A STUDY OF THE EFFECTS OF BIOLOGICALLY RELEVANT PHYSICS TEXTUAL MATERIAL ON STUDENT ATTITUDES AND ACHIEVEMENT IN PHYSICS 231 AT WESTERN KENTUCKY UNIVERSITY

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ABSTRACT

A STUDY OF THE EFFECTS OF BIOLOGICALLY RELEVANT PHYSICS TEXTUAL MATERIAL ON STUDENT ATTITUDES AND ACHIEVEMENT IN PHYSICS 231 AT WESTERN KENTUCKY UNIVERSITY

By

John Philip Holden

Purpose

It is the purpose of this study to assess and compare the effects of experimental textual material in college physics, written within a biological framework, on the attitudes and achievement of undergraduate life science students. Of central concern is the increasing need which students preparing for medicine and the life sciences have for understanding the principles, laws, and methods of physics.

Procedures

Forty-eight undergraduate students enrolled in the course, Introduction to Physics and Biophysics 231, at Western Kentucky University during the Fall semester of the 1972-1973 academic year were the subjects of a study comparing the attitudes and achievement in college physics in terms of the textual material assigned to them.

Three groups of eight students each, one group from each of three lecture sections of Physics 231, received special textual material. These groups were designated the treatment groups.

Three groups of eight students each, one group from each of three lecture sections of Physics 231, received no special textual materials. These groups were designated the control groups.

Following a period of approximately three weeks the treatment and control groups were tested for achievement and attitude differences as determined from separate achievement and attitude tests.

Findings

Multivariate analysis of variance was used to analyze the data obtained from the achievement and attitude tests. Testing at the 0.05 level of significance greater achievement was found to be associated with the special textual material than with instructor designated (control) textual material. No treatment by class interaction effects on attitudes or achievement, and no achievement or attitude differences between classes were found.

The findings of this study indicate that biologically oriented physics textual material can aid in improving the achievement of life science students in college physics.

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CHAPTER I

THE PROBLEM

Need

Education in basic physics is of increasing importance to students of the life sciences. This fact is the source of a particularly acute problem in the undergraduate education of life science students. Major requirements for life science students in many colleges include courses of study in College Physics, in the belief that knowledge of basic laws and principles of physics is necessary to understanding of many biological phenomena. This need is apparent both in an interpretation of specific structural and functional aspects of living organisms and in understanding the physical mechanisms by which biological structural and functional parameters are determined.

Writing on the future of physics, Freeman Dyson, Professor of Physics at Princeton's Institute for Advanced Study, clearly suggests that adequate education in physics will require greater attention to modern biology.

> I take it as self evident that physics will not flourish in isolation from the rest of science. In particular, physics should keep in close touch with biology, as biology rather than physics is likely to be the central ground of scientific

> advance during the remainder of our century . . . I think it is true now, just as it was in 1946, that a tremendous opportunity exists for making major advances in microbiology by means of physical techniques . . . . The idea that physics has to be pure in order to be good, that work on the borderline between physics and biology is beneath the dignity of a true physicist, was wrong in 1946 and is still wrong today.[1]

The science of physics is deeply rooted in biology.

> For the Greeks, the relevance of physics to biology was such a paramount problem that it ultimately led to the codification of the first main type of physics in which organismic concepts became predominant . . . Mechanism was a study to be governed by the concepts of vitalism and not vice versa.[2]

It was Robert Boyle, who in the 17th century in commenting on Harvey's investigation of the movement of the heart and blood in animals, said that it was the presence of "valves in the veins of so many parts of the body" that convinced him of the correctness of the mechanical approach to the problem of the circulation of blood.[3] And, in the 18th century, during which the methods of classical physics became highly developed, the experimental work on combustion and respiration of Laplace and Lavoisier in studying metabolism clearly shows the application of physics in interpreting biological processes.[4]

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[1] Freeman Dyson, "The Future of Physics," Physics Today (September, 1970), p. 23.

[2] Stanley L. Jaki, The Relevance of Physics (Chicago: The University of Chicago Press, 1966) p. 283.

[3] *Ibid.*, p. 287.

[4] Antoine Lavoiser and Pierre Laplace, Memoir on Heat (Paris: The Academy of Science, 1780).

In 1865, Claude Bernard, in his Introduction to the Study of Experimental Medicine, although recognizing the limitations of physical methods in biological studies, not only acknowledges the "powerful support of physico-chemical sciences," but he also repeatedly urges the exactness of physics as a goal to be emulated in physiological research.[5]

In the mid 19th century the contributions to physics by physicians and physiologists were remarkable. Prominent among such contributors were Thomas Young, who developed the basis for the modern wave theory of light; Mayer, who first announced the principle of the mechanical equivalence of heat; and Helmholtz, whose contributions to acoustics, optics, and nerve transmission were outstanding.[6]

Later in the 19th century the alliance between physics and biology was to suffer a severe setback which even today holds the sciences apart to some extent. The disintegration of physics and biology came about largely due to the publication of Darwin's theory of biological evolution. The confrontation between the biologists and the classical physicists grew from the lack of precision in Darwin's evolutionary timetable and the physicists'

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[5] Claude Bernard, Introduction to the Study of Experimental Medicine, 1865.

[6] Jaki, op. cit., p. 296.

insistence on quantifiable precision in science. The attack on Darwin was lead by Kelvin, who challenged evolutionary biology on the basis of classical estimations of the age of the Earth which were much shorter than the time required for biological evolution according to Darwin. At issue was the question as to whether science can be good and yet not quantifiable in the sense of precise physical terms. No doubt the controversy was also nurtured by the Christian beliefs professed by many of the outstanding physicists of that age.[7]

The discovery and investigation of radioactivity in the early 1900's provided the key which was to open the barriers which evolution had placed between physics and biology. By means of radioactive dating, physics almost overnight doubled the estimated age of the Earth and allowed for the time required for the evolution of life proposed by Darwin.[8] Recently radioactive tracer methods have further advanced the credibility of Darwinian evolution in revealing that the nearer two species are on the evolutionary ladder the more readily their DNA strands combine with one another.[9]

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[7] _Ibid._, p. 299.

[8] _Ibid._, p. 314.

[9] B. H. Hoyer, B. J. McCarthy, and E. T. Bolton, "A Molecular Approach in the Systematics of Higher Organisms," _Science_, CXLIV (1964), p. 959.

Currently the interface between biology and physics evidences some very productive advancements in both disciplines. Two examples which illustrate activity at the interface of biology and physics are the development of biobatteries, in which electrical energy is generated through the catalytic action of certain bacteria on otherwise unusable fuels, and studies of photoreception, in the eyes of fish, frogs and beetles, which is providing valuable information in photoelectronics.[10]

Thus, fortunately, the dividing lines between physics and biology are giving way to a new science in which knowledge derives from the active application of physics to biological phenomena. Here, however, a word of caution must be given. Although biological knowledge has significantly expanded as a direct result of the application of the quantifying methods of physics, nonetheless, to plead for a complete reduction of biology to physics would overlook the non-quantifiable aspects of biological phenomena upon which the life sciences have largely developed. The present spirit of mutual cooperation between biology and physics must not fail to maintain the recognition of the wholeness of science

[10]Ernest Gardner, Fundamentals of Neurology (Philadelphia: W. B. Saunders Company, 1968), Ch. 13, p. 190.

lest the 19th century fragmentation within science be repeated.[11] This realization is particularly important as it pertains to physics curriculum development which until recently has been narrow to the extent of almost total ignorance of education and research in the life sciences.

Until recently very little attention has been given to designing the textual material used in general physics courses so that the biological significance of the topics treated is emphasized. College physics texts in recent years have tended to present physics on a highly technical level. One undesirable consequence has been to give basic physics an appearance of irrelevance to other sciences, in particular to the life sciences. Thus at present there is a clear need to improve the presentation of fundamental physics in textual form so as to make its content meaningful to life science students.

In order to determine just how this need is to be met research is required to determine what means, if any, can be established to accomplish the task.

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[11]Medewar, "Zoology," Scientific Thought in the Twentieth Century (London: Watts, 1951), p. 188.

Purpose

This study, is based upon the assumption that there is a need for improved textual material in College Physics courses for life science students. It is an inquiry into the effects of physics textual material, written within a framework of biological phenomena, on student attitudes and achievement in one unit of the course, Introduction to Physics and Biophysics 231, offered by the Department of Physics and Astronomy of Western Kentucky University.

Three goals consistent with this purpose have been established.

1. To determine what effect, if any, Physics Textual Material written within a biological framework has on student achievement in the General Physics course.

2. To determine what effect, if any, physics textual material written within a biological framework, has on attitudes of life science students toward physics itself.

3. To determine what effect, if any, physics textual material written within a biological framework has on attitudes of life science students toward physics textual material.

Hypotheses

To investigate attitude and achievement changes associated with experimental physics material written within a biological framework the following hypotheses will be tested:

1. There will be no significant differences in achievement in physics when the text material is biologically relevant.

2. There will be no significant differences in attitudes toward physics itself when the textual material is biologically relevant.

3. There will be no significant differences in attitudes toward physics textual material which is written to be biologically relevant.

The above hypotheses are stated in test form in Chapter III.

Theory

The research to test the above stated hypotheses has been motivated by years of experience on the part of the investigator in teaching a spectrum of undergraduate physics courses. In teaching courses in General Physics largely populated by life science students the investigator has noted difficulties which these students have commonly shared. These difficulties have seemed generally to arise from two sources: the failure of the course to relate its content to the special interests of the life sciences, and the failure of life science students to appreciate the significance of the course topics toward increasing understanding of biological processes. Prompted by observations which seemed to indicate an increase in favorable attitudes toward the course and an increase in cognitive learning when topics were presented in a biological setting the decision to test the stated hypotheses was made.

Definition of the Terms

Attitudes - Attitudes as used in this study refer to affective reactions toward the subject matter of physics and the textual material used in teaching physics.

Achievement - Achievement as used in this study refers to cognitive understanding of the content of the course unit, Static and Dynamic Properties of Solids and Fluids, presented in Physics 231 at Western Kentucky University, as determined from responses to multiple choice type problems written and administered by the course instructors at the close of the unit.

Biologically Relevant Physics - Biologically relevant physics as used in this study refers to the concepts, principles, definitions and formulas of physics presented within a framework of their significance to various life processes.

Traditional Physics - Traditional physics as used in this study refers to the concepts, principles, definitions, and formulas of physics where they are treated in isolation from other scientific disciplines.

College Physics - College Physics as used in this study refers to those course offerings traditionally called General Physics and/or Introductory Physics.

Limitations of the Study

This study will be limited in the following ways:

1. The study will be limited to investigation of the achievement and attitudes of students participating in Physics 231 at Western Kentucky University during the Fall semester of 1972.

2. The data for the study will be limited to the responses to the attitude questionnaire written and administered by the investigator and to the responses to the achievement examination written and administered by the course instructors.

3. The biologically relevant physics materials used in this study will be written by the investigator and will be limited to the unit: Static and Dynamic Properties of Solids and Fluids.

4. The topics covered in the unit: Static and Dynamic Properties of Solids and Fluids will be limited to those established by the instructors.

5. The topics covered in the unit: Static and Dynamic Properties of Solids and Fluids have been established by the course instructors to be:

    a. the basic definitions of stress and strain
    b. tensile stress, shearing stress, and bulk stress
    c. tensile strain, shearing strain and bulk strain
    d. Young's Modulus, the rigidity modulus and bulk modulus
    e. the definition of viscosity
    f. the rate of flow of viscous liquids, i.e., Poiseuille's Equation
    g. Newtonian and non-Newtonian liquids
    h. Stoke's Law and its relationship to sedimentation rates
    i. diffusion in liquids

j. osmosis and a simple model to explain osmosis
k. surface tension and how it is measured
l. the equation of continuity for incompressible fluids
m. Bernoulli's Equation for non-viscous fluids

Overview

In this chapter, the circumstances suggesting a need for studies pertaining to the effects of textual materials in College Physics on the attitudes and achievement of the life science students have been presented. The purpose of the study, as related to the stated needs, followed by the research hypotheses, definitions of terms and limitations of the study have been presented.

In Chapter II, the literature currently being used in the teaching of College Physics to life science students is reviewed, as are pertinent research studies supporting the research of this dissertation.

The selection of design, a description of the sample and population, instrumentation, and data analysis procedures are presented in Chapter III.

The analysis of data and results of the analysis are presented in Chapter IV. The final chapter contains the conclusions and implications of this study.

CHAPTER II

REVIEW OF THE LITERATURE

Literature which pertains to the teaching of physics within a biological framework can be classified within three categories. The literature in each of these categories supports the premise of need for general text material in which physics is presented in a biologically relevant manner. The review of literature on the following pages is intended to demonstrate the urgent need for development of textual material in which physics is presented in a biologically relevant manner and for studies to determine the effect of such material on the achievement and attitudes acquired by life science students in physics.

Literature Categories

1. Existing textual material in which physics is presented within a framework of biological relevance

2. Opinion articles which call for integration of physics and the life sciences

3. Descriptions of existing courses in which physics is presented in a biologically relevant manner

Existing Textual Material

Contemporary textual materials used in teaching fundamental physics commonly present physics as a discipline unto itself remote from biological phenomena. A broad review of current introductory textbooks in general physics reveals little, if any, content with apparent biological relevance. Two general physics texts published in the 1950s, however, do use biological phenomena in part to illustrate fundamental physics. These texts are: Physics, Its Laws, Ideas and Methods, by Alexander Kolin, and Essentials of Biological and Medical Physics, by Stacy, Williams, Worden and McMorris.

The text by Kolin, written as the text for the college course in physics at the University of Chicago in the early 1950s, is designed to accomplish two purposes:

> to satisfy the requirements of the Division of Biological Sciences in regard to the training in physics of students entering that division, and to satisfy the general education objectives of the college in regard to the training of students in the methods of the physical sciences.[12]

Although Kolin's text does contain frequent references to biological phenomena, these references are largely restricted to the sections on fluid mechanics and optics. That the material in the text is not closely related to

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[12] Alexander Kolin, Physics, Its Laws, Ideas and Methods (New York: McGraw Hill Book Company, 1950), p. vii.

biology is clearly acknowledged by the author: "no attempt has been made to present a complete survey of applications of physics to biology."[13]

Essentials of Biological and Medical Physics, by Stacy, Williams, Worden and McMorris presents physics entirely within the framework of biological phenomena. This text, therefore, may be properly classified as a text in biophysics. However, the level at which it is written precludes its use as a basic text for introductory physics; the text assumes an undergraduate background in physics and mathematics. Each chapter closes with references to a variety of undergraduate textbooks in physics and mathematics to aid the student having insufficient preparation for the content of the chapter. Although this text is written above the introductory level, it could serve as a valuable reference for a course in College Physics, especially for its chapters on Elasticity and the Breaking Strength of Bones, Mechanical Engineering of the Body, The Living Body of Sound, Geometrical Optics and Vision, and sections of the chapter on fluid mechanics.[14]

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[13] Ibid.

[14] Ralph W. Stacy, David T. Williams, Ralph E. Worden, and Rex O. McMorris, Essentials of Biological and Medical Physics (New York: McGraw Hill Book Company, 1955).

Three currently available general physics texts intended specifically for use by life science and pre-medical students are: Physics for Biology and Pre-Medical Students, by Desmond M. Burns and Simon G. MacDonald, College Physics, A Text with Applications to the Life Sciences, by Donald E. Tilley and Walter Thumm, and Physics for Biology and Medicine, by I. W. Richardson and Eiler B. Neergaard.

Although it is not a general physics text in the usual sense, Physics - Understanding Our Environment, by Charles H. Bachman, might also be considered because of its presentation of qualitative descriptions of certain bio-related physical principles.

Burns and MacDonald.--Physics for Biology and Pre-Medical Students, by Desmond M. Burns and Simon G. MacDonald, (1970) is a text in general physics intended for use by biology and pre-medical students. The text covers topics ranging from kinematics and classical mechanics through thermodynamics, classical optics, electricity, magnetism and modern physics. The text is unusual in several respects, notably in that it includes a chapter on probability and statistics and a large number of chapter sections devoted to biological applications of physics. Frequently, however, as in the case of the sections on biological applications of alternating current, the material appears to be thrown in as an after thought following a non-biological treatment of the chapter topic.

In summary, the Burns and MacDonald book adequately presents the usual topics covered in a College Physics text. The presentation is traditional, except for scattered biological illustrations of physics. Probably the mathematical sophistication required of the reader exceeds that of the usual undergraduate life science student.[15]

Tilley and Thumm.--College Physics, A Text with Applications to the Life Sciences, by Donald E. Tilley and Walter Thumm, is one of a multitude of introductory physics textbooks which attempt to introduce physics within the framework of twentieth century advances in physical knowledge. The text is permeated with atomic and nuclear theory, and General and Special Relativity. The chapters on classical physics give only brief treatments of Newtonian mechanics, electromagnetic theory and thermodynamics. Other than scant references to medical applications, direct relevance of this text to the life sciences is left to the imagination of the reader. In terms of a meaningful portrayal of physics

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[15]Desmond M. Burns and Simon G. MacDonald, Physics for Biology and Pre-Medical Students (Reading, Massachusetts: Addison Wesley Publishing Company, 1970).

in biological phenomena the text is a total failure.[16] The text was apparently written as a general physics text, with a few sectional topics of the medical applications of x-rays and radioactive tracers thrown in to attract a wider adoption of the text.

