SPACE RESOURCES FOR TEACHERS

BIOLOGY

Including suggestions for classroom activities and laboratory experiments

A curriculum project prepared by the University of California, Lawrence Hall of Science, Berkeley, California, Harvey E. White, Director.

NSR-05-003-117
NSR-05-003-144

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C., 20546 January, 1969

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $2.75

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During the summer of 1967, an Institute in Space Biology for High School Students was conducted for purposes of tryout and evaluation of the syllabus. The Institute was taught by Mr. Lee and Mr. Mac D. Homan, Concord High School, Concord, California. Special acknowledgment is made to Mr. Lee and Mr. Homan for their assistance, following the Institute, in reviewing and revising the syllabus.

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table of contents

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preface

INTRODUCTION

The purpose of this publication is to bring the high school biology teacher, and thus the student, into focus with respect to scientific advances in space biology. Biological research in the field of space science progresses so rapidly that printed material soon is outdated. Much of the data contained in this publication was derived through personal interviews and examination of the actual research facilities in which the scientists carry on their basic studies. Other information was derived from review of pertinent literature. It is hoped, however, that through study and use of this syllabus that the teacher and student may be made aware in a very personal manner of some of the more recent developments in space science, and attempt to remain abreast of further advances as they occur.

Although this publication may stimulate some alert teacher to develop a new course, even a new curriculum, the project staff conceived it as being a helpful, useful supplement to present biology courses. Many of the chapter topics listed in the table of contents are found in current biology textbooks. Among these are nutrition, gas exchange, oxygen consumption, temperature, radiation, rhythms and chemical evolution. The experiments outlined in "Suggestions to the Teacher for Development" sections at the end of each of the chapters in the syllabus will aid the instructor in bringing new concepts and discovery experiences to his students.

Some of the topics found in the syllabus are not discussed or even hinted at in any "modern" textbook. These are new significant subjects, now a part of the story of man and his desire to penetrate the world of outer space. These are topics which should now be opened to the teacher and student for study and analysis. Included are the following: weightlessness, acceleration and vibration stress, toxicity, biotelemetry, sensory and perceptual problems, spatial disorientation, exploration, and decontamination. Many of these topics, by their very nature, cross discipline corridors and tie together biology, physiology, physics, and chemistry. This is desirable and inevitable in the teaching of science today.

HOW TO USE THIS BOOK

Each chapter introduces the teacher, and through him the student, to a major topic of significance relative to the space effort today. The studies and experiments suggested for development at the end of each chapter include material of interest to more than one student achievement level. There are simple experiments, moderately difficult types, and some expected to be attempted only by superior students.

It is also recommended that the teacher attempt to acquaint himself with the large number of space-related studies in the life sciences that are being published. Sources for these may be noted in Appendix D.

Teachers who wish to introduce their students to the research reports and to use these in their teaching may find the discussion in Appendix C helpful.

Further aids to the teacher include bibliographic data at the end of each unit, and source lists of aerospace literature, cf. Appendix D. Also included is an annotated listing of pertinent films, most of which have been screened and evaluated, cf. Appendix B. Additional instructional films, filmstrips, slides, and film cartridge packages are being produced.

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section 1

LIFE SUPPORT

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The maintenance of life aboard a spacecraft is not a simple matter. Orbiting the earth in a one- or two-man capsule for periods of a few hours to two weeks no longer raises seemingly insurmountable problems. Planning longer trips of one month to more than a year in duration generates multitudes of technicalities and logistics problems involving research into all phases of human physiology and psychology. This necessary research is being conducted in laboratories throughout the United States and abroad.

In the following chapters we introduce some of the many problems of life support, some insight into them and recommended study and laboratory experience which, hopefully, will result in some understanding of the scope and magnitude of the research currently in progress.

NUTRITION

Introduction

Packing a "picnic lunch" for a space traveler will be a very demanding and perplexing task. The choice of ingredients for such a lunch will be determined by the energy needs of the traveler. Such needs, in turn, are related to a number of things, including the length of the journey, and the kind of environment in which the traveler will find himself at lunch time. It is likely, also, that the "space picnic" selections must be made with thought in mind as to what foods may actually be acceptable to the consumer when picnic time finally arrives. On a very long journey some sort of "grow-it-yourself kit" will have to be included for use after the picnic lunch has been consumed. Thus, while there may be no ants for the space traveler to cope with at picnic time, he will find himself faced with a multitude of unique new problems in their place.

Energy Needs

There is little doubt that good nutrition will be essential for maintaining the top physical performance of men living and working under the extreme environmental conditions found in space. Attention must be given not only to the correct quality and quantity of food for the astronaut, but also to the energy requirements which must be provided for the specific activities, and even during rest. The energy requirements for an "average" man are now rather well established, and daily calorie allowances have been set.

The National Research Council (43) recommends for a 25-year-old man, 175 cm. in height, weighing 70 kg., and living at 20° C., an allowance of 2900 kilocalories (kcal) per day. These energy requirements may be increased by a number of factors: an increase in body temperature; an increase in ambient temperature; an increase in body weight; an increase in physical activity; shivering; added clothing or footwear; and psychological stresses. A decrease in physical activity or body weight will cause a decrease in man's energy requirements (12).

The basal metabolism rate (BMR) is measured as the heat produced by an individual at complete rest, several hours after eating, and accounts for at least half of the daily energy requirement. The BMR is rather constant for a given individual, but to determine the exact caloric requirement of a space traveler, it may be necessary to study the individual during actual conditions of space flight. Consolazio (12), of the United States Army Medical Research and Nutrition Laboratory, Denver, Colorado, has suggested that these studies include: energy expenditure measurements, during weightlessness and while wearing pressurized suits; food intake and balance studies; and measurement of sweat rates.

It is not yet known how weightlessness will influence man's energy needs, but evidence presently available indicates that the influence of zero gravitational conditions will be minor, especially in regard to the basal metabolic rate. This consideration may not be particularly important, however, because reserve energy stored in the body can serve to compensate for minor differences in energy intake and output over extended periods (4). Calloway (8) has pointed out that if the caloric needs are overestimated by only 300 kcal per day, for a 4-man crew for one year, an unnecessary weight of 338 lbs. of dehydrated food must be included in the space vehicle.

While it may require less energy expenditure for movements of objects in a vertical plane, tasks normally assisted by gravity may be more difficult in the absence of gravitational force, and may require a higher energy cost. It may be, therefore, that energy gain will approximate energy loss (8).

Astronauts, on presently planned flights, will be mainly engaged in the performance of activities which are sedentary or involve only moderate physical activities. The energy requirements required for such tasks as scientific observation, monitoring and controlling flight, eating and communicating with earth, have been variously estimated to be from 2400 to 3000 kilocalories/day/man.

An estimate of the energy expenditure for various activities during space flight has been made by Calloway (8), and is shown in Table 1.

TABLE 1

ENERGY REQUIREMENTS FOR VARIOUS ACTIVITIES DURING SPACE FLIGHT (8)

ACTIVITY	TIME hr.	ENERGY EXPENDITURE Rate calories/min.	Total Performance calories
Sleep	7	1.2	504
Quiet sitting or standing	12	1.5	1080
Instrumentation	2	1.8	216
Complex neuromuscular tasks	2	2.6	312
Moderate work	1	7.0	420
Total			2532

Adams (1) has estimated the working metabolism at twice BMR under weightlessness, and three times BMR at 1 G. Lawton (31) has calculated that a 3000 kcal/day requirement at 1 G would be reduced to approximately 2360 kcal/day at 0 G. Consolazio (12) has estimated that astronauts on Apollo-type flights will probably spend about 33.5% of the day sleeping, 34% sitting, 28% lying down, and possibly 4.5% studying. The energy expenditure would thus be approximately 2200 kcal/day/man, under these conditions. Caloric allowances for Gemini flights were set at 2500 kcal/man/day, while allowances for the flight phases of the Apollo flights have been set at 2800 kcal.

The caloric requirements for a 150-lb. man belonging to a four-to-six-man crew of a Manned Orbiting Research Laboratory (MORL) have been studied by the Space Medicine Advisory Group (SPAMAG) (64). They are summarized in Table 2.

TABLE 2

CALORIC REQUIREMENTS FOR MANNED ORBITING RESEARCH LABORATORY CREW MEMBERS IN A SHIRTSLEEVE ENVIRONMENT

Suggested Time Schedule	Activity	kcal/hr
8 hrs.	Sleep	70
2 hrs.	Eating	1.5 × Basal
2 hrs.	Exercise	2.5 × Basal
4 hrs.	Rest and relaxation	1.5 × Basal
8 hrs.	Work program:	
	Flight control	2 × Basal
	Reconnaissance	2–2.5 × Basal
	Scientific observation	1.5–2.5 × Basal
	Repair	2–4 × Basal

After Vinograd (64)

Food Requirements

Attention must be given not only to the caloric requirements of man in space, but also to the composition of the fuel that will be provided. In what proportions should the major constituents of an adequate diet of carbohydrates, fats and proteins, be included? A series of experiments are underway at NASA's Ames Research Center, Moffett Field, California, to determine the influence of nutrition on performance. It is hoped that these studies will clarify the relationship between body metabolism and performance capabilities (70).

Although fat, for example, has a high energy yield well over twice that of carbohydrates, it requires additional supplies of oxygen for oxidation. For a given caloric requirement a diet high in fats still presents an overall weight saving. A limit for fat of half of the total calorie supply has been established for the Apollo mission. This would amount to 150 grams of fat/man/day.

It is possible that large amounts of protein may be desirable to provide greater amounts of nitrogen from which to regenerate more protein (23). Protein metabolism also results in end products which require water for their excretion. An allowance of 0.5 grams of high quality protein per kilogram of body weight per day has been suggested, but evidence is of course needed to determine whether this amount will maintain maximum efficiency over an extended period of time (22, 23).

Nutrition and Flight Duration

A logical progression from shorter flights to longer ones is planned by NASA. In the early Project Mercury flights food was not included. Food aboard U. S. flights in 1962, the longest of which was about 9½ hours, included high calorie blend cubes and puréed-tubed applesauce, peaches, beef and vegetables (41). Included aboard the 34½-hour flight of Major Gordon Cooper in 1963 were rehydrated foods and bite-size ready-to-eat foods (35).

On flights such as those in Project Gemini, with durations of 2–14 days, ample food storage was available. The Apollo lunar landing mission is also scheduled for seven to eight days' duration, with up to 18 hours allotted to high calorie demand exploration of the moon's surface. It has been suggested that flights of a few weeks or a month's duration be used for practical testing of recycling systems and equipment, even though adequate food and water could be taken from storage. Longer missions will necessitate dependable regeneration systems.

Ongoing research by members of the Life Support Section of NASA's Manned Spacecraft Center, Houston, Texas, indicates that water and calories are the nutritional requirements most likely to be affected by stresses during short-duration missions (up to 14 days) (30). Presently, available evidence indicates that lack of protein or amino acids will be of little importance during space missions of a few weeks duration, if adequate calories are provided (23).

Vitamin and Mineral Requirements

Consideration must be given to the allowances for the important electrolytes, sodium and chlorine in the circulation. The maintenance of water balance has been shown to be influenced by both high and low salt intakes (15). Excess sweating could account for sodium, calcium, potassium or iron losses which could be important on extended space flights.

Extended periods of weightlessness have been shown to result in loss of calcium from the skeleton. Experiments being conducted at Harvard School of Public Health, Boston, Massachusetts, seek to determine whether the feeding of fluorine might prevent or decrease calcium demineralization. Studies have indicated that isometric exercises may possibly help in preventing calcium loss (25). It has also been observed that emotional state can influence calcium utilization. The allowances of salts providing calcium, sodium, potassium and magnesium for Project Apollo have been set at about 10% above National Research Council recommendations (8).

A joint NASA–U.S. Air Force study is underway at Johns Hopkins University, Baltimore, Maryland. This study, under the direction of Dr. Bacon Chow, is concerned with the effects of various environmental conditions on absorption and metabolism of minerals on cellular metabolic processes relative to iron, zinc, and magnesium absorption and metabolism (65).

Mineral and vitamin recommendations for the Manned Orbiting Research Laboratory presently include: calcium, 0.8 g/day; phosphate, 1.2–1.5 g/day; sodium as NaCl, 4.5–5 g/day with extra allowances for those not acclimatized; vitamin D, 1000 units/day; other vitamins, NAS–NRC minimum daily requirements; minerals, trace mineral supplements if natural foods are not used (64). Present evidence indicates a possible need for higher than normal amount of ascorbic acid, thiamine, and vitamin E during extended space flights (15).

Water Requirements

The most critical physiological need next to oxygen is for water. Man can survive for only a few days without water; with water and oxygen man can survive for weeks. The water supply problem in space is somewhat simplified because water is not chemically altered by the body, and is an end product of metabolism, and of some types of fuel cells. Losses from the body can also be recovered (22).

Johnson (26) recommends a minimum of 2 liters of water/man/day during space missions, with provision for additional amounts if needed. SPAMAG recommendations for the MORL water needs are presently set at 2.5 liters/day (one ml/calorie of food). An absolute minimum of 1.5 liters is recommended (64).

Of the 2–3 liters of water/day lost by man, 1–1.5 liters may be lost in the urine; 100 ml/day in the feces; 900–1100 ml/day through evaporation from skin and lungs (26, 27). Our early manned orbital space flights have shown the speed with which the deleterious effects of a water deficiency can be manifested. Astronauts have lost up to 3 kg of body weight in less than one day, in spite of the fact that over a liter of water was ingested during the flight. Van Reen (63), and others, have pointed out the need for a method to monitor an astronaut's water balance inasmuch as thirst alone does not appear to be a very reliable indicator of water input needs.

Two current NASA research tasks involve water metabolism studies. At Stanford Research Institute, Palo Alto, California, the task objective is to develop and understand certain characteristics and functions of the gastrointestinal tract, with regard to water metabolism. Under the direction of Dr. Doris H. Calloway at the University of California, investigations on the effect of diet and physical activity on water metabolism are also being conducted. A study at the NASA Ames Research Center deals with the mechanisms of voluntary dehydration and water metabolism (65).

The problem of determining whether an astronaut is dehydrating has not been solved. A system which measures the astronaut's mass by determining the rate and extent of oscillations, while lying on a spring-mounted couch, may permit the detection of water balance changes (49).

Food Preparation, Packaging and Storage

Foods taken into space must be highly nutritious, but at the same time they must be lightweight, palatable, acceptable to the astronaut, and meet rigorous requirements for storage and use. Entire new concepts in food preparation, handling, packaging and storage are being developed to meet these challenges in food technology.

For the relatively short-duration flights of the Gemini and Apollo missions, menu items will consist of pre-cooked, freeze-dehydrated foods packaged in zero-G feeders. These freeze-dehydrated foods are prepared by placing pre-cooked frozen foods in vacuum chambers to cause water to be removed by sublimation (42). Freeze dehydration (also called freeze drying) provides an excellent method of preserving food without requiring refrigeration.

During the first space flights, semi-solid and liquid foods were packaged in flexible aluminum tubes. The weight of the aluminum in proportion to the weight of the food was judged to be much too great (59). Transparent feeding tubes composed of layers of laminated plastic films are currently in use to protect the food from water vapor and oxygen invasion, flavor loss, and spoilage (35, 42) (Fig. 1).

The flexible food feeder tube allows foods to be squeezed directly into the mouth without any loss of the contents, while under zero gravity conditions. It also allows for the rehydration of the food by means of a water dispenser which can be inserted into the feeder. A nozzle on the end of a pressurized water tank is placed in the food tube to introduce a measured amount of water (41). In Gemini, the fuel-cell-produced water to be used for rehydration was at cabin temperature (80° to 100° F.), but during Apollo flights

FIGURE 1. *Plastic squeeze bag with dehydrated food being tested. Wright-Patterson Air Force Base, Dayton, Ohio.*

water with a temperature of either 50° F. or 155° F. will be available. This will permit greater variety and acceptability of menu items. Special gravies that rehydrate with 80° F. water will no longer need to be used (24). Under contract to NASA for the development of a feeding system for use in extended space-station-type missions, the Whirlpool Corporation, St. Joseph, Michigan, developed the following program: An astronaut removes a coded, dehydrated man-meal pack from a food storage rack, rehydrates the food, eats, and discards disposable items in the crew-day supply container canister of the previous day. A food console, located in a bank of food storage canisters, combines the food preparation and eating areas (54).

Psychological Aspects of Space Nutrition

Lepskovsky (32) has reminded us of two aspects of nutrition, which were learned in World War II: First, that "Food is not food until eaten," referring to the fact that it requires more than appetite alone to insure the ingestion of food, and that the nutritional value of a food may be totally unrelated to its acceptability. Second, that the opinion of many soldiers in regard to mush-type "K" rations was that "We could undoubtedly survive on these rations a lot longer than we'd care to live."

Research on food acceptability must now be included in planning for the nutrition of man in space. Psychologically, the questions of what the astronaut will want to eat may be as important as what he should eat. Brobeck (4), and others, have urged that diets for space flights be similar to regular diets, rather than being composed of synthetic foods.

In addition to supplying essential nutrients, foods may be a major source of sensory stimuli to a space traveler (32). Such properties of food as texture, flavor, color, sight and odor may be very important on long space flights. In the results of a study to develop concepts for packaging space meals, researchers have emphasized the psychological importance of supplying astronauts with foods which will retain their earthly identity (13).

It has been suggested that if crew members were allowed to take part in the selection of foods for space missions, dissatisfaction and monotony are less likely to appear (9, 52). Brobeck (4) has recommended the selection of men who are in the habit of eating what can be provided, and has pointed out the need for research on the impact of food upon behavior.

The flatulence production of foods must also become a consideration in preparing space menus. In a closed space capsule the ejection of large quantities of flatus is undesirable, both from the standpoint of cabin atmosphere contamination, and because of the noxious olfactory properties of flatus (7, 38).

A six-week experiment to determine whether appearances of foods are important, and whether unfamiliar foods are more or less monotonous on long space journeys, was carried out in 1965 by Dr. Doris H. Calloway and Dr. Sheldon Margen, at the University of California, Berkeley. Another experiment at Wright-Patterson Air Force Base, Ohio, tested freeze-dehydrated and liquid formula diets over a six-week period (60). No consistent psychological, physiological, psychomotor, or social functions of the subjects were found during a 28-day confinement study in which the participants were restricted to dehydrated "space rations" (57). A number of additional experiments which will test food formulas for long distance space travelers are being planned.

Food Replenishment in Space

Providing nourishment sources for long-term flights lasting months or years presents a formidable challenge. Although the chemical synthesis from waste of all needed foods has been suggested, it is biological recycling which has received the most attention from the scientific community. The possibilities and limitations of various potential regenerative methods are currently being explored.

The photosynthetic process is the basis for a number of these regenerative systems. A great deal of attention has in recent years been focused on the use of algae in closed or semi-closed ecological systems. This is in part due to the fact that algae contain more protein, less cellulose and are easier to manage than higher plants (39).

The alga most thoroughly studied, *Chlorella pyrenoidosa*, has been carefully analyzed and found to be rich in carbohydrates, proteins, fat and several vitamins (20, 28, 33, 58). Other species of *Chlorella*, as well as other genera of algae, are currently being examined as to their nutritional capabilities and ability to match given engineering specifications (17, 29, 34). Several techniques, including freeze-dehydration and enzymatic hydrolysis of the cell wall, are being employed to increase the availability of these nutrients (3, 11). A great number of questions remain as yet unanswered concerning the use of algae as a long-term nourishment source (34, 44, 50).

The duckweed, *Spirodela polyrrhiza*, has also been considered to be a desirable component of a closed ecological system (66). It, like algae, is unsatisfactory as a sole source of food when supplied in the dry state. It is fairly rich in nitrogen and indication is that with proper supplementation, it may be a usable food source (68). Several problems associated with the use of *Spirodela* as a long-term flight nourishment source remain unanswered as yet (6).

An increasing amount of research is being directed toward the nutritional potentialities of chemosynthetic life support systems which utilize bacteria, such as *Hydrogenomonas eutropha*. The utilization of the synthetic metabolism of *Hydrogenomonas* to reduce CO_2 to cellular material is under study. It is its potential use in biological regenerative systems (in which it combines hydrogen from the electrolysis of water with carbon dioxide from the astronaut) that has prompted much of the *Hydrogenomonas* research thus far (25). Dr. Doris H. Calloway at the University of California, Berkeley, is carrying out nutritional studies with *Hydrogenomonas*, feeding the bacteria to animals and humans.

Systems for the continuous culture of cells of higher plants are now being devised and tested. Tissue cultures of rose, corn, tomato, ginkgo, and others have been maintained and used in nutrition experiments. The use of plant tissue cultures as food sources in long-term space flights is as yet highly speculative (2, 61, 62).

Interesting speculations have been made by several authors on the use of animals as food during space voyages (6, 7, 46). A number of intermediate animal stages have been variously proposed for space ecological systems. Among these have been listed such biological converters as water fleas, fresh water shrimp, snails, fish, mice, rats, rabbits and goats. It soon becomes obvious that these added organisms produce enormous complications for design of an ecological system for space travel. This matter is complicated without even considering the question of the influence of mouse stew instead of beefsteak upon the morale of a space traveler (46).

The use of high energy nonfat nutrient sources is currently being examined. One of these unusual dietary compounds is 1,3-butanediol (known as BD). Both BD and 2,4-dimethyl-heptanoic acid (DMHA) are undergoing tests in an attempt to gain more information about the processes of energy metabolism, so that more useful compounds may be designed and synthesized (36, 37).

A most interesting way of reducing the weight penalty of the food requirement in space is to distribute the weight cost among several physiological and engineering requirements. The possibilities of using food as radiation shielding, as a heat shield, as containers, or as clothing, may be considered in the future (69).

Many other investigations in the field of food replenishment in space are being carried out. These include studies in the use of chemically defined liquid and nonliquid synthetic diets (formula diets) (56); reduction of metabolism, through induced hibernation, hypothermia, estivation or thyroid suppressing drugs; and water generation on the moon and other planets.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

1. *Laboratory Testing of Representative Freeze-dried Foods.* Most students would be very interested in trying an actual sample of freeze-dehydrated food of the type in use on current space flights. Freeze-dehydrated foods are now available at many camping supply and sporting goods stores. A rather large number of inexpensive astronaut food items have recently been made available to the public by Epicure Foods, Inc., 480 U.S. Route 46, South Hackensack, New Jersey, 07606. Most of these products come in various bar sizes.

"Space Foods" available from Epicure Foods, Inc.

	wt./can
Applesauce Powder	1.5 oz
Mushroom Soup Powder	1.7 oz
Pea Soup Powder	1.7 oz
Fruit Cocktail Bar	1.0 oz
Shrimp Cocktail Bar	0.8 oz
Beef Bites	0.5 oz
Beef Pot Roast Bar	1.0 oz
Chicken & Vegetable Bar	0.7 oz
Chicken Bites	0.7 oz
Spaghetti & Sauce Bar	0.6 oz
Peach Bar	0.7 oz
Corn Bar	0.8 oz
Pea Bar	0.5 oz
Peanut Butter Sandwich Bites	1.0 oz
Toast Bites	0.5 oz
Brownie Bites	1.0 oz
Banana Pudding Powder	2.5 oz
Chocolate Pudding Powder	2.5 oz
Butterscotch Pudding Powder	2.5 oz
Corn Flake Mix	1.3 oz
Tea-Beverage	4.0 oz
Cocoa Beverage Powder	1.5 oz
Orange Beverage Powder	4.0 oz
Pineapple Beverage Powder	1.0 oz
Potato Salad Bar	0.8 oz

Prices vary from 75 cents per can for most items to $1.50 and $2.00 for those containing meat. Each can usually provides one astronaut serving. Other space items are also available, on request, as is a current price list.

A second type of dehydrated foods, not currently in the menu of any space program, but processed in a manner similar to astronaut foods, is also available. One-half pint jars of: apple bites; asparagus bites; banana bites; blackberries; boysenberries; melon balls; cauliflower bites; peach bites; pepper bites; pineapple bites; and strawberries are available, in any desired assortment of a dozen jars, from Epicure Foods, Inc.

A third, more advanced development provides a dehydrated, compressed food that not only retains its quality, but occupies considerably less storage space. This type of item is freeze dehydrated, and in addition, compressed into a wafer of considerably less volume than the original. This new technique has not yet been applied to space food, but it is anticipated that it will be in future programs. Small cans containing three wafers of compressed peas, spinach or shrimp are available from Epicure Foods, Inc.

Several uses might be made of these freeze-dehydrated "space foods" in introducing students to the subject of nutrition in space. A sample of a dehydrated food item might be given to each student and the student told to prepare (rehydrate) and eat the sample. He could then be asked to comment on his reactions to the food, its palatability, fragility, flavor, etc. He also might be asked to consider what difficulties would be presented by having to consume this food at zero gravity and asked what he thinks would have to be done to overcome these difficulties.

Since these freeze dehydrated items are prepared according to the latest procedures recommended for astronaut food, they can be used to acquaint students with problems associated with space feeding. Some of these foods are of the type designed to be eaten as they come from the container while others require rehydration.

The rehydration procedure used by astronauts may be simulated by placing the food items in small polyethylene sandwich bags. (Each item in the "Space Food" cans comes in a small polyethylene bag but it is not large enough for convenient rehydration.) The open end of the bag should be sealed, except for a ½-inch opening, which allows water to be added, and rehydrated food to be squeezed into the mouth.

Student volunteers might wish to follow a complete diet of freeze-dehydrated space meals for a week or longer. If the volunteers weigh themselves at the beginning of the space food diet and again at its conclusion, useful data may be obtained. The volunteers might try to determine if a freeze-dehydrated diet produces a weight loss, by careful weighing at the beginning and end of the dietary regime. Many variables are involved in an experiment of this type: the sensitivity and standardization of the weighing procedure; the amount and type of psychological activity engaged in by the volunteer; the amount of liquid consumed, active rate of subject, etc. The student should be aware of these variables as he evaluates the data.

A number of other possibilities for experimental studies using "space foods" may occur to the teacher or student. For example, each "home-cooked" meal may be weighed for a week and compared with the weights of the freeze-dehydrated meals fed another subject. This could be correlated with weight loss or gain by the volunteers. The caloric values of the students usual diet may be calculated and compared with that of the space foods diet. Chemical determination of the percentage of protein or other nutrients in the space food item may be compared with that of a non-dehydrated item.

A study to test the effects of repetitive eating of limited groups of food items on food acceptance might be undertaken. "Space foods" might be used to determine the acceptability of freeze-dehydrated items during confinement (52, 57).

Gemini flight crew members were provided with four meals each day, planned so that the same menu will be repeated after four days. Table 3 shows two proposed menus for Project Gemini missions.

TABLE 3 **SOME TYPICAL PROJECT GEMINI MENUS (35, 41)**

Days	Meal A	Meal B	Meal C	Meal D
1-5-9-13	Sugar frosted flakes Sausage patties Toast squares Orange-grapefruit j[illegible]	Tuna salad Cheese sandwiches Apricot pudding Grape juice	Beef pot roast Green peas Toasted bread cubes Pineapple cubes Tea	Potato soup Chicken bites Toast squares Applesauce Brownies Grapefruit juice
2-6-10-14	Strawberry cereal cubes Bacon squares Peanut butter sandwiches Orange juice	Corn chowder Beef sandwiches Gingerbread cubes Cocoa	Shrimp cocktail Chicken and vegetables Toast squares Butterscotch pudding Apple juice	Beef with vegetables Spaghetti and meat sauce Toast squares Fruit cake (date) Tea

Other menus were followed for Days 3-7-11 and 4-8-12.

2. A variety of problems dealing with algae cultures may be investigated by individual students. An outline of instructions for growing small cultures of algae was prepared by the Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, University of California, Berkeley (18).

Instructions for Growing Small Cultures of Algae

A. **Prepare an Inoculum:** An inoculum may be obtained in one of three ways:

1. Mail a request to the Botany Department of your state university asking for a culture of either *Chlorella* or *Scenedesmus*.
2. Locate a stagnant pool which is green. Use about a pint of the green liquid as an inoculum.
3. Place a small amount of organic matter (garden soil or dried grass, or similar material) in a liter or two of water to which has been added 0.3 gram of urea. This mixture should be placed in a window and allowed to remain undisturbed until the culture becomes green (approximately 2 weeks).

B. When the inoculum is ready, add it to one of the following media (approximately 100 ml to 1 liter of medium):

1. *Inorganic:* To a liter of tap water add:
   a. 1 gram KNO_3 (or 0.3 gram urea); 0.25 gram $MgSO_4 \cdot 7H_2O$; 0.25 gram KH_2PO_4.
   b. Prepare a stock solution of the following compounds by adding to 1 liter of distilled water: H_3BO_3 – 2.86 grams; $MnCl_2 \cdot 4H_2O$ –1.810 gram; $ZnSO_4 \cdot 7H_2O$ – 0.222 gram; $CuSO_4 \cdot 5H_2O$ – 0.079 gram; MoO_3 – 0.015 gram; $Ca(NO_3)_2 \cdot 4H_2O$ – 59 grams; $CoCl_2 \cdot 6H_2O$ – 0.04 gram. Add 1 ml of this stock solution to solution a.
   c. Also prepare a second stock solution by adding to 1 liter of water, ferric citrate – 5.3 grams; citric acid – 5.3 grams. Also add 1 ml of this stock solution to solution a.

2. *Organic:*
   a. Sewage: To 1 liter of sewage (obtained from your local sewage treatment plant) add 0.3 gram of urea (ammonium phosphate may be substituted for the urea).
   b. Other wastes (ex. chicken manure, packing plant, etc.): such wastes should be highly diluted. The degree of dilution can be learned by experimentation.
   c. The inoculated medium should be allowed to remain undisturbed for four or five days until the mixture turns green.
   d. When the culture is green, mix it thoroughly each day and then remove ¼ to ⅓ of the culture contents and replace with an equal amount of diluted wastes.
   e. Algal cultures may be grown in any of the following containers:
      1) 250 ml to 2 liter Erlenmeyer flasks;
      2) 5 gallon glass carboy;
      3) A miniature outdoor pond made by lining a wooden box with polyethylene sheeting, so installed as to prevent leakage.

f. Harvesting algae: One of three methods may be used:

1) Centrifugation: If you have access to a laboratory centrifuge, centrifuge the algae at approximately 2000 r.p.m. for 10 minutes. Decant the supernatant and remove the green paste. The paste should be spread as a thin sheet (1/8-inch thick) on an aluminum plate (such as a cookie tin) and exposed to moderate heat (80° C) until dry.
2) Flocculation with alum: Add 1% H_2SO_4 to the culture until blue litmus paper begins to turn red. Then add 100 mg of aluminum sulfate to 1 liter of culture. Stir gently, rotating the paddle in one direction only, for 3 minutes. Allow the flocculated material to settle for 1 hour. Then, carefully remove the clear liquid without disturbing the settled floc. The settled floc is then dewatered as follows: Make a box (6" × 6" × 8" deep, or larger if necessary) and fill it with coarse sand to a level 2" from the top. Cover the sand with one layer of blotting paper. Pour the settled floc on top of the paper, and allow to stand for 8 to 12 hours or overnight. The resulting green cake is removed, washed several times to remove the alum and dried as with centrifuged algae.
3) Flocculation with lime: Follow the same procedure as outlined for alum, except: (1) no acid is added; and (2) lime $Ca(OH)_2$ is used instead of aluminum sulfate. The lime must not have been exposed to air; therefore, it should be fresh and should have been stored in a glass bottle tightly stoppered. (3) Litmus paper is not used.

g. The dried algae may be fed to mice, chicks or other small animals.

