THEORETICAL PHYSICS AND PIONEERING RESEARCH IN ILLINOIS MINERALS

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The title of this paper has been deliberately worded to emphasize the cardinal fact that higher physics is universally based on theory and that true research possesses the essential pioneering quality.

The paper is divided into two independent parts; the first half concerns the stuff physics research is made of and the second half illustrates its application to Illinois mineral industries.

UNDERSTANDING OF RESEARCH

According to Westbrook Steele, Executive Director of Institute of Paper Technology, research accomplishments attendant on the first World War led to a condition that might be classified as research worship rather than understanding of research.

Obviously a clear understanding of the prime ingredients of physics research is of higher import than the blind worship of research. The first step to such understanding is a clear delineation of the modus operandi of physics research.

Definition of physics.—It has been stated that what we call physics comprises that group of natural sciences which base their concepts on measurement and whose concepts and propositions lend themselves to mathematical formulation. This realm is accordingly defined as that part of the sum total of our knowledge which is capable of being expressed in mathematical terms. With the progress of science, the realm of physics has so expanded that it seems to be limited only by the limitations of the method itself. The larger part of physical research is devoted to the development of the various branches of physics, in each of which the theoretical understanding of more or less restricted fields of experience and in each of which the laws and concepts remain as closely as possible related to experience. It is this department of science, with its ever-growing specialization, which has revolutionized practical life and given birth to the possibility that man at last be freed from the burden of physical toil.

It is apparent that by this definition physics must be regarded as including such component specialized fields as mechanics, electrodynamics, thermodynamics, hydrodynamics, optics, electronics, constitution of matter, chemical reactions, petrography, and those portions of natural and social sciences possible of mathematical formulation with resultant experimental verification.

Furthermore, secondary physics deals mostly with statics whereas advanced physics is concerned exclusively with dynamics or flow of energy.

Origin of research.—Bacon is the father of what is known as the scientific method which is the basis of physics research. In his *Novum Organum*, perusal of which is recommended to all who aspire to research as a career, Bacon divides research into three progressive steps: induction, experimentation, and deduction. The tools of induction and deduction are mathematics whereas the tools of experimentation are instruments. Since research consists of a composite of these three steps, the absence of any one of the steps disqualifies the work as physics research. Experimentation, unattended by both induction and deduction, resolves itself into routine testing and this is not research. Conversely experimental research is an incongruity unless it is associated with theoretical research.

Physics research.—Due to the urgency of speedy accomplishment, usually it becomes expedient for the research physicist to utilize either recording instruments or assistants to carry out the experimentation. Doubtless Gibbs was the most distinguished of all American research physicists, relying almost exclusively on the experimental findings of others. Likewise, as F. W.. Moulton has noted, Archimedes, Aristotle, Galileo, Newton, Lyell, Darwin, Dalton, and Mendeleef were not simply, or even primarily, observers; their active and penetrating minds grasped the observational and experimental evidence relative to the subject in which they were interested and organized it into coherent scientific thought. Synthesis or deduction is the final and culminating step in the scientific process, but may not always be the product of the same individual who performs the earlier steps.

The present war is based on physics research. Conant has aptly designated it as the "physicist's war." H. B. Ward, Past Permanent Secretary of the A. A. A. S., expresses the belief that K. T. Compton, as the war organizer of American physics, has contributed more than any one else to our forthcoming victory.

The mathematical tool. — Mathematics is the hand-maiden of physics research. And inasmuch as physics deals with the flow of energy, the working knowledge of partial differential equations is the minimum requirement in physics research.

To E. B. Paine, Emeritus Head of the Electrical Engineering Department of the University of Illinois, has been delegated the task of selection of war-time girl-cadets by several large industries. He finds that any cadet who has mastered partial differential equations during her apprenticeship becomes useful as a research aide, regardless of her lack of knowledge along all other lines.

There exists one unfailing yardstick for minimal ability in research in the aforementioned physics sciences. This yardstick is daily usage of partial differential equations. Those who do not possess this ability are superficial in research in the physical sciences.

Inherent research qualities. — In addition to qualities which may be attained through training, a research man must be born with certain inherent qualities. These include character, curiosity, and sense of humor.

Character may be defined as honesty. A. W. Hull states that in research the greatest scientific sin is wishful thinking. Rationalization is diametrically opposed to the spirit of research.

W. R. Whitney holds the opinion that curiosity is the most important research quality. Alan Gregg, of the Rockefeller Foundation, states that if there be some measure of truth in the observation that children seek the unknown but adults fear it, then research is the fountain of eternal youth, for research, whose purpose is to meet the unknown, provides our minds with the perennial freshness and delighted curiosity of youth.

W. T. Chevalier believes that the sense of humor is the most important quality in research. The reason is that humor is based on incongruity or lack of proportion. In order to appreciate lack of proportion one must possess a keen insight into proportion, which is most essential to a research man. Eddington created the imaginary Scottish professor of Geloeology, who thoroughly understood the rules of this hypothetical science of humor, and could infallibly classify any kind of joke—without ever having seen it.

In addition to the above three minimal, inborn research qualities, high success in research depends on brilliancy of imagination.