Richardson and Neergaard.--Physics for Biology and Medicine, by I. W. Richardson and E. B. Neergaard is a well organized text which directly pertains to biological phenomena and medical topics. The text contains only classical treatments of physical phenomena. No modern physics is included. The presentation is rather sophisticated, with the fundamentals of Newtonian mechanics, fluid dynamics, thermodynamics, current electricity, molecular transport theory, acoustics and optics developed in using the calculus of single variables. Absent is any discussion of rotational mechanics, magnetism, static electricity and atomic theory.

Although this text gives a thorough treatment of the topics it presents, the mathematical abilities required of the reader probably exceed those of most undergraduate

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[16] Donald E. Tilley and Walter Thumm, College Physics, A Text with Applications to the Life Sciences (Menlo Park, California: Cummings Publishing Company, 1971).

life science students. The physics is not presented with a biological basis, although there are numerous biological references. Probably the text is well suited to a one semester course in physics for graduate students in medicine and the life sciences, although it is not suitable for use as the sole text in a one year undergraduate general physics course taken by biology students.[17]

Bachman.--Physics - Understanding Our Physical Environment, by Charles H. Bachman is uncommon among introductory physics texts. The text is almost entirely descriptive and as such it can not be considered as a text in physics in the usual sense. In Part five of the book, entitled, Physical Principles Applied to the Human Body, the author treats optics and vision, sound and hearing, body mechanics and electricity and radiation in relation to the human body. The entire text is based upon the premise that important concepts in physics can be presented nonquantitatively without losing legitimacy. Accordingly the text lacks the usual rigor required to unify physics under the general notions of conservation laws and physical principles. After reading Part Five of

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[17] I. W. Richardson and E. B. Neergaard, Physics for Biology and Medicine (New York: John Wiley and Sons, 1970).

this text, one is left with only a vague understanding of the unity of physics. The author is to be commended, however, in that he clearly recognizes the stumbling block which mathematical formalism presents to beginning students and, especially, to life science students. Unfortunately, Bachman's book is too qualitative to adequately prepare students for the formalism required in more advanced study.[18]

Opinion Articles

The need for a general introductory text in which the fundamentals of physics are presented from within the setting of biological phenomena is clearly suggested by Philip Handler:

> Until the laws of physics and chemistry had been elucidated it was not possible even to formulate the important, penetrating questions concerning the nature of life. For centuries students of biology, in considering the diversity of life, its seeming utter distinction from inanimate phenomena, and its general unlikelihood, found it necessary, in their imagination, to invest living objects with a mysterious life force, "vitalism," with which all living organisms were endowed. But in the late eighteenth century, Lavoiser and Laplace were able to show that within the not inconsiderable limits of error of the methods available to them, the recently formulated laws of conservation of energy and mass were valid also in a living

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[18]Charles H. Bachman, Physics - Understanding Our Physical Environment (Croton on Hudson, New York: Bogden and Quigley, 1970).

> guinea pig. The endeavors of thousands of life scientists over the next two centuries have gone far to document the thesis thus begun. Living phenomena are indeed intelligible in physical terms. And although much remains to be learned and understood, and the details of many processes remain elusive those engaged in such studies hold no doubt that answers will be forthcoming in the reasonably near future . . . . Biology has become a mature science as it has become precise and quantifiable. The biologist is no less dependent upon his apparatus than the physicist. Yet the biologist does not use distinctively biological tools. He is an opportunist who employs a nuclear magnetic resonance spectrometer, a telemetry assembly, or an airplane equipped for infra-red photography, depending upon the biological problem he is attacking. In any case, he is always grateful to the physicists, chemists and engineers who have provided the tools he has adapted to his trade.[19]

Addressing himself to current changes in physics and education in physics, H. William Koch, Director of the American Institute of Physics, emphasizes that the trend is away from isolation of physics from the other sciences. In particular Dr. Koch sees an amalgam of physics with chemistry and biology insupport of research and education in the future.[20]

If today physics is unpopular in the minds of a large segment of the population of undergraduate students then attention must be given to this attitude. Writing on this subject, Dr. Adolph Baker maintains that the

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[19] Philip Handler, Biology and the Future of Man (New York: Oxford University Press, 1970), p. 3

[20] H. William Koch, "An Age of Change," Physics Today, (March, 1970), p. 35.

golden age in which physics was held in high esteem in the student mind is past, that in order to maintain a dominant position in the undergraduate curriculum physics must now compete for students.[21]

Although a working knowledge of fundamental physics is necessary to an understanding of much of modern biological science this fact is not apparent to the casual observer nor to the beginning undergraduate. In order to attract students to physics Baker maintains that introductory physics can no longer be taught as a discipline unto itself in a language which is foreign to the student.[22]

Baker's point must be considered in the development of textual materials in general physics for life science students.

An area of growing popular concern in which physics and the life sciences will increasingly blend together is environmental science. In an article pertaining to contributions which physics can make toward solutions of environmental problems, Marvin Goldberger, Chairman of Princeton's Physics Department proposes that the present undergraduate physics curriculum be modified to include an

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[21]Adolph Baker, "Physics and Antiphysics," Physics Today, (March, 1970), p. 35

[22]Ibid.

emphasis on applications of physics to a wide range of environmental problems.[23] Although Goldberger would leave the content of the introductory physics courses essentially unchanged, he does advocate modifying third and fourth year physics courses to include environmental topics. Arguing for the introduction of environmentally related material into the physics curriculum Goldberger writes:

> What is done at present, to a greater or lesser extent, is to ignore essentially everything in the introductory course and to start over again giving finer derivations and so on. My proposal for those two years (the last two years in undergraduate physics) is to teach applications of physical principles to a wide range of (environmental) problems, developing and deepening the theory, as one goes along and as it is needed.[24]

In 1969 the president of The National Academy of Sciences appointed The Physics Survey Committee for the purpose of evaluating the status, opportunities and problems of physics in the United States. The report of the committee's panel on Physics in Biology is presented in Volume 1 of Physics in Perspective. Regarding the interaction between university physics departments, departments of biophysics and the life sciences the panel reports:

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[23] Marvin Goldberger, "How Physicists Can Contribute,' Physics Today, (December, 1970), p. 26

[24] Ibid.

> In practice these departments (Biophysics and the life sciences) do not interact to a large extent with physics departments, although physics courses are increasingly important to their students. In this respect, it is generally felt that physics department do less than chemistry departments to accommodate such students among whom are an increasing number of pre-medical students who desire some physics courses. Revision of the physics curricula to accommodate the needs of these students would be one way in which the interaction of physics and the life sciences could be strengthened.[25]

In an article pertaining to the teaching of physics to nonscience students, John M. Fowler and Richard West of the Commission on College Physics, have written of teaching physics to captive students--students required to take physics in fulfillment of curricular requirements set by other departments within the university.

> These are the preprofessional students in medicine, architecture, dentistry and nursing, who are forced into physics classes by curricular requirements. Problems associated with teaching these captives seem in some ways less difficult than the problems of teaching the broader group of nonscientists. The students are, afterall, already in our classes. They are motivated by other professional requirements, and a good grade (at least in the case of premeds) is desirable in itself. We have, however, largely avoided the deeper problem of understanding why physics is required of these students, and what it is that their curriculum advisers expect in the way of skills, knowledge and learned processes. With the changes that have taken place in most introductory courses, the time for investigation of these deeper problems and clear statements of objectives is overdue.[26]

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[25] National Research Council, Physics in Perspective, Vol. 1, (Washington, D.C.: National Academy of Sciences, 1972), p. 308.

[26] John M. Fowler and Richard West, "What our Left Hand Has Been Doing," Physics Today, (March, 1970), p. 24.

The unmistakable message of this article, and those others quoted above is that there is an urgent need for curriculum revision in the general physics courses taken by life science students. This need is further supported by the survey of the historical interaction between physics and the life sciences and by an examination of existing physics courses populated by students from the life sciences.

Existing Courses

The lack of available textual material in which basic physics is presented within a biological framework is paralleled by the absence of contemporary courses in which physics is presented as it pertains to biology. There is, however, a growing interest in developing college physics courses in which biological topics play an important role.

The School of Physics and Astronomy of the University of Minnesota is presently actively engaged in developing biologically based laboratory experiments for use in the general physics sequence (Physics 1104, 1105 and 1106). Already in use in these courses are experiments entitled: The Cow's Eye--A Natural Optical System, Construction of a Microscope and Telescope, and The Electrocardiogram. In the hope of further developing the lectures which accompany these laboratories and designing other laboratory experiments members of the Minnesota

Physics Faculty are currently attending lectures in the university's School of Medicine in order to appraise the potential needs of pre-medical students. At present the text used to support the lectures in Physics 1104, 1105 and 1106 is Physics, by Atkins. According to Dr. Bruce Eaton, Professor of Physics, University of Minnesota, this text is being used simply because of the lack of a good text with a biological emphasis.[27]

The 1972-1973 catalog course description of Physics 231 and Physics 232 at Western Kentucky University reads:

> . . . a basic course for students of the life sciences, with emphasis on an understanding of the physical principles operative in biological systems and on the application of physical methods in biology and medicine.

During 1972-1973 academic year Physics 231 and Physics 232 have been offered with no specified course textbook, although, frequent references have been made to, Physics for Biology and Pre-Medical Students, by Burns and MacDonald. According to the course instructors this situation, again, derives from the absence of an available general text written with a biological emphasis at a level within the grasp of beginning students.[28]

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[27] Bruce Eaton, Physics Department, The University of Minnesota, Private Correspondence.

[28] James Parks and Thomas Coohill, Department of Physics and Astronomy, Western Kentucky University, Private Correspondence.

At Michigan State University, the course sequence in college physics is offered in two tracks, one intended for life science students and one for general education. At present the text used in both tracks is ,Principles of Physics, by F. Bueche. This text contains no direct reference to biological phenomena. In order to overcome this deficiency, Dr. Jerry Cowen, the lecturer, in the bio-track sequence, supplements his presentations with biological illustrations. However, course study guides written by Dr. Cowen during the 1972-1973 academic year contain no direct biological input.[29]

A novel approach in teaching physics to life science students is offered at Gustavus Adolphus College in St. Peter, Minnesota. There students take a 14-week course in which they study the physics of instruments commonly used in experimental psychology and biological research. The course includes laboratory experiments in living animals, and the physics of hearing.[30]

Until recently, the Santa Fe Preparatory School, Santa Fe, New Mexico, offered a physics course in which biological illustrations were frequently used. According to the course instructor:

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[29] Jerry Cowen, Department of Physics, Michigan State University, Private Correspondence.

[30] Ibid.

> . . . Any phenomenon which may serve to elucidate a fundamental physical principle is a most welcome addition to the class discussion and it is my thesis that, if this example can be drawn not from a purely physical system but from a biologic one, the class gains markedly thereby.[31]

At Coe College, Cedar Rapids, Iowa, each summer the Physics Department offers a general course largely attended by life science and pre-medical students from the University of Iowa. This course is unique in that it compresses the usual one year college physics course into the six-week summer term. This is accomplished by giving a two-hour lecture followed by a one-hour recitation session each morning and a 3 hour laboratory period each afternoon. In recent years the text material in this course has not been biologically related due to the unavailability of a suitable textbook. However, when the course was taught by this writer an attempt was made to relate the class topics to biological phenomena whenever possible.

Although no longer active, a two-year core course for science majors has been offered by Portland State University. The course attempted to integrate the material normally covered in introductory physics, chemistry and biology courses. Although the course was not specifically designed to teach physics in a biological setting,

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[31] Peter Thompson, "High School Biophysics," <u>The Physics Teacher</u> (October, 1967), p. 322.

Dr. Arnold Pickar, Associate Professor of Physics at Portland State University writes:

> Concerning those students who are intimidated by the physics we should offer this observation: We suspect that a few students in the course owe their progress through the physics material to the fact that it came in sections of at most five weeks and had a recognizable relationship to biology; we are not certain they would have been as successful in the conventional physics course.[32]

And, speaking of the textual material used in the course, Dr. Pickar further comments, "No single suitable textbook is available, hence conventional texts have been used."[33]

Student appraisal of the course is reflected in the statement:

> A preliminary evaluation study in which attitudes of students in the core course were compared with those of matched groups of students in the conventional introductory science courses has shown a significantly higher level of overall satisfaction with the core course.[34]

Summary

From the above literature review it is apparent that textual material in which biological phenomena pro-

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[32]Richard Fuller, Physics Department, Gustavous Aldolphus College, Private Correspondence.

[33]Arnold D. Pickar, Physics Department, Portland State University, Private Correspondence, April, 1973.

[34]Arnold D. Pickar, "Core Course for Science Majors Combining Material from Physics, Chemistry and Biology," American Journal of Physics (February, 1960), p. 260.

vide a basis for illustrating and applying the general laws and principles of physics is not commonly available today. The need for such material is reflected in current attempts to incorporate biological phenomena into the content of college physics courses. Chapter III of this study describes the design of an experiment in which biologically oriented textual material was evaluated for its effects on student attitudes and achievement in college physics.

CHAPTER III

DESIGN AND IMPLEMENTATION OF THE STUDY

Overview

This investigation originated with the development of textual material for experimental use in the course Introduction to Physics and Biophysics 231 at Western Kentucky University during the Fall semester of the 1972-1973 academic year. Use of the experimental textual material and collection of data occurred during November, 1972.

The purpose of the study was to determine the relative effects of experimental textual material, combining physics and biology on student attitudes and achievement contrasted with attitudes and achievement where conventional college physics textual material was assigned reading.

The effects of the experimental materials were measured in terms of attitudes towards physics, attitudes towards physics textual material and achievement in physics.

The Population

The study was conducted with undergraduate students at Western Kentucky University. The students were sophomores, juniors, and seniors majoring in the health and life sciences. These students were taking the course to fulfill curriculum requirements established by their major departments, and in this sense they may be considered as captives. Thus, the usual motivational problems associated with non major required courses were encountered.

Physics 231 is taught in three separate lecture sections, two under one professor, and one under another. Due to the fact that sectional enrollment was designated by the individual students at the time of registration sectional equality, as established under a random assignment procedure, could not be established.

The Sample

For purposes of the experiment each of the three lecture sections of Physics 231 were divided into two randomly selected groups. In each section one group received the experimental textual material and the other received no special material.

From the total enrollment of 74 students in the three lecture sections of Physics 231, 62 students cooperated fully in the experiment by returning both achievement and attitude tests pertaining to the experiment. From these students one treatment group of 8 randomly selected subjects, and one control group of 8 randomly selected subjects, were established in each of the three lecture sections of Physics 231. Thus, the sample consisted of three randomly selected treatment groups, and, three randomly selected control groups corresponding to the three lecture sections of Physics 231. Each student in each treatment group had received a copy of the experimental physics textual material whereas each student in each control group had received no special textual material.

Early in the design of the study, the possibility of exchange of trial materials between the treatment and control groups was a matter of concern. Consideration was given to limiting access to the experimental material by placing it on reserve limited to the designated treatment subjects. However, constraints of this nature were rejected on the basis that they impose unusual and artificial study conditions, which could confound the effects of the treatment. Thus, the students participating in this study experienced no unusual controls beyond random assignment to reading materials.

Following the course unit in which the experimental materials were used an achievement examination of the multiple choice type, written by the course instructors, was administered to all students in the experiment. The achievement examination was administered by the regular course instructors as a normal unit examination. Following the achievement examination, the investigator administered the attitude inventory, a Likert-type attitude inventory written by the investigator.

The design of this experiment, The Post Test-Only Control Group Design, is described by Stanley and Campbell as a True Experimental Design. The design may be represented symbolically as:

R	X	0_1
R	X	0_2

Here R represents random assignment of respondents to the treatment and to the control groups, X represents the treatment and 0_1 and 0_2 represent the achievement and attitude tests administered to the treatment and control groups respectively.

This design was selected for several reasons. Primary among them are the controls which the design offers in limiting the effects of the threats to internal and external validity listed below.

Threats to Internal Validity

1. History, the specific events occuring between the first and second measurement in addition to the experimental variable.

2. Maturation, processes within the respondents operating as a function of the passage of time per se (not specific to the particular events), including growing older, growing hungrier, growing more tired and the like.

3 Testing, the effects of taking a test upon the scores of a second testing.

4. Instrumentation, in which changes in the calibration of a measuring instrument or changes in the observers or scorers used may produce changes in the obtained measurements.

5. Statistical regression, operating where groups have been selected on the basis of their extreme scores.

6. Biases, resulting in differential selection of respondents for the comparison groups.

7. Experimental Mortality, or differential loss of respondents from comparison groups.

8. Selection-Maturation interaction, etc., which in certain of the multiple-group quasi-experimental designs, . . . is confounded with, i.e., might be mistaken for, the effect of the experimental variable.[35]

Specifically, the controls on these factors under the Post Test-Only Control Design are indicated by the following table.

Threats to External Validity

Threats to external validity, threats which may invalidate the findings of a study as they might apply to the external population are difficult to delineate. The primary source of this difficulty lies in the tentativeness of inductive logic.

Interaction of Testing and Treatment

Under the assumption of limited generalization, the Post Test-Only Control Group Design avoids the external interaction effect of testing and treatment. This threat

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[35]J. C. Stanley and D. T. Campbell, Experimental and Quasi-Experimental Designs for Research (Chicago: Rand McNally and Company, 1966), p. 5.

TABLE 3.1.--Controls on Threats to Internal Validity.

Threat	Control
History	No Pretest
Maturation	No Pretest
Testing	No Pretest
Instrumentation	No Pretest
Regression	No Pretest
Selection Biases	Random Assignment of Control and Treatment Respondents
Experimental Morality	Random Selection of Respondents from whom data is considered in Analysis
Selection-Maturation Interaction	Short Experimental Period, Randomization

to external validity is particularly troublesome in attitudes where the attitude tests themselves may introduce attitudes which heretofore are not present in the sample.[36]

In that testing only followed treatment in this study this threat of interaction of testing and treatment was reduced by design.