Important:

1. After working with sewerage or other wastes, care should be taken to wash one's hands thoroughly with soap and water.
2. Do not use algae which have been grown on sewage or other wastes for human consumption, at least not until they have been cooked or heated to a temperature of 110° C for 20 minutes.
3. Before using any algae for human consumption, feed some to a mouse. Some algae (blue-green) are poisonous.

A number of devices for the continuous culture of algae have been devised. Most of these are very sophisticated in design, and would be too expensive for students to build (10). The "Microterella," described in the Gas Exchange and Waste Management section of this syllabus, can be built rather inexpensively, however. The "Microterella" (and the "Algatron," which takes advantage of the superior light utilization made possible by spinning the culture as a thin vertical sheet inside the chamber walls) has been used successfully in continuous algal growth experiments at the University of California, Berkeley (19, 21, 45).

A Plexiglas gas exchanger containing fluorescent lamps inside of plastic tubes was built as a part of a study by Future Scientists of America winner, Paul Daubitz, Jr. *Chlorella* was harvested from the culture in the exchanger and fed in dry and paste form to mice (14).

Students may be interested in making comparisons of the protein content of different species of algae. Science Achievement Award winner, James Geil, grew pure cultures of algae on a solid medium in flasks which were placed in an illuminated incubator. Analysis of the dried algae was made by the Kjeldahl method: (a) the sample was oxidized and protein nitrogen converted into ammonium sulfate, (b) the ammonium sulfate was decomposed with strong alkali, steam distilled and the ammonia evolved into standard acid, (c) the standard acid was titrated with standard base and (d) the calculation of the percentage of protein in the sample was determined from its weight and the volume of standard acid neutralized by the ammonia distilled (51).

Rats or mice can be fed diets of algae, as a food supplement or in pure form, and then compared for signs of diet deficiency (55).

3. Student research on plant growth in tissue culture could be useful both in the interest of biosatellite applications, and in possible future long term space mission applications. Even though tissue culture must be done under sterile conditions, the technique is fairly easy to master and is useful for studying nutritional requirements (48). Various types of tissues can be used. Seeds may be allowed to produce stem tissues or root tissues. Small pieces of leaf may be cultured, also. By using a medium containing small amounts of an auxin and small pieces of stem tissues, growth of undifferentiated tissue (calluses) will result (47).

Tissue cultures can be used as food supplements for animals such as weanling mice. The protein content of young tissue can be compared to that of older tissues. Sterile tissues can be compared with bacterial contaminated tissues to find out which is a better food supplement.

A variety of plant tissues have been suggested as suitable for tissue culture experiments. These include rose stem, tomato stem, corn endosperm, carrot root, ginkgo pollen, potato tuber, rhubarb stem, sunflower stem, tobacco stem, and bean stem (25, 62). Tobacco stems have been grown in callus-producing culture medium rotated constantly in a clinostat (2). A higher protein level has been found for tissue grown in continuous culture compared to tissues grown in flasks (62). Several *Arabidopsis* plants will be grown in a chamber containing a sterile solidified nutrient medium on the 21-day biosatellite flight.

Additional Suggestions for Experiments Related to Space Nutrition

1. The problems involved in packaging of foods for space flight may suggest ideas for student research (13). What methods of food preservation and packaging are the most efficient (5, 13, 53)? Food containers must provide water vapor and oxygen barriers, and must be puncture resistant, heat sealable, transparent, flexible and have a minimum of bulk and weight (35).

2. Tests with germicides added to food containers containing waste food or drink might be made (35, 42).

3. Chromatography can be used to investigate any changes in the feces of a rat or mouse, as diets are altered.

4. The effect of heat or cold on the metabolic rates or motor activities of small animals might be studied.

5. A study of the chemical analysis of sweat could be made (chlorides, lactic acid, etc.).

6. Long-term effects of low residue diets on small mammals could be investigated.

7. What is the effect of a "space diet" on the normal intestinal microflora of an organism?

8. How do the growth rates of algae compare when cultured in various media?

9. An analysis of water loss from the body could be made, possibly by placing a watertight bag over the arm and hand measuring the respiration from the skin. Gases might be allowed to flow through and the flow rates used to determine the respiratory quotient. Temperature rise might also be considered as it would relate to conditions produced inside space suits.

10. The routes of nutrient loss from the body involve not only analysis of water loss from the body, but even a study of hair, beard and fingernail clippings. These might be carefully weighed, studied and possibly analyzed.

11. A difficult but interesting investigation would involve trying to find out what forms of various elements (like potassium)

occur in natural food products that make foods taste so differently from ordinary salts, and also why this is different at different pH levels.

12. Could "beefsteak" be grown in tissue culture?

13. The influence of the diet on the normal microflora of the digestive system could be studied. This might involve identification and classification of microbes. Would the use of antibiotics or other chemicals change the microflora? Invertebrate organisms or vertebrates might have a culture implanted in the digestive system, after its normal microflora composition had been changed. Could the microflora of the student himself be modified without harm to the student—large amounts of yogurt, for instance?

14. Mature students might eat a high vegetable diet, collect the feces, and try to find out why the residue was greater.

LITERATURE CITED

1. Ammann, Elizabeth C. B. and Lawrence L. Reed. 1967. Metabolism of nitrogen compounds by *Hydrogenomonas eutropha*. I. Utilization of uric acid, allantoin, hippuric acid, and creatinine. Biochimica et Biophysica Acta 141(1):135–143.

2. Ball, Ernest A. 1964. Growth of a plant tissue culture in the gravity-free state. Semiannual Status Report, 1 Oct. 1963–31 Mar. 1964. North Carolina University, Durham.

3. Becker, Milton J., and Alan M. Shefner. 1963. Research on the chemical composition and digestibility of algal cell walls. Technical Documentary Report No. 63–115. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

4. Brobeck, John R. 1964. Food requirements in space, p. 134–151. *In* James D. Hardy (Ed.), Physiological problems in space exploration. Charles C Thomas, Publisher, Springfield, Illinois.

5. Brown, D. L., and V. K. Viitanen. 1961. Plastic packaging for heat-processed and frozen foods. Aeronautical Systems Divi-

sion Technical Report No. 61–551. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

6. Caidin, Martin. 1965. The greatest challenge. E. P. Dutton and Co., Inc., New York.

7. Calloway, Doris H. 1964a. Flatus, p. 261–263. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

8. Calloway, Doris H. 1964b. Nutritional aspects of gastronautics. Journal of the American Dietetic Association 44:347–352.

9. Calloway, Doris H., John J. P. Bosley, and Orr E. Reynolds. 1962. The emergence of a new technology. American Scientist 50:362–368.

10. Clamann, Hans G. 1962. Soil-less gardening on the Moon, p. 369–384. *In* Lectures in aerospace medicine. School of Aerospace Medicine, Aerospace Medical Division, Brooks Air Force Base, Texas.

11. Conrad, H. M., and S. P. Johnson. 1965. Problems associated with the utilization of algae for food. Activities Report 18:79–85.

12. Consolazio, C. Frank. 1964. Caloric requirements of long flights, p. 111–129. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

13. Crawford, D. C., D. L. Brown, and V. K. Viitanen. 1962. Plastic packaging for space feeding of heat-processed and frozen foods. Technical Documentary Report No. 62–43. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

14. Culturing green algae in closed environmental system. Science World. (Ed. 2) 11(7):21–23.

15. Engel, R. W. 1964. Mineral and vitamin requirements of long flights, p. 147–153. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

16. Goldman, Charles R. 1964. Plant systems in long term flight nourishment sources, p. 311–315. *In* Conference on nutrition in space and related waste problems. Special Publication No.

70. National Aeronautics and Space Administration, Washington, D. C.

17. Golueke, Clarence G. 1960. The ecology of the community consisting of algae and bacteria. Ecology 41:65–73.

18. Golueke, Clarence G. 1965. Instructions for growing small cultures of algae. Mimeographed publication. Sanitary Engineering and School of Public Health, University of California, Berkeley, California.

19. Golueke, Clarence G., J. W. Brewer, H. K. Gee, and W. J. Oswald. 1963. Microbiological waste conversion in control of isolated environments. Third Annual Report. Air Force Cambridge Research Laboratories Report No. 63–469. Office of Aerospace Research, U. S. Air Force, Bedford, Massachusetts.

20 Golueke, Clarence G., and William J. Oswald. 1963. Closing an ecological system consisting of a mammal, algae and nonphotosynthetic microorganisms. American Biology Teacher 25:522–529.

21. Golueke, Clarence G., W. J. Oswald, and H. K. Gee. 1964. A study of fundamental factors pertinent to microbial waste conversion in control of isolated environments. First Technical Report. Air Force Cambridge Research Laboratories Report No. 64–341. Office of Aerospace Research, United States Air Force, Bedford, Massachusetts.

22. Harper, Alfred E. 1964. Proteins in space nutrition. p. 143–145. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

23. Hegsted, D. M. 1964. Proteins in space nutrition, p. 135–141. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

24. Hollender, Herbert A. 1964. Preparation, handling and storage of foods for present space projects, p. 65–69. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D.C.

25. Jenkins, Dale W. 1964. Nutrition and related studies in the Office of Space Science and Applications, NASA, p. 23–27. *In* Conference on nutrition in space and related waste problems.

Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

26. Johnson, Robert E. 1964. Human nutritional requirements for water in long space flights, p. 159–169. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

27. Kleiber, Max. 1964. Animal food for astronauts, p. 299–302. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

28. Konikoff, J. J. 1961. Engineering evaluation of algae for manned space flight. Space Sciences Laboratory, Reprint No. 80. General Electric Space Science Laboratory, King of Prussia, Pennsylvania.

29. Krauss, Robert W. 1964. Combined photosynthetic regenerative systems, p. 289–297. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

30. Lachance, Paul A. 1964. Nutrition and stresses of short term space flight, p. 71–78. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

31. Lawton, R. W. 1960. Food reserves on space trips: A review of metabolic and nutritional requirements. Technical information Series R60SD400. General Electric Co., Missile and Space Vehicle Dept., Philadelphia.

32. Lepkovsky, Samuel. 1964. The appetite factor, p. 191–194. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

33. Lubitz, Joseph A. 1963. Growth and toxicity studies on rats fed *Chlorella* 71105, p. 245–259. *In* Geoffrey H. Bourne (Ed.), Medical and biological problems of space flight. Academic Press, New York.

34. McDowell, Marion E., and Gilbert A. Leveille. 1964. Algae systems, p. 317–322. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

35. Michel, Edward L. 1964. Preparation, handling and storage of foods for present space projects, p. 57–63. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D.C.

36. Miller, Sanford A. 1964. High energy nonfat nutrient sources, p. 343–351. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

37. Miller, Sanford A., H. A. Dymsza, S. R. Tannenbaum, and S. A. Goldblith. 1965. Metabolic studies of energy dense compounds for aerospace nutrition. Aerospace Medical Research Laboratories Technical Report No. 64–121. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

38. Murphy, Edwin L. 1964. Flatus, p. 255–259. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

39. Myers, Jack E. 1964. Combined photosynthetic regenerative systems, p. 283–287. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

40. Nanz, Robert A. 1963. Food in flight. Fact Sheet No. 182. Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas.

41. National Aeronautics and Space Administration. 1965. Nutrition in space: Project Gemini Educational Brief No. 1002. Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas.

42. National Aeronautics and Space Administration. 1965. Foods for use in space. Educational Brief No. 1003. Manned Spacecraft Center, National Aeronautics and Space Administration, Houston, Texas.

43. National Research Council. 1963. Recommended dietary allowances. Sixth revised edition. Publication No. 1146. Food and Nutrition Board, National Academy of Sciences-National Research Council, Washington, D. C.

44. Odum, Howard T. 1963. Limits of remote ecosystems containing man. American Biology Teacher 25:429–443.

45. Oswald, W. J., C. G. Golueke, H. K. Gee, and R. C. Cooper. 1961. Microbiological waste conversion in control of isolated environments. First Annual Report. Air Force Cambridge

Research Laboratories, Air Force Research Division, Bedford, Massachusetts.

46. Pearson, A. M. 1964. Animal food for astronauts, p. 303–304. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

47. Plant hormones in tissue culture. 1962. Science and Math Weekly 2(16):190.

48. Plant tissue culture. 1962. Science and Math Weekly 2(13): 154.

49. Pollack, Herbert. 1964. Handling and storage of food for long flights, p. 93–95. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D.C.

50. Prince, A. E., Paul A. Lachance, and W. D. Gray. 1962. Biologistics for space systems symposium. Technical Documentary Report No. 62–116. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

51. Protein content in green algae. 1959. Science World 6(3): 21–23.

52. Quartermaster Food and Container Institute for the Armed Forces. 1960. Effects of repetitive eating of limited groups of food. Technical Report No. 60–750. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

53. Reddy, Robert E., and Eugene B. Zwick. 1963. Method of preserving frozen food during an aerospace mission. Technical Documentary Report No. 63–31. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

54. Roth, Norman G., and John J. Symons. 1964. Handling and storage of food for long flights, p. 85–91. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

55. Schuele, Edith K. 1962. Algae, food of the future, p. 154–159. *In* Judith Viorst, Projects: Space. Washington Square Press, New York.

56. Scrimshaw, Nevin S., Robert E. Johnson, and Charles S. Davisson. 1964. Panel discussion (on formula diets), p. 367–370. *In* Conference on nutrition in space and related waste

problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

57. Senter, R. J. 1963. Research on the acceptability of precooked dehydrated foods during confinement. Technical Documentary Report No. 63–9. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

58. Taub, Frieda B. 1963. Some ecological aspects of space biology. American Biology Teacher 25:412–421.

59. Taylor, Albert A., Beatrice Finkelstein, and Robert E. Hays. 1960. Food for space travel. Space travel: An examination of current capabilities and future needs. Technical Report No. 60–8. Air Research and Development Command, Andrews Air Force Base, Washington, D. C.

60. Testing nutrition for space. 1964. Today's Health 42(11):6–7.

61. Tulecke, Walter. 1963. Research on tissue cultures of higher plants. Technical Report No. 63–124. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

62. Tulecke, Walter. 1965. Growth of tissues of higher plants in continuous liquid culture and their use in a nutritional experiment. Technical Report No. 65–101. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

63. Van Reen, Robert. 1964. Human nutritional requirements for water in long space flights, p. 171–174. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington D. C.

64. Vinograd, S. P. 1964. Nutritional trends in future manned space flights, p. 17–21. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

65. Voris, Frank B. 1964. Nutrition and related studies in the Office of Advanced Research and Technology. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70, p. 13–15. National Aeronautics and Space Administration, Washington, D. C.

66. Ward, C. H., S. S. Wilks, and H. L. Craft. 1963. Use of algae and other plants in the development of life support systems. American Biology Teacher 25:512–521.

67. Welch, B. E. 1963. Ecological systems, p. 309–334. *In* J. H. U. Brown (Ed.), Physiology of man in space. Academic Press, New York.

68. Wilks, Syrrel S. 1964. Plant systems as long term flight nourishment sources, p. 305–310. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

69. Worf, D. L. 1964. Multiple uses for foods, p. 363–365. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

70. Young, Donald R. 1964. Study of effects of carbohydrates on the body under stress and fatigue, p. 323–328. *In* Conference on nutrition in space and related waste problems. Special Publication No. 70. National Aeronautics and Space Administration, Washington, D. C.

section 1

LIFE SUPPORT

GAS EXCHANGE AND WASTE MANAGEMENT

One of the most critical problems in manned space flight extending beyond thirty days concerns the supply of oxygen and the reclamation of vital elements from the body's waste products. An analogous situation is found on earth. The level of carbon dioxide in the atmosphere may have increased to a point where it is possibly altering the heat balance of the earth (greenhouse effect). In a two- or three-man space cabin the problem of contamination is essentially the same, but it may reach fatal proportions in a very few minutes unless efficient and unfailing controls are provided.

On earth many forces and processes, including photosynthesis, bacterial action, weathering, and a tremendous energy input from the sun, combine to restore and rejuvenate the land, water and air for repeated cyclic use. The elements present on earth when life began and those present today must be of the same mass, although a small amount of the lighter gases able to escape the gravitational pull may have diffused into space. Our world has thus remained essentially closed, except for energy input, since its origin. The space cabin must be an attempt to duplicate this world. This would not be difficult if it were not for the severe weight and power limitations of our craft. Every pound of matter thrust into space at escape velocity requires the expenditure of 2.38×10^7 joules of energy. This is equivalent to burning eighty 100 watt electrical bulbs for 1 hour. A 1-ton satellite would increase this by a factor of 2,000, or the equivalent of burning 160,000 bulbs per hour.

Numerous experimenters have tried to create a truly closed world large enough to contain only a single small mouse; to date no such system has been maintained for extended periods (4). A large enough culture of *Chlorella pyrenoidosa*, supplied with sufficient food and radiant energy, with careful harvesting, will easily supply the oxygen required by an animal the size of man. A bacterial or viral invader, or some of the metabolic waste products such as carbon monoxide, may kill the culture at any moment. This would indeed be disastrous on a space voyage with no green pond handy to seek a new, fresh culture. A diligent search has been made for a culture suitable for animal food. The very bulk of the algae which must be eaten to supply the animal's needs is irritating to the colon. The weight of the culture presents problems also. The eventual solution may involve feeding the algae to a small animal suitable as food for man—perhaps, as one scientist has quipped, "mouse steaks."

Hydrogenomonas eutropha (bacteria) is being considered as a component of a bioregenerative life support system to sustain man in space for long periods of time. The organism would be used to reduce CO_2 to cell material and to return a portion of man's other waste products to the enclosed cycle. Dr. Elizabeth B. Ammann and Dr. Lawrence L. Reed at Lockheed Missiles and Space Company

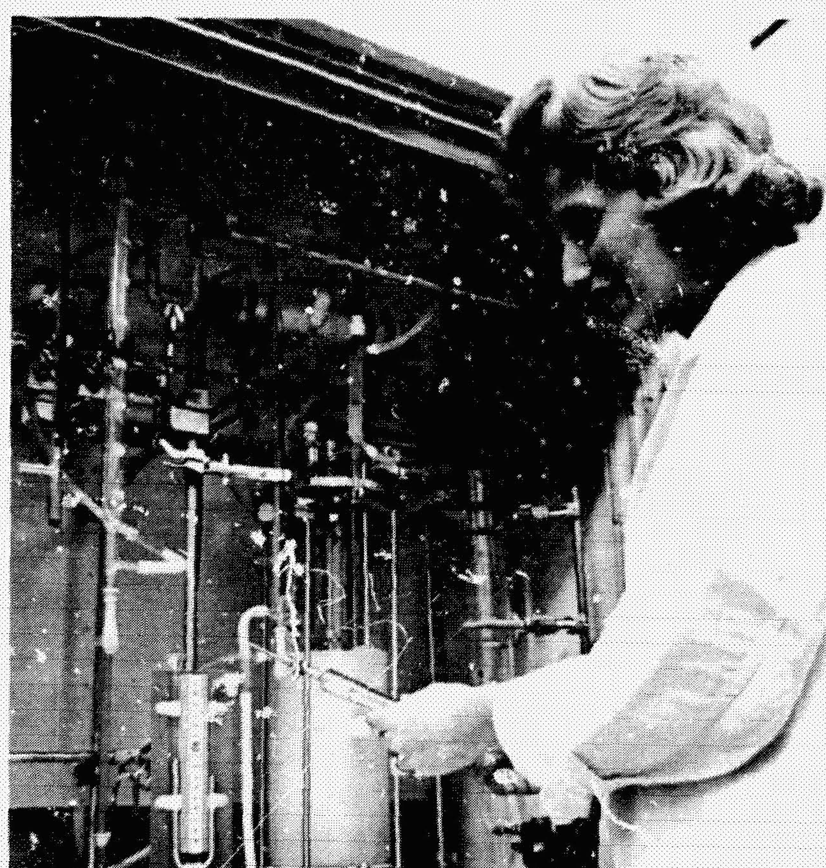


FIGURE 1. *Mrs. Elizabeth B. Ammann is shown with a* Hydrogenomonas eutropha *continuous culture unit, which is being developed for a bioregenerative life support system. The unit utilizes energy obtained from the oxidation of H_2 to form cell material from CO_2 and inorganic salts. The system is under development at Lockheed Missiles & Space Co. Research Laboratories, Palo Alto, Calif.*

Research Laboratories, Palo Alto, California, are currently working on the development of such life support systems (Figure 1).

In the partially closed system containing a mouse and algae, illustrated in Exp. 1, the animal must be continuously supplied with food and water from the outside. The carbon dioxide that the animal expels must be pumped to the algae where it enters the photosynthetic process. Respiratory exchange balance must be maintained between the carbon dioxide and oxygen volume. Also to be considered are the problems which would arise if the animal were fed entirely from the algae, and the feces, urine, and expired water treated to recover pure water, oxygen and as many trace elements as possible. It will indeed be a great scientific achievement when man can make a closed world of the space capsule, meeting the requirements of weight, energy, space limitation, suitability of food, and above all, total freedom from failure (Figure 2).

For flights of less than thirty days the problems are not serious. Chemicals remove the CO_2, and the oxygen is supplied from high pressure tanks. Water is carried in sufficient quantity for very conservative use, and waste water and solids are stored on board or discarded in space (Figure 3).

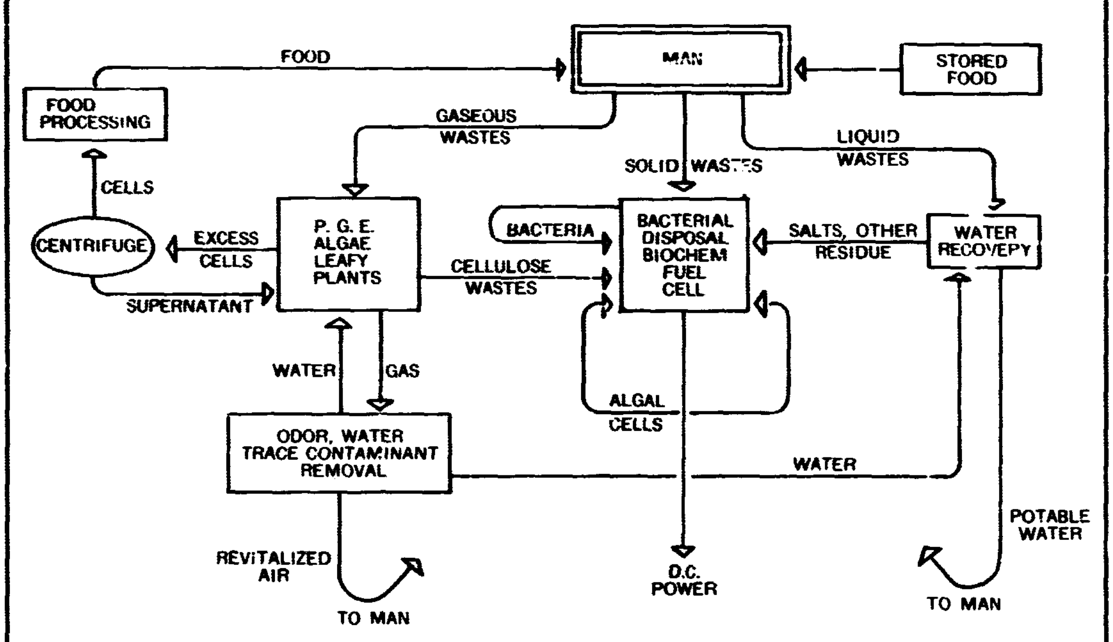


FIGURE 2 *A biological ecological system (4).*

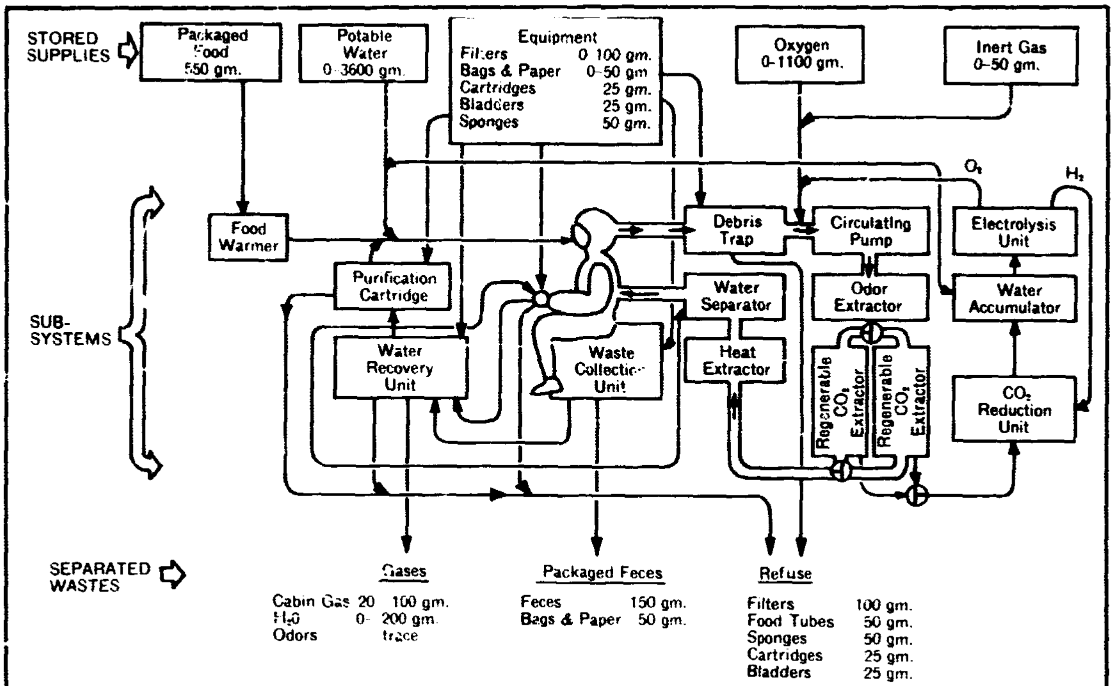


FIGURE 3. *Daily material flow diagram for one man using closed water-oxygen cycle life support system* (7)

Much early life support research was carried out in the hope of finding an efficient, rugged strain of algae that might possibly be tasty and edible. Present efforts center around activities of the physical chemists, who are investigating methods of oxygen recovery. Six of the principal methods are:

1. Fischer-Tropsch synthesis
   a. $CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$
   b. $2H_2O \longrightarrow 2H_2 + O_2$
   c. $CH_4 \xrightarrow{\text{cat.}} C + 2H_2$
2. Reverse water-gas reaction
   a. $CO_2 + H_2 \longrightarrow CO + H_2O$
   b. $2H_2O \longrightarrow 2H_2 + O_2$
   c. $2CO \xrightarrow{Fe_3C} C + CO_2$
3. Hydrogenation
   a. $CO_2 + 2H_2 \longrightarrow C + 2H_2O$
   b. $2H_2O \longrightarrow 2H_2 + O_2$
4. Alkali-metal reactions
   a. $2Na_2 + CO_2 \longrightarrow 2Na_2O + C$
   b. $Na_2O + H_2O \longrightarrow 2NaOH$
   c. $2NaOH \longrightarrow 2Na + O_2 + H_2$

5. Photochemical decomposition
   a. $2CO_2 \longrightarrow 2CO + O_2$
   b. $2CO \xrightarrow{Fe_3C} C + CO_2$
6. Thermal dissociation at reduced pressure
   a. $2CO_2 \longrightarrow 2CO + O_2$
   b. $2CO \xrightarrow{Fe_3C} C + CO_2$

Currently, thermal dissociation at reduced pressures is thought to be most promising. Eventually, some research team may discover the ultimate system, one which would synthesize oxygen and a carbohydrate food from waste water and carbon dioxide.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Enclosing an Ecological System—A *Microterella.*

Introduction

Spacecraft carrying astronauts on extended voyages will need to utilize enclosed environmental systems. Microbiological control of the closed environment in space vehicles involves the establishment of a system in which each member's welfare depends on the combined activities of the group. How well this system functions is determined by how well the needs of each individual are met.

One of these needs involves the exchange of CO_2 and O_2 by the members of the closed environment. In a system of this type, green plants might be used to absorb the carbon dioxide exhaled by mammals, and then release oxygen during the process of photosynthesis.

Much valuable data on closed ecological systems are currently being obtained by researchers using closed and semi-closed systems of various types. One such system which has been very useful to scientists is known as a "Microterella" (Figure 4) (2).

The system described here is not completely closed, since in addition to energy, food for the mouse has its origin outside of the Microterella.

Purpose

The construction of a Microterella permits the study of a number of the problems which are involved in maintaining a closed ecological system for space travel. It is hoped that a number of problems for investigation might occur to the student.

The purpose of this experiment is to find out for what length of time the needs of each member-organism of the Microterella can be met.

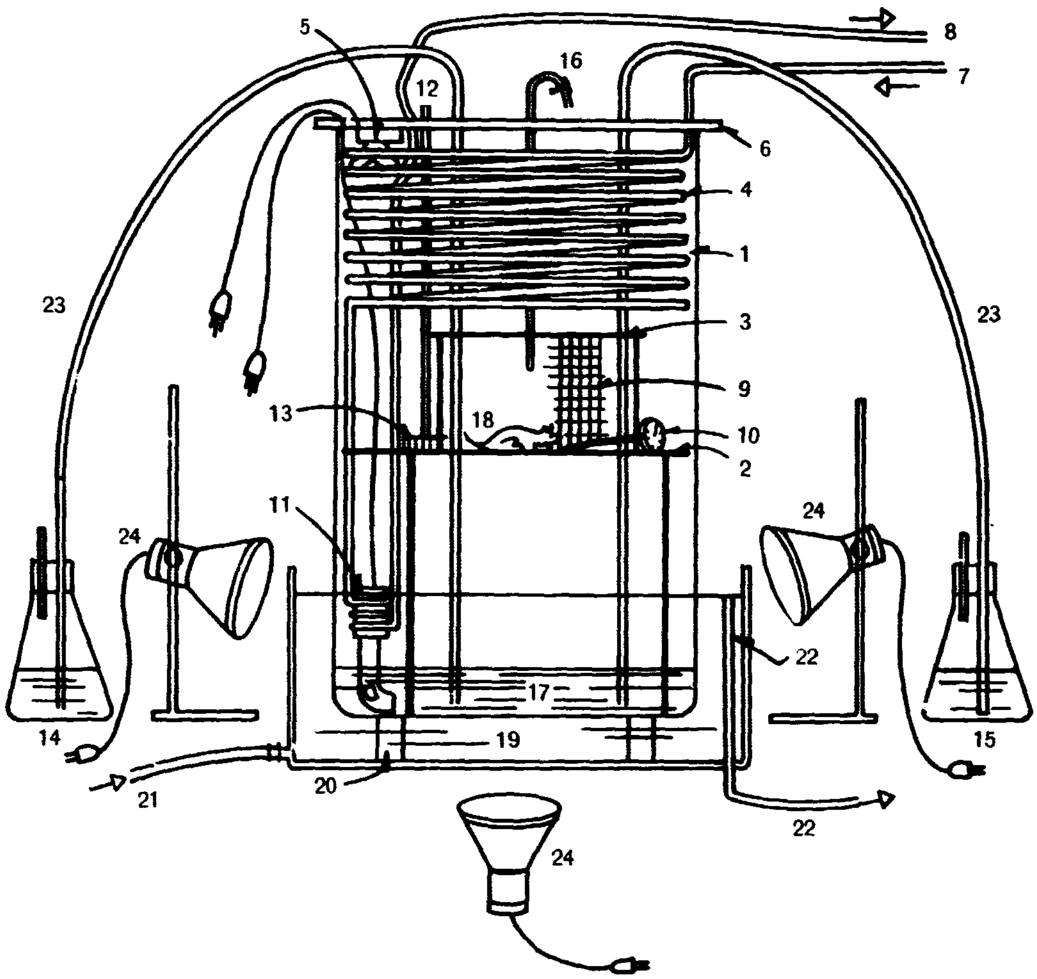
Materials

Large jar or aquarium, 3 or more gallon capacity.
Plastic (or glass) lid (with holes for entry and exit of tubing).
Aluminum tubing for cooling coil, ¼", 25–30 feet.
Glass tubing for influent and effluent ports.
Stirring pump (with motor).
Small fan.
Flask, Erlenmeyer, 1 liter, two.
Two-hole rubber stoppers, for flask.
Support, ring stand with ring, or tripod.
Stopcock grease.
Plastic tubing, 4 feet.
"Hardware cloth" ¼" screen for mouse quarters, about 30 cm × 30 cm.
Reflector spot lamps, 2–4, 150 W. outdoor type, in fixtures.
Thermometer (dial type), one or two.
Water bathtub, large enough to allow Microterella to be cooled.
Mouse, albino.
Culture medium containing *Chlorella*, enough to cover bottom 5–10 cm in depth.
Tubing with Alemite fitting.
Grease gun.
Food for mouse.
Heavy wire or rods, for mouse floor support.
Propeller on shaft.

