers, S.J.

The end of a semester usually affords time to take stock of accomplishment and get it onto the record. Accordingly a number of lecture demonstrations and illustrations are given here: some trite perhaps or well known; others that might suggest some original approach; but all of them indicating a co-ordination of demonstrations with the laboratory work done by college Freshmen in the first semester.

The electrolysis of dilute sulfuric acid provides demonstration material for lectures on oxygen, hydrogen or water. It generally is too difficult and cumbersome for students to perform in the laboratory. It is of course a classic and should be included. The author has published notes on this demonstration in the Hormone.[1]

Any demonstration of the analytical balance provides a time saver for instructors and students before the use of balances in laboratory. A large demonstration balance is used for the purpose.

The demonstration slide rule is of disputed value. In the author's classes, knowledge, practice and use of the slide rule is not required. It is very satisfying, however, to both instructor and students, when

[17] *AAS*, 28 (1936), 424.

numerical solutions can be checked out rapidly on the four foot edition of the Welch Demonstration Slide Rule[2] that hangs over the black board in lecture throughout the course. It is encouraging to note the number of students who pick up slide rule technique on their own after this introduction to it.

Charts and illustrative materials of all kinds are of tremendous value. Certainly the periodic chart of the elements gets first mention. Further, certain charts on the A-bomb, appearing in all of the McGraw Hill serial publications about 1945, have been copied onto 20 x 28 inch Bristol Board, by tracing a lantern magnification and filling in with India ink or with narrow widths of black "Scotch Tape." A whole collection of charts of similar construction is available for all courses in the department. It includes vapor pressure curves and other phase diagrams, the scheme of anion analysis, functions of the periodicity of the elements and the like.

Structure models of crystals and molecules[3] are not lacking. They make for an economy of effort in bringing spatial considerations to the attention of students that is not easily forgotten. Cardboard models of tetrahedra and octahedra are helpful in this connection.

It requires little effort to be alert enough around the department to borrow this Kipp generator or that distilling assembly already set up and show them off in lecture. Even a soda fire extinguisher in the process of being refilled was pressed into service.

By now it is obvious to the reader that the author tends to avoid having to darken the room and give some slide lectures or movies. These are largely relegated to the Chemists' Club so as to give the students some experience with these on their own. One cannot escape them completely. The author makes use of *Life* Magazine's slide strip for the purpose of reviewing the atom. Radiomat slides on modern, or electronic, valence come in handy.

On the more formal side of demonstration one thinks of a number of experiments that are justified more by demonstration than by individual laboratory performance, because of hazard, expense of time or money, economy in laboratory organization and the like.

The demonstration of the rusting of iron[4] with oxygen is one of these. A suitable wad of fine steel wool is degreased in ether, air dried, dipped into a ten percent acetic acid catalyst solution and introduced into an inverted burette towards the tip, and the assembly is set up over a (pneumatic trough) beaker of water (colored with $KMnO_4$). Oxygen from a cartridge ("Sparklet" or $CO_2$-like; obtainable with valve from Daigger, Chicago) is run through the top of the burette to displace the air and bubble for a while through the $KMnO_4$ solution. As the iron takes on the oxygen and rusts, the solution is seen to rise in the burette. For such a demonstration one burette should be reserved from year to year. The cleaning process does not enhance the reliability of the burette if it should find its way back to normal service.

The filling of burettes in lecture demonstration can be an awkward and sometimes exasperating performance. The author salvages broken burettes which can be cut down to an indicated volume of about 25 ml. These can be manipulated more gracefully in lecture than the longer standard variety and generally a volume of 25 ml. suffices for demonstration. The liquid is then best sucked into the burette, not by mouth, rather with a bulb[5] and tube arrangement. A little experimentation and practice will provide the technique.

A dust explosion is sometimes put on. The apparatus can be bought from Cambosco, or easily fashioned at home.

Demonstrations of supersaturation are done economically in a large flask for all to see. Flask and contents can be stored in stock from demonstration to demonstration. If this experimentation is done individually in laboratory, the chemicals are discarded. Compromise suggests making the experiment optional in laboratory.