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[36] *Ibid.*, Stanley and Campbell, p. 18.

Interaction of Selection and Treatment

The threat posed by the interaction of selection and treatment is difficult, if not impossible, to control in any experimental design. All that can be said with regard to this threat as it may have affected this study is that the course in which the experiment was conducted is offered without unusual conditions by two professors having distinctly different personal backgrounds. Although the students who comprised the control and treatment groups may reflect demographic characteristics peculiar to the South Central United States, these characteristics would seem difficult to differentiate from those of other general physics students in small public universities elsewhere in the Central United States. Whether the willingness of the faculty of the Department of Physics and Astronomy of Western Kentucky University to accommodate this study is unusual and introduces selective biases can not be established.

Reactive Arrangements

The threat to external validity posed by the so-called reactive arrangements effect, that is, the effect in which the simple awareness of participating in an experiment may influence the outcome, is impossible to control or evaluate in the Post Test-Only Control Group Design. However, certain precautions were taken to reduce this threat. The trial (treatment) material (physics textual material) was carefully written to present only content which was prescribed by the unit syllabus, written by the course instructors far in advance and independent of the experiment. This fact, along with a strongly worded statement to all students in Physics 231, indicating that the trial material did not differ in physics content from the usual reading material, was intended to effectively overcome reactive arrangement effects. Furthermore, the students were pre-advised that the achievement examination over the unit, would be written by the regular course instructors without regard for any particular textual material.

At the onset the investigator considered writing placebo material for the control group. However, on the advice of personnel within the Office of Research Consultation of the Michigan State University College of Education the use of placebo materials was abandoned. This action was justified on two bases: (1) a placebo itself can not actually replicate other textual material which the trial material is intended to contrast, and (2) any placebo written well enough to appear as an improvement over standard contemporary textual material might produce effects which would confound effects of the actual experimental material.

Finally, the threat of confounding the effects of multiple treatments and thereby jeopardizing the external validity of the findings of this study was reduced by design in the following manner.[37] The possibility of effects due to changes in the established classroom procedures was avoided by allowing the instructors to continue their presentations without experimental alteration. Although, in writing the trial material it was necessary for one of the two instructors to read the trial material and to confer with the writer as to its suitability to the course, the second instructor, responsible for two of the three lecture sections, did not read the trial material prior to or during the experiment. This reduced the possibility of treatment biases creeping into his class-lecture presentations. Furthermore, as described in Chapter IV, the Finn Program was set up to test for differences due to Teacher-Class interactions in order to detect any treatment effects which could be attributed to factors external to the reading materials.

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[37]Lee J. Cronbach, Essentials of Psychological Testing, 2nd Edition (New York: Harper and Row, 1960) p. 103.

Instrumentation

The instruments used in this study consisted of a twenty-five item multiple choice type examination covering the physics content of the course unit to which the experiment was limited, and a Likert type attitude inventory scale designed to measure student attitudes towards physics itself and attitudes towards textual materials covering the unit.

Achievement Test

The achievement test was written and administered by the course instructors independent of contact with the investigator in order to reduce possible reactive effects. This procedure was instigated following the advice given by Stanley and Campbell:

> The present authors are gradually coming to the view that experimentation within schools must be conducted by regular staff of the schools concerned, whenever possible, especially when findings are to be generalized to other classroom situations.[38]

At the suggestion of the investigator, the instructors included only multiple choice type questions on the achievement test. This suggestion was made in order to give each item equal weight in the final analysis. Due to the test's construction by the course instructors, the

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[38] Stanley and Campbell, *op. cit.*, p. 21.

content validity, as well as the reliability of the test depended entirely on the judgment of the instructors alone.

At the outset it was recognized that achievement tests based entirely on multiple choice type questions suffer from at least two serious limitations, (1) the fact that the students are confronted with a series of choices knowing that at least one is correct ignores the real possibility that without that knowledge a correct response might not be given, and (2) the multiple choice examination does not provide for means of testing the student's ability to express himself clearly, to demonstrate his ability to organize data, and to systematically arrive at some desired conclusion. Nonetheless, in view of the need for strict objectivity in scoring the examination in order to compare performance between the treatment and control groups,the multiple choice test appeared to be the most suitable choice among alternatives.[39]

Attitude Test

The attitude test administered to the treatment and control groups was designed according to the Likert Scaling Procedure. The test was written by the investigator and

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[39]Frederick L. Ferris, "Testing for Physics Achievement", Achievement Testing in Physics (New York: American Institute of Physics, 1960), p. 22.

it incorporates 50 item statements each allowing a set of 5 responses, (1) Strongly Agree, (2) Agree, (3) Undecided or Neutral, (4) Disagree, (5) Strongly Disagree. Of the 50 item statements 28 were judged by independent observers to pertain to attitudes directly related to physics textual material, and 22 items were judged to pertain to physics itself. Of the 28 items pertaining to textual material, 10 item statements were judged to be negative in viewpoint, whereas 18 were judged as positive. And of statements pertaining to physics itself, 10 were judged as positive and 12 were judged negative in point of view. Each of the attitude statements was approved by personnel in the Office of Research Consultation of the Michigan State University College of Education on the basis of their individual apparent validity and reliability as discriminating indicators of attitudes towards physics and attitudes towards physics textual material. The statements intended to determine attitudes toward physics itself were, for the most part, based on The Revised Mathematics Attitude Scale, by Aiken and Dreger.[40]

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[40]Aiken and Dreger, "The Revised Mathematics Attitude Scale", ed. Marvin E. Shaw and Jack M. Wright Scales for the Measurement of Attitudes, (New York: McGraw Hill, 1967).

Data Collection Procedure

Due to the Post-Test Only Control Group Design used in this study the only experimental data consist of the achievement test and attitude test scores obtained at the end of the experiment. After initially distributing the trial textual materials and a cover letter addressed to all students in Physics 231 in early November, 1972, the investigator returned to Western Kentucky University after a period of roughly three weeks at which time the tests were administered. The achievement test was administered by the regular course instructors in the absence of the investigator during pre-established examination periods. Following completion of the achievement test, requiring roughly 40 minutes, the investigator was called to the examination room where he distributed the attitude test which was completed and returned by the students within a period of 10 to 15 minutes. The achievement tests were marked by the course instructors and the results were then given to the investigator. The attitude tests were marked by the investigator. The test results are reported in Chapter IV.

Hypotheses

This study is concerned with testing three univariate hypotheses concerning achievement and three multivariate hypotheses concerning attitudes. Each of the multivariate hypotheses involves two dependent variables which can be individually tested under separate univariate hypotheses. The statistical test employed using multivariate analysis of variances is designed to test the multivariate hypotheses. Only if significance is demonstrated for the multivariate F-ratios in testing the multivariate hypotheses is post hoc testing for the univariate hypotheses conducted. The post hoc testing makes use of step-down F-ratios applicable to each of the two dependent variables included in the test of the multivariate hypotheses. The hypotheses are stated below in the null form.

Univariate Hypothesis 1

There will be no differences in achievement between treatment and control groups as determined from the unit physics examination.

Univariate Hypothesis 2

There will be no differences between teacher-class combinations in achievement as determined from the unit physics examination.

Univariate Hypotheses 3

There will be no treatment by class interaction effects on achievement as determined from the unit physics examination.

Multivariate Hypothesis 1

There will be no differences between treatment and control groups in attitudes toward physics and/or physics textual materials as determined from the Likert instrument.

Univariate Hypothesis 1.1

There will be no differences between treatment and control groups in attitudes toward physics as determined from the Likert Instrument.

Univariate Hypothesis 1.2

There will be no differences between treatment and control groups in attitudes toward physics textual material as determined from the Likert Instrument.

Multivariate Hypothesis 2

There will be no differences between classes in attitudes toward physics and/or physics textual materials as determined from the Likert Instrument.

Univariate Hypothesis 2.1

There will be no differences between classes in attitudes toward physics as determined from the Likert Instrument.

Univariate Hypothesis 2.2

There will be no differences between classes in attitudes toward physics textual materials determined from the Likert Instrument.

Multivariate Hypothesis 3

There will be no treatment by class interaction effects on attitudes toward physics and/or physics textual materials as determined from the Likert Instrument.

Univariate Hypothesis 3.1

There will be no treatment by class interaction effects on attitudes toward physics as determined from the Likert Instrument.

Univariate Hypothesis 3.2

There will be no treatment by class interaction effects on attitudes toward physics textual materials as determined from the Likert Instrument.

Analysis of Data

Research specialists within the Office of Research Consultation of the Michigan State University College of Education assisted in determining appropriate statistical procedures, computer program and data processing pertaining to this study. Upon its recommendation, the Finn program, A Generalized Univariate and Multivariate Analysis of Variance, Covariance, and Regression Program was used.[41]

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[41]Jeremy D. Finn, A Generalized Univariate and Multivariate Analysis of Variance, Covariance and Regression Program (Buffalo, New York: State University of New York at Buffalo, 1966).

In the Finn Program univariate analysis of covariance procedure an F ratio was computed for each of the two main effects (materials and teacher class) hypotheses adjusted on achievement and an additional F ratio was computed to test for interaction of teacher-class and materials.

In the multivariate analysis of variance procedure, two types of F ratios are computed, the multivariate F ratio to test for main effects on attitudes and univariate F ratios to test for significance of the individual dependent variables incorporated in the multivariate hypotheses. In other words, here the multivariate F ratio determines whether all dependent variables (two) have combined significance at a specified alpha level, and if significance is found, then univariate F ratios for each dependent variable in the multivariate hypotheses are computed to determine if that variable is significant at a specified alpha level.

Summary

Forty-eight undergraduate students enrolled in Introduction to Physics and Biophysics 231 during the Fall semester of the 1972-1973 academic year at Western Kentucky University and were the subjects in a study comparing the attitudes and achievement in college physics in terms of the textual material assigned to the students.

Three groups of eight students each, one group from each of three lecture sections of Physics 231, received no experimental textual material. These groups were designated the treatment groups.

Three groups of eight students each, one group from each of three lecture sections of Physics 231, received experimental textual materials. These groups were designated the control groups.

Following a period of approximately three weeks the treatment and control groups were tested for achievement and attitude differences as determined from separate achievement and attitude tests.

CHAPTER IV

ANALYSIS OF RESULTS

A description of the experiment upon which this study is based is provided in Chapter III. In this chapter we examine the experimental hypotheses stated in Chapter III.

Table 4.1 below displays the mean achievement and attitude scores of the 48 randomly selected treatment and control students from which the data of this experiment were obtained. The table lists achievement and pre achievement mean scores within the range of 0 to 100, and attitude mean scores within the range of 2 to -2. The achievement mean scores are based on the unit achievement examination (see appendix), the pre achievement mean scores are based on two previous hourly examinations, and the attitude mean scores were determined from the Likert Attitude Scale (see appendix).

The correlation coefficient relating attitudes toward physics and attitudes toward physics textual materials (0.51) is stronger and tends to support the notion that favorable attitudes toward textual material are associated with favorable attitudes toward the subject.

TABLE 4.1.--Achievement and Attitude Mean Scores.

		Achievement	Preachievement	Attitude Materials	Attitude Physics
Class 1	T	89.5	72.8	-0.27	0.36
	C	79.1	66.4	-0.08	0.43
Class 2	T	88.0	77.5	0.66	0.66
	C	82.5	82.8	0.34	0.39
Class 3	T	84.8	88.7	0.39	0.74
	C	82.5	84.7	0.10	0.45

T denotes treatment group, C denotes control group.

Operating on the assumption that previously demonstrated ability in the course would be predictive of achievement in the experiment the two previous achievement test scores were averaged and used as the covariate designated preachievement.

Significance at the 0.05 level requires that the sample correlation coefficient must be equal to, or greater than, 0.288 for a sample size of 48.[42] The correlation coefficients between the four experimental variables, Achievement (Ach), Attitudes Toward Physics

[42]A. L. Edwards, Statistical Methods for the Behavioral Sciences (New York: Rinehart and Winston, 1960), p. 502.

Textual Materials (ATPTM), Attitudes Toward Physics (ATP), and Preachievement (Preach), are presented in Table 4.2.

TABLE 4.2.--Correlation Coefficients Between Variables.

	Ach.	ATPTM	ATP	Preach.
Ach.	1.000			
ATPTM	0.189	1.000		
ATP	-0.036	0.51	1.00	
Preach.	0.423	0.31	0.245	1.00

From Table 4.2 the only significant correlations are between the attitudes toward physics and the attitudes toward physics materials, and, between preachievement and attitudes toward physics textual materia. The relationship between preachievement and attitudes toward physics textual material, although statistically significant (Correlation Coefficient = 0.310) is not strong.

Within the Finn Program a measure of the effectiveness of this covariate as a predictor of achievement on the trial unit achievement test was calculated. The measure involved calculation of a correlation coefficient between the observed achievement score and a predicted achievement score based on preachievement. This correlation coefficient was tested for significance by means of an F ratio. The calculated value of the correlation coefficient between the actual achievement score of one individual and the predicted achievement score for that individual was based on a least squares regression line for achievement using preachievement as a predictor. This correlation coefficient (Multiple R correlation coefficient) calculated to be 0.423 indicated no significant relationship between preachievement scores and scores on the achievement examination. The F ratio, 0.0736, which tested for the significance of this correlation coefficient had a significance level of 0.7875 indicating that for any reasonable alpha level (i.e., 0.05) there is no relationship between preachievement scores and achievement on the trial achievement examination.

Tests of the Achievement Hypotheses

Although Univariate Hypothesis 1 is the hypothesis of primary interest logic suggests that a test of Univariate Hypothesis 3 should be performed first, for, if a significant treatment by class interaction effect exists a test of Univariate Hypothesis 1, pertaining to achievement differences between treatment and control groups, may be logically meaningless.

Univariate Hypothesis 3 was tested in the Finn program by calculating the F ratio (MS for interaction/ MS error) and its associated P value. The P value is the probability of finding a value of the F ratio equal to, or greater than, the particular computed F ratio (0.68).

Comparison of the P value (0.51) with the designated alpha level of 0.05 shows no basis for rejecting Univariate Hypothesis 3. That is, due to the fact that P is greater than 0.05, Univariate Hypothesis 3 was not rejected. If the P value had been less than the chosen alpha level the computed F value would have fallen in the region of rejection for Hypothesis 3. Fortunately for this study, based on this evidence, there is no reason to believe that there is a teacher-class interaction affecting achievement.

Having found no significant teacher-class interaction effect on achievement we now examine Univariate Hypothesis 1 and Univariate Hypothesis 2.

From Table 4.3 the P value for Univariate Hypothesis 1 (0.04) is less than the designated alpha level (0.05). Therefore, based on this fact, Univariate Hypothesis 1, that there will be no differences in achievement between treatment and control groups, is rejected. An estimate of the differences between control and treatment materials indicates that use of the treatment materials resulted in higher adjusted achievement than did use of non treatment materials. The computed estimate of difference between the adjusted achievement scores is 5.99 favoring the experimental physics textual materials.

Turning now to Univariate Hypothesis 2, and again referring to Table 4.3, we find the P value for this hypothesis, 0.88, is greater than 0.05 (the designated

TABLE 4.3.--ANOVA Table for Adjusted Achievement Scores.

Source	df	Adj. MS Between	F	P	Significant
H_1 Treatment	1	429.24	4.49	0.04	yes
H_2 Teacher-Class	2	12.73	0.13	0.88	no
H_3 Interaction	2	65.13	0.68	0.51	no
Error	41				

df denotes computed degrees of freedom; Adj. MS denotes adjusted mean squares.

alpha level). Based on this fact, Univariate Hypothesis 2, that there will be no differences between teacher-class combinations in achievement, is not rejected.

Tests of the Attitude Hypotheses

As in the above analyses, where preachievement is used as a covariate with achievement as the dependent variable, in the following analysis where the dependent variables are attitude measures, again preachievement is used as the covariate. However, just as in the case of achievement, little relationship was found between preachievement scores and attitude scores. This fact is demonstrated in Table 4.4 by the low values of the Multiple R correlation coefficients between attitude scores predicted on the basis of preachievement scores and the measured attitude scores.

TABLE 4.4.--Multiple R Correlation Coefficients Between Predicted and Measured Attitude Scores.

Variable	Multiple R Correlation Coefficient	F	P less than
ATPTM	0.307	4.27	0.045
ATP	0.245	2.62	0.114

The basic design for testing the hypotheses pertaining to attitudes is identical to the design for testing the hypotheses pertaining to achievement. Hence here we repeat the logic of examining first the test for class by materials interaction.

The results of this test indicate no evidence of such interaction. The computed F ratio for Multivariate Hypothesis 3, 0.8199 for 4 and 80 degrees of freedom yields a P value of 0.5163. Since this test of Multivariate Hypothesis 3 indicates no significant interaction, further testing of Univariate Hypothesis 3.1 and Univariate Hypothesis 3.2 would be pointless and, therefore, is omitted.

Turning to Multivariate Hypothesis 1, under which differences in attitudes between treatment and control groups are tested, we find no significant differences in attitudes toward physics textual materials, nor toward physics itself. The F ratio for testing Multivariate Hypothesis 1 was calculated to be 0.957, which with 2 and 40 degrees of freedom yielded a P value of 0.393. Univariate Hypotheses 1.1 and 1.2 were not examined separately.