Procedure—Construction and Assembly of the Microterella

Study the diagram of the Microterella and carefully assemble the apparatus accordingly. Several modifications will probably have to be made in the setup depending on the exact size and nature of the equipment and materials available (for example, if an aquarium is being used instead of a cylindrical container, a number of changes must, of course, be made). The student should feel free to make modifications as desired but keep in mind these suggestions:

a. The tube from the influent flask must be kept filled with the liquid medium at all times.
b. The inlet of the tube leadng to the effluent flask must be kept below the surface of the culture in the Microterella at all times.
c. If the reflector spot lamps are too close to methyl methacrylate (Lucite, Plexiglas, etc.) surfaces, such as that of the water bath, the plastic may become distorted, or even melted.
d. A design which permits illumination with a lamp underneath the culture in the Microterella may not be possible, especially if the water bath is opaque, or if the counter or table top for the Microterella cannot have a circular area removed from it.



1. Chromatography jar, 24" x 12" dia.
2. Mouse quarters, first floor
3. Mouse quarters, second floor
4. Cooling coil
5. Fan
6. Plastic lid
7. Cooling coil, intake
8. Cooling coil, outlet
9. Hardware-cloth ladder
10. Thermometer
11. Stirring pump
12. Alemite grease fitting for food tube
13. Food trough
14. Influent flask
15. Effluent flask
16. Gas sampling port
17. Algae
18. Mouse
19. Cooling bath
20. Support
21. Cooling water input
22. Cooling water overflow and output
23. Plastic tubing
24. Reflector spot lamp

FIGURE 4. *Microterella (1)*

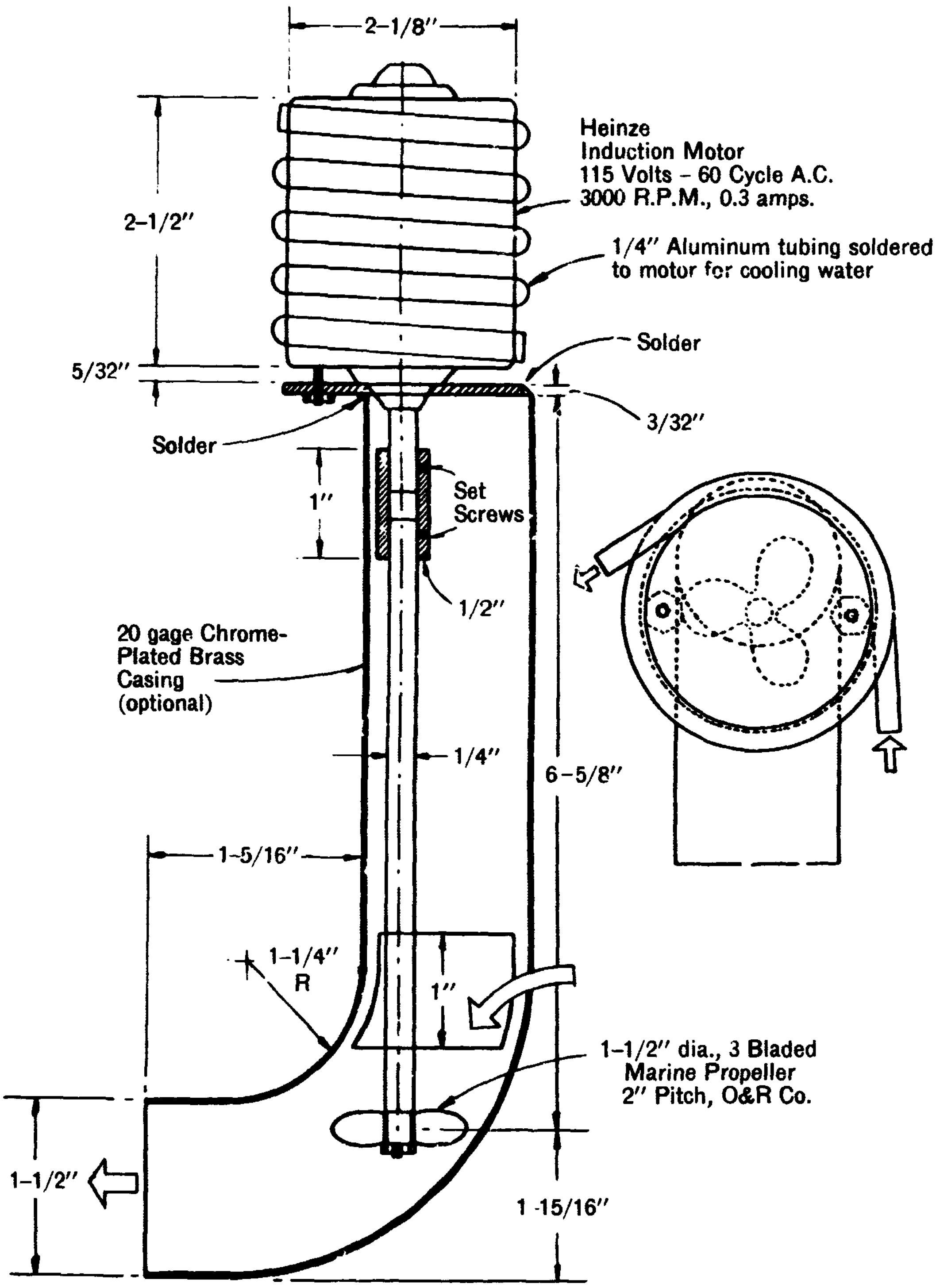


FIGURE 5. *Schematic diagram of downdraft propeller pump (1).*

e. Some details, such as the method of fastening the food tray, the fan motor mounting assembly, attachment of cooling coil inlet to water faucet, etc., are not shown in detail or described. These should be designed to best fit individual laboratory needs.
f. Copper, brass or bronze parts should not be used.

The cooling coil may be omitted from the stirring pump motor. In this way the higher temperature of the pump will prevent condensation of water inside the motor. The "drain pipe" casing may be omitted from the propeller pump design, if desired.

Preparation of the Culture and Influent and Effluent Flasks

Inoculate various standar liquid media with *Chlorella* and allow it to grow in a well illuminated place (but not in direct sunlight) until the culture becomes green. (For media suggestions see "Nutrition" chapter.) Add the culture to the Microterella. Set up the influent and effluent flasks making sure that the tubes leading to the culture extend below the level of the culture and that they are full of the proper liquid. The influent flask should contain additional medium (without algae). It must be added to the culture in the Microterella periodically (perhaps twice a day). At the same time, an equal amount of medium—containing algae—must be withdrawn from the culture in the Microterella. These actions are brought about by a siphoning action caused by raising or lowering the proper flask (at the proper time). Either liquid will flow until the level in the Microterella is level with the liquid in the flasks. When the liquid in the influent flask has lowered so that medium is nearly down to the level of the lower end of the glass tube leading from the flask, the experiment will have to be discontinued. The effluent flask will initially have to be filled with medium, containing culture, until the level is the same as that inside the Microterella.

After all the parts of the Microterella have been assembled, each of the important component parts should be tested. This should include tests of:

a. The operation of the air circulation fan.
b. The efficiency of the pump in circulation in the culture.
c. The operation of the internal cooling system, with all lamps turned on.
d. The ease of the addition of food with a grease gun.
e. The mechanics of adding to, and withdrawing from, the culture.
f. The circulation of the water bath and its cooling effectiveness with all the lamps turned on.
g. The spacing of the lamps for proper illumination.

When all of these tests have been completed and the components have performed well, the Microterella may be sealed for a "test

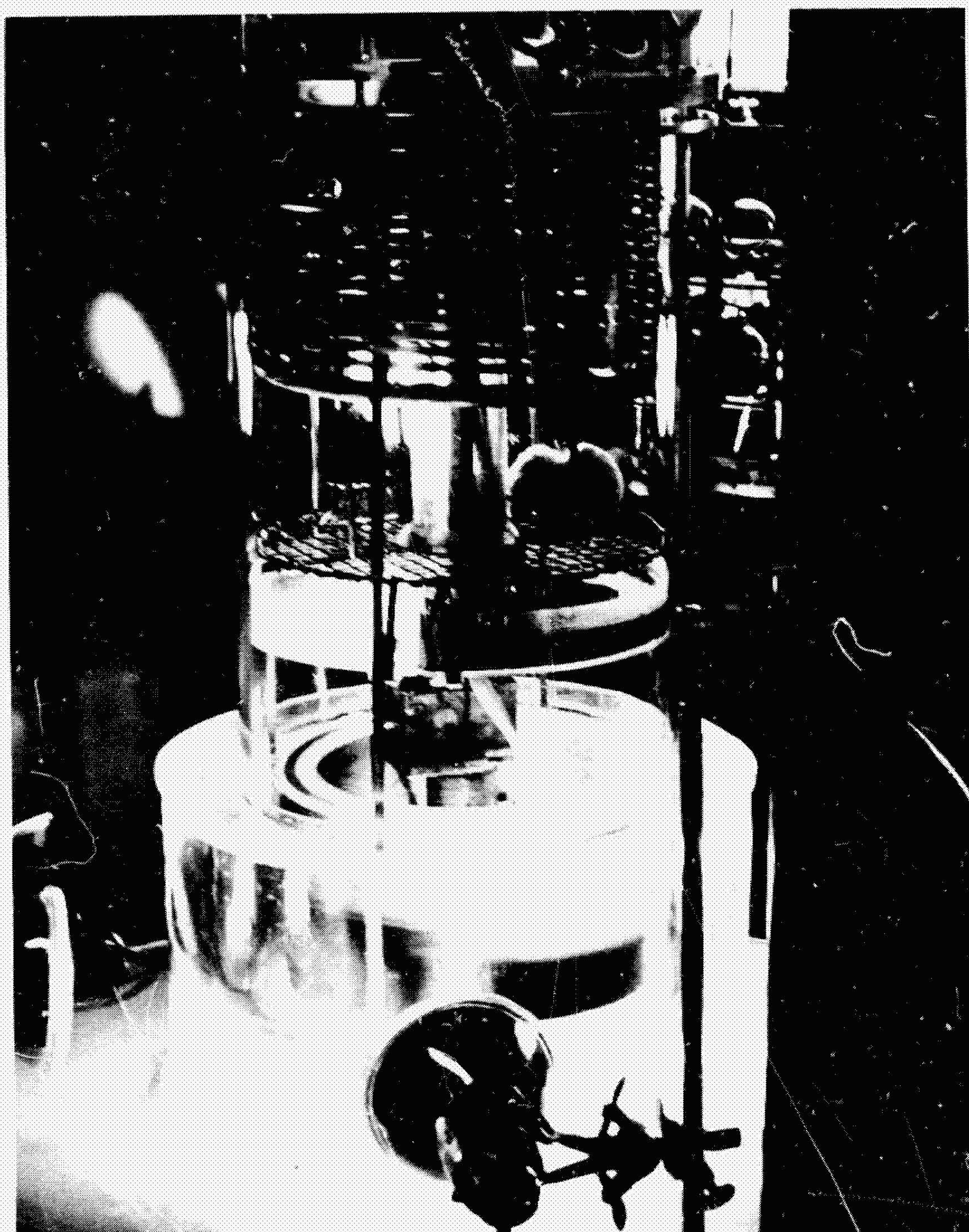


FIGURE 6 *A closed ecological system consisting of algae, bacteria and mice (2).*

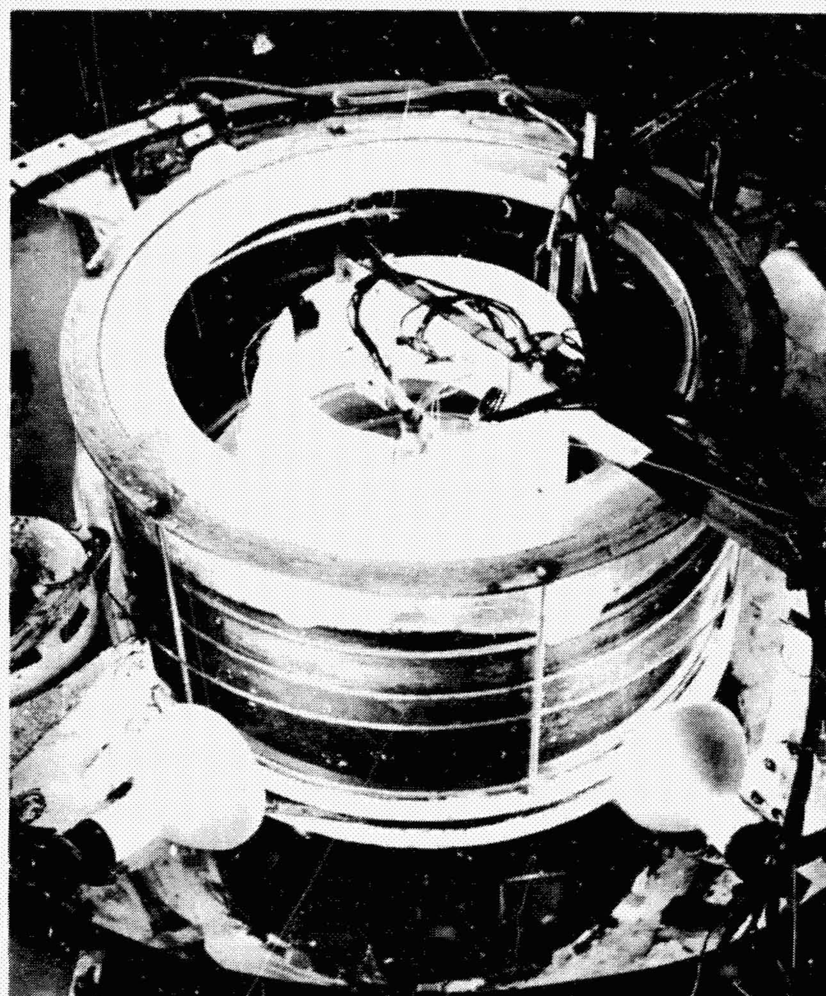


FIGURE 7. *A light growth unit for gravity-free conditions (2).*

run." This should be first done without a mouse. Weigh the mouse before and after the run.

Data and Analysis
(for the student)

What kind of data could be collected in an experiment such as this? Some suggestions are as follows:

a. Record the time and the amounts of new medium introduced and amounts of culture removed. What might be done with the effluent culture besides discarding it?
b. Note and record any changes in the appearance of the culture medium.
c. Which type medium grows algae most efficiently?
d. Can you devise a way of determining: the physiological condition of the mouse?

the amount of food consumed?
the amount of feces produced?
the amount of activity of the mouse?
the time spent sleeping?
the time spent obtaining water? (how is water obtained by the mouse?)
how the rate of respiration and pulse rate can be determined?

e. Make a record of the temperature changes in the Microterella.
f. What additions can you make to this brief list?

Discussion

1. How long were the needs of each member-organism in this nearly closed system met?
2. What modifications need to be made to prolong this time?
3. What additional data would have been desirable to have available?
4. Which of the data that were collected seemed to be the most valuable in indicating when all needs of the inhabitant were being met?
5. If a procedure could be developed to determine the carbon dioxide content and the oxygen content of the Microterella, would these data be useful in determining whether a balance between the vital gases in the Microterella was being reached?

For Additional Investigation

1. What is the optimum depth of the *Chlorella* medium?
2. Could other species of algae be grown instead of *Chlorella*?
3. What changes in the balance might be produced with additional lamps? Fewer?
4. What is the optimum rate for adding to and removing culture liquid?
5. Can the effluent be enriched and reused?
6. What importance do the mouse feces play? What would be the effect of collecting and discarding the feces rather than allowing them to drop directly into the culture?
7. Assuming a change in color of the culture might be due to a macronutrient deficiency, how could this be corrected?
8. To what extent might the volume and weight of the non-mammalian part of the system be reduced without adversely affecting the gas and liquid balance?

Additional Suggestions for Experiments for Gas Exchange and Waste Management

1. Algae can be collected from many local habitats to determine how many different types of algae can be cultured. Check any hot springs for thermal types. Attempt to culture and identify each type. At Lockheed Missiles and Space Company Research Laboratories, Palo Alto, California, the late Dr. Victoria Lynch identified twenty-two different cultures.

2. Each culture should be tested for its ability to survive during extended time periods. Temperature and light conditions should be varied to discover which strain is the most resistant to environmental changes.

3. Select jars of different sizes, ranging from one gallon to five gallons, and using a variety of plants, snails, a small goldfish, mosquito fish, or other species, set up several closed system environmental aquariums. With proper selection and preparation, life can be maintained for possibly six months in a corked and wax-sealed container. This is a highly recommended experiment for any age level student capable of understanding the purposes and procedures.

4. One of the methods for the removal of carbon dioxide is its absorption by lithium hydroxide solution (calcium or barium hydroxide could also be used). It has been discovered that LiOH has bacterial properties, a fortunate bonus in air purification in a space cabin. Air could be tested before and after treatment to prove this effect (5).

5. Ask the students to design an experiment which will determine what quantity of carbon dioxide a given amount of algae will use in photosynthesis and what quantity of oxygen is given off at the same time. From this experiment, determine the quantity of dry algae and the weight required at the same time to sustain an astronaut for one day on the oxygen produced by the culture.

6. Distill samples of urine and identify some of the more easily recognizable products of this distillation. Approximately one hundred and fifty-eight components can be found in a complete analysis of human urine. Solid electrolytes, nitrogen compounds, amino acids, vitamins, miscellaneous organic compounds and hormones range in quantity from trace amounts of a high 35,000 milligrams per 24 hours. Normal urine has a specific gravity of 1.002 to 1.035 and a pH of 4.6 to 8.0. The table below lists all components having an abundance greater than 500 mg/24 hours (6).

	Range
Chloride (as NaCl)	7,600 – 15,000
Chlorine	2,800 – 12,600
Phosphorus (as P)	700 – 1,600
Inorganic (P)	700 – 1,300
Potassium	1,120 – 3,920
Sodium	1,750 – 6,580
Amino Acids (total)	1,100 – 2,800
Ethanolamine	1,100 – 3,219
Total Nitrogen	1,100 – 21,000
Urea	14,000 – 35,000

7. It is possible to grow algae on urine. In the growth process, the urine will partially break down. Distillation of the residue will show a marked difference in the ammonia content from that of pure urine.

Other Experiments

Recommended by Dr. Donald Eckbert, General Electric Company, Valley Forge, Pennsylvania

1. This experiment would involve studies of viability under various concentrations of gas. Comparisons could be made with various concentrations of gases such as 100% oxygen, 75% oxygen and 50% oxygen atmospheres. This could be repeated with similar amounts of nitrogen, carbon dioxide, methane or almost any gas that could be conceived that might simulate the environment of another planet.

2. Study amoeba growth rates in a closed system. Ten or twenty amoebae may be put into a closed vessel and their growth rate compared to a like number of amoebae in an open vessel. Both groups should have food added to their environment. The actual numbers of amoebae should be counted daily using binocular microscopes. Comparisons could be made to see whether the growth rate varies in one of the groups or the other.

3. An additional experiment could be done using the same organisms in an oxygen environment compared to a carbon dioxide environment. It is possible that the experimenter might wish to use a microspirometer. Dr. Donald Eckbert has indicated that this could be manufactured by a student for less than $10.

4. Also suggested is a desiccation experiment using the breath of a mouse. The exhalations of the mouse would be absorbed in a desiccator which would regulate the readings of a manometer. One could inject oxygen into the chamber to maintain pressure and measure the use of oxygen. It might be possible to compare normal mice with mice under hypophysectomy.

5. Another possibility is the observant effect on rats living in a condition of elevated temperatures where all transpired water is continuously removed from the environment. A blood pressure record might also be kept.

6. Study the effect on the red blood cell count of rats living continuously in a low pressure, low humidity environment.

7. Study the role of sunlight and the energy involved in hydrolysis.

8. Study the recovery of potable water from human urine. See General Electric Co. reference in the appendix.

LITERATURE CITED

1. Ammann, Elizabeth and Victoria H. Lynch. 1965. Gas exchange of algae: I. Effects of time, light intensity, and spectral-energy distribution on the photosynthetic quotient of *Chlorella pyrenoidosa*. Applied Microbiology 13:546–551.

2. Golueke, Clarence G. and William J. Oswald. 1963. Closing an ecological system consisting of a mammal, algae and non-photosynthetic microorganisms. American Biology Teacher, Vol. 25(7), p. 522–528.

3. Konikoff, J. J. 1962. Oxygen recovery by the catalytic dissociation of carbon dioxide. Aerospace Medicine, Vol. 33, p. 974–979. Space Sciences Laboratory, Missile and Space Vehicle Department, General Electric Company, Philadelphia, Pennsylvania.

4. Konikoff, J. J. 1963. Closed ecologies for manned interplanetary flight. Report No. R63sd83. Space Sciences Laboratory, General Electric Missiles and Space Division, Philadelphia, Pennsylvania.

5. Markowitz, Meyer M. and Eugene W. Dezemelyk. 1964. A study of the application of lithium chemicals to air regeneration techniques in manned, sealed environments. Technical Documentary —Report No. 64–1, Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

6. Webb, Paul (Ed.). 1964. Bioastronautics Data Book. NASA Special Publication 3006. Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D. C.

7. Zeff, J. D., R. B. Neveril, D. A. Davidson and R. A. Bambenek. 1961. Storage units for waste materials. Report 61–200. Life Support Systems Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

section 1

LIFE SUPPORT

OXYGEN CONSUMPTION

Providing the oxygen requirements of astronauts during space flight is a major problem. Oxygen is undoubtedly the most critical of all gases to be supplied in the environment.

The amount of oxygen consumed depends upon a number of internal and external factors, and it is therefore difficult to establish average consumption rates for man. A resting man may use 350 ml of oxygen per minute while a man at maximum exertion may use over twelve times this amount of oxygen. An astronaut will require between 400–500 liters of oxygen per day. For a 30 day flight to the moon, one astronaut alone would require 12,000 liters of oxygen.

The question of how the oxygen requirements of astronauts can be minimized is currently receiving much attention. Consideration has also been given to the concentration of oxygen in relation to the pressure which may be safely breathed, and to the use of 100% oxygen in space cabin environments. Froese (1) has shown that rats consume the same amount of oxygen, whether breathing air or pure oxygen.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

The Effect of Ambient Temperature on the Metabolic Rates of Homeotherms.

Introduction

Dr. Raymond Hock of the University of California, White Mountain Research Station, Bishop, California, is presently investigating hibernation in rodents. These studies may possibly lead to the use of induced hibernation as a means of reducing oxygen, food and waste requirements during extended space travel (3).

Another consideration has been the effect of cooling, or hypothermia, on oxygen consumption. Cooling reduces the rate of biochemical reactions and, therefore, less oxygen is required. Experiments have shown that at very low temperatures mammals begin to shiver and thus increase their oxygen consumption. Several warm-blooded animals, including rodents, are able to lower their body temperature if the oxygen pressure is reduced. This reduction of metabolic rate causes a reduction in oxygen consumption. Additional research is needed on the subjects of temperature regulation, oxygen consumption and hypothermia in relation to space travel (2, 4, 5).

Purpose

The purpose of this experiment is to determine the ambient temperature which provides for minimal oxygen consumption. In this way, reduced metabolic rates might be maintained for long space missions by reducing the air temperature within the space suit.

Materials

Calibrated scale
Pointer
Two containers of slightly different diameters (i.e. Styrofoam cup with slightly smaller diameter than tin can).
Glue
Rubber tubing
One-hole rubber stopper
Glass tubing
Pinch clamp
Cotton
Saturated KOH solution
Thermometer
Mouse (or frog)
Glass jar (large, with rubber stopper, three-hole)
Water bath

Procedure

Select two containers, one of which will easily fit into the other. Affix pointer to the top of the smaller container (container A), Figure 1. Use glue to fasten the stick. Drill a hole in the center of the bottom of the larger container (container B), Figure 2. The diameter of the hole should allow the one-hole stopper to just enter. Adjust the height of the tube to the top of the container.

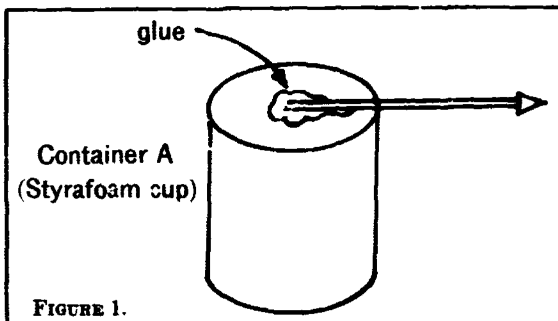


FIGURE 1.

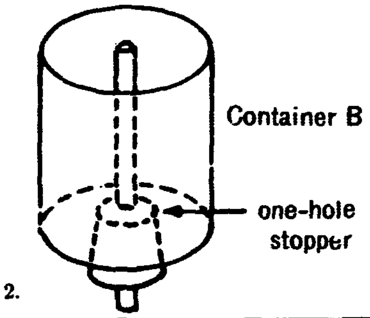


FIGURE 2.

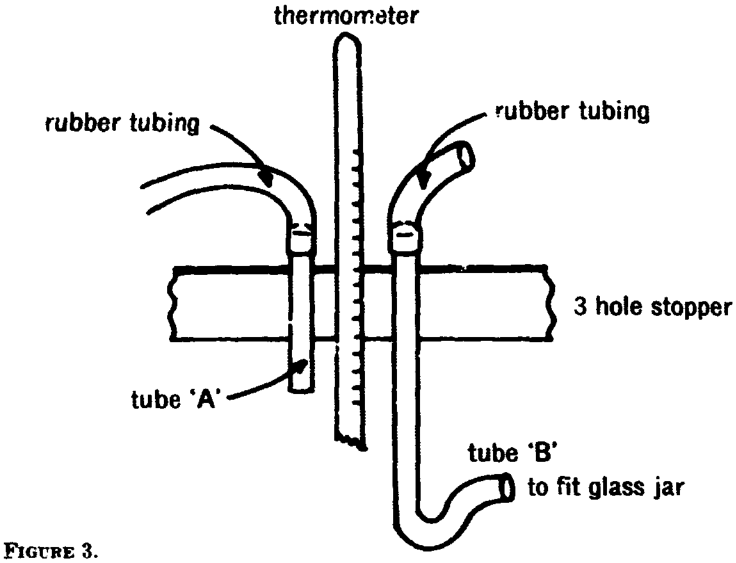


FIGURE 3.

Tube A is a straight piece while Tube B is bent as in Figure ?.

To Tube A attach a length of rubber tubing and affix the other end of this tube to the center of container B. Tube B should be attached to a piece of tubing which will be pinched shut after potassium hydroxide is added. The jar can be weighted with sand so that it sinks in a pan of water. Ice can be added to the water to produce varying ambient temperatures within the jar.

The apparatus should be assembled as in Figure 4.

As the test animal consumes oxygen, container A will sink in the water of container B. The change in levels can be observed on the scale. The markings on the scale can be calibrated by introducing known amounts of air into container through the attached hose. Make several calibrations.

Once the scale is calibrated, you are ready to begin experimentation. Place a test animal in the jar. Stopper and attach the rubber hose of Tube A to the center tube of container B. Add saturated potassium hydroxide to fill bend in Tube B. Stuff cotton into the bent end, as indicated in Figure 5. Close the other end by pinching the rubber tube with a pinch clamp. The potassium hydroxide in the cotton will remove the carbon dioxide exhaled by the animal. Why is this necessary? Record the original level of air in container A and allow the test animal to remain sealed in the jar. Add ice to the water surrounding the jar and maintain a constant temperature while oxygen consumption is being recorded.

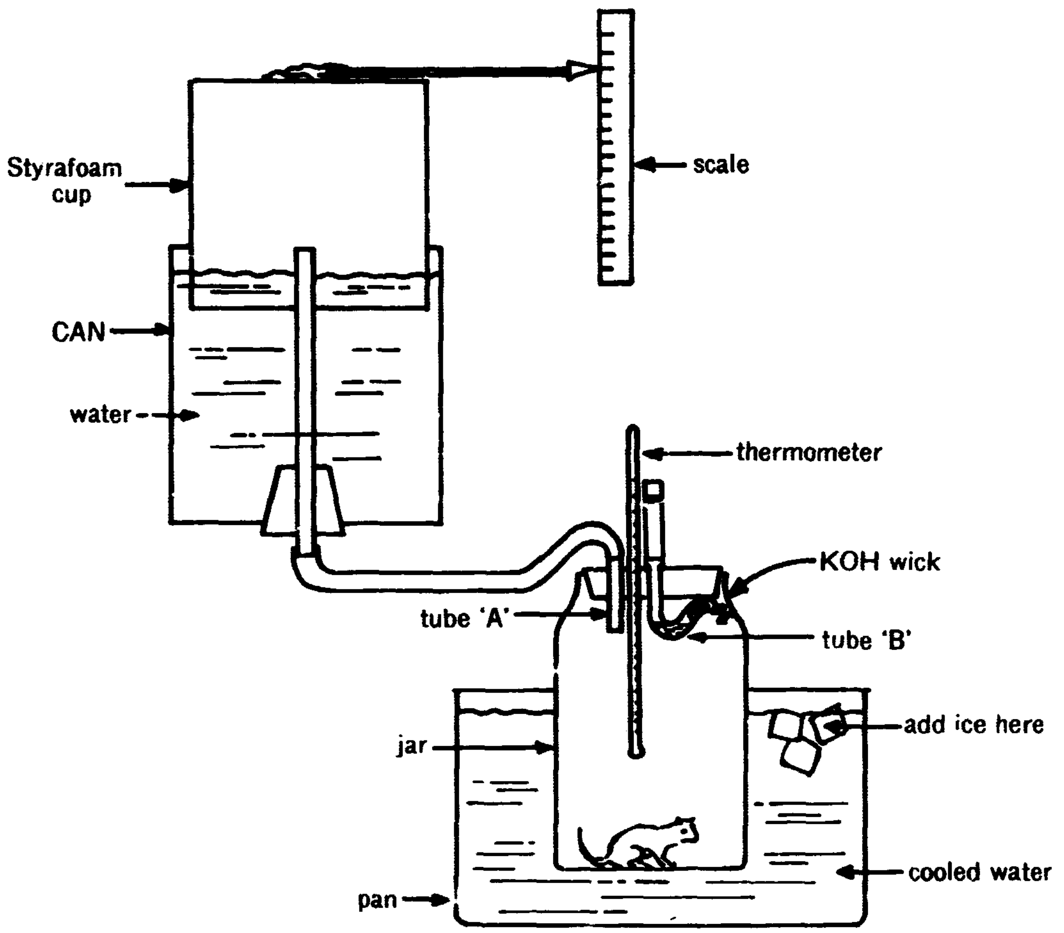


FIGURE 4.