It is always well to keep a good collection of solutions of common chemicals at the lecture desk, along with some conical glasses for the demonstration of colors, precipitates and the like. The ubiquitous wash bottle is also a must. One should not forget to inspect the ground glass stoppers before lecture and make sure that the bottles can be opened without delay. The wash bottle might run dry at times! It seems reasonable too to raid exhibit cases from time to time and pick up samples safe enough to be passed around in lecture. But bouncing putty leaves the lecture desk only by accident and under its own power. In this way the Cottrell precipitator is borrowed from exhibits. It creates an occasion for a smoke in the classroom.

The author's use of ball bearings and frame for the illustration of the states of matter and the gas laws is probably known to many readers. A frame like a picture frame, with glass and other contents removed, is constructed and lined along the inner periphery with live pressure tubing. Into the enclosure are introduced ten or fifteen "glassies" or steel ball bearings of about one half inch diameter. The frame measures about fifteen by twenty inches. On vibrating the frame horizontally in contact with the surface of the desk, so that each point of the frame describes roughly a two to three inch circle, a kinetic picture is produced wherein each of the particles bounce around the enclosure haphazardly colliding with each other and with the walls of the container. No great strain on the imagination is required to improvise and produce simulations of the states of matter, certain aspects of Boyle's and Charles' laws, Brownian movement, mechanical aspects of equilibrium, osmotic pressure and the law of partial pressures. They have been described elsewhere.[6] The point is that interest can be gained in such an illustration and it can be shown that the more difficult concepts, such as the ideal gas and the law of partial pressures can be presented forcefully on this background, efficiently as to time and effort spent, not to mention students' returning them very rationally on being quizzed.

Our conductivity kit is composed of a spare parts box from the service. It contains two sockets on a clamp, wired in series, an assortment of bulbs of different wattages, including neon lights and a multifilament[7] bulb that is provided with a built-in switching arrangement to pick off three wattages, not to mention an assortment of electrical accessories, which include wired series taps, screw-in taps and the like. The box is arranged so that it can be used for a ring stand for the sockets. The lower socket takes the electrode system: a lamp whose glass is broken off,[8] leaving only the filament leads and the base.

Using an A.C. source through a variable transformer (Variac or Powerstat) a number of conductivity experiments can be performed. Generally a demonstration galvanometer is used to indicate conductivity instead of the bulb system. In that case the current has to be rectified. This is accomplished by using a meter rectifier, obtainable at low price in almost any radio parts store,[9] or rectifying at the source with heavier equipment such as battery eliminators.

A classical conductivity experiment is the conductivity titration of barium hydroxide with sulfuric acid. Solutions somewhat more dilute than tenth normal have to be used, as dictated by the solubility data of the barium hydroxide. Initial conductivities fall off to a minimum which indicates the stoichiometrical point of the formation of barium sulfate, which is negligibly soluble, and of water. Excess acid causes the conductivity to increase again. Here a graph board[10] comes in handy. Other conductivity experiments include the conductivity of water which has been passed through an ion-exchange system, laboratory distilled water before and after blowing carbon dioxide from the breath through it, tap water, sugar solution, alcohol, glacial and dilute acetic acid. Blowing through conductivity water in order to get a neon bulb to glow makes a spectacular experiment. Control of current with a variable transformer is necessary in many of these experiments in order to establish convenient or critical voltages.

The demonstration Geiger Counter[11] seems to be a must in chemistry courses today. Most departments have pre-war uranium and thorium samples which can be tested. Much of the orange glazed kitchenware,[12] surviving the war, contains uranium in the glazed part: "Fiestaware", for example. This comes as a surprise to many students, who are young enough to swing incense at uranium. Thus the idol is shown to have clay feet.

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# Physics

## GEODETIC MEASUREMENTS BY MEANS OF A SOLAR ECLIPSE

FRANCIS J. HEYDEN, S.J.