In examining Multivariate Hypothesis 2, under which differences in attitudes between classes was tested no significant differences were found. The F ratio for testing Multivariate Hypothesis 2 was calculated to be 1.215, with 2 and 40 degrees of freedom yielding a P value of 0.311. Again, because of multivariate non-significance Univariate Hypotheses 2.1 and 2.2 were not examined separately.

Summary of Results

1. Testing Univariate Hypothesis 1 indicated directional differences in achievement between treatment and control groups as determined from the unit physics examination favored the experimental physics textual material.

2. Testing Univariate Hypothesis 2 indicated no differences between teacher-class combinations in achievement were determined from the unit physics examination.

3. Testing Univariate Hypothesis 3 indicated no treatment by class interaction effects on achievement as determined from the unit physics examination.

4. Testing Multivariate Hypothesis 1 indicated no differences between treatment and control groups in attitude toward physics and/or physics textual materials determined from the Likert instrument.

5. Testing Multivariate Hypothesis 2 indicated no differences between classes in attitudes toward physics and/or physics textual materials as determined from the Likert instrument.

6. Testing Multivariate Hypothesis 3 indicated no treatment by class interaction effects on attitudes toward physics as determined from the Likert instrument.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to compare and assess the effects of contemporary and experimental college physics textual materials on attitudes and achievement in Physics 231 at Western Kentucky University during the fall semester of the 1972-1973 academic year. The effects examined fell into three categories: Content Achievement, Attitudes Toward Physics Textual Materials, and Attitudes Toward Physics.

A 25 item unit examination of the multiple choice type, written by the course instructors, comprised the instrument which measured achievement. A Likert type attitude scale, written by the investigator, was used to assess the attitudes. Both the achievement examination and the attitude scale were administered as post tests only at the close of the experimental course unit.

The hypotheses of the experiment were tested using the multivariate analysis of variance procedure provided by the Finn Program. The univariate hypotheses pertaining to achievement, and the multivariate hypotheses pertaining to attitudes, were tested at the 0.05 level of significance. The summary below describes the pertinent results of this study.

Summary of the Results of Hypothesis Testing

Univariate Hypothesis 1

Greater achievement was associated with the treatment material than with instructor designated (control) textual material.

Univariate Hypothesis 2

No differences were found between teacher-class combinations in achievement as determined from the unit physics examination.

Univariate Hypothesis 3

There were no treatment by class interaction effects on achievement as determined from the unit physics examination.

Multivariate Hypothesis 1

No differences were found between treatment and control groups in attitudes toward physics and/or physics textual materials as determined from the Likert instrument.

Multivariate Hypothesis 2

No differences were found between classes in attitudes toward physics and/or physics textual materials as determined from the Likert instrument.

Multivariate Hypothesis 3

No treatment by class interaction effects on attitudes toward physics and/or physics textual materials were determined by the Likert instrument.

Due to the failure to find significance in testing Multivariate Hypotheses 1, 2 and 3, Univariate Hypotheses 1.1 1.2, 2.1, 2.2, 3.1 and 3.2 were not tested.

Conclusions

Based on the findings of this study the following conclusions seem justified.

1. Achievement in college physics on the part of life science students can be improved by use of textual material in which physics is presented within a framework of direct biological relevance.

2. Achievement in college physics on the part of life science students can be improved by use of textual material in which physics is presented within a framework of direct biological relevance without regard to particular teacher-class combinations.

3. Achievement in college physics on the part of life science students does not appear to be influenced by unique interactions between the material, the instructor and the class which it is used.

4. The attitudes of life science students toward physics and/or physics textual material do not appear to depend on the biological relevance of physics textual material.

5. The attitudes of life science students toward physics and/or physics textual materials do not appear to differ between teacher-class combinations.

6. The attitudes of life science students toward physics and/or physics textual materials do not appear to indicate unique interaction effects between the textual materials and teacher-class combinations. Experience of this investigator, however, suggests that this conclusion be regarded as tentative.

Implications from the Study

Based on the findings of this study the following implications are presented for consideration.

1. Achievement in physics on the part of life science students is in part related to the context in which physics textual materials is presented. The content of college physics textbooks should increasingly relate to the major areas of interest of student readers. College physics courses intended for life science students should incorporate biologically relevant textual readings in order to improve achievement in physics.

2. Although the differences in attitudes toward physics and physics textual materials between treatment and control groups in this study were not statistically significant, it seems reasonable to speculate that attitude differences may become significant over an extended experimental period. This may be particularly true where the biologically related textual material is introduced early in the physics course, thus avoiding the establishment of attitudes which may be difficult to change in a short period toward the completion of the course, as was the case in this study.

3. From the survey of currently available college physics textbooks (Chapter II) and the findings regarding achievement (Chapter IV) it is apparent that immediate attention should be given to publication of textual materials in which biological phenomena, requiring general physical principles for understanding, provide the framework in which physics is presented.

Recommendations for Future Investigations

The following recommendations are made based on the findings, conclusions, and implications of this study.

1. A basic assumption of this study is that learning from textual materials is related to the expressed major academic interests of students in general level

courses. Further studies are needed to determine the validity of this assumption.

2. The attitude measures of this study were made following a brief (3 week) experimental period. Studies are needed to determine the validity and reliability of measures pertaining to improving attitudes over brief periods.

3. The increased achievement associated with the trial reading material of this study is encouraging. Comparative long term studies of achievement based on extensive readings are needed to determine the strength of the findings of this study.

4. Based on the assumption that historical factors of widely different varieties influence the attitudes and achievement of students investigations are needed to delineate these factors as they pertain to the education of life science students in basic physics.

5. Just as special textual materials may be valuable in teaching physics to life science students so may it be that other special physics textual material written for students of psychology, the earth sciences, etc., may be valuable. Such materials should be written and evaluated.

APPENDICES

APPENDIX A

EXPLANATORY LETTER TO THE STUDENTS OF PHYSICS 231 AT WESTERN KENTUCKY UNIVERSITY

To The Students of Physics 231, Fall Semester, 1972-
Western Kentucky University

Your cooperation is requested in support of a study of reading materials which have been written for use in this course. The class is being divided into two groups for the purpose of the study. You will be assigned to one of these groups. One group will be requested to read the normal reading materials selected by your instructor. The other group will be assigned to read some materials which have beenwritten to cover the same topics, but in a somewhat different manner. If you are selected to read the normal course readings, please do not read the materials which will be assigned to the other group. In other words, we will appreciate your cooperation in reading only the materials which are assigned to you.

This study is being made by personnel from The Science and Mathematics Teaching Center of Michigan State University. The results of the study may have significant effect on the writing of other materials for use in courses such as Physics 231.

Your grade in this course, Physics 231, will not depend on which materials you are assigned to read since each set contains the same physics. At the end of the unit you will be examined in the normal way by your instructor. His examination will not be geared to either group, but rather to the material covered in the course.

APPENDIX B

PHYSICS ACHIEVEMENT TEST

Fall, 1972

Name ____________________

PHYSICS 231

PROPERTIES OF MATTER

1. A technical name given to force per unit area is

   a. stress
   b. strain
   c. modules
   d. tensile strength
   e. shear

2. The direction of motion of the diffusing particles in the process of diffusion is

   a. same as the concentration gradient
   b. opposite the concentration gradient
   c. perpendicular to the concentration gradient
   d. dependent on the type of particle
   e. irrelevant

3. A shearing stress that acts on a body affect its

   a. length
   b. width
   c. volume
   d. shape

4. Poiseuille, while studying the flow of water through narrow tubes, found that

   a. the rate of flow was directly proportional to the pressure gradient
   b. the rate of flow was independent of area
   c. the rate of flow was independent of viscosity
   d. the rate of flow was directly proportional to viscosity

5. The retarding force on a small sphere moving with velocity v in a viscous fluid may be calculated using

   a. Newton's third law
   b. Ficke's Law
   c. Stoke's law
   d. Pitot's law
   e. Stefan's law

6. Blood and synovial fluid are examples of liquids which

   a. are Newtonian
   b. are non-Newtonian
   c. flow as Poiseuille
   d. have flow rates proportional to the pressure gradient
   e. are conservative

7. For equally applied pressures, the rate of flow of water through a hypodermic needle twice the diameter of another but equal in length is

   a. 1/2 as great
   b. 1/4 as great
   c. 2 times as great
   d. 4 times as great
   e. 16 times as great

8. Bernoulli's equation is a consequence of the law of conservation of

   a. mass
   b. energy
   c. momentum
   d. fluid
   e. intensity

9. Ficke's law states that the rate of diffusion per unit area

   a. is inversely proportional to the concentration gradient of the solute
   b. is directly proportional to the viscosity of the liquid
   c. is directly proportional to the concentration gradient of the solute
   d. is independent of concentration

10. If fluid is flowing through the pipe and P_1 and P_2 and P_3 are the values of the pressure at the points indicated, then

   a. $P_1 = P_2 = P_3$
   b. $P_1 > P_2 < P_3$
   c. $P_1 < P_2 < P_3$
   d. $P_1 < P_2 > P_3$

11. Archimedes principle states that the bouyant force on an object is equal to

a. the force of gravity
b. the weight of the displaced fluid
c. the viscosity gradient
d. the surface tension of the object

12. Hooke's Law states that

a. stress is equal to strain
b. strain is independent of stress
c. stress is directly proportional to strain
d. shear is directly proportional to the bulk modulus

13. Besides Hooke's Law - Robert Hooke is famous for

a. the discovery of cytoplasm
b. the discovery of bacteria
c. the discovery of the cell
d. the discovery of the nucleus

14. The diffusion coefficient of Urease in a water like medium is 2.5×10^{-7} cm^2 /sec and Urease has a molecular weight of 5×10^5 daltons. The time it takes a ureas molecule to traverse a cell of diameter 10^{-3} cm is

a. 1.4 sec
b. 1.0 sec
c. 0.05 sec
d. 0.50 sec

15. The terminal velocity of a sphere falling in a viscous medium is

a. directly proportional to the viscosity
b. independent of gravity
c. independent of the density of the fluid
d. can be increased by centrifugation

16. According to Stoke's Law the retarding force = F is

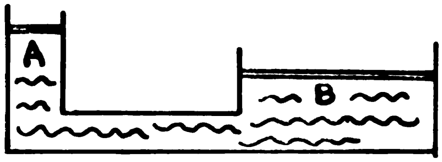
a. $6\pi\ a\ \eta v$

b. $\frac{4}{3}\ \pi\ a^3\ \rho g$

c. $\frac{\lambda}{9}\ a^2\ \eta v$

d. $(\rho-\rho_o)\ g\ \frac{v}{r}$

17.



Fluid connects piston A to piston B. If B = 10A in area, what is the upward force on B when there is a downward force of 5 newtons on A

a. 2
b. 50
c. 25
d. 5

18. Active transport across cellular membranes can be fully explained by

a. diffusion
b. osmosis
c. osmosis and diffusion
d. can't be fully explained

19. When a pearl is dropped in a bottle of Prell, it's velocity quickly becomes const (acc=0) because

a. there are no net unbalanced forces on the pearl
b. the bouyant force is balanced by the viscous force
c. the viscous force is greater than the force of gravity
d. the weight of the pearl is negligible.

20. The osmotic pressure is found by experiment on weak solution to be

a. directly proportional to the volume of the solution
b. inversely proportional to the temperature
c. directly proportional to the concentration of solute
d. inversely proportional to the thickness of the membrane
e. directly proportional to the area of the membrane

21. Blood leaves the heart through the aorta with a velocity of 40 cm/sec. If the cross sectional area of the aorta is 2 cm^2 and the density of blood is 1 gm/cm^3, the mass transport of blood will be

a. 80 gm/sec
b. .016 gm/sec
c. 251 gm/sec
d. 504 gm/sec

22. Whenever possible liquids tend to assume the shape with the least surface area (usually a sphere). This is a result of

a. their inherent viscosity
b. their molecular weight
c. cohesive forces in the liquid
d. laminar flow

23. The stress on a body is removed after the body has passed its elastic limit. The body will now

a. return to its original shape
b. remain deformed
c. return to a smaller size than it was originally
d. oscillate indefinitely

24. The critical vel at which lamuar flow changes to turbulent flow can be calculated from

a. $(p-n)\frac{a^4}{R}$

b. $\frac{10000\eta}{pR}$

c. $1/2h\rho gr$

d. $p + \rho gh$

25. The pressure at any point in a liquid does <u>not</u> depend on
a. the denisty of the liquid
b. the distance from the free surface (height)
c. the acceleration due to gravity
d. the shape of the vessel

APPENDIX C

LIKERT TYPE ATTITUDE SCALE

Attitudes Toward Physics

Your response to the following items will permit us to determine what life science students think about certain aspects of physics. There are no right or wrong responses to the Items in this questionnaire and the results will not be used in any way for grading purposes in this course.

Please indicate the degree to which you agree or disagree with each of the statements by responding once to each Item on the separate answer sheet. Mark your response to each Item by selecting one of the following responses:

1. Strongly agree
2. Agree
3. Undecided or neutral
4. Disagree
5. Strongly disagree

PLEASE RESPOND TO ALL ITEMS

1. I plan to take more physics than is required for my major.

2. I am always under a terrible strain in physics classes.

3. The theory of elastic materials has little relation to biology.

4. When I hear the word physics I have a feeling of dislike.

5. Physics makes me feel secure and at the same time it is stimulating.

6. Understanding how solutes diffuse in solutions interests me.

7. The reading material for this unit increased my interest in the physics of living organisms.

8. I am interested in learning more about surface tension.

9. The feeling I have toward physics is a good feeling.

10. A knowledge of Poiseulli's Equation would be helpful to a medical doctor.

11. It is my belief that physics is very important to understanding anatomy.

12. Biological illustrations tend to make physics more confusing.

13. I might like to be a biophysicist.

14. It is my belief that a course in physics should be required for biology majors.

15. Physics makes me feel as though I am lost in a jungle of formulas and I can't find my way out.

16. I might recommend the reading material for this unit to a friend in biology.

17. Biology is more interesting if you know some physics.

18. Physics makes me feel uncomfortable, restless, irritable, and impatient.

19. Physics is fascinating and fun.

20. I do not like physics, it scares me to have to take it.

21. Stoke's Equation for bodies falling in viscous media is very interesting.

22. Physics is a subject which I have always enjoyed.

23. Readings in physics reflect little concern for the interests of biologists.

24. I really like physics.

25. Very little physics can be learned from studying living organisms.

26. I feel at ease in physics, and I like it very much.

27. Physics is more relevant to biology than I thought it was.

28. Bernoulli's Principle is difficult to understand.

29. Physics is not very important in understanding life processes.

30. I feel a definite positive reaction to physics; it is enjoyable.

31. I have never like physics, it is my most dreaded subject.

32. Knowing some physics tends to make biology appear more difficult.

33. I am happier in physics classes than in other classes.

34. I wish that I could see more relevance of the material in this unit to biology.

35. I approach physics with a feeling of hestiation resulting from a fear of not being able to do the problems.

36. I am more interested in physics than I was several months ago.

37. Physics is very interesting and I enjoyed this unit more than others.

38. A medical doctor should have a general competence in physics

39. I felt less secure in this unit than in others.

40. This unit was more interesting than I though it would be.

41. The reading material in this unit was a relief from other reading material used before in the class.

42. It makes me nervous to think that physics may be important in biology.

43. My mind goes blank, and I am unable to think clearly when working a physics problem.

44. The difficulty of physics outweighs its value to biology students.

45. I was happier in this unit than in others.

46. It is my belief that biologists should have a general competency in physics.

47. I would be glad just to pass this course.

48. I might be inclined to put off taking this course until I am a senior.

49. I would like more readings like the ones for this unit.

50. Knowing some biology tends to make physics seem less relevant to biology.

Answer Sheet - Attitudes Toward Physics

Item Number	Response 1	2	3	4	5
1.	______	______	______	______	______
2.	______	______	______	______	______
3.	______	______	______	______	______
4.	______	______	______	______	______
5.	______	______	______	______	______
6.	______	______	______	______	______
7.	______	______	______	______	______
8.	______	______	______	______	______
9.	______	______	______	______	______
10.	______	______	______	______	______
11.	______	______	______	______	______
12.	______	______	______	______	______
13.	______	______	______	______	______
14.	______	______	______	______	______
15.	______	______	______	______	______
16.	______	______	______	______	______
17.	______	______	______	______	______
18.	______	______	______	______	______
19.	______	______	______	______	______
20.	______	______	______	______	______
21.	______	______	______	______	______
22.	______	______	______	______	______

23. _____ _____ _____ _____ _____

24. _____ _____ _____ _____ _____

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44. _____ _____ _____ _____ _____

45. _____ _____ _____ _____ _____

46. _____ _____ _____ _____ _____

47. _____ _____ _____ _____ _____

48.	_____	_____	_____	_____	_____
49.	_____	_____	_____	_____	_____
50.	_____	_____	_____	_____	_____

APPENDIX D

EXPERIMENTAL TEXTUAL MATERIAL

Elastic Properties of Matter
Fluid Mechanics I
Fluid Mechanics II
Fluid Mechanics III

ELASTIC PROPERTIES OF MATTER

This paper is intended to present some of the basic notions involved in the study of elastic materials. After you have read this paper you will be expected to be able to write quantative descriptions of elastic materials using the definitions of tensile stress, shearing stress, bulk stress, tensile strain, shearing strain, and bulk strain. In addition, you will be expected to be able to write the equations representing Young's Modulus, the modulus of rigidity, and bulk modulus, and to verbally explain the meanings of each of these. Your instructor may require you to use each of these definitions and equations to solve basic physics problems.