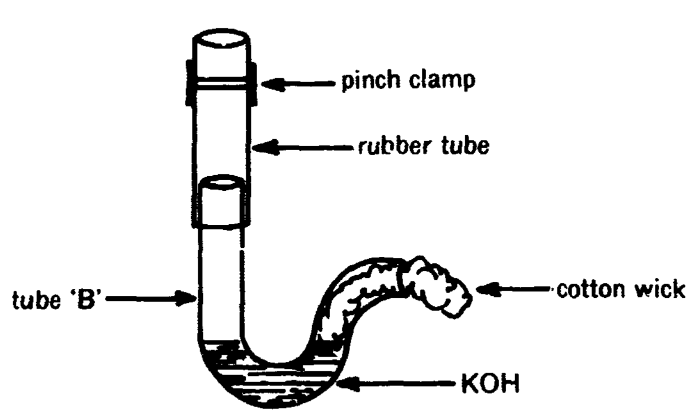


FIGURE 5.

Determine the volume of oxygen consumed per minute for several ambient temperatures. This can be calculated from the total oxygen consumed divided by the total time of the experiment.

Example: 30 cc of oxygen in 10 minutes = 3 cc of oxygen consumed per minute.

Determine the minute oxygen consumption rate for 20°, 15°, 10°, 5°, 0° Centigrade using room temperature as a control. Graph the results.

Discussion

1. What conclusions can you make about the effect of ambient air temperature on metabolic rate?

2. Which ambient air temperature provided the minimum metabolic rate?

3. What additional factors would have to be considered before this temperature could be used within space suits?

Additional Investigation

This same apparatus may be used to investigate several space problems. Here are a few problems that are currently being considered by space scientists:

1. To what extent does hypothermia induce drowsiness or sleep?

2. How might the reduced activity associated with hypothermia affect the astronaut's ability to rapidly recover maximum performance efficiency?

3. Could hypothermia provide relief from the psychological and physiological problems associated with long term confinement and boredom?

4. In what ways could forced astronaut hibernation be beneficial for long space flight?

5. Compare the metabolic effects of hypothermia in homeotherms with poikilotherms as a simulated study of estivation and hibernation.

LITERATURE CITED

1. Froese, G. 1960. Effect of breathing O_2 at one atmosphere on O_2 consumption of rats. Journal of Applied Physiology 15:53.

2. Hardy, James D. 1961. Physiology of temperature regulation. Physiological Reviews 41:521.

3. Hock, R. J. 1960. The potential application of hibernation to space travel. Aerospace Medicine 31:485.

4. Lewis, F. John, Peter Connaughton, and Gordon Holt. 1961. Prolonged hypothermia, p. 331–334. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

5. Parkes, A. S., and Audrey Smith. 1962. Space transport of life in the dried or frozen state, p. 33–34. *In* G. V. E. Thompson (Ed.), Space research and technology (British Interplanetary Society). Gordon & Breach Science Publishers, London.

6. Webb, Paul (Ed.). 1964. Bioastronautics Data Book. NASA Special Publication 3006. Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D. C.

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section 2

PHYSIOLOGICAL ASPECTS

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TEMPERATURE STRESS

Experimentation has demonstrated man's ability to survive for extended periods in environmental temperature extremes of +600° Fahrenheit and —70° Fahrenheit (5). The two important considerations related to his survival at these extremes are body protection and exposure time. However, the space voyager in his insulated space suit will not encounter these extremes. Therefore, in essence, the temperature, relative humidity and air movement requirements of the suited astronaut will not be different from those required of the earthbound sedentary worker. Without protective clothing, the astronaut would be exposed to lethal environmental temperature extremes.

Space environmental temperatures vary considerably with altitude. The regions of temperature variation divide the earth's atmosphere into two layers. The layer immediately adjacent to earth is called the troposphere. The outer layer which surrounds the troposphere is termed stratosphere. The troposphere is characterized by a consistent decrease in temperature with increase in altitude. The stratosphere is characterized by a fairly uniform temperature of −67° Fahrenheit. In general, the temperature of the upper air decreases steadily with altitude until the stratosphere value of —67° Fahrenheit is approximated.

The atmosphere above thirty miles consists of ions rather than diatomic gases found in the troposphere and stratosphere. These ions are the result of photochemical and photoelectric reactions between atomic molecules and solar ultraviolet radiation. The height of the respective atmospheric layers is compared in Table 1. The "temperature" of the ionosphere rises consistently with altitude and approaches a value of 3600° Fahrenheit. One must use caution, however, when considering ionospheric temperature, because at these altitudes air density is so reduced that the concept of temperature loses its usual meaning. Here, temperature relates to the mean kinetic temperature of the gas molecules which is related to their velocity. One might assume that a spacecraft at an altitude of 115 miles where the ambient gas temperature is 752° Fahrenheit would be at thermal equilibrium with the gas and also be 752° Fahrenheit. However, because of the extremely rarefied concentration of gas molecules at this altitude, the gas-heat transfer is negligible. Buettner and Haber have calculated that a polished aluminum surface with a thermal shield backing would have a surface temperature of 234° Fahrenheit at 115 miles altitude, where the kinetic gas temperature is 752° Fahrenheit (2).

TABLE 1

ATMOSPHERES	SPHERES	LAYERS	APPROXIMATE HEIGHT (miles)
Space			Above 1200
Outer	Exosphere		600 to 1200
Inner	Ionosphere	Atomic	250 to 600+
		F ($F_1 + F_2$)	95 to 250
		E	50 to 95
		D	30 to 60
	Stratosphere	Upper mixing	30 to 50
		Warm	15 to 30
		Isothermal	8* to 15
	Troposphere	Advection	1.2 to 8*
		Ground	6 ft to 1.2 mi
		Bottom	0 to 6 ft

* *Average.*
The symbols F, E and D refer to respective ionized regions of atmosphere.

In 1924. the United States Bureau of Standards developed a United States standard atmosphere based on yearly average data for composition, pressure and temperature changes with altitude. During the 1950s, approximately 400 sounding rockets were fired by the United States, primarily devoted to studies of the ionosphere. During the International Geophysical Year of 1957 and 1958, at least 200 additional launches were made from sites in both hemispheres. Data from these flights extended the original standard atmosphere to include the ionosphere. Recent information relative to temperature changes with altitude is graphically illustrated in Table 2.

The sources of internal space cabin heat will very likely be the collective result of:

1. *The astronauts' metabolism and cabin machinery operation.* Man produces about 100 gram calories per hour with moderate activity (4). When combined with involved water vapor, we

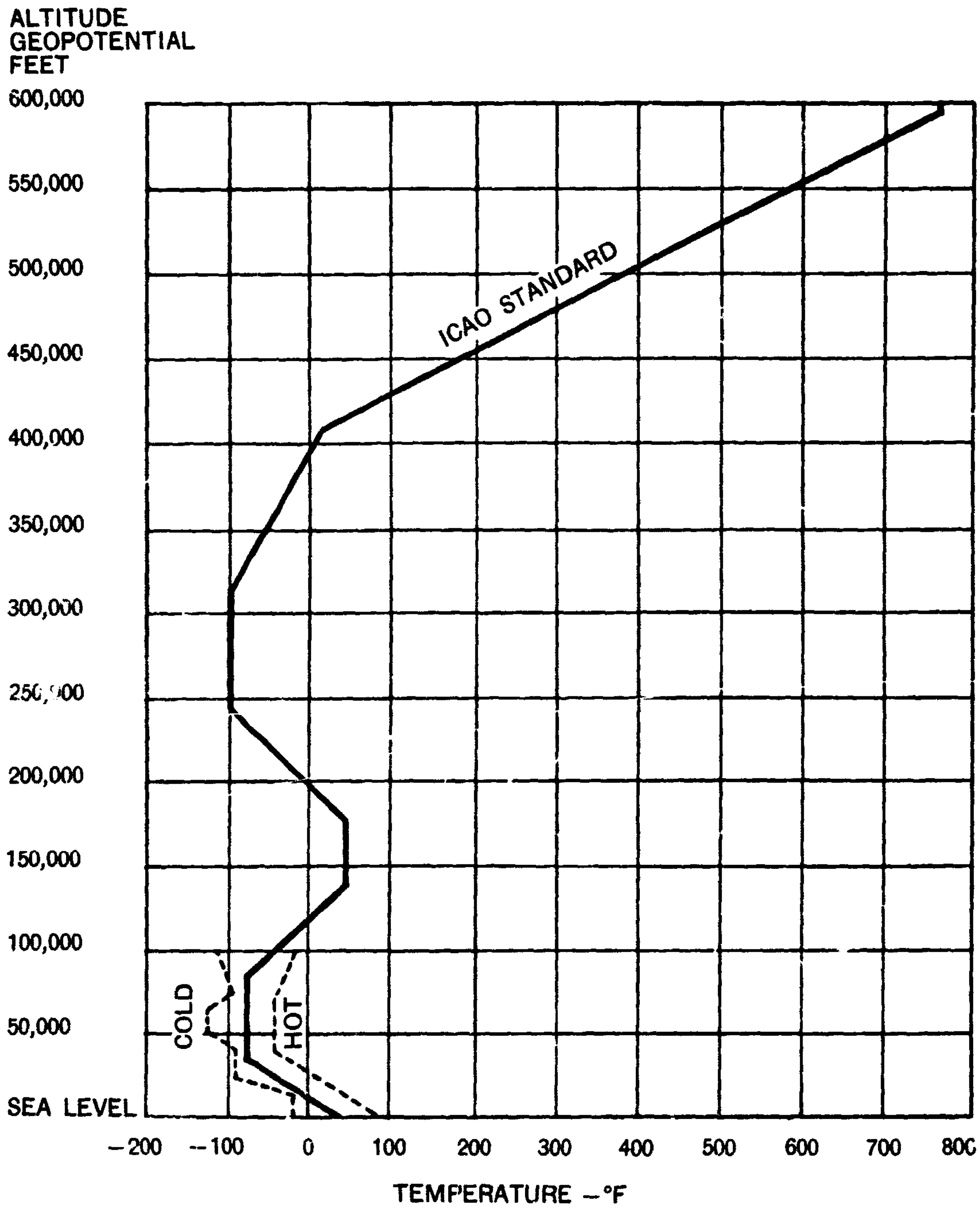


TABLE 2 *The standard atmosphere of the International Civil Aviation Organization (ICAO) (consistent with the ARDC standard atmosphere. 1956). Below 100,000 feet, two added curves represent the hot and cold variations from the standard atmosphere. ARDC—Air Research and Development Command.*

find optimum conditions for the development of a rather humid atmosphere in which heat is poorly tolerated. Together with other sources of heat, the degree of metabolically evolved heat may reach dangerous levels.

2. *Friction with atmospheric gas particles.* During blast-off and especially during re-entry, when high speeds through the more dense atmosphere are attained, the surface temperature of the spacecraft reaches several thousand degrees and, depending upon the nature and efficiency of insulation, a certain amount of this heat is transferred to the craft's interior. However, while in orbital flight, frictional heat is negligible because of the extremely low gas density at orbiting altitudes.

3. *Solar radiation.* Solar radiation energy amounts to about 1.94 gram calories per minute per square centimeter. This is a solar constant and, without atmospheric protection, objects in outer space receive the full intensity of this energy. The thermal effect will depend upon the nature of the material, its color and efficiency of insulation. Therefore, the environmental temperature of the spacecraft in orbit could be fairly accurately controlled by the careful selection of the composition and color of the exterior surface. However, the spacecraft is repeatedly exposed to periods of energy absorption and periods of heat loss. During the "night" phase, when the earth is interposed between the sun and the spacecraft, heat is radiated from the spacecraft and the surface temperature may be as low as −86° Fahrenheit, whereas when exposed directly to solar radiation, the surface temperature may reach +500° Fahrenheit (1, 5). The extremes of space temperatures clearly indicate the vital nature of temperature control.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Place thermometers under various types of insulating materials. Some good insulating materials include:

a. Asbestos
b. Two layers of tinted auto glass with air space between
c. Aluminum foil layers
d. Aluminum foil layers separated by felt layers
e. Diatomaceous earth bricks
f. Fire brick as used in fireplace
g. Heat-resistant ceiling insulation materials
h. Rubber
i. Lead foil

Subject both reflective and plain surfaces of insulating materials to as many varied types of heat sources as you can devise, including:

a. Infra-red lamps
b. Bunsen burner flames
c. Floodlight heat
d. Sunlight
e. Electric hot plate
f. Electric barbecue starter

Compare the results. What materials afford the best protection from heat sources? Which materials protect the thermometer from sun radiation effects? From the infra-red heat rays?

Construct a table comparing the results. Summarize conclusions drawn from your own findings. From the evidence gathered what materials would appear most suitable for space suit designs? What color should be used for space suit external layer? Why? For spacecraft? Why?

Repeat experiments using telemetering device described in chapter on Biotelemetry.

LITERATURE CITED

1. Armstrong, Major General Harry G. (Ed.). 1961. Aerospace medicine. Williams & Wilkins Company, Baltimore, Maryland.

2. Buettner, K. and H. Haber. 1952. The aeropause. Science 115: 656–659.

3. Garrett Corporation. 1958. The High Altitude Chart. Los Angeles, California.

4. Strughold, H. 1950. Epitome of space medicine, Vol. 9. United States Air Force School of Aviation Medicine, Randolph Air Force Base, Texas.

5. Webb, Paul (Ed.). 1964. Bioastronautics Data Book. NASA Special Publication 3006. Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D. C.

section 2

PHYSIOLOGICAL ASPECTS

WEIGHTLESSNESS

Man orients the position of his body at any one time by the operation of his sensory receptors; i.e., by the action of his eyes, possibly in some instances by the ears, by the activities of the semicircular canals in his inner ear, by the pressure effected on the pressure receptors (the Pacinian corpuscles), and by the tension of the muscles as conveyed to him by the muscle spindles. However, in the weightless state there will be no gravity exerted on the otoliths or the semicircular canals, the antigravity muscles will be relaxed and will not initiate sensory impulses and the Pacinian corpuscles will be relieved of pressure. Therefore, under weightless conditions only vision remains. However, recent findings have indicated that tolerance to weightlessness develops quickly and that both man and animals can learn by training and experience to orient themselves by vision alone (1).

One of the principal concerns of space scientists is the potential physiological and performance effects of prolonged weightlessness. It is not known to what extent normal biology is gravity dependent. After long periods of weightlessness, can man quickly return to a gravity environment and function efficiently?

This weightlessness aspect of space research presents problems to the human being. Only research conducted within this environment can provide solutions to these problems. Essentially, the matter centers around two considerations. First, what is the effect of zero gravity on the central nervous system which is responsible for spatial orientation and control of position and movement of the body and its organs? Second, what is the effect on the autonomic nervous system which regulates physiologic processes including respiration, circulation, digestion, and general homeostasis?

Until recently research data consisted of information taken from short-term parabolic flights which provided up to 20–30 seconds of weightlessness. Therefore, it is only from simulated studies that researchers can evaluate any long-term effects. Most of the long-term simulated weightlessness data have been obtained from water immersion, bed rest, and free-fall studies. The validity of information obtained from such "simulated weightlessness" will only be proven during actual space missions. However, these actual short-term flights and simulations hint at real and potential hazards. Astronaut Glenn reported fatigue and weakness during his brief exposure to weightlessness. Titov in his longer exposure to weightlessness experienced fatigue and nausea. Gerathewohl reports that 30 percent of the individuals in his trajectory studies experienced discomfort, nausea, or severe motion sickness (3).

The physiological parameters significantly affected by zero "g" include neuromuscular control, spatial orientation, vestibular mechanisms, cardiovascular system, gastro-intestinal system, waste elimination, and skeletal muscle activity. Simulation and trajectory studies have shown a decreased activity in the cardiovascular system, anti-gravity reflexes, i.e., vasoconstriction and blood rerouting, following real and simulated "weightlessness." The major effect of weightlessness on circulation is abolition of the normal hydrostatic action imposed on the heart by the height of the column of blood above the heart. Blood pressures tend to follow those noted for the supine and prone position (6). The expected change in blood and water distribution during weightlessness will most likely result in neural and hormonal regulation phenomena, which lead to water and mineral loss, a decline in blood volume, and generalized alteration in cardiovascular reactivity (1). These physiological changes may well decrease re-entry acceleration tolerance.

Other physiological effects reported include altered fluid balance and increased diuresis (8).

The inactivity associated with the simulated studies must also account for part of the noted physiological changes. In particular, effects of disuse of muscle and bones and concomitant disturbances in calcium and nitrogen balance (2). However, since life in a spacecraft will probably be restrictive, this mixture of effects may be appropriate and desirable.

Early immersion simulation studies showed impairment of motor skills, namely "overshooting." Dr. von Beckh showed that subjects in a weightless state rapidly compensated for this condition (13). The neuromuscular compensation for gravity is commonly seen when an individual is handed an object which appears heavy but is in fact very light. Neuromuscular compensation results in the exaggerated elevation of the recipient's hand.

Astronauts and cosmonauts subjected to long periods of weightlessness have reported rapid compensation for the effects of weightlessness and have performed motor skills with only minimal loss in efficiency. Cosmonaut Yuri Gagarin's final statement about the weightlessness state was, "I was convinced that weightlessness does not affect at all man's fitness for work (1)." Research by Dr. Siegfried Gerathewohl and Major Edward Brown, as well as information from astronauts and cosmonauts, indicate that short periods of weightlessness will have no significant effect on performance.

Extensive immersion studies by Captain D. E. Graveline indicate cardiovascular dysfunction in individuals returned to normal gravity conditions after long periods of weightlessness (4, 5).

These physiological responses to long-term weightlessness and in particular the effects that follow return to a gravity environment present a major area of inquiry. Several countermeasures have been proposed—planned exercise to maintain muscle tone, support of the cardiovascular system by positive pressure breathing, and periodic inflation of constriction cuffs on the arms and legs. Dr. Wernher von Braun has suggested that an artificial gravity be provided by rotation of the spacecraft (7).

Captain Ashton Graybiel of Pensacola Naval Air Station in Florida, working with NASA's Coriolis Acceleration Platform, has shown human performance not to be significantly impaired with "spacecraft" rotation up to 5 rpm.

A basic consideration of gravity effects on cellular level will be explored in NASA's Biosatellite Program (11). These cellular effects must ultimately have their explanation in the physical behavior of matter within cells. Gravity-influenced behaviors such as protoplasmic streaming, nutrient and waste transport, and sedimentation of cell constituents will be closely studied. In addition scientists wish to investigate cellular reproduction and early development under zero gravity. Frog and aquatic insect eggs show a strong gravity orientation during early cleavages. If frog eggs are rotated so that the animal pole is held downward following the first cleavage, two abnormal animals result, united like siamese twins. It appears that early development may be controlled in part by the distribution of certain intracellular components brought about by gravity orientation. Under conditions of weightlessness this distribution may be affected and result in aberrant development.

Lyon, in 1963, suggested that the directional growth of plants and plant roots is probably due to a sedimentation phenomenon and plant hormones (9). The recent work of Katsuzuki Yokoyama, NASA Ames Research Center, Moffett Field, California, has proven that the direction of plant growth is extremely gravity dependent. In what direction will plants grow in the zero gravity of space? A simulation of zero gravity or more precisely randomization of directionality is provided by the clinostat in which the plant is rotated so that the pull of gravity is continual and is in all directions. It was shown that certain plants grew slowly and developed fewer and smaller leaves; while others had about 25 percent greater replication of fronds and had greater elongation of certain plant parts (13). It will be extremely interesting to compare the effects under zero conditions in the orbiting spacecraft. (See Figures 1, 2, 3, 4, Experiment 1.)

Absence of gravity may have far-reaching consequences in the homeostatic aspects of cell physiology. The outstanding characteristics of living cells which are most likely to be influenced by the absence of gravity are: the capability of the cell to maintain its cytoplasmic membrane in a functional state, the capacity of the cell to perform its normal functions during the mitotic cycle, and the capacity of the cytoplasm to maintain the constant reversibility of its sol-gel system (13).

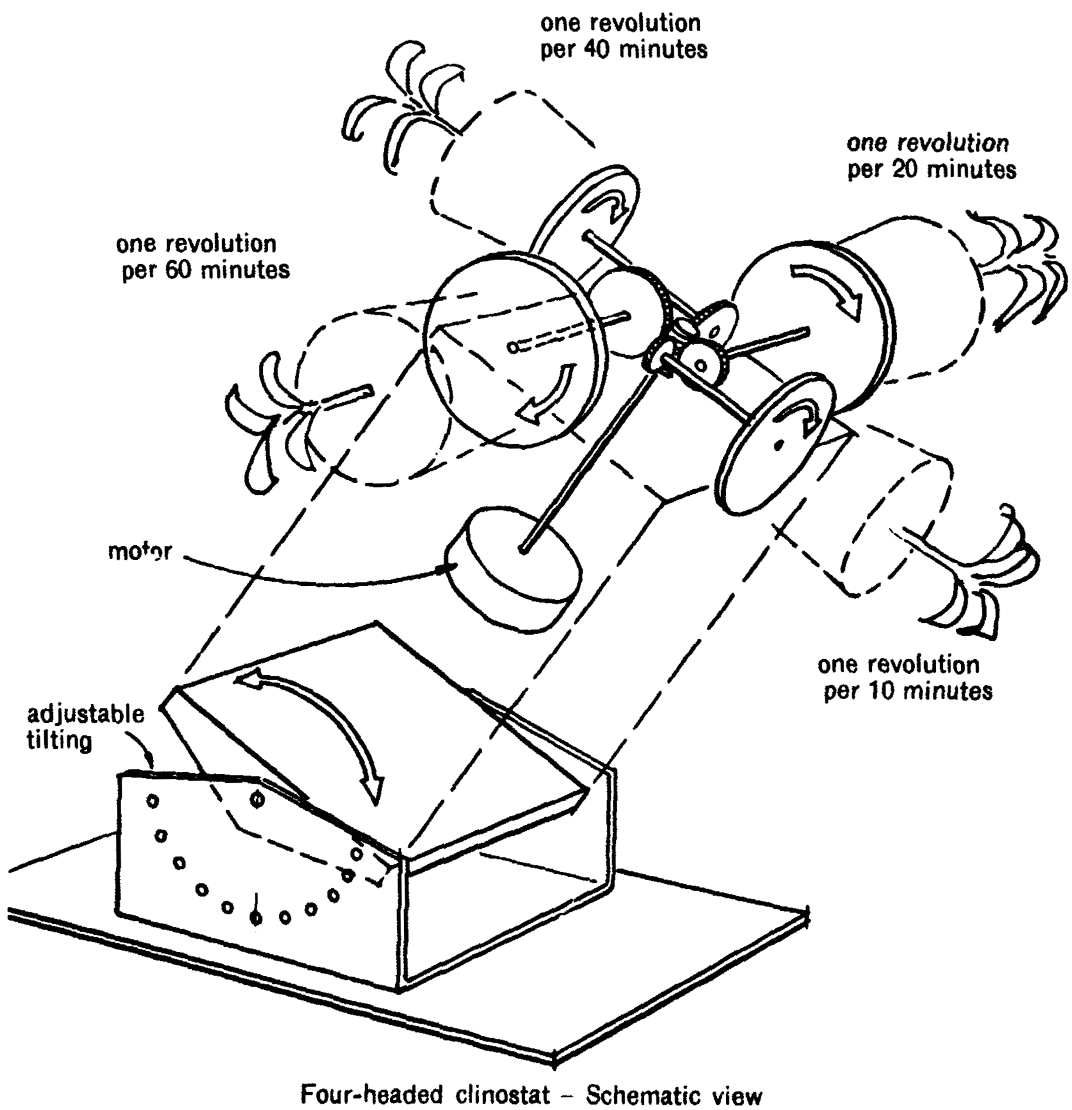
SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

1. *Gravity Orientation.* Wheat seeds, oats, beans and peppers with endosperm kept moist are rotated along various axes. At intervals of about one hour and continuing for forty-eight or more consecutive readings, measurements of root growth and angulation can be made and compared to nonrotated specimens. Using a clinostat one can study patterns of growth and development of roots, stems, leaves and flowers on agar grown seedlings in petri plates and tubes. After germination the plants can be transplanted to pots and the studies continued. Try a series of experiments at various inclinations. The results will be highly stimulating to all concerned: such experiments may have great significance relative to raising food on long space voyages and in manned orbiting research laboratories (MORL). An electric clock motor is suitable for use as the clinostat rotator. See Circadian Rhythms chapter for a description of how to use such a motor for various rotational speeds. Another suitable motor is a Synchron BH14RD-5, 4 rpm, 110 v., 60 c., 5 w. Motors which permit fewer rpm are more desirable for clinostat use, however.

2. *Development Aberrations in Frog and Aquatic Insect Embryos as a Result of Abnormal Gravity Orientation During Early Cleavage.* Fertile eggs are held upside down following first cleavage and allowed to continue development. They can be held in this position

and kept moist by constructing a glass or plastic chamber, the sides of which press onto the egg without crushing.

3. Study sea urchin egg fertilization under various conditions of temperature, centrifuging and clinostat orientations.



Four-headed clinostat - Schematic view

FIGURE 1. *Experiment 1.*

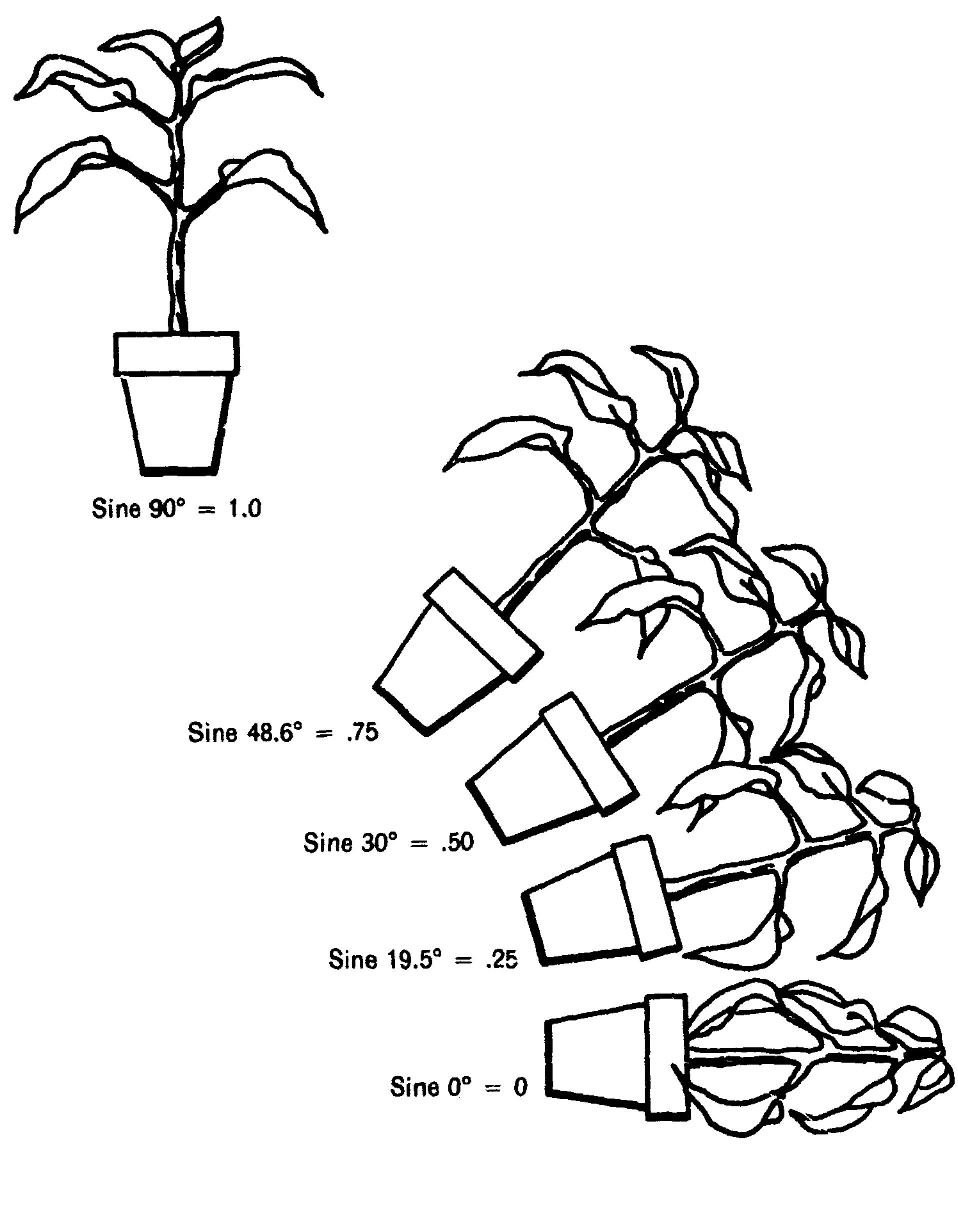


FIGURE 2. *Experiment 1.*

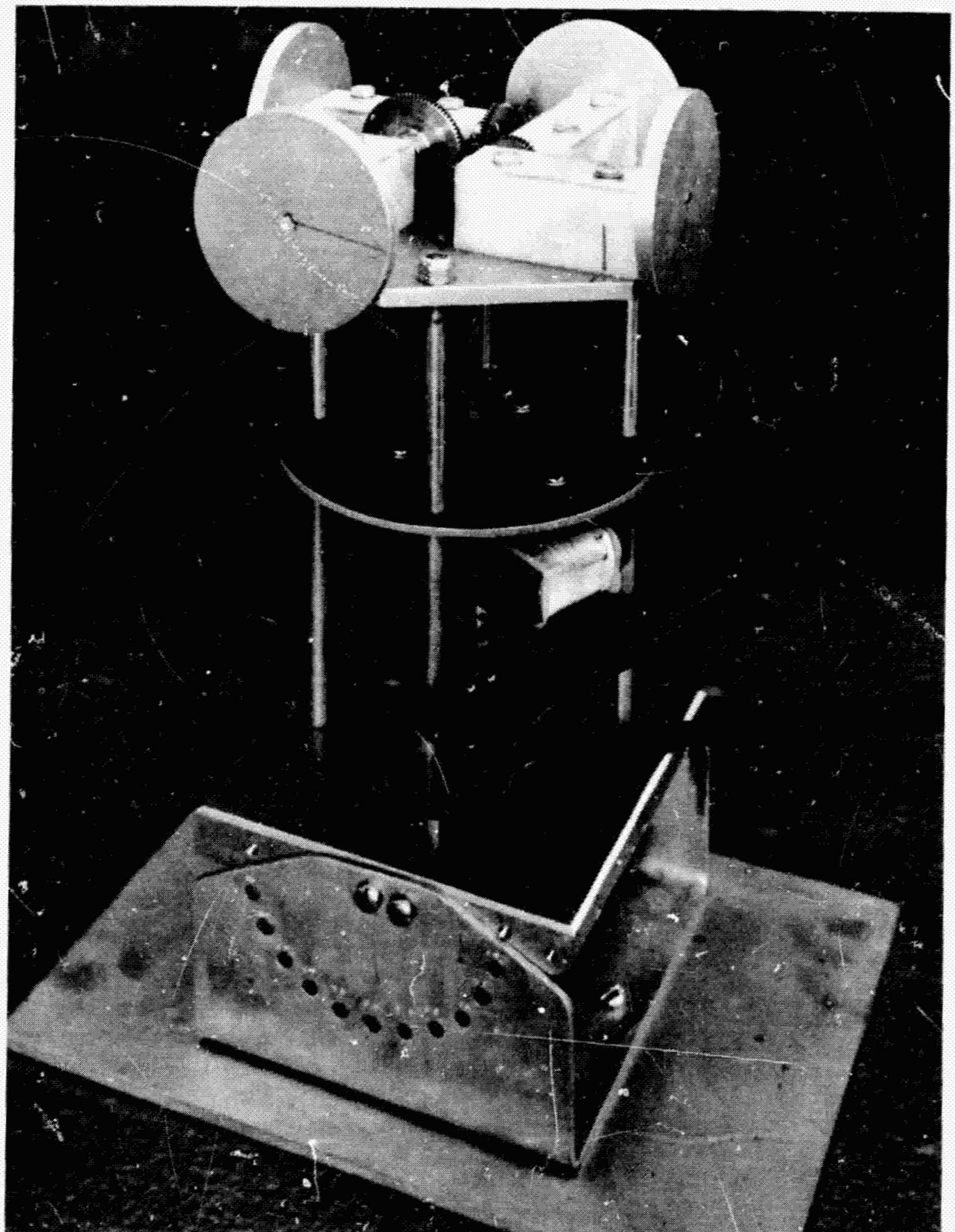


FIGURE 3. *Four-headed clinostat from Kats..zuki Yokoyama at Ames Research Center, Moffett Field, California.*