It has been the good fortune of Georgetown Observatory to receive an invitation to participate in several eclipse expeditions to various parts of the world in the past twenty years. All of these expeditions in the past featured one particular task for Georgetown, and that was the exact observation of the times of contact of the eclipse. On the first expedition of 1932, Father Paul McNally brought along a selenium cell and a Wulf filar electrometer with which to measure the light curve of the diminishing and increasing light of the sun just before and after the period of totality. Father Wulf had suggested such an experiment as a very accurate means of observing the instants of second and third contact.

This photo-electric device failed at Fryburg in 1932 but afterwards a Master's thesis describing the method and the instrument was submitted by a student in the Physics department of Georgetown. The thesis was placed on a shelf in the library and the method was discarded in favor of a photographic one devised by the staff members of the Naval Observatory and Father McNally.

The new method was carried out successfully by Dr. Willis of the Naval Observatory in 1937, by Father McNally in 1940 and by Father L. C. McHugh and myself in 1947. It has one serious drawback which was evident in all three eclipses. The probable error of the mean for the result was too large for really precise work on the relative positions of the sun and the moon. In 1947 Georgetown made a special effort to reduce the probable error of the observation to a minimum. The final error was $\pm 0.13$ seconds for the correction between predicted and observed time of mid-eclipse. It was generally agreed that this error is too large for the use of such a method in geodetic measurements.

Briefly the geodetic problem when applied to a total eclipse consists in the determination of the exact instants when two observers on different points along the path of the eclipse are on the axis of the shadow. The axis of the shadow is the line joining the center of the sun and the moon. From the knowledge of the motions of the sun and moon and the parallax of the moon, it is possible to compute from these times the position of the observer in three dimensions, namely, his latitude, longitude and distance from the center of the earth.

This method has two great advantages. First of all it eliminates the influence of deviations of the vertical. Secondly it saves a tremendous amount of time and money. Theoretically speaking we should get a first order geodetic line between the two observers without having to triangulate between them. There are only three such lines that have been measured over a large distance on the surface of the earth in the past. One is the meridian arc in the western part of the United States, another the arc in Russia and Siberia and the third, the arc of the thirteenth meridian east of Greenwich which runs from South Africa to northern Europe. This last arc has been under survey for almost fifty years and it has large gaps still to be closed. From such arcs we derive our knowledge of the size and shape of the earth.

Now in order to make a similar measurement of a long line from the observation of a solar eclipse we have to cope with several very difficult problems. Observationally, we have to determine the time of mid-eclipse, or the passing of the axis of the shadow and the duration of the eclipse (interval between second and third contact) to within $\pm 0.05$ seconds of time. Otherwise the observation is not sufficiently precise for first order work.

Secondly, the computational work involved requires some assumptions which will need rectification later on. For example, the parallax and the mean longitude of the moon are not as certain as we would desire. We must assume them to be the best possible values. At least they will be constant for any eclipse.

Now to beat the observational problem the method of measuring the instant of minimum light was revived and adapted to a high speed time recorder. The equipment was designed as carefully as possible to give a symmetrical light curve while being recorded at high speed. The first test of the equipment was made by Dr. John P. Hagen of the U. S. Naval Research Laboratory on the site of an eclipse camp in the Aleutians in 1950. Although the weather was rainy and completely overcast during the eclipse, a successful observation was obtained. The probable error, however, was not small enough. We were inclined to blame this fault on the weather which would have made a total failure of any other expedition.

In September of last year the U. S. Air Force obtained approval to make an expedition to Africa for observation of the eclipse of February 25, 1952. The approval was very late and only after the approval was it possible to start the red tape moving for the equipment. The tape moved so slowly that Georgetown finally agreed to purchase the parts of the special equipment and to build the units for six separate observation sites in the observatory shop at Georgetown.

As soon as a part was finished it was quickly tested and then turned over to the personnel of the various sites so that they could learn how to operate it. Incidentally none of the personnel provided by the Air Force had been on an eclipse expedition before nor had any of them ever operated equipment of the type we intended to use. In fact one of the test projects was to see if such sites could be successfully manned by inexperienced personnel. After two weeks of training, the equipment was all packed for shipment and not seen again until our arrival in Khartoum.