In living animals certain motions arise from elastic recoil which is the property of returning to an initial form, or state, following deformation. Two materials which are elastic and which partly account for motion in animals are resilin, and abductin. These materials compare in their elastic properties to soft rubber. Resilin is found in the thoraxes and at the wing bases of some insects and its elasticity contributes to the flapping of the insects' wings. Abductin is an elastic protein found in scallops, it composes the hinge of the scallops' shell and by elastic recoil it acts to spring open the shell.

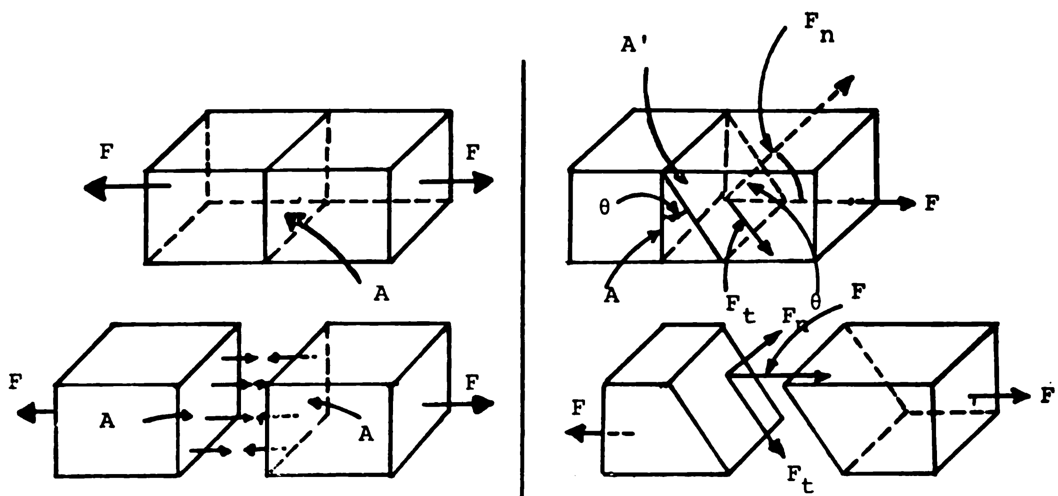
For our purposes the actual physical forms of resilin and abductin in insects and scallops is not important. The important thing is that both resilin and abductin are elastic biological materials. The question of physical interest to which we will direct ourselves is, just how elastic are these springy biological substances? How is elasticity measured and how do resilin and abductin compare to other elastic materials?

Actually the theory of elasticity is a detailed and complicated part of physics which concerns the nature of the atoms and molecules which make up the many elastic materials. The elasticity of rubber, which is much like that of resilin and abductin, is fundamentally different from that of steel. The differences between these two kinds of elasticity is account for by changes in the entropy of the rubberlike molecules as they are stretched and by changes in the internal energy of steel as its atoms are displaced from their normal crystaline arrangements. Rather than consider these microscopic characteristics of elastic materials, we shall direct our attention only to the macroscopic notions of elasticity.

Actually there are essentially three ways by which elastic materials can be deformed. They can be <u>pulled apart by tensile stresses</u>, they can be <u>sheared by shearing stresses</u>, and they can be <u>compressed by bulk stresses</u>.

As this suggests, the notion of stress is of fundamental concern in the study of elasticity, and we shall consider three types of stress, tensile stress, shear stress, and bulk or compressional stress.

Tensile stress is defined as the ratio of the distorting force to the cross sectional area of the object in tension or linear compression. Consider the sketches below:



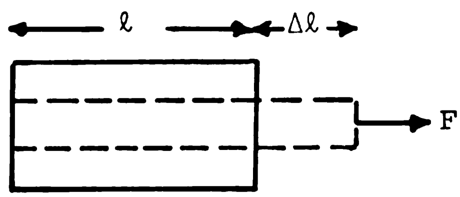
I

II

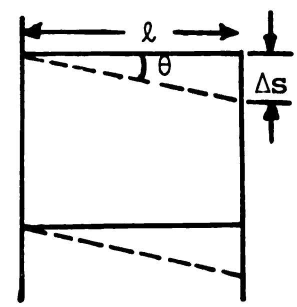
In figure 1 the body experiences a tension force F which is distributed over the perpendicular cross sectional area A. Here the object experiences a tensile stress defined as the ratio of the force F to the cross sectional area A, i.e. tensile stress = F/A. In figure 11 we consider a cross sectional area which is inclined at the angle 0 with respect to the perpendicular or normal cross sectional area. We call this inclined cross sectional area A'. Now, with respect to A' the force F has components F_n and F_t. F_n is the component perpendicular to A' and it is called the normal component of F. F_t lies along A' and it is called the tangential component of F.

In the case of the hinge mechanism of the scallops, the abductin material which composes the hinge experiences both tangential and normal forces over any given cross section when the scallops shells are closed. In all cases where a given body experiences a normal force over a cross section the ratio of the force F_n to the area of the cross section to which it is perpendicular, is called the normal or tensile stress. That is tensile stress = F_n/A'. Likewise the ratio of the tangential or shearing component of force to the cross sectional area over which it is distributed is called the tangential or shearing stress, i.e. Shearing Stress = F_t/A.

Associated with both normal and tangential stress are physical deformations. For normal stress the associated deformation is called normal, or tensile, strain. Normal, or tensile, strain is defined as the ratio of the elongation of the stressed body to its non-stressed length, that is, tensile strain $=\Delta l/l_o$, where Δl is the elongation and l_o is the non-stressed length. And, in similar manner the ratio of the tangential deformation, or bending of a body, to the length of the body, is called shearing strain, i.e. shearing strain = s/l, where s is the deflection of the body from its' initial position and l is the length of the body. The ratio, s/l is of course, the measure of the deformation angle in radians provided that s is small.



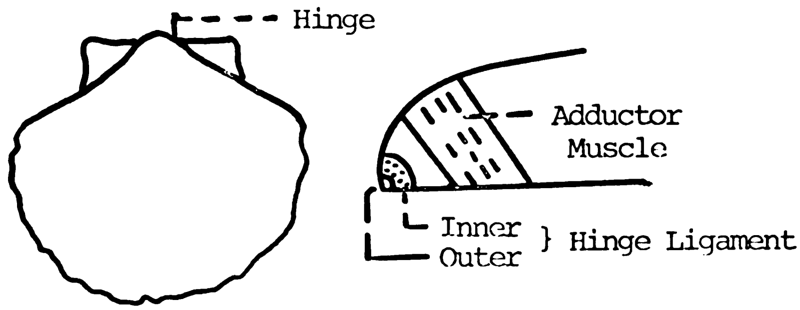
Tensile Strain



Shearing Strain

There remains one other type of deformation to which we must direct our attention. This type is known as compression. Compression is associated with the change in volume of a body experiencing applied pressure. A fish for example experiences compression or bulk strain due to the pressure of its surrounding water. Bulk stress is the pressure associated with the change in volume of a body corresponding to the applied pressure. Bulk stress is therefore expressed by the ratio of applied force to the area over which it is applied, F/A = compressional or bulk stress . The corresponding strain is the measure of the distortion of the body under the applied pressure. It is the ratio of the change in the body's volume, ΔV to the initial volume V_o. Bulk or compressional strain = $\Delta V/V_o$.

The sketch below shows a transverse section of a scallop. Note that the hinge is actually composed of an outer and inner ligament, the inner ligament is compressed and the outer is stretched while the shell is closed. It is the combined action of the contraction of the outer ligament and the expansion of the inner ligament which "pops" open the shell upon release of the adductor muscle. If removed from the shell the inner ligament bounces like rubber when dropped, thus demonstrating its elastic nature.



Now, an interesting property of elastic materials is that within certain limits, from a state of no stress to a stress value at which permanent distortion occurs, the stress is directly proportional to the corresponding strain. For cases of tension and compression where strain is measured as the ratio of the change in length Δl, of a body to its original length, l, the proportionality constant, Y, is called Young's Modulus.

$$\text{Stress} = (\text{Young's Modulus})\ (\text{Strain})$$

or

$$F/A = Y\ (\Delta l/l_o)$$

Thus, by applying a certain stress to a body and measuring the corresponding strain the value of Young's Modulus for the material composing the body can be determined.

$$Y = (\text{Stress}/\text{Strain})$$

$$Y = (F/A \div (\Delta l/l_o)$$

For example, suppose that from the inner hinge ligament of a scallop one cuts cylindrical segment, which has a cross sectional area of 1/100 cm^2 and a length of 1 cm. While under a tension of 500 dynes, it is observed that the length of the segment increases by 1.25×10^{-3} cm. Thus, for Young's Modulus we have:

$$Y = \frac{500\ \text{dynes}/10^{-2}\ \text{CM}^2}{1.25 \times 10^{-3}\ \text{cm}/\ 1\ \text{cm}}$$

or

$$Y = 4 \times 10^7\ \text{dynes}/\text{cm}^2$$

Actual measurements of the value of Young's Modulus for the inner hinge ligament material of scallops yield values ranging from 1.3×10^7 to 4×10^7 dynes/cm^2.

Here some attention should be given to the importance of Young's Modulus. Young's Modulus is the proportionality constant which indicates how elastic a material is. From the first equation above, it is seen that for any given stress applied to a body there is an accompanying strain. For materials having large values of Young's Modulus, the corresponding strain is less than for materials having smaller moduli. Below is a table which gives the values of Young's Modulus for several biological and non-biological materials.

Notice the large range of values reported for the various materials. Can you account for the tremendous increase in the value of Young's Modulus in comparing abductin, for example, with mild steel? See following table.

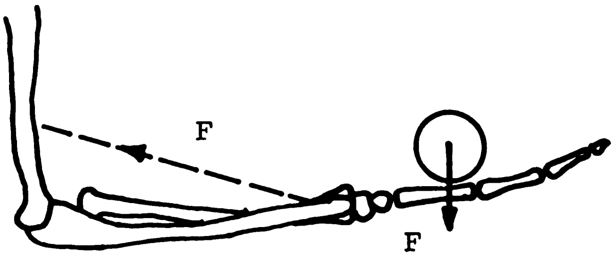
Recalling that a body may be deformed under shearing stress, F_t/A' and that the corresponding strain is measured as the angular deformation of the body, $\Theta=\Delta s/l$, we can write the expression for the shear modulus of a substance as the ratio of the shearing stress to the shear strain. That is: Shear Modulus $S=F_t/A'\ \Theta$, where F_t is the shearing component of the force which is distributed tangentially over the cross sectional area A'.

Shearing stresses and accompanying strain in bones are reduced by muscular tension. For example, consider the human forearm extended horizontally holding a heavy

MECHANICAL PROPERTIES OF VARIOUS MATERIALS

	Young's Modulus (dyn/cm^2)	Authority	Tensile strength (dyn/cm^2)	Authority
Metridium mesogloea	c. 3×10^4	Alexander,1962 1964a		
Resilin	$1\ 8 \times 10^7$	Weis-Fogh,1961a	3×10^7	Weis-Fogh, 1961b
Abductin	$1\text{-}4 \times 10^7$	Kelly & Rice 1967		
Elastin	6×10^6	Bergel, 1961		
Collagen	10^{10}	Harkness, 1961	$5\text{-}10 \times 10^8$	Elliott, 1965
Bone	10^{11}	Smith & Walmsley, 1959	10^9	Evans, 1957
Locust cuticle	10^{11}	Jensen & Weis-Fogh,1962	10^9	Jensen & Weis-Fogh 1962
Lightly vulcanized rubber	$1\ 4 \times 10^7$	Ferry, 1961		
Oak	10^{11}	Hodgman,1965	10^9	Hodgman, 1965
Mild Steel	2×10^{12}	Hodgman,1965	5×10^9	Hodgman, 1965

object in the hand. The weight F of the object produces a shearing stress at the wrist. This stress is reduced by the tension force F' exerted by the brachioradialis, biceps, and brachialis muscles.



Quantitative analysis of anatomical shearing stresses and strains is difficult. However, shearing stresses and strains have been measured in segments of biological materials and shear moduli obtained. On the following pages are tables listing elastic moduli of animal bones. These data should be taken as only representative. Physical properties of biological materials vary greatly depending on age, wetness, etc. The tables following are from the text: Mechanical Properties of Bone, 1973, Charles C. Thomas Publisher.

The measurements reported in these tables are useful in comparing the relative strength of bones and in understanding the structural design of animal skeletons. To illustrate this, let us determine the shear deformation in a section of cattle femur measuring 40 cm. in length and having an uniform cross sectional area of 50 cm^2. To simplify let us assume the bone is homogeneous throughout

Table I.--Tensile properties of wet and air-dried compact bone

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
			Ultimate Tensile Strength (kg/mm^2)			
			Wet Bone			
Femur	12.1±0.18	11.3±0.21	10.0±0.21	8.8±0.15	10.3±0.30	7.1±0.26
Tibia	11.3	13.2±0.28	11.8±0.53	10.8±0.39	12.0±0.30	-
Humerus	10.2±0.13	10.1±0.07	10.2±0.56	8.8±0.73	10.5±0.42	-
Radius	12.0	13.5±0.16	12.1±0.71	10.0±0.34	12.5±0.36	-
			Air-dried Bone			
Femur	14.9±0.13	13.5±0.08	11.5±0.43	10.5±0.11	-	-
Tibia	-	14.5±0.15	15.0±0.70	13.1±0.58	-	-
Humerus	-	12.2±0.14	12.2±0.15	10.1±0.21	-	-
Radius	-	14.7±0.16	15.5±0.56	13.0±0.37	-	-
			Ultimate Percentage Elongation			
			Wet Bone			
Femur	0.75±0.008	0.88±0.20	0.79±0.017	0.68±0.010	0.76±0.016	0.65±0.017
Tibia	0.70	0.78±0.008	0.86±0.033	0.76±0.028	0.78±0.016	-

Table I.--Continued

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
Humerus	0.65±0.005	0.76±0.006	0.77±0.029	0.70±0.033	0.70±0.026	-
Radius	0.71	0.79±0.009	0.87±0.053	0.73±0.032	0.81±0.022	-
			Air-dried Bone			
Femur	0.58±0.011	0.77±0.014	0.73±0.026	0.61±0.010	-	-
Tibia	-	0.64±0.004	0.79±0.042	0.69±0.037	-	-
Humerus	-	0.62±0.009	0.72±0.037	0.61±0.030	-	-
Radius	-	0.71±0.013	0.77±0.035	0.67±0.019	-	-
			Modulus of Elasticity (kg/mm^2)			
			Wet Bone			
Femur	2550	2500	1500	1490	1750	1390
Tibia	2380	2450	1480	1720	1800	-
Humerus	1780	1830	1570	1460	1850	-
Radius	2280	2590	1550	1580	1900	-

Table I.--Continued

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
			Air-dried Bone			
Femur	3360	2580	1780	1870	-	-
Tibia	-	3320	1970	2060	-	-
Humerus	-	2630	1800	1830	-	-
Radius	-	3340	2250	2140	-	-

Table II.--Modulus of rigidity ($X10^4$ kg/mm^2) of wet long bones, in anteroposterior bending

Source of Bone	Femur	Tibia	Humerus	Radius	Ulna
Horses	28617	17835	11871	7317	-
Cattle	8445	5046	6230	2453	-
Wild Boars	671	228	363	87	86
Pigs	354	163	247	81	54
Dogs	42	35	5	10	8
Cats	37	46	5	7	14
Rabbits	9	11	5	1.0	0.9
Guinea Pigs	10	0.9	0.7	0.2	0.2
Domestic Fowls	13	23	8	0.9	6

Table III.-- Compressive properties of wet and air-dried compact bone

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
		Ultimate Compressive Strength (kg/mm^2)				
			Wet Bone			
Femur	14.5±0.16	14.7±0.11	11.8±0.11	10.0±0.07	13.3±0.15	12.0±0.28
Tibia	16.3	15.9±0.14	13.3±0.22	10.6±0.11	14.1±0.20	-
Humerus	15.4	14.4±0.13	11.0±0.15	10.2±0.16	13.6±0.13	-
Radius	15.6	15.2±0.15	12.3±0.16	10.7±0.16	13.5±0.22	-
			Air-dried Bone			
Femur	19.9±0.16	22.5	16.0	14.2	-	-
Tibia	-	22.5	16.7	14.7	-	-
Humerus	-	-	15.5	14.2	-	-
Radius	-	-	16.5	14.7	-	-
		Ultimate Percentage Contraction				
			Wet Bone			
Femur	2.4	1.7±0.02	1.8±0.02	1.9±0.02	1.8±0.03	2.1±0.02

Table III.--Continued

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
Tibia	2.2	1.8±0.02	1.8±0.02	1.9±0.02	1.6±0.03	-
Humerus	2.0±0.03	1.8±0.02	1.8±0.02	1.9±0.02	1.7±0.02	-
Radius	2.3	1.8±0.02	1.8±0.02	1.9±0.02	1.7±0.02	-
Air-dried Bone						
Femur	2.1±0.03	2.0	2.0±0.02	2.0±0.02	-	-
Tibia	-	2.0	2.0±0.02	2.0±0.02	-	-
Humerus	-	-	2.0±0.02	2.0±0.02	-	-
Radius	-	-	2.0±0.02	2.0±0.02	-	-
Modulus of Elasticity (kg/mm^2)						
Wet Bone						
Femur	940 ± 47	870	600	490	720	540
Tibia	850	-	670	510	800	-
Humerus	900	-	560	500	750	-
Radius	840	-	630	530	780	-

Table III.--Continued

Bone	Horses	Cattle	Wild Boars	Pigs	Deer	Ostriches
			Air-dried Bone			
Femur	1380 ± 45	1080	730	610	-	-
Tibia	-	1080	750	670	-	-
Humerus	-	-	710	640	-	-
Radius	-	-	750	650	-	-

and that it is subjected to a normal shearing force of 6×10^3 newtons. From Table 11 the shear or rigidity modulus of wet cattle femur bone is 8445×10^4 kg/mm^2, which equals 8.23×10^{10}n/m^2. Applying the defining equation for shear modulus and solving for s we have:

$$s = 4 \times 10^{-1}\text{m}\ (8 \times 10^3\text{n}/5 \times 10^{-3}\text{m}^2)\quad 82.3 \times 10^{10}\text{n/m}^2$$

or

$$s = 7.7 \times 10^{-5}\text{m} = 0.08 \text{ mm}$$

From this simplified calculation we see that indeed cattle femur bone is quite rigid. This fact is quite important to the non bow-legged cow!