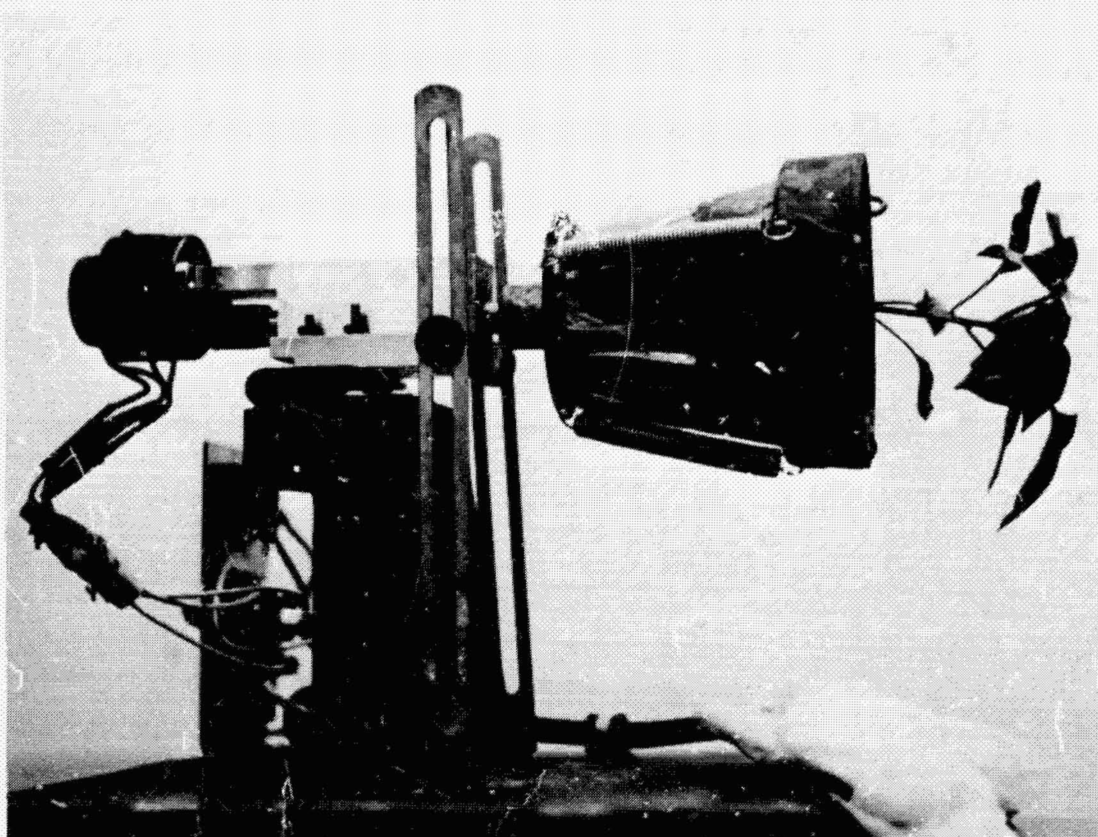


FIGURE 4. *Single-headed clinostat showing method of plant attachment, from Katsuzuki Yokoyama at Ames Research Center, Moffett Field, California.*

LITERATURE CITED

1. Brown, J. H. U. (Ed.). 1963. Physiology of man in space. Academic Press, New York.

2. Dietrick, J. E., G. D. Whedon and E. Shorr. 1948. Effects of immobilization upon various metabolic and physiological functions of normal man. American Journal of Medicine 4:3–36.

3. Gerathewohl, S. J. 1959. Weightlessness. *In* F. F. Gantz, Man in Space. Duell, Sloan and Pearce, New York.

4. Graveline, D. E., R. Balke, R. E. McKenzie and B. Hartman. 1960. Psychobiologic effects of water immersion induced hypodynamics. National Aeronautics and Space Administration, Washington, D. C.

5. Graveline, Duane E. 1961. Maintenance of cardiovascular adaptability during prolonged weightlessness. Technical Report 61-707. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

6. Hine, Charles H. 1965. Physiological effects and human tolerances. National Aeronautics and Space Administration, Washington, D. C. (N64-24610).

7. Lansberg, M. P. 1960. Some consequences of weightlessness and artificial weight. Journal Brit. Interplanetary Soc. 17.

8. Lawton, R. W. 1962. Physiological considerations relevant to the problem of prolonged weightlessness: a review. Astronautical Sciences Review 4:1-16.

9. Lyon, C. J. 1963. Auxin transport in leaf epinasty. Plant Physiology 38:567-574.

10. McKinney, R., M. Montgomery and C. F. Gell. 1963. A study of the effects of zero gravity on cell physiology 14:291-306. *In* E. T. Benedikt and R. W. Halliburton (Eds.), Physical and biological phenomena in a weightless state. Advances in the Astronautical Sciences, Western Periodicals Company, North Hollywood, California.

11. National Aeronautics and Space Administration—Ames Research Center. 1965. Publication A6824. Biosatellite project. Ames Research Center, Moffett Field, California.

12. Simons, John E. and Melvin S. Gardner. March 1963. Weightless men, a survey of sensations of performance while free floating. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

13. Space Science Board, Committee on Environmental Biology. 1964. Report of Panel on Gravity. Space Science Board, Washington, D. C.

14. Starkey, D. G. 1959. CVA Report E9R-12349. Astronautics Division, Chance Vought Aircraft, Inc., Dallas, Texas.

section 2

PHYSIOLOGICAL ASPECTS

ACCELERATION AND VIBRATION STRESS

While reading this report, you are held in your chair with a force of one gravitational unit or 1 g. During take-off acceleration, the astronaut is pressed into his seat by forces equalling 6 to 10 g's. Under these conditions a person could weigh up to 10 times his present weight. Normal physiology and performance efficiency are greatly modified by "g" forces of this magnitude. The extent of the impairment depends upon several factors; the rate of onset, the duration and in particular the direction of acceleration related to body position (Figure 1). The physiological systems most seriously affected by acceleration forces are the cardiovascular and respiratory mechanisms.

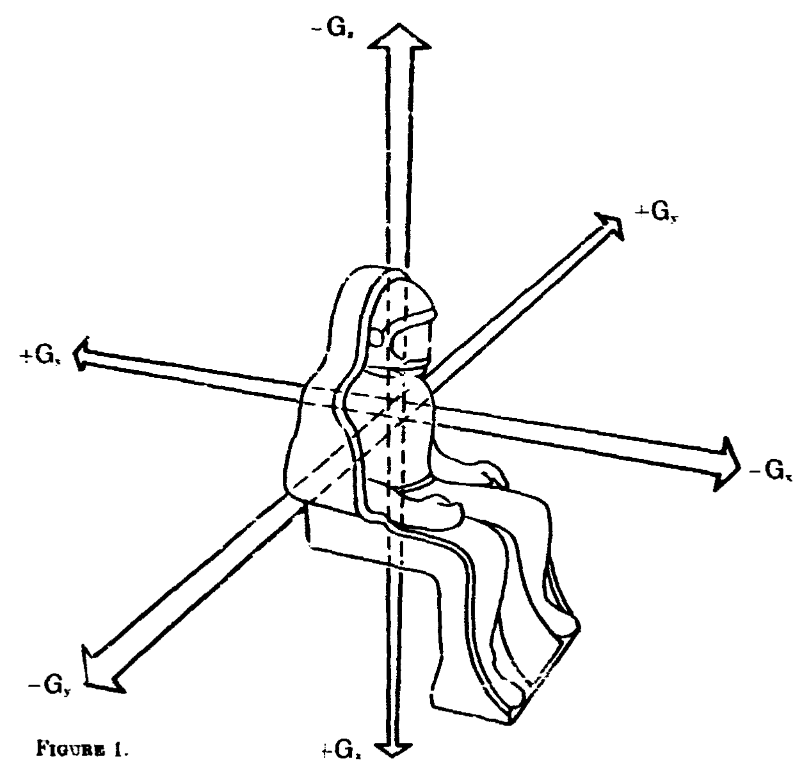


Figure 1.

When a seated astronaut is accelerated along the $-G_z$ axis (Figure 1), cerebral blood flow is greatly impaired. In addition, decreased retinal blood flow results in initial dimming of vision at 3 g's with total visual blackout at 5 g's (2). The rod and cone cells of the retina are extremely sensitive to oxygen lack and fail to respond to light stimuli if deprived of oxygen for just a few seconds. The resulting blindness is not necessarily accompanied by loss of consciousness. In fact, there may be no evidence of hearing loss or unconsciousness while completely blinded due to retinal hypoxia. This can be easily demonstrated by partially occluding the retinal arterial blood supply with your finger. The retinal rods and cones quickly fail and reversible "blindness" results. Close your eyes and place your index finger at the lateral margin of each eyelid. With your finger held in position, open your eyes and press gently but firmly against the eyeball. This pressure occludes the arterial blood supply and hypoxia blindness quickly ensues.

Since these visual effects occur with accelerations of 4 to 5 g's along the $-G_z$ axis, obviously the astronaut would be unable to function visually during take-off acceleration if he were seated in this ($-G_z$) position within the space capsule. During take-off, the astronaut is subjected to acceleration forces of 6 to 10 g's.

Experimentation with the human centrifuge has shown man's tolerance to acceleration stress to be greatest when the acceleration is along the $-G_x$ axis (3). In this position, where the acceleration vector is perpendicular to the body axis, no visual or cerebral symptoms are associated with acceleration up to 20 g's. The only vascular effect at such high levels of acceleration is on the small blood vessels of the skin where petechial hemorrhages occur in those areas not supported to afford counterpressure. Adequate support with body-contoured chairs greatly reduces this hemorrhagic response.

However, $-G_x$ acceleration produces marked anatomical changes in the dimensions of the thorax. Roentgenograms taken during $-G_x$ acceleration detect a considerable decrease in the ventro-dorsal diameter of the thoracic cage. In addition, the diaphragm is displaced upward by the abdominal contents (8). These anatomical alterations greatly restrict the respiratory mechanism. With $-G_x$ acceleration forces of 10 to 14 g's, the amount of air which can be voluntarily ventilated (vital capacity) may be reduced by 80%. Above 12 g's this vital capacity is so greatly reduced that oxygenation of the blood is below viable limits (4). Breathing 99.6% oxygen during acceleration can delay hypoxia effects but not prevent them. In summary, respiratory physiology is severely affected by $-G_x$ acceleration as a result of increased weight of the thoracic wall and abdominal contents which immobilize the thorax and diaphragm and, therefore, alter normal ventilation mechanisms.

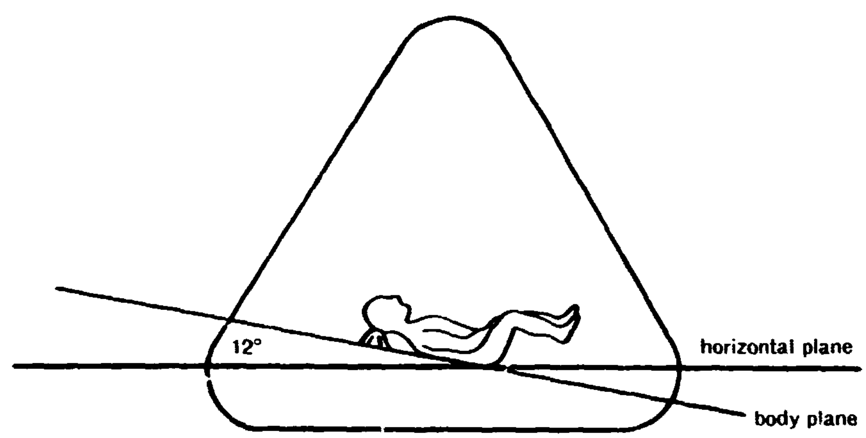


FIGURE 2.

In view of these physiologic responses, NASA's Manned Spacecraft Center staff at Houston, Texas, has experimented with pilot postures within the capsule to determine which posture minimizes the adverse effects of acceleration. The most favorable position appears to be a modified reclining position with the body angle of 12° with respect to the spacecraft's horizontal axis (1) (Figure 2). This research has shown no variation in acceleration tolerance when the hip is flexed. This position is, therefore, assumed by the astronaut not only for eventual orbital posture orientation, but also for arterial hypotension compensation. Positive pressure suits or bladders could also support the peripheral vascular system and reduce hypotension resulting from any $-G_z$ acceleration component.

In addition to the physiologic stresses of acceleration forces, one must also evaluate the degree of impaired judgment and performance with particular reference to accuracy and competency of coordination of responses. The astronaut must be able to pilot his vehicle during acceleration. Therefore, both physiologic and performance considerations must be carefully evaluated before the astronaut is subjected to "g" forces of acceleration.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Acceleration Stress

1. Study the effect of simulated "g" forces on chicks, using a turntable.
2. Study the effect of simulated "g" forces on mice, frogs, fish, lizards, snails or potted plants.

Considerable vibration is experienced by astronauts during lift-off and boost phases of space flight and also during re-entry into the earth's atmosphere. Such vibration consists of forces of various directions, magnitudes and frequencies and of a periodic and oscillatory nature (11).

Roman and Coerrman (10) have shown that certain frequencies of vibrations are more damaging to mice than others. Several studies of vibration tolerances of humans at constant acceleration have been made. These also indicate variations in the human vibration tolerance curves (6). Work done at the Naval Medical Acceleration Laboratory in Johnsville, Pennsylvania, showed that a human exposed to a 20–25 cycle-per-second (cps) vibration evidenced nausea, internal bleeding and cramps. Other symptoms of humans exposed to vibration at frequencies from 1–20 cps have been described (7, 9). These include head pain, blurred vision and a painful lump in the throat. At 6–8 cps, the jaw resonates so as to make it impossible to speak. Heart and lung displacement may cause chest pain. Abdominal pain and pelvic pain have been found to be associated with distortion and stretching of internal structures. Post-experimental weariness has also been found to be associated with exposure to vibration.

It will be important for man to be able to continue to make quick decisions and responses under conditions of much noise and vibration. Therefore, basic knowledge of man's ability to perform under vibration stress is vital. It appears that considerable physiological investigation remains to be done in this field.

Vibration Stress

The Effect of Vibration on Human Performance and Reaction.

Introduction

Changes in human reaction time under two conditions of vibration stress will be studied.

Purpose

The purpose of this experiment is to examine human performance under simulated conditions of lift-off or re-entry vibration. Two types of reaction times will be determined, one involving reaction to a visual stimulus and the other involving reaction to an audible command (5).

Materials

1. Chair with arms
2. One wide belt
3. Large sponges
4. Scale (meter stick or calibrated dowel)
5. Ring stand with two ring clamps

Procedure

The "astronaut" is seated, and harnessed into a chair by means of a belt placed across the diaphragm. The legs of the chair are placed on large sponges or similar material (i.e., foam rubber, coiled springs), so that the chair can easily be agitated by two students. The vibrations need not be gross and exaggerated, but uniform. Experimentally, the class might try conducting the experiments for three levels of vibrations (weak moderate and strong).

Align two ring clamps on a ring stand in such a manner that a scale will fall freely through the rings. The "astronaut's" hand is placed under the bottom ring and rests comfortably on the base of the stand. The "astronaut's" fingers are positioned ready to pinch the scale as it falls between them. The scale is aligned so that it falls freely between the index finger and the thumb of the "astronaut." The scale is held so that readings can be made showing distance it has fallen when caught.

Reaction Time to a Visual Stimulus

The student holds the scale in position. The "astronaut" is informed to pinch the scale at the moment he sees it begin to fall. When released and pinched by the "astronaut," a recorder can read the scale to see how far it fell. This measurement can be carefully made while the "astronaut" continues to hold the scale between his fingers. In order to obtain controlled values for comparison, this test should be conducted ten times without vibration. Determine the normal average reaction time. The results could be graphed for each trial. The same number of trials are conducted while the "astronaut" is undergoing "space flight vibration." Compare both results. What is the effect of vibration? What effect does the vibration have on his reaction time and how might this response affect human performance during lift-off and re-entry?

Reaction to an Audible Command

The experiment is conducted as before, but the "astronaut" will pinch the scale in response to a command given by a student or a signal from a buzzer. A student observer will give the command "mark" and immediately release the scale. Once the scale is caught, the student observer will determine how far it fell, which is a measure of the reaction time. Perform several control experiments without vibration stress and determine the normal response. What is the effect of vibration stress on reaction time to an audible command? How might this response affect space flight?

Additional Questions Relating to Reaction Time

1. What is the combined effect of noise and vibration on reaction time?
2. How is reaction time affected by long-term periods of confinement and silence?
3. To what extent is reaction time affected by colored lights?
4. What is the effect of fatigue and monotony on reaction time?

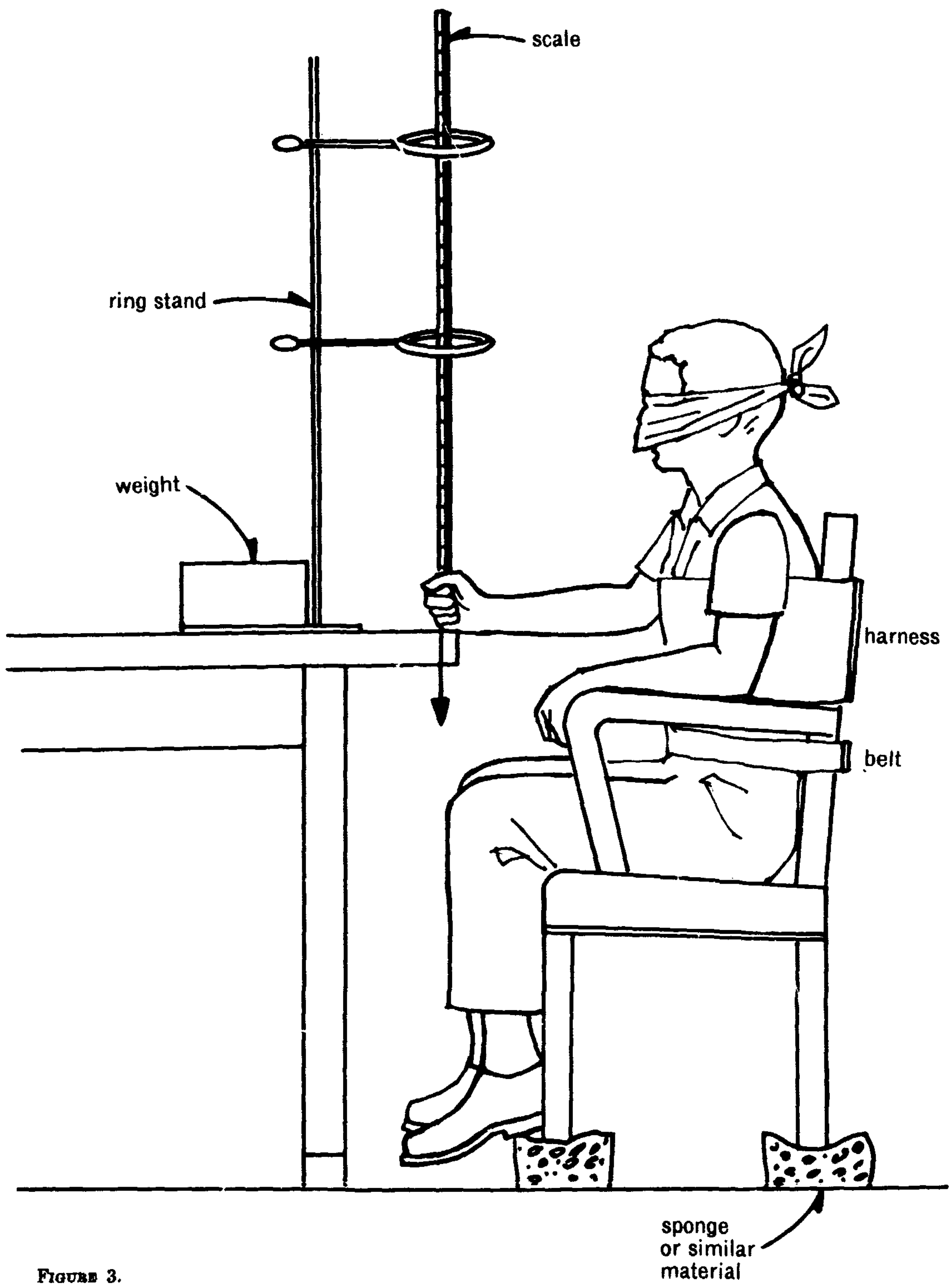

scale
ring stand
weight
harness
belt
sponge
or similar
material

FIGURE 3.

Additional Suggestions for Investigation

1. An alternative procedure—have a seated "astronaut" hold a stopwatch in his hand. He will start the watch and an observer, at a specified time, will sound a buzzer and the time it takes the "astronaut" to stop the watch will be recorded.

2. An amoeba experiment to study the reactions of a normal large cell. Use the largest amoeba available, probably genus *Pelomyxa* (*Chaos*). Experiments which could be done on amoebae that would tie in with studies would be reactions of the protozoans to vibration, noise, radiation, speed, centrifugal stress and possibly to the effects of magnetism.

3. Subject fruit flies, *Drosophila melanogaster*, to mechanical vibrations of 10–80 cps and study comparative mutation rates against normally reared control flies.

4. Carry on sound vibration experiments in similar fashion.

5. Dr. Don Eckbert of General Electric, Valley Forge, Pennsylvania, suggested that vibration experiments and sound irritation experiments might be conceived using tuning forks or a speaker cone from a radio set ranging between 2 and 2,000 cycles. It has been discovered that 60 to 80 cycles per second is a critical range resulting in chromosome aberrations above that point. Humans can tolerate apparently somewhat less than 10 cycles per second. Dr. Eckbert also suggests the possibility of an accelerometer experiment in order to measure toleration to various rates.

LITERATURE CITED

1. Alexander, W. Carter. 1964. Unpublished data. National Aeronautics and Space Administration Manned Spacecraft Center, Houston, Texas. Quoted from Bioastronautics data book, p. 51. Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D. C. (NASA SP–3006).

2. Brown, J. H. U. (Ed.). 1963. Physiology of man in space. Academic Press, New York and London.

3. Chamber, R. M. 1963. Operator performance in acceleration environment, p. 193–320. *In* Burns, Neal M., Randall Chambers and Edwin Hendler (Eds.), Unusual environments and human behavior. The Free Press of Glencoe, The Macmillan Company, New York.

4. Cherniak, N. S., A. S. Hyde and F. W. Zechman, Jr. 1959. Effect of transverse acceleration on pulmonary function. Journal of Applied Physiology 14:914–916.

5. Clark, Carl C. 1962. Human control performance and tolerance under severe complex vibrations with a preliminary historical review of flight simulation. The Martin Company, Baltimore, Maryland.

6. Goldman, D. F. and H. Von Gierke. 1960. The effects of shock and vibration on man. Report 60:3, Naval Medical Research Institute, Bethesda, Maryland.

7. Hardy, James D. 1964. Acceleration, p. 152–195. *In* James D. Hardy (Ed.), Physiological problems in space exploration. Charles C Thomas, Publisher, Springfield, Illinois.

8. Hershgold, E. J. 1960. Roentgenographic study of human subjects during transverse accelerations. Aerospace Medicine 31: 213–219.

9. Magid, Captain Ed B., R. Coerrman and G. H. Ziegenrvecker. 1960. Human tolerance to whole body sinusoidal vibration. Journal of Aviation Medicine 31:915.

10. Roman, Captain James A. and R. Coerrman. 1959. Vibration buffeting and impact research. Journal of Aviation Medicine 31:118.

11. Von Gierke, Henning E. 1964. Transient acceleration, vibration and noise problems in space flight, p. 27–75. *In* Karl E. Shaefer (Ed.), Bioastronautics. The Macmillan Company, New York.

section 2

PHYSIOLOGICAL ASPECTS

RADIATION

The hazardous radiations to be encountered by outer space voyagers involve energy ranges of great magnitudes. The ionizing radiations of outer space include energies in the range of 1/1000 MeV (million electron volts) up to 10 trillion MeV (31). The term "ionizing" refers to the interaction of atomic radiation with matter. This interaction involves molecular collisions during penetration, in which positive and negative ions are formed along the path of the incident radiation. This radiation consists of a particulate component made up of electrons, protons, neutrons and atomic nuclei.

In addition, there is often an electromagnetic component which includes the ultraviolet, gamma and X-rays (Table 1). The ionizing radiations of outer space are derived principally from three sources: the primary cosmic radiation, geomagnetically trapped radiations of Van Allen, and solar flare emissions. Cosmic radiation is probably the least understood even though numerous experiments have been conducted in this area for the last thirty years. No clear understanding has emerged in regard to safe or tolerable levels.

The composition of cosmic radiation was established in 1948 (11). Cosmic radiation consists largely of protons (hydrogen nuclei) and alpha particles (helium nuclei). However, the nuclei of heavier elements such as iron can also be found in cosmic radiation. Cosmic rays approach the earth from all directions and evidence indicates their origin is beyond our solar system (Table 1).

The atmosphere of the earth provides an effective shield against much cosmic radiation. The one-hundred-mile atmosphere of earth has a shielding power equivalent to three feet of lead (24). However, the higher energy components of cosmic radiation can easily penetrate the atmosphere and several hundred feet of earth as well. The biologic effects of this penetrating radiation are not clearly established.

The radiation exposure outside of the protection of the atmosphere will be considerably higher and will constitute an area of real concern for outer space travel.

TABLE 1 (18)

NATURE AND LOCATION OF ELECTROMAGNETIC AND PARTICULATE IONIZING RADIATIONS IN SPACE

Name	Nature of Radiation	Charge	Mass	Where Found
Photon	Electromagnetic	0	0	Radiation belts, solar radiation (produced by nuclear reactions and by stopping electrons) and everywhere in space.
X-ray	Electromagnetic	0	0	
Gamma ray	Electromagnetic	0	0	
Electron	Particle	$-e$	1 m*	Radiation belt and elsewhere.
Proton	Particle	$+e$	1840 m*	Primary cosmic rays, radiation belt, solar flares.
Neutron	Particle	0	1841 m*	Secondary particles produced by nuclear interactions involving primary particle flux.
Alpha particle	Particle	$+2e$	4 amu	Primary cosmic radiation (nucleus of helium atom).
Heavy primary nuclei	Particle	$\geq +3e$	$\geq$6amu	Primary cosmic radiation (nuclei of heavier atoms).

m = mass electron*
amu = atomic mass unit

Radiation exposure to astronauts in low-level orbits is greatly reduced by the shielding of the atmosphere. Also, the Earth's magnetic field diverts a portion of outer space radiation. In addition, the Earth itself shields the astronaut, since portions of outer space radiation are kept from the astronaut by the Earth's mass.

In addition to the primary cosmic radiation, the space traveler will encounter a secondary cosmic radiation hazard with potentially more serious consequences. As the cosmic radiation passes through matter, it dissipates portions of its energy in collisions with electrons and atomic nuclei. A primary cosmic particle may collide directly with another atomic nucleus and the resulting explosion scatters atomic debris in all directions. This debris consists of fragmented nuclei, electrons, mesons, neutrons, positrons and other elementary particles (Figure 1).