The six sites were located along the path of the eclipse, one at Libreville on the Atlantic Ocean, another at Bangui in the middle of French Equatorial Africa, a third at Khartoum, which was the general headquarters because it was more or less in the middle of the six sites. A fourth site in the desert at Port Sudan on the Red Sea and a fifth at Qaisumah in Arabia were chosen. The sixth site was placed off the path of the eclipse deliberately in order to test the applicability of the method at a point outside the line of totality.

The equipment worked very well. Difficulties on the day of observation were strictly due to human beings. The time signals which we needed so badly were rebroadcast by the Voice of America station in Tangiers. The original signal came from WWV of the Bureau of Standards in Washington. Now the Russians have about a thousand transmitters, as I have been told, dedicated to jamming propaganda stations. They treated our time signals as propaganda. With so much interference, we must admit defeat, as far as time signals are concerned, for our two sites in Saudi Arabia, but we managed to hear through the jamming signals in all of the African sites.

The inexperienced personnel are responsible for the rest of the trouble. One observer, having failed to indicate the zero seconds on his record during the actual observation, tried to cover his mistake by putting the marks in afterwards. After seventeen hours of frustration this cruel deed was discovered. Other observers made blunders that everyone makes while working under pressure. One man turned the wrong control on the apparatus and lost a part of the observation. Others apparently forgot to guide the instrument at the very critical times near the beginning and end of totality. These human failures have multiplied the problems of measuring the records for final reduction. But with all of them the probable error of a preliminary reduction is smaller than that obtained from any previous method.

The mathematical work promises to be very involved. No one, as far as I know, has ever reduced the path of an eclipse to a geodesic. It appears that we have a job of numerical integration to be done on an electronic computer. At present we are preparing the computation for such a process.

In the meantime the Air Force is satisfied that the experiment has been successful. While many critics still feel that we may never get the accuracy we desire, they also admit that no other method so far known promises to give a geodetic measurement across oceans or difficult terrain with a first order accuracy. Until we get a final result free from instrumental and personal failures we shall not know for certain whether or not our method or even the total eclipse of the sun provide the best way of determining a long line on the surface of the earth.

# Obituary

## REV. JOSEPH J. SULLIVAN, S.J., 1892-1952

It is with a deep sense of loss that we report the passing of the Reverend Joseph John Sullivan from this life on November 4, 1952. Father Sullivan was born in Boston, Massachusetts on March 2, 1892. After graduating from Boston College High School, he entered the Society of Jesus at Saint Andrew's on the Hudson in 1910. From 1915-1918, he studied philosophy and science at Woodstock College in Maryland, where he received the A.B. degree in 1918. He became professor of chemistry at Canisius College and served there from 1918 to 1921. From 1921 to 1925 he was a student of theology again at Woodstock College, being ordained to the priesthood in 1924, and receiving his M.A. degree in 1925. He worked for his Ph.D. degree in chemistry at Johns Hopkins University from 1925 to 1928 under Dr. F. O. Rice and was awarded the degree in 1928. From 1928 to 1929 he spent a year of ascetical theology at St. Andrew's on Hudson.

From 1929 to 1933 he was professor of chemistry and chairman of the department of chemistry at Boston College; from 1933 to 1942 he held similar office at the College of the Holy Cross in Worcester, Massachusetts, with the additional duty of Director of Graduate Work.

During the period 1928 to 1942, he was active in many associations, especially the American Association of Jesuit Scientists, of which he was President from 1932 to 1933; the Northeastern Section of the American Chemical Society, as a member of the Board of Control of its publication, the *Nucleus*, from 1929 to 1933, and also as one of its National Councillors in 1940; and the Worcester Chemists' Club, of which he was President from 1941 to 1942. He was further active on the Broadcasting Committee of the Northeastern Section from 1928 to 1935. About 1941 he broadcasted on scientific topics over WGY in Schenectady. Other memberships included the Franklin Institute, the American Association for the Advancement of Science, the American Chemical Society, The Faraday Society, Fellow of the Chemical Society (London), the German Chemical Society, the New England Association of Chemistry Teachers and the Catholic Round Table of Science.

The years 1942 to his death were spent mostly at Weston College, except for two years after the War at Boston College. He was Professor of Chemistry at both institutions.