Finally as an illustration, let us consider the compressibility of solids. The bulk modulus of a solid determines the extent to which a body of the material will experience a volume change due to pressure applied uniformly over its surface. Here the stress is the applied pressure and the strain is the relative volume change. Thus, we write the equation for bulk modulus as:

$$B = (F/A) \div (\Delta V/V_o)$$

Suppose we use the bulk modulus of wet horse humerus bone to determine the pressure required to crush the bone to the extent that its volume decreases by 0.05%. From table 111 we have: B=900 kg/mm^2. Again, we may first convert to proper mks units:

$$B = 900 \text{ kg/mm}^2 \times 9.8 \text{ n/kg} \times 10^6 \text{mm}^2/\text{m}^2 = 8.82\times10^{10}\text{n/m}^2$$

By direct substitution into the above equation we obtain:

$$8.882 \times 10^{10} n/m^2 = (F/A \div 5 \times 10^{-4}$$

or

$$F/A = 4.41 \times 10^7 \ n/m^2$$

This pressure, 4.47×10^7, n/m^2 is roughly the hydrostatic pressure of water at a depth of 4.4 km. Unless our horse is a sea horse he need not worry about the prospects of significant changes in his skeletal volume due to compression!

FLUID MECHANICS I

Some knowledge of the mechanics of fluid motion is necessary to understanding the means by which living organisms maintain their vital functions. In this reading we will consider only some of the fundamental concepts of fluid mechanics. This subject is one of the most difficult in physics. For this reason it is usually treated rather lightly by life scientists. However, to do so is to lose an understanding of some of the most fundamental aspects of life supporting mechanisms.

After studying this paper the reader will be expected to know the basic definition of viscosity and to be able to express it in equation and verbal terms. He should also expect to be called upon to solve elementary physics problem calculations by use of the defining equation for viscosity. In addition the reader will be held responsible for Poiseuille's equation, he should be able to write the equation, to use it in elementary calculations such as those given in this paper, and he should be able to infer certain real physical phenomena of fluid flow based on an understanding of Poiseuille's equation. And, finally the reader will be expected to be able to distinguish between newtonian and non-newtonian fluids and by so doing account for relevant characteristics of fluids in motion.

The French physician, J.L.M. Poiseuille, studying the flow of blood through capillary blood vessels, observed the peculiar motion of red blood corpuscles. As had been reported by others Poiseuille noted that at times neighboring red corpuscles appeared to move with equal speed, and then on occasions one or more of them would change speed, rotate, and continue to flow with the blood. This observation had been previously used to support the idea that the corpuscles possessed the ability to move by themselves. However, as a consequence of his work, in 1843, Poiseuille was able to account for this peculiar red corpuscle motion on the basis of the dynamic properties of fluids alone and thus to discredit the notion of self moving red corpuscles. In order to understand Poiseuille's explanation one must first gain an understanding of some of the fundamental properties of moving fluids. We shall thus begin our study by considering the concept of viscosity, a property of fluids which plays a very important role in all fluid motion and in particular in Poiseuille's explanation.

Perhaps viscosity may best first be understood by thinking of a very wide and very long river having a flat smooth bottom. Imagine the river to be flowing such that its velocity at the lower surface increases linearly from zero to a maximum value at the upper surface. (The notion of zero velocity at the very bottom should present no conceptual difficulty; after-all fish resting in a stream use this fact in order to remain in a stationary position . . . this is most easily done near the bottom where the current decreases to zero.) We will denote the height of the fluid above the bottom as, y, and the current velocity at any point in the river as v. From these terms we define the velocity gradient of the river as the rate at which the velocity increases with respect to height above the river bottom. That is:

$$\text{Velocity Gradient} = \frac{\Delta v}{\Delta y}$$

The river bottom tends to drag the river in the direction opposite to the flow. If we denote a unit area (1 cm^2) of the bottom water surface as A, and the drag force of the bottom acting tangentially over this area as F, we can define a shearing stress, analogous to that which we studied for solids, applied to the fluid composing the river as:

$$\text{Shearing Stress} = F/A$$

For many fluids the ratio of the shearing stress to the velocity gradient is a constant which we shall denote as η; this constant is called the viscosity of the fluid.

$$\text{Viscosity, } \eta = (F/A) \div (\Delta v/\Delta y)$$

Fluids for which this equation holds, that is fluids for which the shearing stress is directly proportional to the velocity gradient, are called newtonian fluids. Fluids for which this relationship does not hold are called non-newtonian fluids. Verbally we may define viscosity as the drag force per unit area per unit velocity gradient.

The common (C. G. S.) unit of viscosity is the poise. The poise is defined from the above equation:

$$1 \text{ Poise} = (1 \text{ dyne}/\text{cm}^2) \div (1 \text{ cm/sec/cm})$$
$$= 1 \text{ dyne sec/cm}^2$$

The table below gives the viscosity of several newtonian fluids at different temperatures.

Water at 0°C	0.0178
Water at 20°C	0.0100
Water at 100°C	0.0030
Mercury at 0°C	0.00125
Mercury at 100°C	0.00091
Glycerin at 20°C	6.8
Air at 0°, 760 mm of pressure	0.133×10^{-3}
Air at 100°C, 760 mm of pressure	0.245×10^{-3}

Consider now a tube in which a viscous fluid is flowing. By comparison to the fluid motion in our long and wide river we can see that the drag force of the tube's wall acting on the fluid is greatest nearest the wall and least in the center. It is from this basis that Poiseuille determined the equation which expresses the volume rate of discharge of a fluid flowing through a pipe. This equation, Poiseuille's equation, may be written as:

$$q = \frac{R^4 \Delta P}{8\eta L}$$

Here q is the volume of fluid discharged through the pipe per unit time (cm^3/sec), R is the pipe's radius (cm), P is the pressure difference (dynes/cm^2) from one end to the other over the length L (cm), and η is the viscosity of the fluid (poise).

Although the theoretical development of this equation lies outside of this presentation interested students are referred to page 572 in the text: Physics for Biology and Pre-Medical Students, by Burns and MacDonald for an intuitively based development of the equation.

From Poiseuille's equation we note some very important aspects of fluid motion. As might be expected the rate of discharge (q) is inversely proportional to the length of the tube (L) and directly proportional to the pressure difference along its length. More surprisingly, however, is the fact that q is directly proportional to the <u>fourth power</u> of the tube's radius; thus for example, narrowing the radius of a tube to one fourth of its initial size reduces the flow to 1/256 of its initial rate, or, tripling the radius of a tube increases the rate of flow 81 times.

The circulation of flow through our tissues, although not strictly described by Poiseuille's equation, is controlled by the cross-sectional changes of the blood vessels. In particular only very small changes in the radii of capillary blood vessels are required to produce tremendous effects on blood flow. If the arteries had rigid walls the blood would flow through them in spurts due only to the pumping of the heart. This, however, is not the case. The arteries swell slightly as the heart contracts, storing blood and elastic energy. (The elastic energy is stored largely in the elastin, an elastic protein, which makes up a large portion of the arterial walls.) Then by elastic recoil the stored blood is pumped on through the capillaries with ease due to their slightly expanded state as predicted by Poiseuille's equation. Hence, due to this expansion, the flow rate is regulated through the arterioles and capillaries, and less work is required of the heart to pump the blood throughout the body.

At this point it is perhaps worth mentioning the long established medical practice of prescribing wine in the treatment of "high blood pressure". Ethyl alcohol, the alcohol in wine and other alcoholic beverages, is readily absorbed into the bloodstream whereupon there is a corresponding dilation of the blood vessels. This expansion, by Poiseuille's equation, is associated with a decrease in the pressure required to maintain the bloodstream.

Although this phenomenum is suggested by Poiseuille's equation,strictly speaking Poiseuille's equation applies only to newtonian fluids, and, blood is not a newtonian fluid. The reader will recall that for newtonian fluids the velocity gradient is directly proportional to the shearing stress applied to the fluid, $F/A=\eta\Delta v/\Delta y$. This equation, which defines η the viscosity of the fluid, does not hold for non-newtonian fluids of which blood is one. Blood is made up of component cells and molecules which, due to their shapes and sizes become intertwined as the blood flows. This intertwining disrupts laminar flow, the layered flow exemplified by sheets of fluid slipping over each other as in the case of our river imagined earlier.

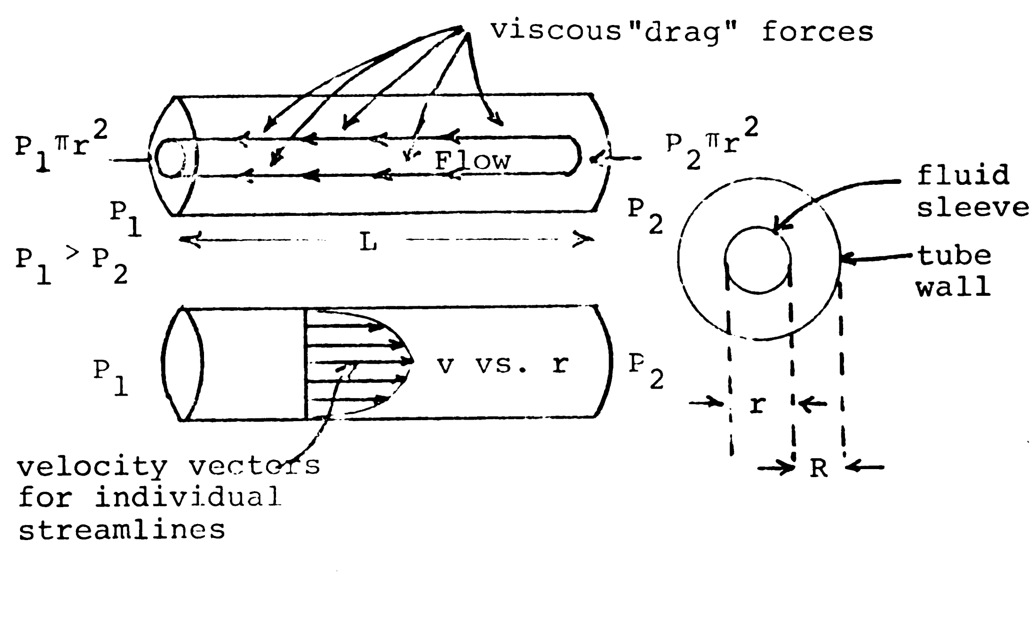
In that example, and any other in which the flow is laminar, fluid layers slip past each other without exchanging material between adjacent layers. In fact the term streamline comes from the notion of a line lying along one of these layers which pass undisrupted along in the direction of fluid motion. A streamline is a line which indicates the direction of velocity within a current in which there is no turbulence, or exchange of matter across lamina.

We can now understand Poiseuille's explanation regarding the peculiar motion of the red blood corpuscles. The corpuscles, several microns across in size, occasionally shift across streamlines. In crossing these streamlines the corpuscles experience rotational forces which result in applied torques which produce rotational acceleration of the corpuscles and thus their peculiar observed motions.

The torques which long molecules experience in crossing streamlines are due to the fact that the fluid in the center of a tube flows more rapidly than the fluid nearer the tube wall. This is consistant with the fact that the viscous drag increases as the tube wall is approached. Thus for fluid flowing in tubes of constant radius we can visualize the flow as consisting of concentric sleeves of fluid moving with increasing velocity corresponding to decreasing radius. And by use of some simple calculus and the assumption that the fluid is flowing at a constant discharge rate; it can be shown that the velocity of any particular sleeve of fluid is given by the equation:

$$v = \frac{P_1 - P_2}{4\eta L}(R^2 - r^2)$$

Where P_1-P_2 is the difference across the length of the tube L, and η is the viscosity of the fluid. R is the radius of the tube and r is the radius of the tube for which v, the velocity, is being determined. It is important to remember that this equation applies <u>only</u> to newtonian fluids. The sketch below illustrates the velocity distribution of streamlines for a newtonian fluid flowing through a tube. Keep in mind that fluids of homogeneous composition made up of spherically symmetric molecules tend to be newtonian whereas fluids composed of high polymers and solutions of high polymers are non-newtonian.



For solutions of high molecular weight polymers the velocity gradient is not proportional to the shearing stress; in fact, the viscosity generally decreases as the stress and velocity gradient increase in these solutions.

Perhaps here is a good point in which to give a sample calculation based on the concepts we have been discussing. Although blood, as indicated above, is non-newtonian, we may, for slow discharge rates assume that Poiseuille's equation applies to blood. This type of assumption is common in physics where one wishes to obtain an order of magnitude estimation under the realization of the limitations underlying the assumptions implicit in the estimation.

Let us calculate the pressure difference between the ends of a capillary blood vessel which is 2×10^{-3}cm in diameter and has a length of 5×10^{-2}cm/sec and that the viscosity of blood is 7.2×10^{-2} Poise. First off let us realize that the discharge rate of the blood is given by the product of the cross-sectional area of the capillary and the average velocity of the blood, i.e., $q=(\pi R^2)$ v. Then by rearranging Poiseuille's equation in order to solve for P, the pressure difference, we obtain:

$$\Delta P = \frac{8q\eta L}{R}$$

And, by substituting in the data given above we obtain the desired pressure difference,

$$P = 9043 \text{ dynes/cm}^2$$

or

$$P = 9 \times 10^3 \text{ dynes/cm2}$$

The reader is strongly encouraged to perform the above calculation in order to prove to himself the validity of the result. His attention is called also to the fact that this pressure difference corresponds approximately to 1/100 atmospheres which is quite a small pressure difference. (What is the driving force?)

This paper is intended to present a fundamental description of the following topics: bodies falling in viscous media, sedimentation rates, diffusion phenomena in liquids, osmosis, and surface tension of liquids. After reading the material below you will be expected to be able to write Stoke's Equation and to use that equation in explaining phenomena which are appropriately described by it, e.g., preliminary diagnostic tests for pregnancy, infection, and malignancy. Your instructor may also ask you to use Stoke's Equation in solving certain physics problems similar to the example given in this writing. Concerning diffusion you will be expected to know Fick's Equation, to be able to write it and to know the meanings of the terms it includes, i.e., the diffusion coefficient, the concentration gradient, and the mass transfer rate. On osmosis you will be held responsible for knowing the equation which expresses the final osmotic pressure in a volume of solution given its temperature, and concentration. You should also be able to discuss the qualitative aspects of osmosis at the level presented. And finally, you will be expected to be able to write the definition of surface tension, to write expressions for it in terms of force and energy as given in the discussion.

The specific biological applications of each of the above mentioned topics which are discussed in this article should be also understood in order to exemplify the physics inherent in them.

In 1938, E. Newton Harvey published an article on properties of protoplasm in Volume 9 of The Journal of Applied Physics (pp. 68-80). In his article Dr. Harvey discusses the use of the centrifuge to separate different materials contained in living cells. This separation is in the form of layers distinguished by the densities of the different materials. Other scientists have used very high speed centrifuges to separate biological materials, such as sugar molecules, from their solutions, and to separate and thereby identify different protein molecules from biological fluids. Each of these procedures is an example of sedimentation of objects within a viscous medium. In each case individual particles are forced to settle out of a fluid in which they are initially found.

Any object falling in a viscous fluid eventually acquires a constant velocity called its terminal velocity. Small objects, that is objects which have large cross-sections compared to their volumes, have lower terminal velocities than do large objects composed of the same material. (Smoke particles fall slower than do lumps of picnic charcoal!) A lump of charcoal 1 cm. in radius has a maximum cross-sectional area to volume ratio of 3/4, whereas, by comparison, a smoke particle having a radius of 5×10^{-4}cm. has a maximum cross-sectional area to volume ratio of about 20×10^{48}. The tremendous difference in these ratios largely accounts for the vastly different rates at which the bodies fall.

The parachute slows the rate of a body's fall by increasing its cross-sectional area; the parachute used artificially by man is naturally used by certain animals and plant seeds to reduce the rates at which they fall. Actually the sedimentation rates of small objects falling in viscous media are determined not only by their sizes but also by their densities. For equal size the more dense the material the greater the terminal velocity. The sedimentation rate of red blood corpuscles in vitro is commonly used in medical diagnosis. Sedimentation rates for red blood corpuscles may increase from about 15 mm. per hour to 45 mm. per hour in cases of pregnancy, infection, and malignancy.

A body of any shape will, of course, experience opposing drag as it falls in a viscous fluid. Due to the mathematical complexities in calculating the drag force which retards the motion of most bodies we will consider only the case of a spherical body falling in a viscous medium. Here the calculations are relatively simple.

In 1845, George Stokes, an English physicist and mathematician deduced an equation which expresses the drag force acting on a spherical body moving with velocity, v_T, in a medium having viscosity, η; this equation, Stokes' Equation may be expressed in the following form:

$$F_d = 6\pi\eta r v_T$$

Here F_d is the viscous drag force (dynes), η is the viscosity of the medium in which a sphere of radius r (cm) is falling at velocity v_T (cm/sec). Readers interested in a dimensional analysis type development of this expression are referred to the text Physics for Biology and Pre-Medical Students, by Burns and MacDonald.