These, in turn, may have similar collisions thus producing tertiary radiations. Therefore, the astronaut will be exposed to increased primary cosmic radiation which penetrates his vehicle and, more

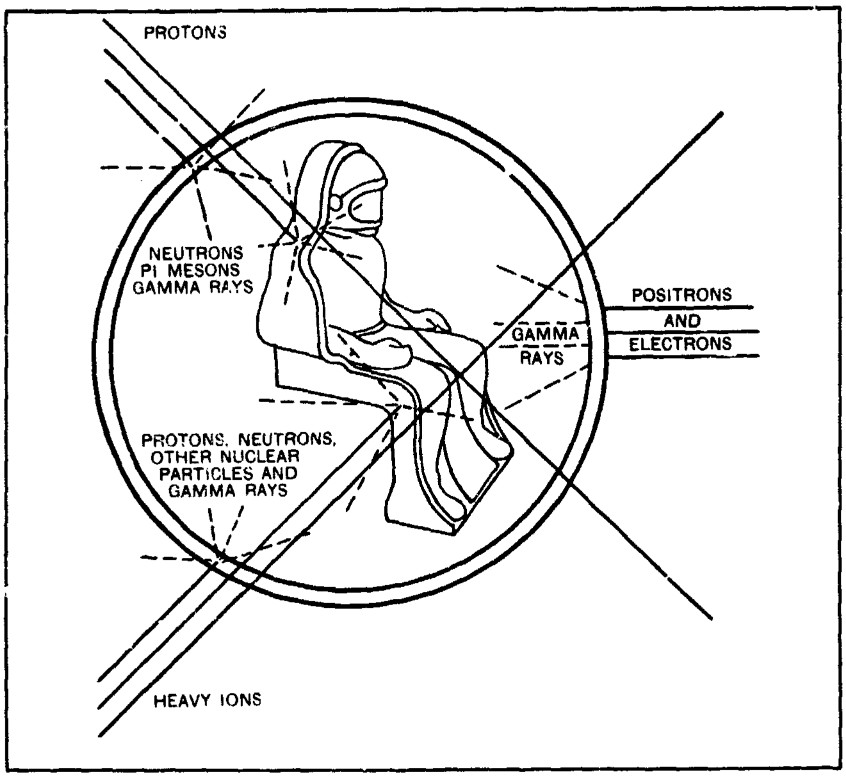


FIGURE 1. *The fates of particles meeting a manned vehicle. Electrons and positrons are stopped by the vehicle wall, which then emits the bremsstrahlung (gamma rays). Protons and heavy ions may hit a target in the wall, or within the cabin, or they may pass right through. Wherever a target is hit, these particles produce characteristic showers of secondary particles, as shown (31).*

important, he will be exposed to the intense secondary radiation resulting from collisions between cosmic radiation and the material of his spacecraft (23, 8).

In this regard, shielding may augment the secondary radiation rather than provide protection to the pilot. Many scientists have estimated that the space traveler will encounter radiation many times greater than the maximum permissible exposure from cosmic radiation alone (30). However, the hazards of cosmic radiation continue to be a matter of conjecture since the relative biologic effects have not yet been clearly established.

United States and Russian space probes have mapped geomagnetically trapped belts of protons and electrons (Van Allen). It appears that personnel in spacecraft launched into outer space with minimal shielding might be exposed to 2–50 roentgens as they traverse these belts (3) (Figure 2).

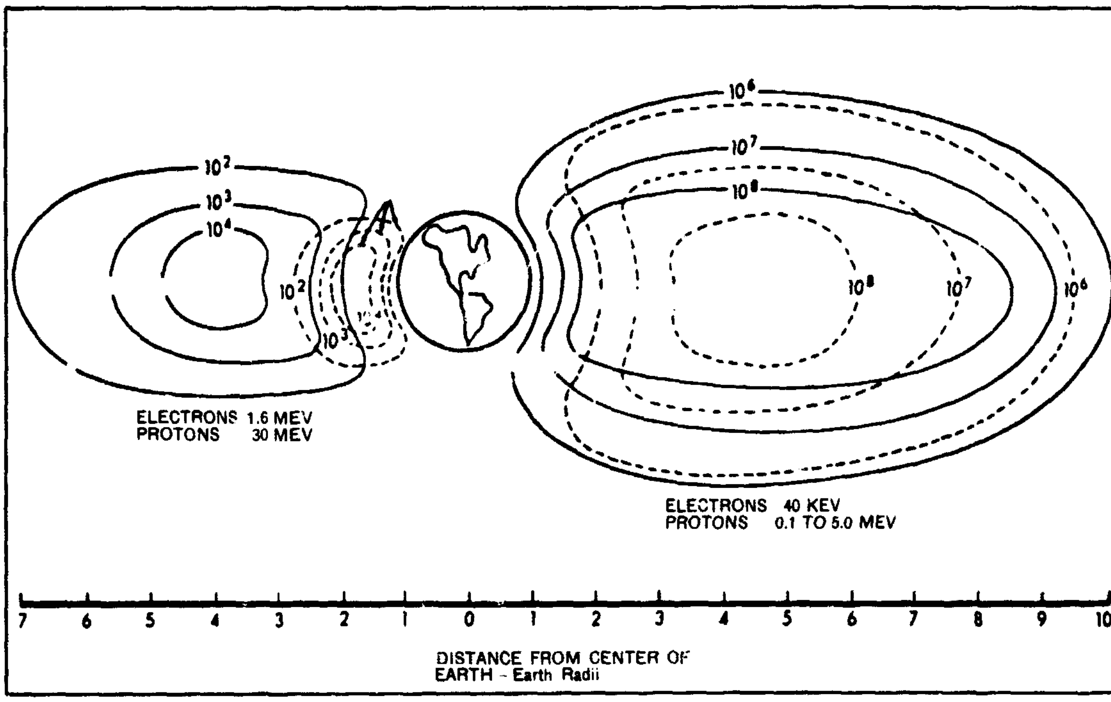


FIGURE 2. *Trapped radiation and solar protons. This is a representation of the radiations trapped in the Earth's magnetic field, known as the "Van Allen belts" (3).*

There is little evidence of biologic damage in these dose ranges. However, the cumulative effect of all outer space radiation may constitute a serious biologic hazard.

The trapped radiation within the Van Allen belts combined with solar source radiation and cosmic rays may expose the space voyager to doses of 200 rad (1[illegible]). This dose is presently considered tolerable, but undesirable. Man is relatively radiosensitive with a lower medial lethal whole body dose of approximately 450 rad. However, the tissues of man show variable radiosensitivity.

Some tissues, including the skin, are comparatively resistant. Also, damaged or destroyed epidermal cells can easily be replaced. Nerve tissue, however, is nonregenerative. Fortunately, however, considerable loss is possible before obvious impairment results. Reproductive and embryonic cells are extremely sensitive to radiation.

In this regard, as one assesses the biologic effects of radiation, the distinction must be made between specific physiologic injury and

TABLE 2 (4) **RADIATION DAMAGE TO HUMAN MALE GONADS**

Dose	Response
100 rad	Reduced fertility; reduced sperm count and increased frequency of abnormal sperm
200–300 rad	Temporary sterility for approximately 12 to 15 months.
400–500 rad	Temporary sterility for 18 to 24 months.
500–600 rad	Permanent sterility probably, if individual survives.

TABLE 3 (15) **EXPECTED EFFECTS FROM ACUTE WHOLE-BODY RADIATION IN MAN**

Dose in rads	Probable Effect
0 to 50	No obvious effect except, possibly, minor blood changes.
50 to 100	Vomiting and nausea for about 1 day in 5 to 10% of exposed personnel. Fatigue, but no serious disability. Transient reduction in lymphocytes and neutrophils.
100 to 200	Vomiting and nausea for about 1 day, followed by other symptoms of radiation sickness in about 25 to 50% of personnel. No deaths anticipated. A reduction of approximately 50% in lymphocytes and neutrophils will occur.
200 to 350	Vomiting and nausea in nearly all personnel on first day followed by other symptoms of radiation sickness, e.g., loss of appetite, diarrhea, minor hemorrhage. About 20% deaths within 2 to 6 weeks after exposure. Survivors convalescent for about 3 months.
350 to 550	Vomiting and nausea in most personnel on first day, followed by other symptoms of radiation sickness, e.g., fever, hemorrhage, diarrhea, emaciation. About 50% deaths within 1 month; survivors convalescent for about 6 months.
550 to 750	Vomiting and nausea, or at least nausea, in all personnel within four hours after exposure, followed by severe symptoms of radiation sickness, as above. Up to 100% deaths; few survivors convalescent for about six months.
1000	Vomiting and nausea in all personnel within 1 to 2 hours. Probably no survivors from radiation sickness.
5000	Incapacitation almost immediately (several hours). All personnel will be fatalities within one week.

long-range population effects. Table 2 indicates the sensitivity of the male gonads to radiation while Table 3 itemizes the more significant effects of acute whole-body radiation.

Duplication of all outer space radiation energies with accelerators is not possible at this time. Therefore, a valid evaluation of the biologic effect of outer space radiation will most likely come from space probes containing organisms exposed to this radiation for considerable lengths of time. The biosatellite will be the first extensive endeavor to evaluate the biologic effects of outer space radiation.

Recent Investigations on Radiation Effects

During the past decade both the study of the biological effects of radiation and the use of radioactive isotopes have become increasingly common in the high school biology laboratory. This is, in part, due to the special training which thousands of biology teachers have received at Atomic Energy Commission-National Science Foundation Summer Institutes in Radiation Biology. It is due also to the availability of a number of excellent publications containing laboratory procedures in radiobiology.

The majority of the experiments described in these publications deal with the use of radioisotopes as tracers. Certain of the others, however, may be suitable for use in introducing students to the problems of radiation safety during space flights.

Procedures for experiments involving irradiated dormant seeds, for example, have been outlined by Hermias and Joecile (13), Lang (17), Shaw (27), and others. Seeds may be irradiated locally, or they may be obtained from any one of several commercial suppliers.

A second, and perhaps more unique, approach to the subject of radiation in space might be made through a study of some of the experiments currently being undertaken as part of NASA's Biosatellite Project. The three-day flight of the Biosatellite Project (also included is a twenty-one-day flight and a thirty-day flight) is scheduled to include seven radiation biology experiments (1). These are primarily genetic in nature and will involve lysogenic bacteria (*E. coli*), mold spores (*Neurospora*), a higher plant (*Tradescantia*), and an insect (*Drosophila*). An experiment to study the effects of radiation on wing abnormalities in a flour beetle (*Tribolium*) will also be included in the three-day Biosatellite flight. The principal investigators are Dr. John V. Slater and Dr. Brenda Buckhold of the University of California, Berkeley. *Tribolium* larvae will be exposed at zero gravity to 1200 rads of gamma radiation, and then compared to non-irradiated flight and ground controls in regard to wing abnormalities.

The confused flour beetle, *Tribolium confusum* Duval, has recently been found to be of much interest in radiobiological studies (29). This 4 mm reddish-brown beetle is a cosmopolitan species, and a common granary and pantry pest. The adult beetles, when subjected to various forms of irradiation during the pupa stage, exhibit a number of wing abnormalities. These indicate that radiation-induced injury was received during embryonic development. The membranous wings and elytra may be warped, and are displaced from the normal position. The membranous wings may be blistered and they may not fold properly beneath the elytra (2).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

1. Students may rear flour beetles in whole wheat flour mixed with from 2–4% nutrient yeast powder (2, 29), or by using one of the methods suggested by Park (20). Quart jars with perforated tops may be used as containers, and the cultures may be incubated in the dark at 30° C. (28).

   The insects may be separated from the medium with a 20 mesh/inch soil sieve, and the pupae may be removed from the sieve with a camel's hair brush and placed in petri dishes for irradiation. If the cultures are cleared of pupae (the pupa stage lasts six days), and subsequently developed pupae are harvested at known times after clearing, pupae of an approximate known age can be collected (28). This is necessary because it has been found that pupae of *Tribolium* are radiosensitive for only thirty-two hours after their formation (29).

   The pupae may be irradiated with X or gamma radiation. A dose of 1200 rads will ordinarily produce about 12% abnormalities (however, if given over the entire radiosensitive period, none are produced). Cobalt 60 therapy units may be used to supply gamma irradiation, or an X-ray therapy unit may be used to obtain the desired exposure. Settings used by Lang (17) for irradiating seeds with doses of 1000 roentgens were: 200 kilovolt potential (KVP) at 15 milliamps (m.a.), no filter, with an exposure distance of 25 centimeters for 78 seconds. With a General Electric 250 KVP Maxitron X-ray machine operated at 30 m.a. and 250 KVP, filtered with 1.2 mm of aluminum, a dose rate of 1425 roentgens/minute may be obtained 23 cm from the target (27). Settings such as these may serve as a guide for determination of *Tribolium* irradiation exposures.

2. Ultraviolet light may also be used to irradiate *Tribolium* pupae (6, 25, 26). This may be done fairly easily in the high school biology laboratory, and may present an opportunity to illustrate synergistic factors (combined factors working together) which influence the embryonic differentiation and development of *Tribolium*. A group of pupae may be irradiated with ultraviolet light and then incubated, some at 30° C. and some at 38° C. It has been found that when the pupae are exposed to a small amount of radiation and the temperature is raised, the number of abnormalities do not merely double, but increase three or four times.

3. A variety of other conditions including vibration (shaking on a screen), ether vapor exposure, lowered temperatures, and an increase in CO_2 content, all mimic radiation-produced effects in *Tribolium*. Even the pressure applied while handling or transferring

the pupae can produce an increase in the number of abnormalities. During routine handling of *Tribolium* pupae even slight downward pressure on the pupae can raise the control abnormalities 1–2% (29). The importance of adequate controls as well as extreme care during handling must be stressed.

4. Students may also be interested in making comparisons between *T. confusum* and the red flour beetle, *T. castaneum* (Herbst). The effect upon longevity of *Tribolium* adults of a single dose of X-ray or gamma radiation may also be determined by students, by modifying the procedures outlined by Cork (9), or Cornwell, Crook and Bull (10). An excellent summary of other recent work on insect control by irradiation may be found in O'Brien and Wolfe (19).

Biosatellite Radiation Experiments

A brief description of the other six Biosatellite Project radiation biology experiments may serve to suggest other student research problems. Because it has been estimated that space radiation will be less than 3 rads for the three days of flight, a 1.25 curie source of Sr^{85} wil be flown with the experiments. This source will deliver from 300 to 6000 rads to separate experiments, depending on location in the capsule (1).

1. Chromosomal mutations in *Neurospora* will be studied by exposing conidia to a combination of gamma radiation and zero gravity. The conidia packages will receive from 500 to 6000 rads of radiation. Any mutational changes will be compared to ground controls to discover any synergism or antagonism between radiation and zero gravity. The principal investigator is Dr. Frederick J. de Serres, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

2. Budded stalks of *Tradescantia*, heterozygous for color, and growing in a nutrient-containing, water-tight stalk holder, will be irradiated with 300 rads of gamma radiation at zero gravity. The flowering stalks will be examined after recovery, to determine changes in color in a linear series of cells which comprise the stamen hairs. The principal investigator is Dr. A. H. Sparrow, Brookhaven National Laboratory, Long Island, New York.

3. A known genetic strain of female *Drosophila*, previously mated with known genetic males, will be exposed to 2000 rads of gamma radiation at zero gravity. Successive generations will be studied for post-flight genetic damage to maternal and paternal reproductive cells. The principal investigators are Dr. E. A. Altenberg and Dr. L. Browning, Rice Institute, Houston, Texas.

4. Larvae of *Drosophila* will be exposed to 1300 rads of gamma radiation at zero gravity. The larvae will be allowed to hatch

into adults, and histological and cytogenetic examinations will be made to compare these fruit flies with controls, especially in regard to possible somatic damage. The principal investigator is Dr. I. I. Oster, Bowling Green State University, Bowling Green, Ohio.

5. *Salmonella* bacteria will be lysed with viral materials and packages exposed to radiation doses of 500 to 2500 rads of gamma radiation at zero gravity. The viral titer will be determined and compared to controls, to ascertain whether or not viruses can proliferate within bacteria at zero gravity. The dose response curves for a number of radiogenetic endpoints will be determined in this, and other, Biosatellite experiments. The principal investigator is Dr. R. H. T. Mattoni, N. U. S. Corp., Washington, D. C.

6. Male *Habrobracon* wasps will be exposed to gamma radiation doses of from 500 to 4000 rads at zero gravity. During postflight examination the wasps will be mated to determine the extent of genetic changes, such as the appearance of dominant and recessive lethals, and chromosome translocation frequencies. Historical and cytogenetic examinations will be made. The principal investigator is Dr. R. C. von Borstel, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

   Students may wish to rear *Habrobracon* on caterpillars of the Mediterranean flour moth, *Anagasta* (*Ephestia*) *kuhniella* (Zell.). The adult wasps may be fed a honey-water mixture (7, 21, 32).

The student who wishes to experiment with the effects of ultraviolet light, X-rays or gamma radiation will find a great diversity of organisms suitable: algae, bacteria, slime molds, yeast molds, ciliates, flagellates, rhizopods, hydra, planarians, nematodes, gastrotrichs, rotifers, cladocerans, copepods, ostracods, isopods, arachnids, millipedes, annelids, as well as many species of insects. The student's opportunity of making contributions to the scientific fund of knowledge, concerning the effects of radiation on these organisms, is also great (22, 27).

LITERATURE CITED

1. Ames Research Center. 1965. Staff of experiments and life systems. Biosatellite Project experiments in review. NASA Ames Research Center, Moffett Field, California.

2. Beck, James S. 1963. Effects of X-irradiation on cell differentiation and morprogenesis in a developing beetle wing. Radiation Research 19:569–581.

3. Bouquet, Frank L. 1963. The radiation hazard of space. Space/Aeronautics, p. 72–77.

4. Brown, J. A. H. 1963. Human fertility in nuclear warfare, p. 94–107. *In* J. H. Rust and D. J. Mewissen (Eds.), Exposure of man to radiation in nuclear warfare. American Elsevier Publishing Company, Inc., New York.

5. Brown, J. H. U. (Ed.). 1963. Physiology of man in space. Academic Press, New York.

6. Buttolph, L. J. 1955. Practical applications and sources of ultraviolet light, p. 41–93. *In* Alexander Holleander (Ed.), Radiation Biology, Vol. II, Ultraviolet and related radiation. McGraw-Hill Book Company, Inc., New York.

7. Clark, Arnold M. and Mary Ann Rubin. 1961. The modification by X-irradiation of the life span of haploids and diploids of the wasp *Habrobracon* sp. Radiation Research 15:244–253.

8. Clark, Carl. 1964. High energy radiations, p. 47–99. *In* James D. Hardy (Ed.), Physiological problems in space exploration. Charles C Thomas, Publisher, Springfield, Illinois.

9. Cork, J. M. 1957. Gamma-radiation and longevity of the flour beetle. Radiation Research 7:551.

10. Cornwell, P. B., L. J. Crook and J. O. Bull. 1957. Lethal and sterilizing effects of gamma radiation on insects infesting cereal commodities. Nature 179:670.

11. Freier, Phyllis, E. J. Lofgren, E. P. Ney, F. Oppenheimer, H. L. Bradt and B. Peters. 1948a. Evidence for heavy nuclei in the primary cosmic radiation. Physical Review 74:213–217.

12. Freier, Phyllis, E. J. Lofgren, E. P. Ney, F. Oppenheimer, H. L. Bradt and B. Peters. 1948b. The heavy component of primary cosmic rays. Physical Review 74:1818–1827.

13. Hermias, Sister Mary and Sister Mary Joecile. 1963. Radioactivity: fundamentals and experiments. Holt, Rinehart & Winston, Inc., New York.

14. Hine, Charles. 1965. Physiological effects and human tolerances. National Aeronautics and Space Administration, Washington, D. C. (N 64–24610).

15. Keller, J. W. 1962. Long range NASA shielding requirements, p. 662–681. *In* Proceedings of the symposium on the protection against radiation hazards in space. United States Atomic Energy Commission, Washington, D. C. (TID–7652).

16. Kimball, R. F. 1955. The effects of radiation on protozoa and the eggs of invertebrates, other than insects, p. 285–331. *In* Alexander Holleander (Ed.), Radiation Biology, Vol. II, Ultraviolet and related radiation. McGraw-Hill Book Company, Inc., New York.

17. Lang, Clarence T. 1965. Influence of high energy radiations on dormant seeds. American Biology Teacher 27:487–492.

18. Newell, Homer E. and John E. Naugle. 1960. Radiation environment in space. Science 132:1465–1472.

19. O'Brien, R. D. and L. S. Wolfe. 1964. Radiation, radioactivity and insects. Academic Press, New York.

20. Park, Thomas. 1937. The culture of *Tribolium confusum*, p. 463–466. *In* James G. Needham (Chairman), Culture methods for invertebrate animals. Dover Publications, Inc., New York.

21. Producing mutations in wasps with X-rays. 1963. Science World, Edition 2, 13(5):22–24.

22. Reaction of amoebae to X-ray exposure. 1963. Science World, Edition 2, 13(5):26–28.

23. Saylor, W. P., D. E. Winer, C. J. Eiwen and A. W. Carriker. 1962. Space radiation guide. Technical Documentary Report No. 62–86, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

24. Schaefer, Herman J. 1955. Biological significance of the natural background of ionizing radiation—observations at sea level and at extreme altitude. Journal of Aviation Medicine 26: 453–462.

25. Scott, Jesse F. and Robert L. Sinsheimer. 1955. Technique of study of biological effects of ultraviolet irradiation, p. 119-163. *In* Alexander Holleander (Ed.), Radiation biology, Vol. II, Ultraviolet and related radiation. McGraw-Hill Book Company, Inc., New York.

26. Shankel, D. M. and O. W. Wyss. 1961. Studies on mutations induced by nonlethal dosages of ultraviolet light. Radiation Research 14:505–517.

27. Shaw, Edward I. 1963. Laboratory experiments in radiation biology. TID–18616. Division of Technical Information, U. S. Atomic Energy Commission, Washington, D.C.

28. Slater, John V., A. Rescigno, Nabil M. Amer and C. A. Tobias. 1963. Temperature dependence of wing abnormality in *Tribolium confusum*. Science 140:408–409.

29. Slater, John V., John Lyman, C. A. Tobias, N. M. Amer, J. S. Beck, Marian Beck and A. J. Slater. 1964. Heavy ion localization of sensitive embryonic sites in *Tribolium*. Radiation Research 21:541–549.

30. Tobias, Cornelius A. 1959. Radiation hazards in space flight. *In* Rudolph A. Hoffman, Radiation hazards of primary cosmic particles. Technical Report 59–32. Air Force Missile Development Center, Holloman Air Force Base, New Mexico.

31. Webb, Paul (Ed.). 1964. Radiation, p. 133–157. *In* Bioastronautics Data Book. Scientific and Technical Information Division, Publication 3006, National Aeronautics and Space Administration, Washington, D. C.

32. Whiting, P. W. 1937. Technique of culturing *Habrobracon juglandis*, p. 489–491. *In* James G. Needham (Chairman), Culture methods for invertebrate animals. Dover Publications, Inc., New York.

section 2

PHYSIOLOGICAL ASPECTS

TOXICITY

How often do we think of the breathing of pure oxygen as being a hazard? The widespread knowledge of the uses of this gas for accident victims, stroke and heart attack patients, in surgical rooms, and most recently in high pressure chambers might lead one to believe that pure oxygen is sort of a "panacea"—a sort of highly desirable "cure all." Joseph Priestley, who discovered oxygen, called it "dephlogisticated air" and pinpointed the problem when he wrote:

> . . . But, perhaps we may also infer from these experiments that though dephlogisticated air might be very useful as a medicine, it might not be so proper for us in the usual healthy state of the body; for as a candle burns out much faster in dephlogisticated air than in common air, so we might, as may be said, live out too fast and the animal powers be too soon exhausted in this pure kind of air (8).

Exactly as Priestley predicted, it has been shown that prolonged exposure to pure oxygen at normal pressure may remove most of the nitrogen present in the body cavities. If these body cavities are poorly ventilated, the oxygen trapped within them may be absorbed by the circulating blood, and once it is removed, a low pressure is produced in the cavity causing it to collapse, a condition known as pulmonary atelectasis; in addition pain arises in the middle ear and the paranasal sinuses (2).

To prevent this from occurring, the oxygen pressure being fed to the astronaut must be lowered to approximately one-third of an atmosphere of pressure (4–5 psig) or furnished at a higher pressure, but diluted with another gas such as helium. Extensive research to find the ideal pressure and the most suitable gas for use as a dilutant is presently under way in both the United States and Russia. A normal atmospheric pressure system suffers the danger of explosive decompression in case of a system failure or the penetration of a meteoroid. The low pressure, pure oxygen system has shown such undesirable side effects as congestion and hoarseness which were noted in the Gemini VII astronauts partway through the mission.

The mechanism of the body's demand for oxygen works as follows. As muscular work is performed, there is a demand on the body systems for energy, and this energy must come from the oxidation of the sugars and starches stored in the body. As the work load increases, more carbon dioxide, one of the products of this energy-producing process, goes into the blood. As the concentration of CO_2 rises, an automatic mechanism responds which increases the breathing rate in an attempt to remove it. If the subject is at a high altitude without an oxygen mask and the body notes this lack of oxygen, the command is to breathe faster. At a high altitude, this does not really bring in much additional oxygen. The carbon dioxide in the blood continues to increase and the breathing becomes faster and faster in an attempt to remove it from the blood. The net result is a loss of both oxygen and carbon dioxide at the same time and the subject becomes dizzy, spots appear before the eyes and then blackout occurs. This process is called hyperventilation. This effect has been noted many times among mountain climbers. Many of the visitors to the Mt. Barcroft Laboratory (12,450 ft.) at the University of California White Mountain Research Station of the University of California located near Lone Pine, California, experience similar symptoms (10).

If there is to be any gaseous exchange between the body and the outside atmosphere, the partial pressure of the CO_2 gas and H_2O vapor in the lungs must be greater than the partial pressure of these components in the incoming atmosphere. The pressure of these two gases in the lungs makes up 11% of the total pressure regardless of the altitude or outside air pressure. The combined internal pressure of these two components and their retention always remains constant.

At 50,000 feet, the pressure of the atmosphere is down to 1.69 psig which is precisely 11% of the normal atmospheric pressure. The pressure exerted by the water vapor and carbon dioxide trying to escape is the same as the pressure of the oxygen trying to come in. There is little or no exchange and the subject suffers critical hypoxia and oxygen starvation in seconds, and death soon follows. The lungs become a deadly bellows and there is a futile gasping for air.

This fact leaves us with just two choices for a space cabin atmosphere. One is to carry as much of the normal earth's atmosphere as is vital and feasible in the cabin in containers, and the second choice is to operate at a lower pressure. The quickest and easiest approach would be the use of nitrogen and oxygen much as it is found here on the earth. This has been the approach in the Russian research program where the early development of large boosters made it possible to disregard the added weight of the gases and utilize the double hull to protect against explosive decompression in case of penetration by a meteorite.

TABLE 1 **CONTAMINANTS IN SUBMARINE ATMOSPHERES (12)**

Compounds Identified or Suspected in Submarine Atmospheres

Compound	Chemical Formula	Suspected Source	Limit (max.) for 90-Day Dive	Remarks
Acetylene	C_2H_2		2.5%	limit based on lower explosive limit
Acrolein	CH_2CHCHO	cooking		
Arsine	AsH_3	battery gassing	0.01 ppm	
Ammonia	NH_3	scrubbers	25 ppm	limit noted is for 60-day dive
Carbon dioxide	CO_2	breathing	1%	
Carbon monoxide	CO	smoking	25 ppm	
Chlorine	Cl_2	chlorate candles	0.5 ppm	
Ethylene	C_2H_4	polyethylene decomposition		
Formaldehyde	CH_2O	cooking, combustion		
Freon-12	CCl_2F_2	air conditioning	500 ppm	see also HCl, HF, and $COCl_2$
Hydrocarbons (other than CH_4)		paints		
Hydrogen	H_2	battery gassing	3%	limit based on lower combustible limit
Hydrogen chloride	HCl	Freon decomposition	0.1 ppm	
Hydrogen fluoride	HF	Freon decomposition	0.1 ppm	
Mercury	Hg		0.05 mg/m^3	
Methane	CH_4	sanitary tanks	5.3%	limit based on lower explosive limit
Methyl alcohol	CH_3OH		3 ppm	
Monoethanolamine	$OHCH_2CH_2NH_2$	CO_2 scrubbers	1 ppm	
Nitrogen	N_2			
Nitrogen dioxide	NO_2	burners, smoking	0.5 ppm	
Nitric oxide	NO	burners, smoking		
Oxygen	O_2		17% min	
Ozone	O_3	precipitators	0.05 ppm	
Phosgene	$COCl_2$	Freon decomposition	0.1 ppm	
Stibine	SbO_3	battery gassing		highly unstable; limits: 1 hr-1 ppm; over 24 hr-0.05 ppm
Sulfur dioxide	SO_2	oxidation sanitary tank gases		
Triarylphosphate		compressors	0.06 ppm 1 mg/m^3	

Logically, space cabin atmosphere research would closely parallel the closed environmental system of the submarine (9, 12). Research carried out in nuclear submersibles over extended periods has shown that contaminants do appear in the atmosphere and a constant monitoring system must be utilized and scrubbers provided to remove those known to be highly toxic. These contaminants were found in the form of gases, vapors, aerosols (including liquids, solids and dust), microbes and ions. A list of some of these is found in the accompanying table (12).

A nuclear submarine may carry a crew of 140 men and have a volume of approximately 140,000 cubic feet. This would mean that each member of the crew would have a free air space equivalent to a room 10×10×10 feet. In this space, the crew is allowed to carry on most of the activities of normal surface living. Smoking produces large amounts of carbon monoxide and other equally dangerous hydrocarbons. The cooking of the food is known to produce the aerosols, and other hydrocarbons arise from cleaning solvents, fuels, lubricants, adhesive and paint thinners. In the early stages of its development, radioactive decay products were found due to the use of luminous dials. The breakdown of Freon in the cooling equipment gave rise to some highly undesirable gases.

TABLE 2 **CONTAMINANTS IN MERCURY SPACECRAFT (9)**

Contaminants Identified in the Atmospheres of Mercury Spacecraft

Contaminant	Formula	Concentration ppm**	Limit (max.) for 90 Days
1 Freon-114*	$CF_2Cl\text{-}CF_2Cl$	60–6000	
2 Ethylene dichloride	$CH_2Cl\text{-}CH_2Cl$	0–40	
3 Toluene*	$C_6H_5CH_3$	3–20	
4 *n*-Butyl alcohol	C_4H_9OH	0–4	
5 Freon-11	$CFCl_4$	0–3	
6 Vinyl chloride	$CH_2=CHCl$	0–3	
7 Ethyl alcohol*	C_2H_5OH	0–3	
8 *m*-Xylene	$C_6H_4(CH_3)_2$	0–3	
9 Vinylidene chloride*	$CH_2=CCl_2$	0–2	
10 Methylene chloride*	CH_2Cl_2	0–2	
11 *o*-Xylene	$C_6H_4(CH_3)_2$	0–1	
12 Benzene*	C_6H_6	0–1	
13 Methylchloroform	CH_3CCl_3	0–1	
14 Trichloroethylene	$CHCl=CCl_2$	0–1	
15 Acetone	CH_3COCH_3	0–1	
16 Methyl ethyl ketone	$CH_3COC_2H_5$	0–1	

TABLE 2 **CONTAMINANTS IN MERCURY SPACECRAFT (9) (continued)**

Contaminants Identified in the Atmospheres of Mercury Spacecraft (continued)

Contaminant	Formula	Concentration ppm**	Limit (max.) for 90 Days
17 Methyl isopropyl ketone	$CH_3COC_3H_7$	0–1	
18 Ethylene	$CH_2=CH_2$	0–1	
19 *n*-Propyl alcohol	C_3H_7OH	0–1	
20 Acetaldehyde	CH_3CHO	0–1	
21 Ethyl acetate	$CH_3COOC_2H_5$	0–1	
22 Freon-114, unsym.	$CFCl_2CF_3$	0–1	
23 Methyl alcohol*	CH_3OH	0–1	3 ppm
24 1,4-dioxane*	$(CH_2)_4O_2$	0–1	
25 Cyclohexane*	$(CH_2)_6$	–	
26 Formaldehyde	CH_2O	–	
27 Hexamethylcyclo-trisiloxane	$(CH_3)_6(SiO)_3$	–	
28 Freon-22	CHF_2Cl	–	
29 Freon-23	CHF_3	–	
30 Freon-12	CF_2CCl_2	–	500 ppm
31 Freon-125	CF_3CF_2H	–	
32 Hexene	C_6H_{12}	–	
33 Propylene	C_3H_6	–	
34 *n*-Butane	C_4H_{10}	–	
35 Butene-1	C_4H_8	–	
36 iso-Pentane	C_5H_{12}	–	
37 *n*-Pentane	C_5H_{12}	–	
38 Propane	C_3H_8	–	
39 *n*-Hexane	C_6H_{14}	–	
40 2,2-Dimethylbutane	C_6H_{14}	–	
41 trans-Butene-2	C_4H_8	–	
42 cis-Butene-2	C_4H_8	–	
43 Acetylene	C_2H_2	–	2½%
44 3-Methylpentane	C_6H_{14}	–	
45 Carbon dioxide*	CO_2	–	1%
46 Di-oxene	$(CH_2)_2(CH)_2O_2$	–	

* *These contaminants were common to the atmosphere of the first three U.S. manned orbital flights.*

** *The values listed represent the approximate minimum concentrations which would have ensued had all of the recovered contaminant been dispersed in the free volume of the cabin at one time.*

From the standpoint of morale, it might be desirable to allow some of the comforts of normal living on extended space voyages, and the time will come when unlimited power from solar and nuclear sources will make it possible to clean the atmosphere just as it is done in a submarine, but for the present the pure oxygen atmosphere is highly restrictive.