The fruits of research.—The accomplishments of research are invention. Invention may be defined as something new. Also invention includes novelty and originality in (a) processes, (b) equipment for carrying out the processes, and (c) products made by means of such processes and equipment. Often, and perhaps usually, inventions are not immediately utilized, but eventually use is found for most, if not all, inventions. The basic inventions having to do with production of electricity antedated its industrial use by two generations. In this war, perhaps radar is the most important of all weapons; again with a generation between its invention and its use.

RESEARCH IN ILLINOIS MINERALS

Having considered briefly the nature of physics research, attention now will be focused on its applications to Illinois minerals. Such applications may be illustrated by citing a few examples. Since the research in Illinois minerals is most extensive, the limits of time permit only the review of selected illustrations, which will be confined to physics research carried out by the Illinois Geological Survey.

The topics for discussion comprise theoretical research in fields as follows: heat of combustion of coal calculated from energy liberated due to interdisplacement of valence electrons during combustion; air classification of pulverized material; plastic flow of coal; electric condenser demulsification of oil; smoke index as a quantitative measurement of the smoke content of coal; and effects of partial prevolatilization of coal and concentration of fusain on the smoke content of resultant briquets.

Heat of combustion of coal.—The bituminous matter of coal consists of aromatic hydrocarbons with molecular arrangement approaching that known for corresponding pure hydrocarbons. By means of quantum mechanics, the orbits of valency electrons before and after combustion of a particular type of hydrocarbon are known and the energy liberated due to interdisplacement of valency electrons during combustion may be calculated. The resultant calorific formula for bituminous coals is

$$q = 252\ [H + C/3 - O/12.5] \quad (1)$$

where q is the heat of combustion in cal. per gr. and H, C, O are percentages by weight of hydrogen, carbon, and oxygen, respectively.

This formula holds throughout the range of rank of coal from peat up to anthracite. In the anthracitization or carbonization of coal, the carbon changes from a hydrocarbon to a free carbon (carbon-carbon bond) and therefore the constant 252 changes to 240.

The oxygen in coal reduces the effective hydrogen in coal, which may be considered numerically as the total percentage hydrogen less 0.08 percentage oxygen. From this follows the concept of a hypothetical pure CH coal, composed only of carbon and effective hydrogen. The composition of this CH coal for all ranks of coal from peat up to anthracite is remarkably constant, consisting of 5.0 ± 0.5 hydrogen and 95.0 ± 0.5 carbon, with a calorific value of 9250 ± 100 cal. per gr., this constancy being within experimental accuracy.

From this CH coal concept and from the constancy of composition, it follows that the coalification process, up to the anthracite stage, was carried out under conditions of geologic equilibria of energy level.

Air classification. — Classification consists of separating a granular material into two (or more) screen sizes. Also a mixture of two materials possessing different densities, but the same screen size may be classified into its two components. Air classification is carried out under conditions of turbulent flow. The theory of air classification may be developed as follows:

The downward gravitational force on a spherical particle is

$$f = \frac{\Pi\, d^3\, D_p\, g}{6} \qquad (2)$$

where d, D_p are the diameter and the density of the particle, respectively.

Newton has shown that the upward force is

$$F = \frac{\Pi\, d^2\, D_m\, V^2\, C_d}{8} \qquad (3)$$

where D_m, V, C_d are the density, the velocity and the drag coefficient of the air.

The critical velocity of the air at which the particle remains suspended, obtained from solving the above equations, is

$$V_c = \left[\frac{4\, D_p\, d\, g}{3\, D_m\, C_d} \right]^{1/2} \qquad (4)$$

Zahn has discovered the relationship between the drag coefficient and Reynold's number, R, as follows:

$$C_d = 28/R^{0.85} + 0.48 \qquad (5)$$

Also Reynolds has shown that

$$R = \frac{D_m\, d\, V_c}{\nu} \qquad (6)$$

where ν is the viscosity of the air.

Since the drag coefficient changes with velocity, direct calculation of the critical velocity is difficult, if not impossible. However, a graphical solution may be readily obtained. From equations 4 and 6

and $$V_c = \left[\frac{4\, D_p\, g\, \nu\, R}{3\, (D_m)^2\, C_d} \right]^{1/3} \qquad (7)$$

$$d = \left[\frac{3\, \nu^2\, R^2\, C_d}{4\, D_p\, g\, D_m} \right]^{1/3} \qquad (8)$$

Then various values of Reynolds' number are taken one at a time, the corresponding drag coefficient is calculated from equation 5, and a graph is plotted for critical velocity versus particle diameter.

The resultant graph approximates a straight line, the equation of which is

$$V_c = A\, d - B \qquad (9)$$

where A is the slope of the line and B is the intercept. For clay particles, density 1.8, the numerical values of A and B are 6687 and 22.5, respectively.

Air carrying capacity A_c may be defined as the weight (gr) of material carried upward through unit cross sectional area (cm^2) per unit time (sec.).

Experimental results show a straight line relationship between air carrying capacity and the velocity less critical velocity. The equation of which is

$$A_c = K\, (V - V_c) \qquad (9a)$$

where K is the concentration of material in the rising stream in units of gr. per cc. For clay the constant K, has a numerical value of 0.016.