Now, from Newton's Law of Motion we know that for a body moving at a fixed velocity the sum of the external forces acting on the body is zero. The gravitational force, Fg, which acts on a body, it's weight, is simply the product of the body's volume, density, and the gravitational field. For a sphere this product may be written as $4/3\pi r^3 \rho g$, where $4/3\pi r^3$ is the volume of a sphere of radius r (cm), ρ is the sphere's density (gm/cm^3), and g is the gravitational field (cm/sec^2). Within a fluid this gravitational force is always opposed by the force of buoyancy (by Archimede's Principle). The force of buoyancy is simply the product of the volume of the fluid the body displaces, the density of that fluid, and the gravitational field. Thus, for a completely submerged sphere: $F_b = 4/3\pi r^3\rho' g$, where $4/3/\pi r^3$, the volume of the sphere is also the volume of fluid displaced, ρ' is the density of that fluid, and g, again, is the local gravitational field. F_b is, of course, the buoyancy force.

Having now established expressions for the gravitational and buoyant forces which act on a spherical body we can add the viscous drag force given by Stokes' Equation and equate the sum to zero in accord with Newton's law.

$$F_b + F_d + F_g = 0$$

or

$$F_b + F_d = F_g$$

And, realizing that F_g acts downward in opposition to F_b and F_d we may delete the negative sign and write:

$$F_b + F_d = F_g$$

Now substituting in the expressions for F_b, F_d, and F_g, from above we finally have:

$$4/3\pi r^3 \rho' g + 6\pi r^3 \rho g$$

Which may be solved for v_t yielding:

$$v_t = 2/9 \frac{r^2 g}{\eta} (\rho - \rho')$$

This expression, a very important one, gives us a means of determining the terminal velocity (v_t) of a sphere falling in a viscous medium.

To illustrate let us use the above equation to determine the rate at which some red blood corpuscle of radius r = 4 microns (1 micron = 10^{-4}cm) settles out of blood plasma for which we will assume the density, = 1.04. Here we are assuming that red blood corpuscles are spherical in shape where in fact they are more or less saucer shaped. Let us further assume that the density of the red corpuscle is 1.08, and that the viscosity of blood plasma is 0.072 poise (remember that 1 poise = 1 dyne sec/cm^2). Making the appropriate substitutions into the given expression we obtain:

$$\frac{v_t = 2/9\ (4 \times 10^{-4} \text{cm})^2\ (9.8 \times 10^2\ \text{cm/sec}^2)\ \ (1.08 - 1.04)\ \text{gm/cm}^3}{7.2 \times 10^{-2}\ \text{dyne sec/cm}^2}$$

or

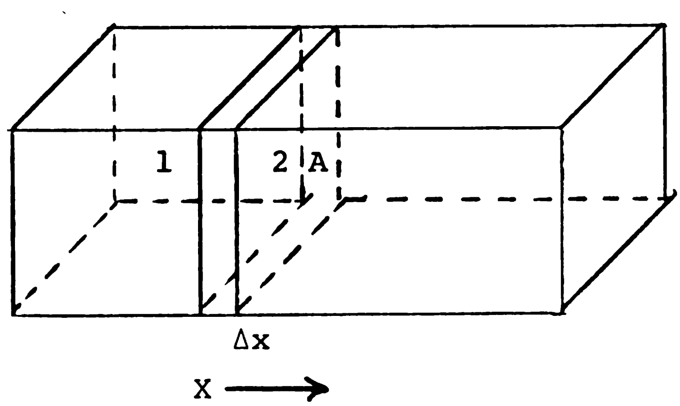
$$v_t = -.196\ \text{cm/sec or } 705\ \text{mm/hr}$$

This result is quite obviously at odds with the sedimentation rates for red blood corpuscles reported earlier; the difference in this result compared to the experimentally reported values is due to the assumption that the corpuscle in our calculation is spherical--a very bad assumption--saucers don't resemble spheres very well! Here, however, the reader is encouraged to reflect on the importance of shape in influencing the rate at which bodies do fall in viscous media and on the biological significance of altering shapes of such important things as red blood corpuscles! One can also speculate as to the shape of raindrops and the possible effects of altering that shape.

Here it should be emphasized that the discrepancy in the experimentally reported sedimentation rates and the result obtained in our example above is intentional; the reader who may now have doubts concerning the validity of Stoke's Equation for spherical shaped objects falling in a viscous media is referred to the classical Millikan Oil Drop Experiment from which the fundamental unit of electrical charge was determined thereby establishing the quantum nature of electricity.

Life processes are abundant in phenomena in which substances spontaneously diffuse from regions of higher concentration into regions of lower concentration. The inky fluid secreted by squids and octopi in time of danger quickly diffuses to form a protective cloud about the animals, sugar molecules diffuse from the chloroplasts in plant cells throughout the cell protoplasm, and digestive enzymes diffuse within the stomach fluid of animals. In all cases of spontaneous diffusion the flow occurs across some physical gradient. Electric charge diffuses across a gradient of electrical potential, thermal energy diffuses across a temperature gradient, and solutes diffuse across gradients of chemical potential, or, as mentioned above, solutes diffuse from regions of higher concentration into regions of lower concentration. The rate of diffusion of a solute into its solvent, across a concentration gradient, is described by Fick's Equation which may be written as:

$$\Delta m/\Delta t = - D\ A\ \Delta c/\Delta x$$



Here Δm is the mass of solute which diffuses Δx across the area A during the time interval, Δt. ΔC is the difference in concentration ($C_1 - C_2$) of the solute from side 1 to side 2 of the partition shown in the sketch above. D is the proportionality constant which determines the rate of diffusion, and it is, therefore, called the diffusion coefficient. Although, as in all equations of physics, the units in Fick's Equation are arbitrary, commonly m is in grams, t is in seconds, D is in meters^2 per second, and C is in grams/meters^3 and x is in meters. In this unit system the diffusion coefficient for biologically important molecules, according to Burns and MacDonald, ranges from $1 \times 10^{-11} m^2$/sec to $100 \times 10^{-11} m^2$/sec.

The diffusion coefficient in the above equation actually depends on the temperature and viscosity of the partition through which the solute passes as well as on the size of the solute particles themselves. The equation for the diffusion coefficient of solutes in liquids was first obtained by Einstein; it is:

$$D = \frac{kT}{6\eta\pi r}$$

Here k is Boltzmann's constant, 1.38×10^{-23} joules/deg Kelvin, T is the temperature in degrees Kelvin, η is the viscosity in newton seconds per square meter, and r is the radius in meters. (Note that in order to determine the diffusion coefficient in m. k. s. units viscosity can not be given in poise units.) Readers interested in the actual derivation of the expression for the diffusion coefficient are referred to: Physical Chemistry, by F. Daniels and R. A. Alberty.

One important consequence of the above equation should be considered here; recalling that the mass of a spherical particle is proportional to the cube of its radius, or that the radius of a uniform spherical particle is inversely proportional to the cube root of its mass we see that the diffusion coefficient for solutes in liquids is inversely proportional to the cube root of the solute particle mass. This, of course, assumes that the particles are spherical, which in fact is nearly so for many. The significance of this relation of the diffusion coefficient to particle mass is demonstrated by the fact that solute molecules of vastly differing masses exhibit very nearly identical diffusion coefficients. The table below by Dr. James Parks should verify this fact.

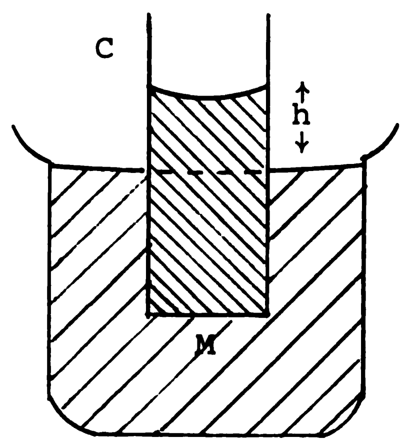
Glycine	75	95×10^{-3} M^2/Sec.
Cytochrome C	1.3×10^4	10×10^{-3} "
Hemaglobin	6.8×10^4	6.2×10^{-3} "
Urease	4.8×10^5	3.5×10^{-3} "
Southern Bean Mosaic Virus	6.0×10^6	1.34×10^{-3} "
Bacteriophage T_2	2.0×10^8	3×10^{-4} "

At this point the reader is cautioned that the relationship, $D\alpha 1/m1/2$, applies only to diffusion in liquids. For gaseous diffusion the diffusion coefficient is inversely proportional to the square root of the mass of the diffusing particles, i.e., $D\alpha\ 1/m1/2$.

We now come to the topic of osmosis. Diffusion and osmosis may well be the two most important life supporting processes; it is by diffusion and osmosis that food is ultimately absorbed by organisms. Osmotic pressure (see below) plays a major role in the turgor of plants. Plant root cells are separated from their environment by a semi-permeable membrane and a rigid cell wall. Exterior to the plant root the osmotic pressure is lower than it is within the root. Hence, due to the inelasticity of its epidermis, a given root maintains its structural rigidity. Application of commercial fertilizers in high concentration near the roots of plants may reverse the osmotic pressure balance between the root and the soil, and a corresponding limpness of the plant may occur.

"Good Ole Kentucky Cured" hams also provide an illustration of osmosis. The hams are actually preserved due to difference in osmotic pressure across the cell membranes of the ham. Corresponding to this pressure difference is a decrease in the water content of the ham and thus its preservation.

In order to understand osmosis consider the figure below:



Here we have a cylinder C closed off by a membrane M made perhaps of an animal bladder. The cylinder contains a solution of salt, sugar, or some other easily soluble substance, and the beaker into which the cylinder extends is filled with pure water. At the outset the level of the solution in the cylinder is adjusted to coincide with the level of the surrounding water, but, in time the solution in the cylinder rises to a definite height above the water level as shown. This rise in the level of the solution can be shown to be due to the water passing from the beaker through the membrane into the cylinder. That the solute in the cylinder barely passes through the membrane into the beaker can be demonstrated by chemically testing the contents of the beaker. The membrane is thus said to be semipermeable. The pressure required to lift the solution to the height h is called the final osmotic pressure of the solution. This pressure depends on the final concentration and temperature of the solution, and in fact for dilute solutions it is equal to the pressure which the dissolved substance would exert if it were present as a gas in the volume occupied by the solution. This fact is called Van't Hoff's rule. It may be expressed as:

$$P\,V = n\,R\,T$$

Where in MKS units P is the osmotic pressure in newtons per square meter, V is the volume in cubic meters, n is the number of moles of the solute present, T is the temperature in degrees Kelvin, and R is the universal gas constant 8.31 Joules per mole-degree.

Actually, the final osmotic pressure of a solution is the pressure at which there is no further increase in the volume of a solution due to the influx of solvent through the membrane. At this point an equilibrium is set up where the amount of solvent entering the solution exactly equals the amount of solvent leaving the solution; prior to this point we may consider that there is only solvent entering the solution, or, that the difference between the influx of solvent and the efflux of solvent is a positive value. At final osmotic pressure the exchange of solvent across the membrane is zero. At any time prior to reaching this final steady state the osmotic pressure of the solution is less than the final pressure and depends on the temperature and the concentration (higher) of the solute. For a detailed discussion of this the reader is referred to the text: Physical Chemistry, 2nd Edition, by Daniels and Alberty (pp. 183 - 187).

By extending hair like appendages mosquito larvae suspend themselves from the surfaces of water pools; however, when the pools are sprayed with oil the mosquito larvae sink and drown. Large water beetles are commonly seen running over the surfaces of ponds, lakes, and streams and yet these same beetles, when dead, tend to sink when immersed in water. A significant number of human babies (about 25,000) die in the United States each year shortly after birth due to collapsed lungs, and in recent years a number of patients, having undergone surgery with the aid of artificial heart and lung machines, succumb to lung failure following the operation. Each of these phenomena illustrate an important property of liquid surfaces, surface tension.

Surface tension may be understood only by considering the composition of liquids. The freezing of a liquid produces crystals which can be demonstrated by x-ray techniques to consist of particles arranged in orderly ways. It is reasonable to assume that these particles are also the fundamental material of which the unfrozen liquid is composed. Thus we may surmise that the distinction between solid and liquid is that while in the liquid state the particles (molecules or atoms) are not held in rigid positions, but rather that they are free to move amongst themselves whereas in the solid crystal the particles are each assigned specific sites.

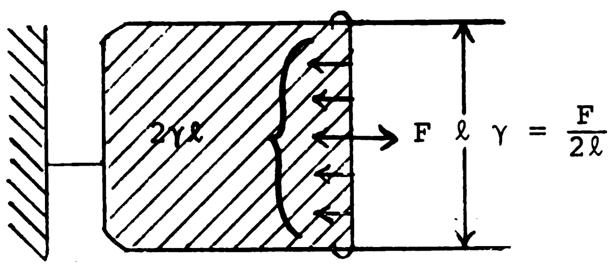
Now, if one considers the liquid particles to be exerting mutually attractive forces on each other then it is easy to see that they would be pulled together so as to occupy the least possible volume. That this is in fact the case is demonstrated by liquid drops which tend to be spherical. A sphere occupies the least volume for a given surface area of all geometrical forms.

Given that molecules of a liquid do exert mutually attractive forces on each other, it is also easy to see that the molecules lying at the surface of a liquid are tightly bound to the liquid by these cohesive attractive forces. This attraction compares closely to that of objects lying on the Earth's surface in which case they are held in position by the mutual attraction of the Earth for them, or by their attraction for the Earth. (The Earth weighs very little on the surface of a pumpkin!) Thus it is that the attraction of liquid molecules one for another accounts for surface tension. Molecules at the surface of a liquid resist being separated and thus are able to support objects more dense than the liquid itself. This phenomenon may also be thought of in terms of potential energy; the liquid molecules tend to arrange themselves such as to reduce their potential energy to a minimum. White blood corpuscles have as a primary function the removal of dead particles and bacteria from the blood. When a white corpuscle (lymphocyte) encounters a smaller foreign particle the lymphocyte surrounds and ingests the alien particle. This process can be shown to be one of surface tension in which the lymphocyte material actually ingests the foreign object by reducing their mutual surface area and thereby their potential energy.

Another illustration of the biological importance of surface tension is its contribution to the elasticity of lungs. The lungs provide the largest surface of the human body which comes into contact with the outside environment. The total lung surface area of normal adults is roughly equivalent to that of a tennis court. This enormous surface area is due to the presence of hundreds of millions of tiny air pockets called alveoli. These alveoli expand and contract with each breath and it is through them that oxygen is absorbed into the blood. The surface tension of the fluid which coats the individual alveolus has been shown to account for most of the elasticity of the lungs. By way of contrast to elasticity as previously discussed it must be mentioned here that surface tension forces do not depend on the degree to which a surface is deformed. It will be recalled that materials which are truely elastic obey Hooke's Law, which of course, expresses the restoring force of an elastic material in terms of its deformation.

However the surface tension of a liquid can be altered by changing the concentration of surface active substances which may be added to it. Soaps and synthetic detergents are common examples of substances which lower the surface tension of water. The surface tension of the fluid which coats the alveoli in mammalian lungs is altered by changing the concentration of a kind of detergent secreted by cells proximal to the alveoli. This is done in a most peculiar way which enables the lungs to perform their vital functions. Inelasticity of infant lungs corresponding to an invariant concentration of the lung fluid detergent is associated with infant death due to respiratory failure. For detailed discussion of this phenomenon readers are referred to studies by Charles Clifford Macklin of the University of Western Ontario. We will return to the topic only briefly at the close of this writing.

Up to this point our discussion has been qualitatively descriptive; now we must quantitatively define surface tension. Consider the figure sketched below:



The figure portrays a U-shaped wire frame on which a movable slide wire is mounted. Within the region bounded by the slide wire and the U is a liquid film, perhaps a soap film. This film of course has two surfaces, each of which joins the slide wire along its length l. Now, applying a static force F to the slide wire is opposed by an equal force due to the film. This opposing force is proportional to twice the length of the slide since the slide is pulled upon by both surfaces of the film along its length. Hence, we may write the proportion:

$$F \alpha \; 2 \cdot l$$

and by injecting the proportionality constant γ we have:

$$F = 2\gamma l$$

γ is the surface tension of the film. In words we may thus define the surface tension as the ratio of the surface force perpendicular to the length along which it acts. Commonly, surface tension is measured in units of dynes per centimeter, dynes/cm. At body temperature the surface tension of pure water is about 70 dynes/cm, that of blood plasma is about 50 dynes/cm, and lung fluid varies from a maximum of about 40 to a minimum of about 2 dynes/cm.

An alternate way of defining surface tension is in terms of the work required to expand the surface. Suppose that we move the slide wire in the figure above a distance X perpendicular to its length l. In so doing we increase the total film surface by an amount given by the product $2 \cdot l \cdot X$. The work done is simply the product of the force F and the distance the slide wire is moved X. Dividing this work by the increase in area yields:

$$\frac{\text{work}}{\text{increase in area}} = \frac{F \cdot X}{2 \cdot l \cdot X} = \frac{F}{2 \cdot l}$$

This ratio, $F/2 \cdot l$ is our previous definition of surface tension γ. Thus, now we have a new way of defining surface tension:

> Surface tension is the work required per unit area to increase the area of the surface.