One extremely significant factor present in the space capsule, mentioned previously, is the lower pressure. This permits a greatly increased "boiloff" from all of the materials used in the construction of the ship, including the metals themselves. Present flights do not permit the astronaut to breathe this cabin atmosphere. He is connected to a closed loop system in the capsule which removes the gases produced by the body, passes them through a cleaning, cooling and chemical rejuvenation system which returns pure oxygen at the proper pressure and temperature.

During EVA (extra-vehicular activity), a chest or back-pack could provide its own complete earth atmosphere. U.S. astronaut Edward H. White II in his "space walk" was connected to his oxygen supply by an "umbilical cord." The problem of toxicity will not become serious until we approach the degree of technological sophistication of the manned orbiting laboratory, a trip to Mars or an attempt to establish a colony on the moon Under such circumstances, a controlled atmosphere will be needed to allow the crew to move about freely, without the necessity of cumbersome helmets and umbilical cords.

Research on low ambient pressure environments and toxicity is being carried on by Anton A. Thomas, M.D., at the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio (11). Four dome-shaped altitude chambers with the necessary air lock, contaminant feed and drainage systems have been built to facilitate continuous exposure of a large number of various species of animals, without interfering with either the pressure or contaminant concentration.

These "Thomas Domes" were designed by Dr. Thomas and are engineered, installed and currently being operated by the Aerojet-General Corporation under a contract with the Air Force. The facility was designed to provide both fundamental experimental capabilities in space cabin toxicology and a quick reaction capability in the toxicological qualification of space cabin materials. Since there is mutual Air Force and NASA interest in these areas, the toxicological information generated serves both military and civilian space requirements. Some of the experiments being carried out include the following:

1. Does a 5 psi, single gas, oxygen atmosphere cause pulmonary irritation or functional impairment during a 90-day exposure?

2. Will a 2-week exposure, under similar circumstances, show any appreciable pulmonary change?

3. Will a pulmonary irritant (nitrogen dioxide), in graded doses, show a more pronouncedly irritating effect during a 2-week exposure to 5 psi oxygen environment than under ambient pressure and normal atmospheric composition?

4. Will a pulmonary irritant that also exhibits marked systemic effects (ozone) be more toxic under the above conditions?

5. Will a systemic poison (carbon tetrachloride) that has no pulmonary irritating effect at the concentration employed exhibit more pronounced enzymatic and histologic change due to low ambient pressure environments?

Other future plans include the toxicological qualification and screening of Apollo space cabin materials using small animals and exposing them to the boil-off products of plastic, insulating materials, adhesives, lubricants, etc., in a recirculating gassing system. One of the domes will be used as the environmental envelope while the animals are housed in small glass jars. More distant future plans include the toxicological testing of complete life support systems and subsystems (11).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

There are a number of topics which can be discussed further but it is not advisable to use live mammals and sacrifice them in order to demonstrate the action.[1]

1. *Oxygen Insufficiency.* Mice when subjected to an environment of lowered and finally depleted oxygen will show the classic symptoms of anoxia: cyanosis which is especially evident in the tail, feet, ears, lips and nose, progressive weakness, disorientation, lethargy, unconsciousness and finally death.

[1] *Attention of the teacher is called to state or local ordinances regarding the use of mammals as experimental animals in the high school laboratory. Teachers are urged to carefully observe the recommendations of the National Association of Biology Teachers as set forth in the "Code for Use of Animals in High School Biology Courses" which is reprinted in Appendix E of this manual.*

2. *Oxygen Excess.* It is difficult to demonstrate the effects of excess oxygen without special equipment and time-consuming procedures (1, 4, 5). The administration of 100% oxygen to rats at 769 mm Hg, for example, will cause symptoms like those associated with anoxia, but progressing over a longer period of time, and without cyanosis. The death of rats receiving 100% oxygen (at sea level) would occur after three to seven days. The danger from combustion of pure oxygen, and difficulties involved in designing the necessary metering and control devices for oxygen, tend to make its use in toxicology experiments in the high school laboratory unsuitable (6).

3. *Contamination.* Nitrogen dioxide (NO_2), an exhaust product of nitrogen fuels, has been used to illustrate effects of contamination. Mice, when exposed to NO_2 in a closed container for an hour or less, show signs of acute pulmonary edema. This condition is produced when pressure in the capillary beds is raised so high that the capillaries begin to leak a proteinaceous fluid which is derived from the blood. As this fluid accumulates in the lungs, gas exchange is seriously impaired. Finally, the fluid, mixed with air, is exuded from the mouth and nostrils.

Contamination from Other Sources

Other contaminants may become introduced into space cabin atmospheres by such occurrences as improper functioning of equipment.

The potential importance of such events may be demonstrated in the laboratory by the action of cigarette smoke on cilia.

1. The cilia lining the respiratory tract perform the important function of removing foreign particles, bacteria, and liquid droplets from the lungs. Interspaced with the cilia are the goblet cells, which secrete mucus capable of forming a sheet over the interior of the bronchial tubes. The cilia beat in a cephalad direction, moving the mucus toward the mouth. Solid particles trapped in the mucus also move toward the mouth so they can be removed from the body. Many agents have a ciliostatic effect and cause excess mucus to be built up, with the result that particulate matter is not removed from the lung.

   The esophagus of a single-pithed frog may be used to demonstrate ciliostatic activity. A pin can be used to mark a starting point in the opened esophagus. A small piece of cork (2–3 mm in diameter) can then be placed on the inner esophagus surface and observed, or a line of carbon black may be painted on the esophageal surface with a small pointed brush. The time required for the cork or the carbon black particles to move a given distance from the pin should be noted. A cigarette can now be lit and its smoke allowed to drift across the esophagus. Again, the time required for the cork to move a given distance should be noted. It will be seen that the mucous flow will slow or stop.

2. Clams, fresh water or marine, may also be used to demonstrate the ciliostatic action of cigarette smoke, in much the same way as with the frog. One valve of the clam may be removed and a small piece of cork placed either on the cilia of the gills or cilia of the mantle.

Of the 175 or more probable contaminants of space vehicles, a number may be found as well known chemicals available to high school science laboratories. These include: ozone (produced by ozone generators); ammonia; benzene (warmed without a flame); carbon monoxide (generated); methane (natural gas); hydrogen sulfide (generated); hydrogen chloride HCl (warmed); and many others. It may be seen that the possibilities for further experimentation in the field of toxicology (the branch of biological science which deals with the adverse effects of chemical substances on living tissue) are numerous.

LITERATURE CITED

1. Cavalli, R. D., C. H. Hine and Robert R. Wright. 1965. Research on therapy of pulmonary edema associated with oxidizers. Technical Report No. 65–178. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

2. Comroe, J. H., Jr., R. D. Dripps, P. R. Dumke and M. Deming. 1945. Oxygen toxicity. Journal of the American Medical Association 128:170.

3. Ganong, William F. 1963. Review of medical physiology. Lang Medical Publications, Los Altos, California.

4. Gast, Joseph H. and R. D. Cavalli. 1963. Some toxicity studies on boron nitride and boron carbide. Paper presented at meeting of American Chemical Society, Division of Water and Waste Chemistry, Los Angeles, California.

5. MacEwen, J. D. 1965. Contaminant generation methods and techniques, p. 18–26. *In* Proceedings of the Conference on Atmospheric Contamination in Confined Spaces. Technical Report No. 65–230. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

6. McNerney, James M. 1965. Preliminary results of toxicity studies in 5 psi 100% oxygen environments, p. 98–123. *In* Proceedings of the Conference on Atmospheric Contamination in Confined Spaces. Technical Report No. 65–230. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

7. Monma, M. and R. W. Rinehart. 1963. Method of detection and quantification, p. 155–169. *In* Symposium on toxicology in a closed ecological system. Lockheed Missiles and Space Company, Sunnyvale, California.

8. Priestley, J. 1906. The discovery of oxygen. Alembic Club Reprints, 7. University of Chicago Press, Chicago, Illinois.

9. Saunders, R. A. April 1963. Contamination pattern in the enclosed atmosphere of Mercury spacecraft, p. 709–723. *In* T. & A. Proceedings of the first space vehicle thermal and atmospheric control symposium. Technical Report No. 63–260. Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

10. Tenney, Stephen M., J. E. Remmers and John C. Mithoefer. 1964. Hypoxichypercapneic interaction at high altitude, p. 263–272. *In* W. H. Weihe (Ed.). The physiological effects of high altitude. The Macmillan Company, New York.

11. Thomas, Anton A. September 1965. Low ambient pressure environments and toxicity. Technical Report No. 65–93. Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

12. U. S. Navy. 1962. Submarine atmosphere habitability data book. NAVSHIPS No. 250–649–1, Revision No. 1. Bureau of Ships, Navy Department, Washington, D. C.

section 2

PHYSIOLOGICAL ASPECTS

BIOTELEMETRY

In the past, the monitoring and recording of biological information from both animal and human sources was seriously impeded by the necessary and often cumbersome electrical connections. In recent years, research and development has managed to reduce this problem by the use of radio telemetry (3).

Presently the transmission and reception of data from space probes is made possible by electrical devices called transducers, or sensors, and the new science known as telemetry. These transducers are electronic devices which respond to physical or biological events with the production of an electrical current. For instance, a phonosensitive device placed over the heart might respond to each sound of the heart with the production of an electric impulse. The characteristic intensity, frequency and duration of the formed current would be related to the heart sounds. An appropriate receiver could record these transmissions on tape or on an oscilloscope and produce a visual record as well. The receiver might translate the characteristics of the transmitted signal into actual reproduced sounds of the heart valves. In order to record any specific data, i.e., cosmic radiation, temperature, blood pressure, respiration, trajectory or fuel supply, a transducer is required—a device which will electronically respond to the specific phenomena. This electronic response can be stored on magnetic tape and transmitted rapidly at a more appropriate time. Figure 1 illustrates a simplified relationship of the instrumentation employed in radio telemetry.

The Tiros and Nimbus weather satellites make use of the Vidicon transducer in which a visual image is collected and intensified on photoconductor materials such as antimony trisulfide (8). A light-sensitive scanner records on magnetic tape the light and dark areas along a horizontal scan. The light intensity from point sources is translated into an electronic signal. It has specific characteristics and is transmitted to earth, where the signals are translated into light intensities to produce a complete picture equivalent for the Vidicon tube. A similar process was carried out for the Mars probe in 1965.

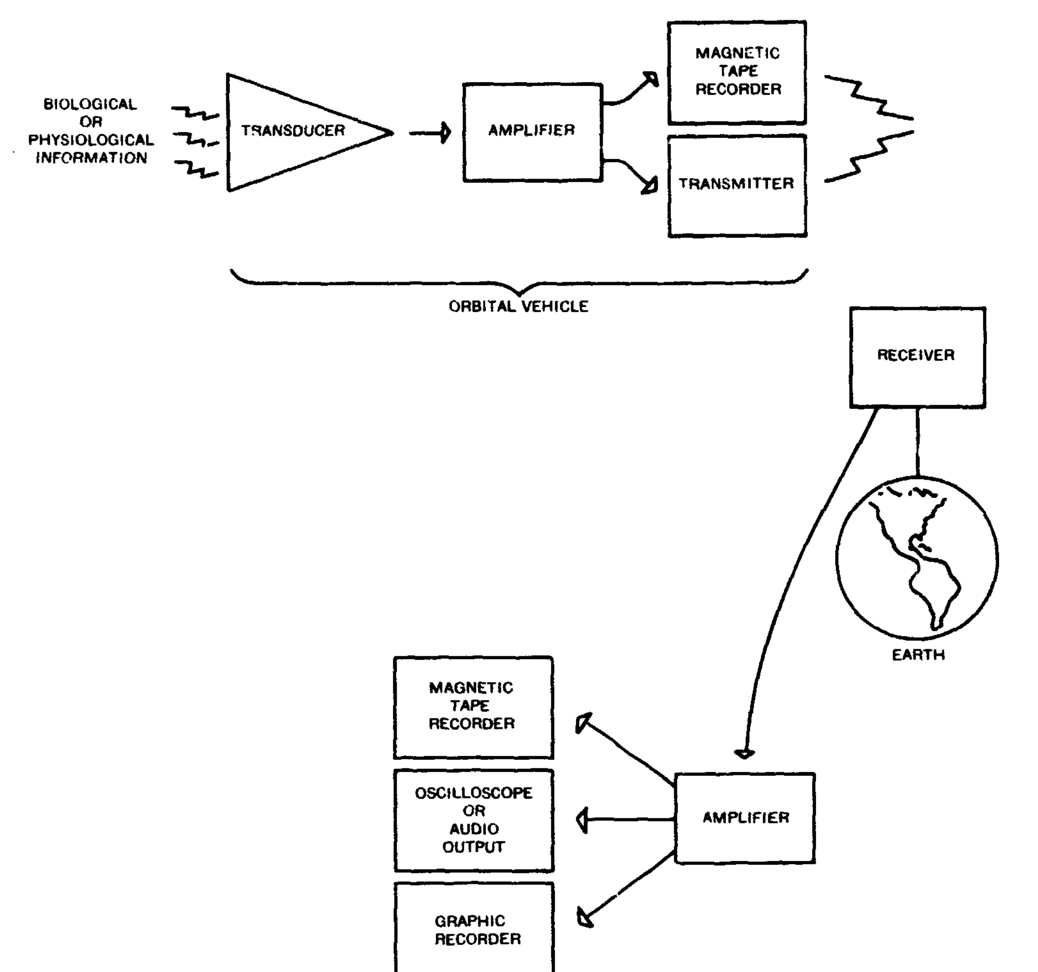


FIGURE 1.

Attached to the astronauts are a variety of transducers for the monitoring of several biological parameters such as heart rate, electrocardiogram, respiration, temperature and blood pressure. Each transducer responds to its parameter with an electronic signal of known wavelength. Variations in the intensity and duration of these signals will correspond to variations in the biologic parameters. Gordon Deboo and Thomas Fryer of NASA Ames Research Center, Moffett Field, California, have designed a miniature biopotential telemetry system (2, 9, 10). It employs standard, inexpensive and commonly available components. It is easily assembled and the finished product is the diameter of a penny and the height of a stack of three pennies. It can transmit the electrocardiogram up to 100 feet.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Microminiaturization has enabled scientists to develop transducers, transmitters and stimulators of microscopic dimensions (1). In addition, microminiaturization has greatly reduced the quantity of operating power needed for many sensor circuits. Technicians of the General Electric Company have developed microcircuits which are powered by the 0.01–0.09 volt bioelectric potentials of living organisms (5). This development will enable the physiological parameters such as temperature and heart rate to be monitored remotely for as long as the animal lives.

Dr. Ralph Stuart MacKay of the Space Sciences Laboratory and Medical Physics Division, University of California, Berkeley (now at Boston University), has done considerable work in the area of radio telemetry (6, 7). One of his simple temperature-sensitive circuits conveniently demonstrates the principles of telemetry and an interested high school student could quickly and easily construct the transmitter. In order to facilitate construction, the parts are far from miniature. However, when completed, the unit can be implanted or used directly to monitor environmental temperature. Figure 2 illustrates a pictorial diagram of this radio transmitter.

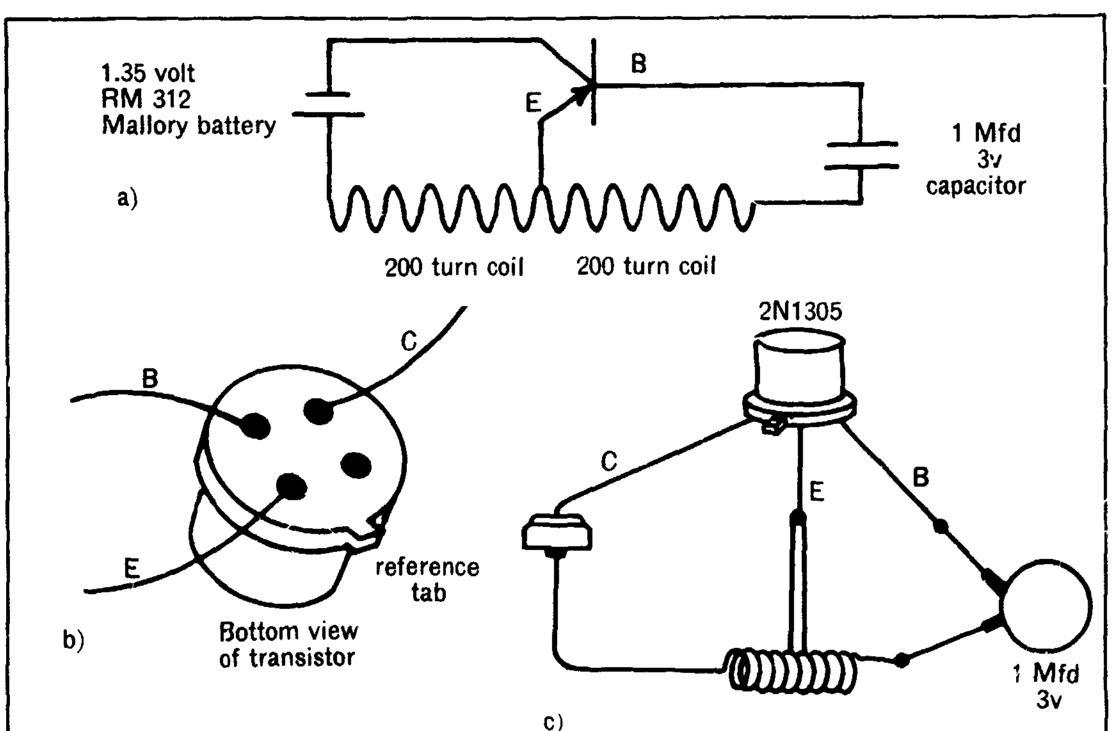


FIGURE 2. *The construction and operation for the temperature-sensitive MacKay radio transmitter is simple and its application is limited only by one's imagination. The details of its construction follow.*

Construction Details of a Temperature Sensitive Radio Transmitter

1. *Components needed*

Approx. Cost

a. PNP type transistors, 2N1305 or equivalent (any high gain, low current, minimal leakage transistor will be satisfactory) $0.55

b. One, 1 Mfd (1.0P) 3 volt disc ceramic capacitor (e.g., Centralab UK–105) .30

c. One 1.4Y (e.g., Mallory RM 312) mercury cell battery .25

d. Spool of #38 enameled wire, $\frac{1}{8}$ lb. (e. g. Belden 8071–38 T–2 Isonel) 2.85 (for a $\frac{1}{2}$ lb. spool, which is enough wire for 30–40 coils)

e. Standard AM radio (tube type or transistor)

f. Household cement (e.g., "Duco")

g. Solder and soldering gun or soldering "pencil"

2. *Construction*

a. *Preparation of Coil.* Make a crude spool using cardboard discs as sides and a matchstick or toothpick axle. Space the discs approximately $\frac{1}{4}$" apart. Slightly oil the match stick in the area where the spool will be formed or spray with a "Teflon" spray (e.g., "Fluoroglide"—Figure 3).

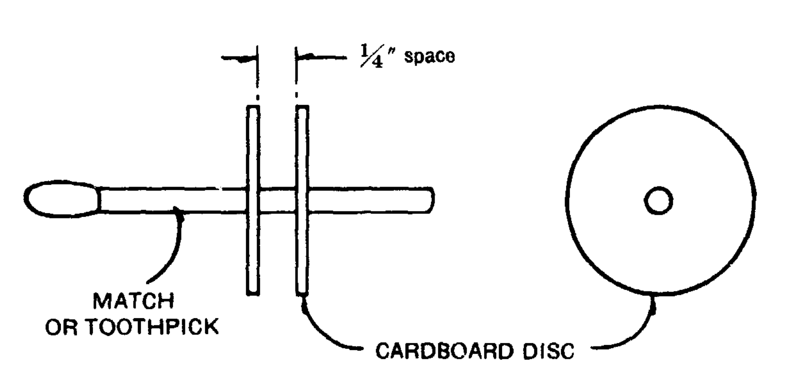


FIGURE 3.

Place a large drop of household cement onto the spool space. Immediately begin to wind #38 enamel wire around the matchstick between the cardboard discs. Leave several inches of wire free, for eventual connections. The entire coil will require about 25–30 feet of wire. The cement will dry and maintain the coil's shape. Tightly wind 200 turns of wire into the cement, adding more cement as needed. On the 200th turn, loop out approximately 8 in. of wire, add more cement and continue to wind an additional 200 turns over the previous coil. Cover the cement and allow to dry. Cut the wire, leaving approximately 8 in. of wire for eventual connections. Slide the coil off the matchstick or toothpick and remove the cardboard discs. The finished coil should resemble the illustration in Figure 4.

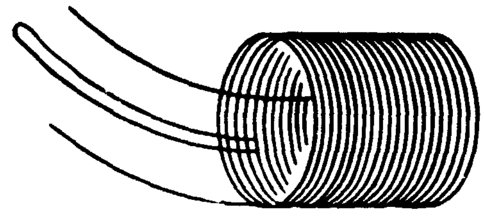


FIGURE 4.

b. The enamel must be removed from the end wires and a portion of the wire loop of the coil, in order to make good electrical connections. This is done by carefully and quickly passing the wires into the flame of a match and observing the dull color change, or by gentle scraping with a knife or razor blade. The circuit will not be completed if the enamel covering is not removed prior to soldering; however, caution must be used to avoid melting the wire of the loop if a match flame is used.

c. Identify the emitter, collector and base lead wires to the transistor (See Figure 2b). In order to produce a compact product, these wires may be shortened but it is recommended that the beginner leave plenty of wire to work with and not be concerned with size.

d. Solder the base transistor wire to one of the capacitor wire leads. This connection may be twisted together first, and then soldered. *CAUTION:* The transistor must be protected from high heat. Therefore, divert the heat of soldering away from the transistor by holding the transistor wires with forceps, tweezers or pliers while soldering. This is known as a heat sink. Melt the solder on the gun and daub onto the twisted connection. *DO NOT overheat* and use a minimum of solder. The transistor may be protected from heat damage by spraying with a material such as "Propellon Instant Freeze."

e. Solder the other capacitor lead wire to one of the coil *end* wires.

f. Solder the coil loop to the transistor emitter wire. Remember to use the heat sink.

g. The battery may now be connected. A temporary connection can be made by using a narrow slice of rubber tubing to hold the transistor collector wire and the coiled wire to the battery surfaces. In this way, the battery can easily be replaced when dead. A "solder foot" can be made on the collector and coil wires for better battery contact. This is a drop of solder on each side of the coil. The transistor collector wire connects to the negative side of the battery (smaller surface) and the coil wire to the positive or larger surface of the battery (See Figure 5). Care should be taken so that hot solder does not touch the battery.

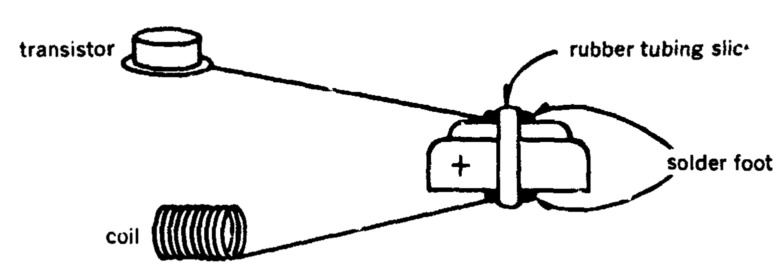


FIGURE 5.

h. If the coil connections are free of enamel and the transistor is not heat damaged, the transmitter should be putting out a strong signal. Turn on the radio and tune to a quiet area. Turn up the volume and place the radio close to the transmitter. You should hear a continual clicking sound. The time interval between the clicks is temperature-dependent. Transmission distance of from one to four feet has been obtained with transmitters of this design.

3. *How the Temperature-Sensitive Transmitter Works*

An electric charge will gradually build up on the condenser in such a way as to block the operation of the transistor. As a result, the oscillations periodically "turn themselves off" for the time interval it takes for the condenser to discharge backward through the transistor. Now the resistance of the transistor to charge flowing the "wrong" way decreases with increasing temperature. Thus, the radio-frequency signal periodically "turns itself on and off" at a "blocking" frequency which itself conveys temperature information.

4. *Determination of Environment Temperature Using Radio Telemetry*

a. Calibration of transmitter: place the transmitter and a thermometer in a glass jar. Count the number of clicks per 10 seconds and record. Place the jar in water and record the temperature and number of clicks per 10 seconds. Make several such determinations for a wide range of water temperatures. Do not exceed 170° Fahrenheit, however! Construct a graph which indicates the relationship of temperature to number of clicks. (Figure 6.)

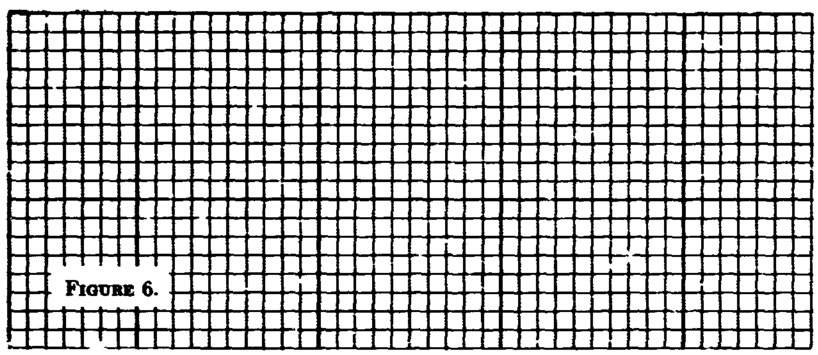


FIGURE 6.

b. Once the graphic relationship is prepared, the temperature of any unknown environment may be determined simply by placing the transmitter in the environment and counting the number of clicks per 10 seconds and reading the temperature directly from the graph. The transmitter may be calibrated for finer temperature ranges if desired.

c. The transmitter parts may be bent into a more compact configuration. Be careful not to short any of the connections. However, remember that the enamel on the copper wire acts as an insulator and contact between two enameled wires is permissible. When the compact unit has been tested for satisfactory operation it may be covered completely with plastic bathtub sealer (e.g., "Silastic"). When dry, this entire unit may be surgically inserted into an animal and its temperature may be monitored via radio telemetry by simply placing the AM radio near the animal. In this way, the response of homeotherms and poikilotherms to a cold environment may be compared. The interval temperature of hibernating animals may be monitored without disturbing the animal. Many applications of this temperature-sensitive transmitter are possible and will occur to teachers and students. Its construction and use demonstrate to the student several simple principles of radio telemetry. The following equation will enable one to calculate the temperature for any signal interval:

$$\text{unknown temperature} = \frac{\text{test signal interval} \times \text{known temperature}}{\text{known signal interval}}$$

The Use of Temperature-Sensitive Radio Transmitter to Determine the Thermal Protection Provided by Various Proposed Spacesuit Materials.

Introduction

In the voids of space man will be exposed to great temperature extremes. Astronaut White was exposed to a temperature range of a high of 250° F to a low of —50° F depending upon which side of him was facing the sun. His spacesuit had to protect him from these extremes. The temperature is produced by the infrared rays of the sun striking an unprotected surface. In order for man to work and maneuver in space, he must be protected from these high temperatures. Therefore, the selection of materials for spacesuits requires considerable research to determine relative thermal reflective properties.

Purpose

The purpose of this experiment is to test the telemetering unit on various material simulating problems of material analysis in selection of spacesuit fabrics. In this way, familiarity with the use and analysis of telemetry information will be gained. This same transmitter can be used for numerous other temperature monitoring experiments.

Materials

Infrared heat lamp
Samples of "possible spacesuit materials"
  a. Aluminum foil
  b. Aluminum paint-sprayed cloth
  c. White cloth
  d. Colored cloth
  e. Dark cloth
  f. Rubber
  g. Lead foil
AM radio (tube type or transistor)
Stopwatch
MacKay or Deboo-Fryer transmitter

Procedure

Clamp the heating lamp to a ring stand and position it to shine on the table surface. Place the temperature transmitter under the lamp. Determine the temperature change in the unprotected transmitter exposed to the heat lamp. Record the transmitter temperature for each minute for a total of five minutes (Figure 7). Extreme care should be taken not to overheat the transmitter!

Place various material samples over the transmitter and repeat the experiment. Which material offers the best protection from high temperatures? Consider that the space suit must be strong, flexible and airtight as well as heat-reflective. Experiment with various combinations and thicknesses of materials which might provide these desirable characteristics (4).

Note: Refer to Temperature Stress chapter for similar experiment using thermometers as recording devices.