His technical interests were largely centered on reaction rates, dynamic isomers and the vitreous state of matter. He was a master glass blower and his hobbies included photography and outdoor activities. Indeed he was the faculty founder of the Outing Club at the

College of the Holy Cross.

His professional interests naturally embraced the contribution of chemistry to education. Having tasted the fresh blood of research, he realized its vital function in education and did his utmost to pass this finding on to others and to transfuse it in all of his educational activity.

He published continually in the JESUIT SCIENCE BULLETIN, notably his prophetic Presidential Address to the Association in 1933 on the Disintegration of Atoms in which he envisioned the great potentiality of atomic energy. He taught his students to write and publish and his efforts were enviously effective. It was he who installed the new and enlarged library of chemistry at the College of the Holy Cross. His better known publications include the following: "Repair and Construction of Laboratory Glassware," *Report of the New England Association of Chemistry Teachers*, 41, 22-26 (1939); "Curious Costs of Water," *Taste and Odor Control Journal*, 7, (12), 1-3 (1941); "The Air We Breathe," *Nucleus* (Broadcasting Supplement), 44, 146-149 (Jan. 1932); "The Water We Drink," *ibid.*, 45, 149-152 (Jan. 1932); and with F. O. Rice, "Keto-enol Isomerism and the Mechanism of Homogeneous Reactions," *Transactions of the Faraday Society*, 24, 678-682 (1928); also, "Catalytic Studies on Acetoacetic Ester," *Journal of the American Chemical Society*, 50, 3048-3055 (1928).

May he rest in peace. *bafSJ*

# Reviews and Abstracts

ACID-BASE TITRATION IN NONAQUEOUS SOLVENTS, by James S. Fritz. The G. Frederick Smith Chemical Co., 867 McKinley Ave., P.O. Box 1611, Columbus, Ohio. 8°, viii + 47 pp. 1952.

This very significant pamphlet and long desired work finally provides a compendium that reduces to analytic practice the many contributions on acid-base theory that have appeared over the last twenty years. For, besides the brief and clearcut review of modern theories, the work offers at least fourteen practical procedures which include the estimation of primary, secondary and tertiary amines, amino, carboxlyic and phenolic acids, alcohols, enols, imides and salts. Potentiometric methods are emphasized, but many indicator methods are included. Similarly organic assays predominate over the inorganic; and naturally, micro methods, over the macro. Withall principles are discussed for each category of samples; many applications are listed; and suggestions for new applications are made. Journal references extend well into the year 1952. Whatever emphasis is given to perchloric acid, the publisher's product, seems to be justified by the development of the text.

This is a timely contribution to the current academic trend of extending the content of the standard qualitative organic analysis course to include the estimation of functional groups largely by titrimetric methods. If the publisher's past practice of issuing revised editions of his analytic pamphlets from time to time is at all indicative, it can be hoped that this important field of chemistry will be kept up to date in this way for years to come. *bafSJ*

THE STORY OF COPPER, by the Bureau of Mines, Department of the Interior, Washington, D. C., in cooperation with the Phelps Dodge Corp., color and sound, 16 mm., about thirty minutes running time.

One is carried in this story from the pre-historic discovery of copper, through the bronze age, through the discoveries of sources of copper during the nineteenth century, the open-pit and underground mining, the concentration, smelting and refining, not to mention the transportation of the ores, right up to date and everyday uses for the element. This story is given in vivid detail; captions for the divisions of the story and subdivisions of the processing are highlighted and repeated often enough to impress the viewer in sound pedagogical style.

The color and grandeur of the film, especially the tiers on tiers in mountainous proportions of the open-pit mines, the furnace scenes in the smelting operations and the electrolytic refining processes are equally impressive and calculated long to tenant the imagination of the audience.

A chemical audience might desire a little more of the chemical background of smelting, flotation and electrolytic processes. Our readers would have been delighted if a little more positive matter could have been introduced into the historical part, something probably from the early history of copper in the vicinity of Lake Superior, as contained in Father Dablon's report in volume 54 of the Jesuit Relations.

Never the less this movie is at once, educational, artistic and entertaining. It pays to show it. *bafSJ*