Here caution must be envoked not to equate the work required to expand the surface with the increase in surface energy. As the surface is expanded energy is lost corresponding to a decrease in the temperature of the liquid. For a liquid in contact with its own vapor the surface tension depends only on the composition of the liquid and the temperature. To illustrate the correspondence of surface tension and temperature several data for water are listed here:

Surface Tension (dynes/cm)	Temperature (°C)
75.6	0
72.8	20
66.2	60
58.9	100

One further point should be made concerning the new definition of surface tension; from the cgs units of work and area we see that the unit of surface tension can also be given as ergs per cm^2. Dimensionally, this is equivalent to dynes per cm.

Now we can understand more about the role of surface tension in mammalian lungs. In order for the lungs to cyclicly expand and contract the surface tension of the lung fluid must vary from a maximum of roughly 40 dynes/cm at full inflation to a minimum of only several dynes/cm. This is necessary so that the lungs may contract when filled with air and freely expand while inhaling. The decrease in surface tension of the lung fluid during contraction corresponds to an increase in the concentration of the surface active detergent secreted by the special cells mentioned earlier. Likewise the necessary increase in surface tension of the lung fluid on inhaling corresponds to a decrease in the concentration of the lung detergent.

The decrease in temperature associated with increasing surface tension is also important within the lungs as they perform a major role in the regulation of body temperature.

In the case of the infant respiratory distress syndrome a deficiency of the lung detergent contributes to the lack of elasticity necessary for breathing.

FLUID MECHANICS III

In this paper the reader will study two fundamentally important equations of fluid mechanics, the equation of continuity and Bernoulli's Equation. These equations are discussed in terms of specific biological applications. After reading this paper the reader will be expected to be able to write the equation of continuity in the form it is given below, and, to be able to write Bernoulli's Equation. He should also be able to discuss each equation in terms of its physical significance, i.e., the reader should be able to explain the limitations of each equation as it applies to fluid motion and to account physically for the terms in each equation. The instructor may also assign calculations and inference deduction type problems based on the equation of continuity and Bernoulli's Equation; thus, special attention should be given to the sample problems given in this writing. It is recommended that the reader spend some time speculating on applications of these equations outside of the specific areas discussed here.

Rockets are propelled by the ejection of mass. The propelling force, by Newton's Law, is the reaction force to the exerted on the ejected mass by the rocket. The velocity of a rocket can be determined by applying the principle of conservation of momentum and derivations of simplified equations of motion for rockets are commonly given in textbooks and lectures on general physics. In nature the squid is an organism which propels itself by ejecting mass (water), thus, in a way the squid itself may be thought of as a living rocket. Deriving the equations of motion for a squid would be a very difficult task if, in fact, it could be done. However, we can study one basic equation of fluid motion which is directly applicable to the squid's motion. This equation is commonly known as the equation of continuity.

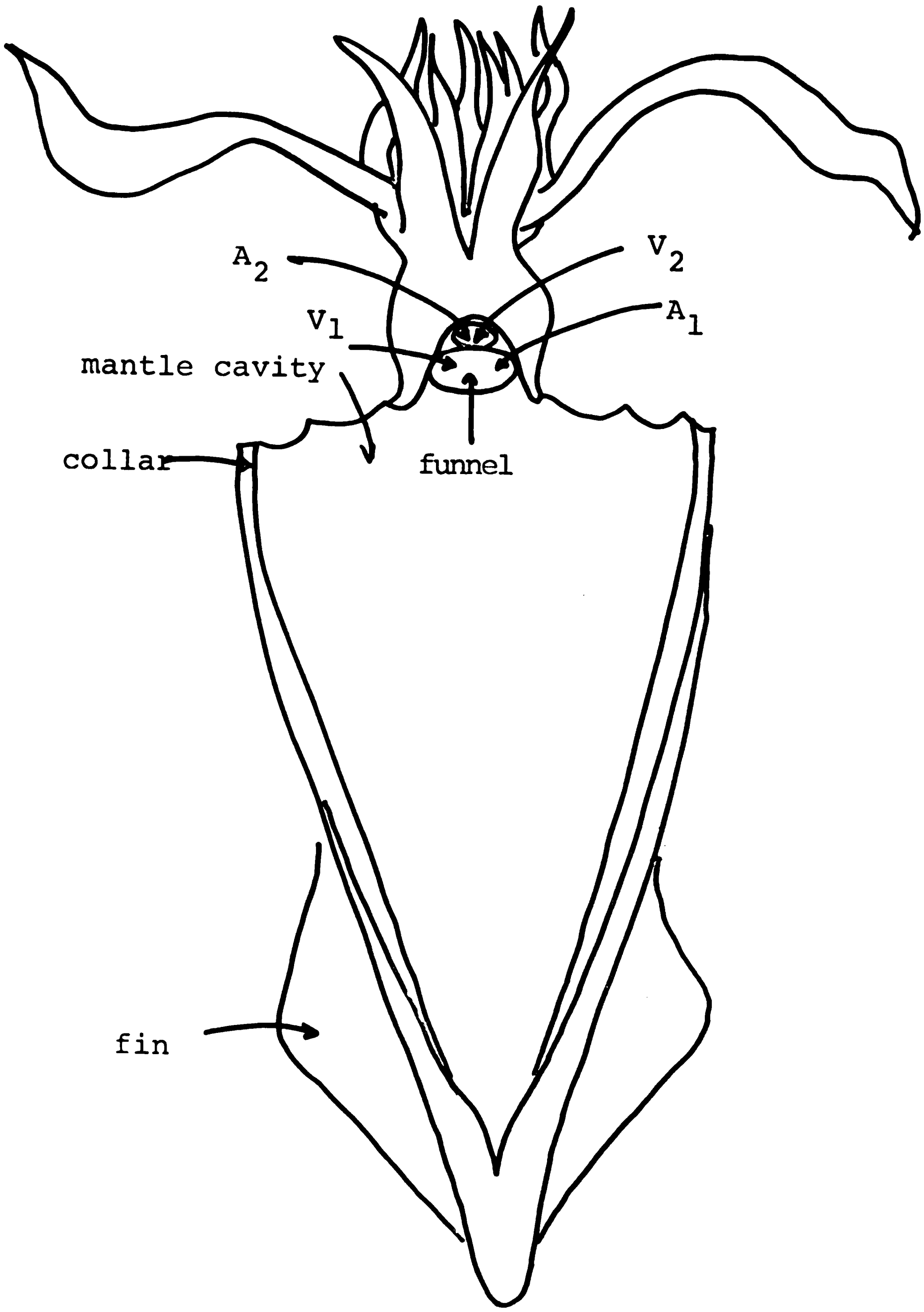
Although the equation of continuity may be written in several ways, each of which has vast applicability, we will consider this important equation in only a limited and simplified form. For our purposes we will consider the equation of continuity as simply a mathematical statement of the fact that the rate at which mass flows into a container must equal the rate at which mass flows from the container if the net mass of the container remains unchanged. Before actually writing the equation of continuity, let us consider a part of the squid, the funnel, as the container to which we will apply the equation.

The funnel of the squid is shown in the diagram on the next page. Immediately prior to executing escape motion the squid fills its mantle cavity with water which enters the cavity just inside the collar. When the mantle contracts this water is tightly sealed inside and forced into the funnel. The rapid escape motion of the squid is attained by the ejection of this water through the orifice of the funnel.

The motion of the squid attained by the discharge of water through the funnel is like a torpedo, the head of the squid and its enclosed funnel trails behind the main body. It is important to notice that the funnel itself varies in cross sectional area and is constricted toward the opening. Water ejected by the squid, therefore, passes through progressively smaller cross sectional areas of the funnel as it is discharged. (See following diagram).

Now water is nearly incompressible. This suggests that the rate of mass transfer of water (grams per second, etc.) passing through a rigid closed tube must be the same through all cross sections. In the squid the mass of water per second flowing through the progressively smaller cross sections of the funnel is identical for each cross section.

This fact, that the rate of mass transfer of an incompressible fluid through any cross-sectional area of a closed rigid tube is expressed by the equation of continuity. By letting ρ designate the mass density (mass per unit volume, m/V) of an incompressible fluid, and v,


A2
V2
V1
A1
mantle cavity
collar
funnel
fin

represent the fluid's average velocity (length travelled per unit time, l/t), where A represents the cross-sectional area through which the fluid passes we note that the product ($\rho A \cdot v$) is the rate at which the fluid mass passes through any section of the tube of length l.

$$\rho \cdot A \cdot v = m/V \cdot A \cdot l/t = m/V \cdot V/t = m/t$$

It should be noted that here the product of the cross sectional area A, and its length l, is V the volume of our chunk of fluid having mass m. And, because as we have indicated, the rate at which fluid mass passes through any cross section (m/t) is the same for all cross sections, we can write:

$$\rho A_1 \cdot v_1 = \rho A_2 \cdot v_2$$

This expression is the more common form of the previous equation. It is the equation of continuity, where A_1 is the area of any cross section through which fluid flows at velocity v_1, and A_2 is another cross section of the same tube through which the fluid flows at velocity v_2. The areas A_1 and A_2 are represented in our figure of the squid.

For the squid the equation of continuity expresses the fact that the animal can eject water at a high velocity v_2 by slowly constricting its mantle cavity and inducing water to flow through A_1 at velocity v_1.

In general in accord with the equation of continuity the velocity of an incompressible fluid flowing in a rigid tube increases at constrictions and decreases in expanded regions of the tube. This fact is commonly observed when fluid passes through any funnel. As with all equations of physics, the equation of continuity can provide meaningful information only when a consistent set of units is assigned to its terms. For example, if density is given in grams per cm^3 the velocity of the fluid should be in cm per second and the cross sections should be measured in square centimeters.

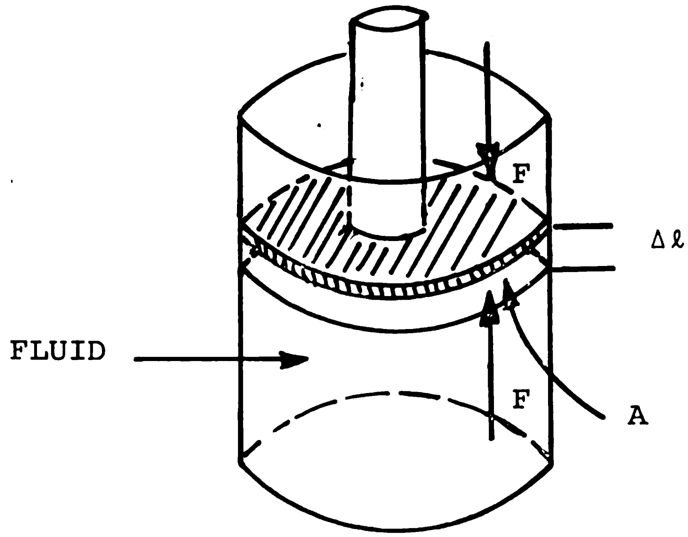
Here an example calculation may illustrate the usefulness of the equation of continuity. Suppose that the diameter of the orifice of a certain squid's funnel is 1 cm. and the diameter of the funnel internal to the squid where water is flowing outward at 10 cm./sec. is 1.5 cm. what is the average velocity of the water as it leaves the orifice? This problem may be solved by direct substitution into the equation of continuity.

$$\rho A_1 \; v_1 = \rho A_2 \; v_2$$

$$1 \cdot (1.5/2)^2 \text{cm.}^2 \cdot (10 \text{ cm/sec}) = 1 \cdot (1/2)^2 \text{cm}^2 \cdot (v_2)$$

Thus, the velocity of efflux of the water is more than doubled by reducing the diameter of this squid's funnel by one-third.

At this point, before we consider the development of Bernoulli's Equation, we must direct our attention to considering a topic which is of crucial importance in the approach we will take in understanding Bernoulli's Equation. Let us consider a cylinder which is filled with a fluid which is very slightly compressible. Imagine that this cylinder contains a piston which has a cross sectional area A which seals off the cylinder.



Applying external force to the piston is evidenced by a corresponding decrease in the volume of the fluid. Under the influence of additional externally applied force the piston moves to compress the fluid until the reaction force of the compressed fluid just equals compressing force. If we assume that the compression is only slight and can be measured by the small displacement Δl the piston moves then we can equate the work done on the fluid by the piston with the product of the applied force F and the distance moved Δl. Now pressure is force per unit area. Hence we can write:

$$P = F/A$$

and multiplying both the numerator and denominator of this fraction by 1 we obtain:

$$P = F \Delta 1/A\Delta 1$$

This, by the equivalence of work and energy can simply be rewritten as:

$$P = E/V$$

where E is the energy which the fluid obtains due to the work done on it by the piston, and V is the volume equal to the product of the cross-sectional area A of the cylinder through which the piston has moved the distance $\Delta 1$. From this we see that pressure may be thought of as pressure energy, i.e. pressure energy per unit volume. For detailed presentations of this concept the reader may wish to refer to any standard text on thermodynamics.

Now let us consider a horizontal tube in which a unit volume (1 cm^3) of liquid at position a has pressure energy P. If the liquid is flowing in the direction shown in the figure below and has velocity v_1 at position 1, then by the equation of continuity a unit volume will have greater velocity v_2 at position 11 where the tube is constricted. Recalling that the kinetic energy of a body of mass m (in this case the unit volume of liquid) is given by the expression $K.E = 1/2\ m\ v^2$, where v is the velocity, we see that the unit volume at 11 has greater kinetic energy than the unit volume at 1. This increase in kinetic energy is obtained at the expense of pressure energy. That is as the unit volume of liquid increases it velocity it pressure decreases. For the case where the flow is horizontal we thus may write:

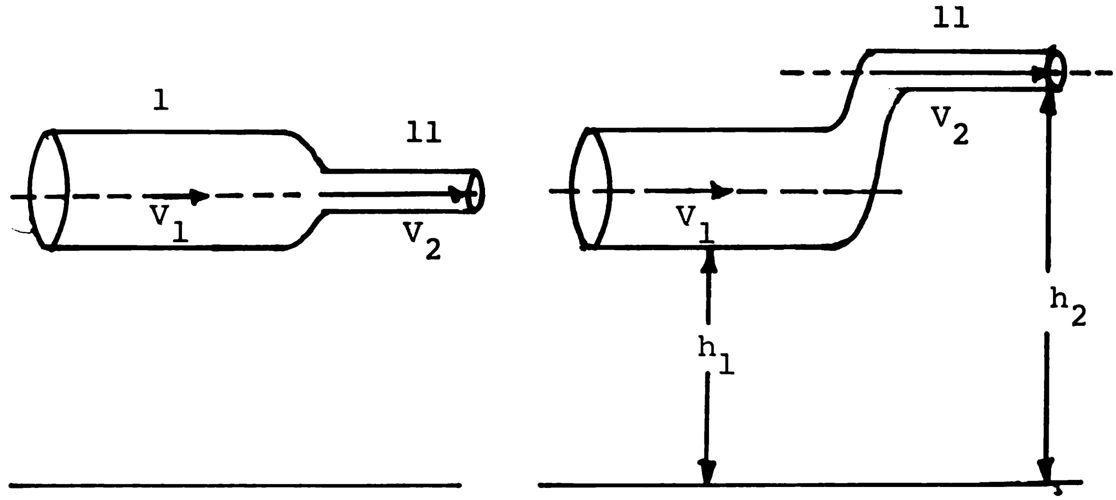
$$E = P + 1/2\ (\rho v^2)$$

where E is the total mechanical energy of the unit volume of liquid, is the density (mass per unit volume) of the liquid, and v is its velocity.

This expression for total mechanical energy is not complete, however; it does not include the gravitational potential energy of the unit volume of liquid. This omission is, of course, alright if in fact there is no change in gravitational potential energy of the fluid as it flows through the tube; this is the case for a horizontal tube. However, we may assign a height h_1 to the segment of the tube at position 1, in the second figure below, and a height h_2 to the segment at position 11. With these heights in mind we can now write the gravitation potential energies at the two positions as $\rho g h_1$ and $\rho g h_2$. Thus, by including the gravitational potential energy of the unit volume of fluid we can write:

$$E = P_1 + 1/2\ (\rho v_1^2) + \rho g h_1 = P_2 + 1/q\ (\rho v_2^2) + \rho g h_2$$

This is Bernoulli's Equation. It is a statement of the principle of conservation of energy.



Bernoulli's Equation provides the basis for understanding the so called Bernoulli Effect. This effect is simply that an in crease in the velocity of a fluid is accompanied by a decrease in pressure. In order to understand this effect let us consider a horizontal tube such as in the first figure on the preceding page. Since the tube is horizontal, and thus the gravitational terms on both side of the equation are equal, we can write:

$$P_1 + 1/2\ \rho v_1^2 = P_2 + 1/q\ \rho v_2^2$$

or

$$P_2 = P_1 + 1/2\ \rho (v_1^2 - v_2^2)$$

where the subscripts 1 and 2 correspond to the regions 1 and 11 in the figure. From the equation of continuity we know that $v_2 > v_1$, thus, $(v_1^2 - v_2^2)$ is a negative number. This implies that P_2 is less than P_1, or that for increased velocity there is an accompanying decrease in pressure.

This fact has many important consequences. The common experience of difficulty in breathing in a strong wind is due to the fact that the flow of air beneath the nostrils is accompanied by a decrease in pressure which makes breathing difficult. The gliding flight of birds and the lift of airplane wings is also largely due to the Bernoulli Effect. In both cases air flows more rapidly relative to the wing surface on the upper side. The corresponding pressure difference at the wing surfaces accounts for the upward lift force. The curved flight of a spinning baseball is also due to the same principle. As the ball spins the velocity of the air relative to the ball is increased on one side and decreased on the other. The force due to the pressure difference across the ball accounts for the ball's curved flight. In order to make this clear perhaps the reader should sketch a spinning ball in flight and analyze the air velocity to the right and left of the spinning ball.

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