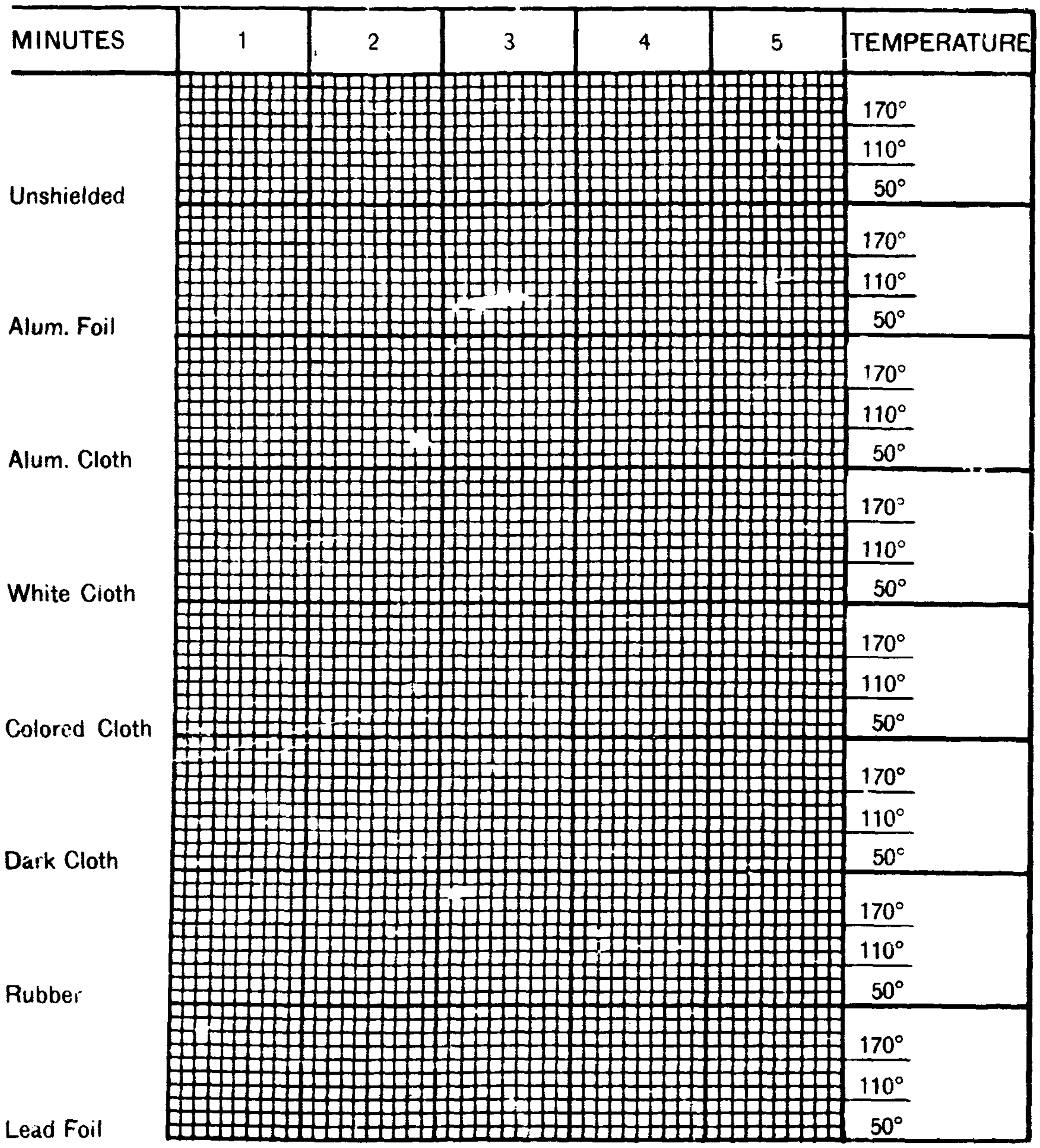


FIGURE 7. *Transmitter temperature shielded with various materials.*

LITERATURE CITED

1. Caceres, C. (Ed.). 1965. Biomedical telemetry. Academic Press, New York.

2. Deboo, Gordon J. and Thomas B. Fryer. 1964. A miniature biopotential system. NASA Technical Memorandum X–54068. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

3. Geddes, L. A. 1962. A bibliography of biological telemetry. American Journal of Medical Electronics 1:294–299.

4. Gemini Spacesuits. 1965. NASA Educational Brief No. 10004. National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas.

5. Konikoff, J. J. 1964. Research study of the utilization of bioelectric potential. Final Report, General Electric Company, Space Sciences Laboratory, Missile and Space Division, Philadelphia, Pennsylvania.

6. MacKay, R. Stuart. 1963. Radio telemetry from inside the body. New Scientist 19:650–653.

7. MacKay, R. Stuart. 1964. A progress report on radio telemetry from inside the body, p. 275–291. *In* Biomedical Sciences Instrumentation, Vol. 2. Proceedings of the Second National Biomedical Sciences Instrumentation Symposium. Instrumentation Society of America, University of New Mexico, Albuquerque, New Mexico.

8. Mesner, Max H. 1965. Television in space. Electronics 38 (10):80.

9. Subminiature biotelemetry unit permits remote physiological investigation. 1964. NASA Technical Brief 64–10171. Technology Utilization Division, National Aeronautics and Space Administration, Washington, D. C.

10. Winget, C. M. and T. B. Fryer. 1966. Telemetry system for the acquisition of circadian rhythm data. Aerospace Medicine 37(8):800–803.

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section 3

PSYCHOLOGICAL ASPECTS

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SENSORY AND PERCEPTUAL PROBLEMS

Man in space will encounter a multitude of problems of a psychological nature. The great unknowns of the hostile environment of space and the continual threat to man's very survival will constitute a significant psychological stress. When such additional conditions as prolonged isolation, confinement, altered circadian rhythms, sensory alterations and weightlessness are considered, the importance of psychological aspects of manned space missions can be better appreciated.

Vision

Psychologically, it is very important for man to be able to see during space flight. He will not be able to depend greatly upon his other sense receptors because of their modification by weightlessness. Man's visual environment in space will be unlike that on earth and so will present numerous problems.

The space environment changes visually as an ascent from the earth is made. Light is no longer scattered by air, dust and water molecules. The colors on earth begin to fade out at about 70,000 feet. and at about 95 miles, the sky overhead appears black. The sun and the stars appear brilliantly outlined against the relative blackness of space. This contrast with the visual field presents potentially serious problems. The astronauts' pupils may be dilated during brief exposures to glare conditions thus increasing the seriousness of the problem (15).

Precautions must be taken to prevent retinal burns caused by infrared radiation. Current evidence indicates that protective devices such as goggles, filters, sun visors and light-scattering painted surfaces within space vehicles will reduce such high contrasts and danger from glare. Considerations must also be given to protection from ultraviolet radiation. However, such wavelengths may be almost completely absorbed by the window ports of the space vehicle.

Measures to prevent the biological effects of high energy alpha and proton irradiation must be taken. Attention must be given to periods of unusually high solar activity, called solar flares, and to the amount of time that man will spend in flight through belts of intense radiation (21). The eventual use of nuclear-powered space vehicles will make it necessary to further consider this hazard to the radiation-sensitive eyes of man.

The biological effects of various chemical fuels may be important to man's vision. Visual symptoms produced by these chemicals can be severe. Inhalation of ordinary methyl alcohol has been found to cause blindness (15). The more exotic fuels also can produce visual symptoms and astronauts must be provided with adequate fume detectors and protective devices.

Acceleration has been found to cause visual symptoms including decreased visual acuity, peripheral dimming of vision, variable reaction time and even complete loss of vision. Such symptoms could be produced by the intense acceleration and deceleration experienced during landings and re-entry. Special couches to help the body absorb shock are used in spacecraft to partially reduce visual impairment (10).

When there are no details in a visual field, the eyes have nothing on which to focus and become myopic (space myopia). In space, the absence of such details could cause an astronaut to be unable to tell whether his eyes were focusing at infinity or at some nearby point. Thus, an astronaut might not see a relatively close object at all, or judge it to be far away (9, 24). Constant visibility of the stars, due to the lack of atmospheric dispersion, may provide necessary cues with which to compare objects outside the space vehicle. Additional cues for distance and size accommodation of astronauts' eyes could be provided by comparison with the size of the earth or the moon (6).

The report by Major Gordon Cooper in 1963 that he could see and recognize a train while orbiting the earth in a space capsule caused surprise to many. Since then, many reports of such details have demonstrated that man's visual capabilities during orbital flight are much greater than had been anticipated (11, 26). Gemini VI astronauts were able to observe smoke of a New Mexico rocket sled test. According to Brown (7), the distinguishing elements of clearly recognizable objects must have dimensions of 1500 feet when viewed from an altitude of 100 miles.

Observations of other vehicles in space could be a difficult problem, especially if the amount of light that the vehicle reflects is not great. Rendezvous and visual detection while in orbit not only involve familiarity with the object, but its relationship to other objects such as stars. It is possible that fluctuation in illumination due to orbiting through light-dark cycles might affect tracking, visual detection and rendezvous. This might become especially important during construction and operation of an orbiting space station.

Training in recognition of celestial bodies may be needed for the purpose of determining position and to check on a stellar guidance system during earth-lunar and interplanetary flight (6, 7).

Hearing

The most important link between man in space and man on the earth's surface is through communication. Psychologically, it is important that this link be maintained. On long-term flights, the ability to talk with people on earth or to hear music being played may be extremely important to astronauts (7).

Vestibular and Kinesthetic Senses

During weightlessness, the otolith organs in man's vestibular apparatus will not function as they normally do to sense positions. The perceptual and motor performance of man in space will, therefore, depend to a large extent upon the muscle, pressure and posture senses (9). Such tasks as manipulation of tools or objects may be difficult if gravity-dependent kinesthetic cues are missing (7).

Other Senses

Brown (7) has discussed the possibility of the use of olfactory signaling systems to indicate such things as malfunctioning equipment. The problem of unpleasant odors in the space cabin environment will have to be considered, especially during long flights. The possibility of using low amplitude tactual stimulation to maintain peripheral circulation and muscle tone has been offered (7). The sense of taste, of course, will be important if the astronaut is to enjoy meals on extended space flights. Space meals to date have been prepared with a concern for palatability as well as nutrition and will continue to be so prepared, according to Dr. A. E. Prince, Chief of Physiological Research Department, Wright-Patterson Air Force Base, Ohio (personal interview).

Spatial Disorientation

In space, the vestibular and kinesthetic inputs with which man normally maintains his orientation may be unavailable or unreliable. It is possible for the astronaut to perceive his position in space inaccurately and thus become psychologically disoriented. He may misinterpret or even ignore what sensory information may be available to him (9). This may especially be true during long periods of isolation.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

1. Introducing the problems of sensing and perceiving while in space might logically begin by exploring the visual world of man on earth. Most students are quite fascinated by optical illusions and this interest can be used to help them become aware of several problems involving perception. Students might be permitted to view a large drawing or projection of a necker cube (Figure 1). Reactions of the students to the shifting and reshifting, which will continue for as long as they view the cube, should produce interesting discussion. The students may suggest several other variations, including modifications of the size, color and number of the cubes. There are many other well-known illusory figures which seem to turn themselves inside out and then back again.

   A "hallway" (Figure 2), for example, suddenly becomes a "rectangular megaphone" or "speaker." The "block of wood" (Figure 3) alternately appears to either have a small "block" touching it or to have a rectangular piece cut out of one corner.

   The reversible staircase (Figure 4) appears to be attached upside down to some imaginary ceiling and then suddenly appears to be quite normal.

   Students will undoubtedly know of other such illusory figures (Figure 5) and may even be challenged to "design their own." Originals of many excellent and well-known optical illusions, prepared as overhead projection transparencies, may be found in the March-April issue of Educational Age (published by 3-M Co., St. Paul, Minn. 55119, 1966).

2. A second area which should provoke student interest deals with images which persist even after an object is no longer in view. Many of these afterimages are rather well known. Negative afterimages in which a color pattern which is complementary to that of the original image may be interesting to the students. Staring at a bright, solidly colored piece of paper for a minute and then looking at a gray or white background will produce such complements.

   Additional information concerning visual space perception and other examples of figural aftereffects may be found in general psychology texts such as Ruch (20) and in books on the subject of optical illusions. Excellent full-page plates of complementary test patterns which may be used to demonstrate the color changes that take place when a negative afterimage of a brightly colored stimulus is formed on the retina are found in Brindley (3).

A further aftereffect, but in three dimensions, is described by Prentice (19). Here, a curved card such as a 3" by 5" lined index card is held in front of a similar straight card. If an observer looks steadily at a point on the curved card and then at the corresponding point on the flat card behind it, the flat card's surface will appear to be curved in the opposite direction.

Figures which are produced when periodic printed rulings of various types and colors are made to overlap (moire patterns) may be used to illustrate aftereffects of perception (18, 22). Even the currently popular optical art (op art) which provokes visual images can be used advantageously in the classroom. If students close their eyes and then apply pressure with the fingers to the outer edges of both eyes, patterns will be produced. It has been found (17) that a whitish pattern is "seen." This pattern quickly gives way to flickering geometric figures of characteristic types. An excellent booklet, "The Color Tree," which tells the story of color and includes many demonstrations in color perception, is available for $.50 from Interchemical Corporation, 67 West 44th Street, New York, N. Y. 10036.

3. Bartley (1) has described a simple experiment to illustrate brightness discrimination. If a beam from a projector is cast on a sheet of black construction paper which is hanging in the doorway of a dimly illuminated room, the paper will appear white. When a piece of white paper is placed between the construction paper and the projector, the part of the construction paper that can still be seen will again appear black. When a highly reflecting white paper is placed so as to partly overlap the black paper, changes in the intensity of the illumination do not alter the original appearance of the construction paper.

4. Dr. Israel Goldiamond and Dr. Jarl Dyrud of the Institute for Behavioral Research, Silver Spring, Maryland, have been investigating a variety of complex perceptual phenomena including spatial and temporal discrimination. Conditioning procedures with various animals are being utilized to study motion, size, form and color discrimination including interrelationships between brightness, hue and saturation. Brightness contrast effects may be illustrated by placing two identical gray paper discs, side by side, one against a white background and the other against a black background. The spot which is surrounded by white appears darker to most humans. Blough (4, 5) and others have studied these with pigeons.

5. Another area which offers possibilities for student research into perceptual problems is that of depth perception (12). The visual perception of depth can be appreciated by merely looking through a window at a row of trees which are at different distances. When

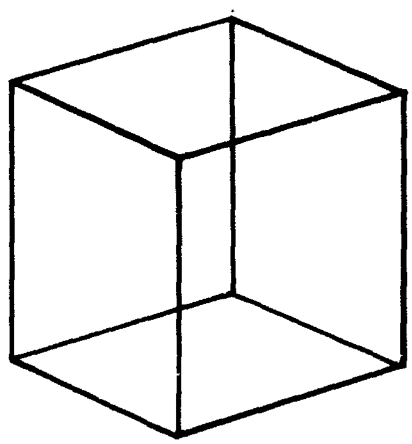


FIGURE 1.

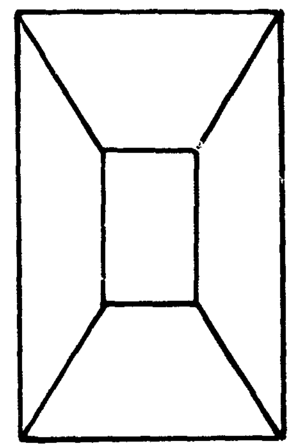


FIGURE 2.

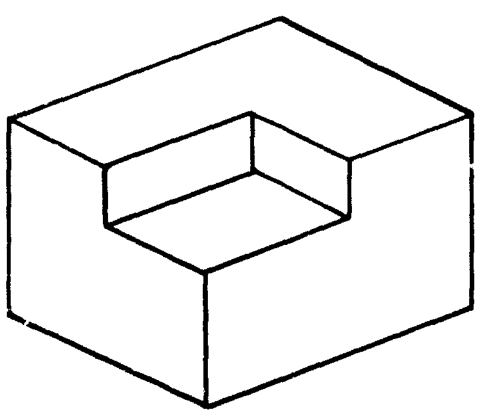


FIGURE 3.

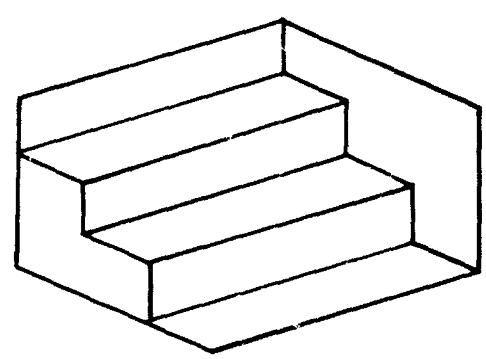


FIGURE 4.

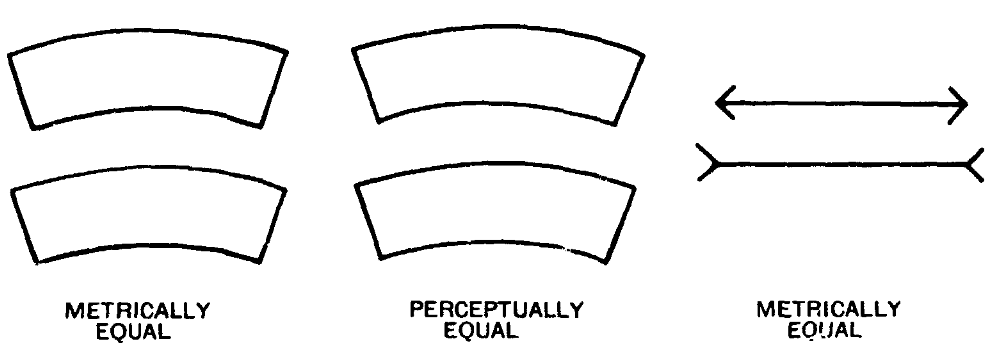


FIGURE 5.

one eye is covered, the tree shapes appear more as a mass of leaves. Spatial separation in depth, during the absence of secondary cues to depth perception, may be studied by suspending two thin strings (weighted to hang plumb) at different distances from the observer. By varying such factors as the distances of the plumb lines from each other and from the observer, the lighting intensity, diameters of the thread, etc., a basis for several student experiments in stereoscopic depth perception may be found (16).

Caidin (8) has described experiments performed at Ling-Temco-Vought, Inc., Dallas, Texas, in which test subjects seated in a darkened room attempted to estimate the distance between themselves and objects. The objects, including a three-inch cutout d. signed to simulate a man at 600 feet, were placed at various distances up to 800 feet from the observer. It was found that even though the size of the object was known, the distance could not be estimated easily even by experienced pilots.

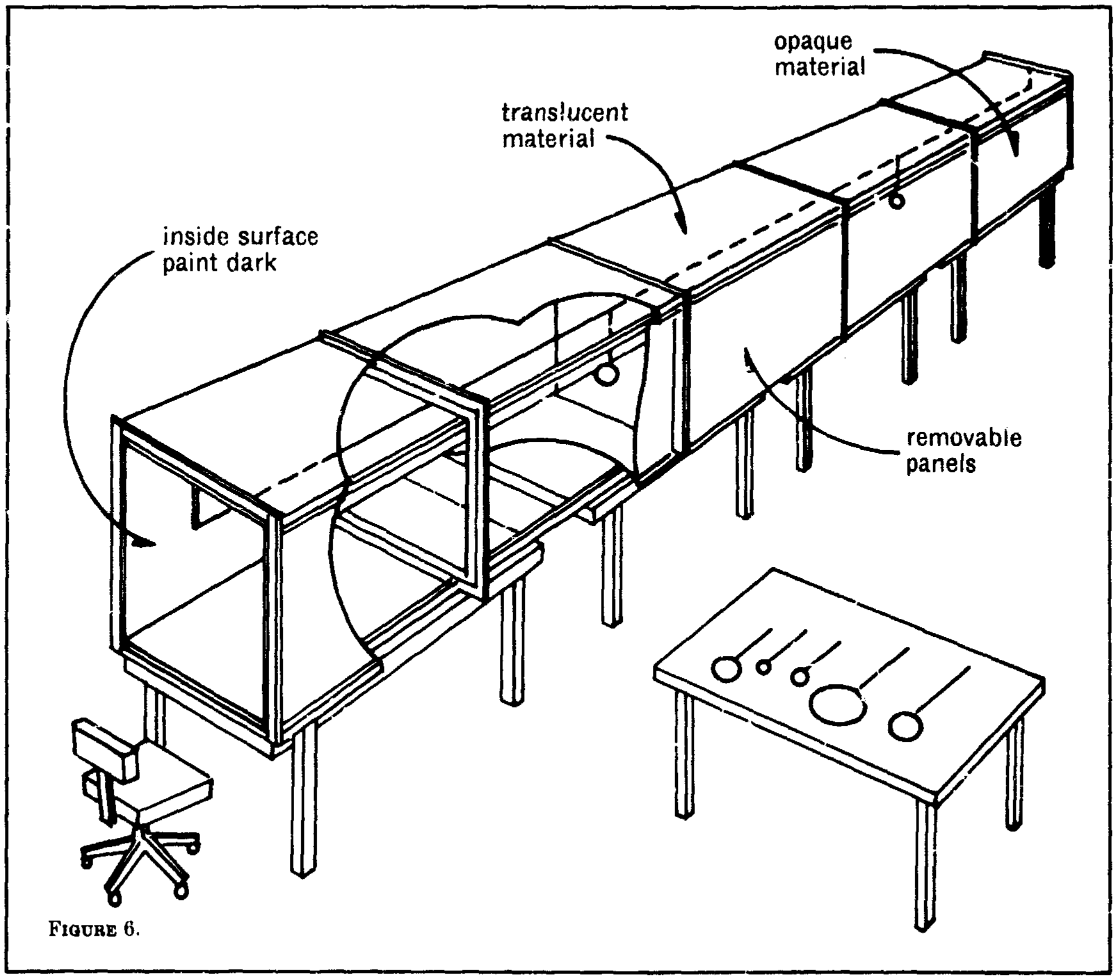


FIGURE 6.

Although empty visual field myopia may not be as great a problem in space flights as it is during high altitude flights within the earth's atmosphere, it may be used as an illustration of depth perception. The purpose, therefore, would be to illustrate that lack of reference points in the field of vision can adversely affect size and distance perspective (2). The test apparatus would be set up as shown in Figure 6. One side should be constructed on a framework in such a way that it is easily removable for changing the disc sizes and their distances from the viewer. If wrapping paper is used, care should be taken that shadows of the wooden supports do not show through. The apparatus might possibly be designed so that the heavy wire (on which the discs are hung) is outside of the school building. This should be done in such a way that there are no reference points (such as the bricks of the school building) visible from the viewer's position.

Operating procedure would be as follows. The student would be permitted to view all materials and apparatus before beginning the experiment. He then sits on the chair at the open end of the viewing device. One at a time, he is shown a series of cardboard discs or Styrofoam balls of various sizes at various distances from his eye. A chart is provided on which he indicates his response with reference to the distances and disc sizes. The viewer then faces away from the viewing device while another student changes the disc size, its distance from the subject, or both. A record of the actual distances and sizes should be prepared by a student for later checking of the viewer's responses and comparison of them.

A comparison of the number of correct responses by each individual student could be made. From the study of the data collected by the entire class, it should be possible to answer such questions as follows: Which disc sizes were "missed" most often? Which distances were the most difficult to judge? Were any particular discs especially difficult to judge at certain distances?

Additional related investigations might be made by using a viewing chamber which has a flat-black interior. Representative questions might include: What is the result of using shapes other than circles or spheres? Would disc color make a difference in the ability to perceive distance? What changes result from the use of only one eye at a time? Can an experiment be designed to determine the influence of contrast within the field of vision upon size and distance perception?

The distorted room demonstration is perhaps one of the best known devices for illustrating perceptual problems. Such rooms are designed in such a way that an observer sees the interior as rectangular, even though one corner is twice as far away as the other corner. The corners appear equidistant from the observer, and objects placed in the corners seem to be equidistant as well.

Students may wish to design and construct a small distorted room. Suggested dimensions are 20" high, 16" wide and 24" long on one side and 12" long on the other. Details of other features which may be incorporated into the design of such a distorted room are found in Bartley (1), Wittreich (25) and Ittelson (13).

A small working model of the famous Ames trapezoidal window may also be built by students. A window might be constructed from cardboard and rotated with a barbecue motor or phonograph turntable motor, geared to rotate at 4 rpm. A small display rotating motor (such as a Synchron BH14RD–5, 4 rpm, 110 volts, 60 cycles, 5 watts) may possibly be obtained by a student. If space stations are to be rotated to produce the effect of partial gravity within the station, astronauts approaching the station might have some difficulty with depth perception. These illusory movements should be more clearly realized by students after they have watched the revolving trapezoidal window.

Both the distorted room and the trapezoidal window are demonstrated in Part II ("The Limitations of the Senses") of the motion picture "Sense Perception" (Moody Institute of Science, Los Angeles).

6. Students may wish to investigate lighting, visibility and legibility in the design and arrangement of instruments. To give students some idea of what types of studies and investigations have been made, a partial listing is presented here.

   a. Matching visual forms which are slightly disparate in contour.

   b. Visual contact discrimination as a function of pre-exposure to light.

   c. Apparent size of objects viewed through telescopes.

   d. Perceived movement in depth as a function of object luminance.

   e. Absolute identification of color for targets presented against white and colored backgrounds.

   f. Comparative effectiveness of speed of detection of visual stimuli in the prone and seated positions.

   g. Relations between the rate threshold for the perception of movement and luminance for various durations of exposure.

h. Estimates of visual perceived closure rates.

i. Visual field restriction and apparent size of distant objects.

j. Effect of grid lines in the field of view upon perception of motion.

k. Temporal predictions of motion inferred from intermittently viewed light stimuli.

l. Relative effects of using the dominant and non-dominant eye.

m. Visual discrimination time—the time required to recognize simple patterns at equal distance from the eye and patterns at alternately far and near distances.

n. The speed and accuracy of dial readings as a function of dial diameter and spacing of scaled divisions.

o. Peripheral viewing of dials.

p. Amplitude, apparent vibration, brightness and type size in relation to numeral readings.

q. Factors determining legibility of letters and words printed in "dot" patterns with pure black and white when the patterns are degraded in varying amounts.

r. Pictorial vs. symbolic instrument displays.

s. Legibility of type as a function of reflectance of backgrounds under low lumination.

t. Width, letter stroke width, spacing and other variables in the design of digits.

u. Visual texture perception.

v. Effects of pupil size and flash duration on acuity during the dark adaptation.

w. Effects of red and other colors of light on instrument reading.

LITERATURE CITED

1. Bartley, Samuel H. 1958. Principles of perception. Harper and Row, New York.

2. Beasley, Gary P. and Jack E. Pennington. 1965. Range estimation of familiar targets presented against a black background. Technical Note No. D–2845. National Aeronautics and Space Administration. Washington, D. C.

3. Brindley, G. S. 1963. Afterimages. Scientific American 209(4): 35–93.

4. Blough, Donald S. 1961. Experiment in animal psychophysics. Scientific American 205(1):113–122.

5. Blough, Donald S. and Patricia Blough. 1964. Experiments in psychology. Holt, Rinehart and Winston, Inc., New York.

6. Brown, John L. (Ed.). 1961. Sensory and perceptual problems related to space flight. National Academy of Sciences-National Research Council, Washington, D. C., publication No. 872.

7. Brown, John L. 1964. Sensory and perceptual problems in space flight, p. 209–230. *In* James D. Hardy (Ed.), Physiological problems in space explorations. Charles C Thomas, Publisher, Springfield, Illinois.

8. Caidin, Martin. 1965. The greatest challenge. E. P. Dutton and Company, Inc., New York.

9. Chambers, Randall M. and Robert Fried. 1963. Psychological aspects of space flight, p. 173–256. *In* J. H. U. Brown (Ed.), Physiology of man in space. Academic Press, New York.

10. Clark, William B. and James F. Culver. 1965. Space ophthalmological problems. Space World E–2–16:10–13.

11. David, Heather M. 1965. GT–4 adds to visual acuity debate. Missiles and Rockets 16(25):36–37.

12. Gogel, Walter C. 1965. The equidistance tendency and its consequences: problems in depth perception. Federal Aviation Agency, Office of Aviation Medicine, Oklahoma City, Oklahoma.

13. Ittelson, William H. 1960. Visual space perception. Springer, New York.

14. Luckiesh, M. 1965. Visual illusions: their causes, characteristics and applications. Dover Publications, Inc., New York.

15. Miller, James W. (Ed.). 1962. Visual problems of space travel. National Academy of Sciences-National Research Council, Washington, D. C.

16. Ogle, Kenneth N. 1962. The visual space sense. Science 135: 763–771.

17. Oster, Gerald. 1965. Optical art. Applied Optics 4:1359.

18. Oster, Gerald and Yasunori Nishijima. 1963. Moire patterns. Scientific American 208(5):54–63.

19. Prentice, W. C. H. 1962. Aftereffects in perception. Scientific American 206(1):44–49.

20. Ruch, Floyd L. 1958. Psychology and life. 5th edition. Scott, Foresman and Company, Chicago, Illinois.

21. Schaefer, H. J. 1960. Tissue ionization dosages in proton radiation fields in space. Journal of Aerospace Medicine 31:807–816.

22. Strong, C. L. 1964. Moire patterns provided both recreation and some analogues for solving problems. Scientific American 211(5):134–138.

23. Tolansky, S. 1964. Optical illusions. Pergamon Press, New York.

24. Whiteside, T. C. D. 1962. Problems of empty visual fields, p. 118–120. *In* Armond Mercier (Ed.), Visual problems in aviation medicine. The Macmillan Company, New York.

25. Wittreich, Warren J. 1959. Visual perception and personality. Scientific American 200(4):56–60.

26. Zink, Donald L. 1965. Visual experiences of the astronauts and cosmonauts, p. 13–27. *In* C. A. Baker (Ed.), Visual capabilities in the space environment. Pergamon Press, Ltd., Oxford.

section 3

PSYCHOLOGICAL ASPECTS

SPATIAL DISORIENTATION

In order for man to sense rising or falling, gravity is required. Gravity exerts a force on mineral crystals called *otoliths* in the utricle of the ear. These crystals press down on sensitive nerve cells and impulses are transmitted to the brain (Figure 1). In this way, man perceives or senses whether he is accelerating in a straight line, up or down, side to side, or forward and backward. For instance, in an elevator that is rising rapidly, the otoliths are pressed down on the nerve cells to a greater degree and one experiences the sensation of rising. If the elevator is descending, there is less otolith pressure and the experience of falling is observed (1).

Therefore, man's ability to perceive straight line acceleration is directly dependent on the force of gravity on the otoliths. What will be the effect of weightlessness on man's ability to perceive linear acceleration? Without this ability will man lose his orientation and be unaware of his motion in space? To what degree will the astronauts' motor skills, vision and performance be affected by long-term weightlessness? These are questions of great concern to the space scientists. They are questions currently being explored through extensive experimentation (2).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

The Vestibular Effects of Acceleration and Rotation on Human Performance

Introduction

The perception of motion is made possible by two mechanisms in the ear. The mechanism involving the semicircular canals enables man to perceive rotary motion. Fluid in the canals moves in response to rotation and this movement bends sensitive nerve cells which send impulses to the brain (Figure 1). In this way, rotation is perceived.

However, this mechanism does not require the force of gravity. In the weightlessness of space, the fluid within the semicircular canals may move more freely and nerve cells may bend more easily. To this extent, weightlessness may produce disorientation and involuntary eye movement even though the mechanism is not strongly gravity-dependent.

Purpose

The purpose of this experiment is to introduce the student to orientation and equilibrium mechanisms and to demonstrate muscle and visual response to unusual motion. It is suggested that the teacher ask for a volunteer to perform this experiment.

Materials

Swivel chair
Ball
Wastepaper basket

Procedure

Have a student "astronaut" sit in a swivel chair. He should hold his head straight upright and forward. The "astronaut" should also grasp the arms of the chair firmly while he is rotated clockwise. Uniform motion rather than speed is most important. After 30 seconds of rotation, the chair should be stopped abruptly by the person turning it.

Ask the "astronaut" to look straight ahead. Notice the eye movements of the "astronaut." Can you identify a fast and slow component of the eye movements? This eye movement is called *nystagmus.* It is produced as a result of fluid movement in the semicircular canals. Eye movements in response to rotary motion are part of man's normal equilibrium reflexes. When the rotation is exaggerated, the eye movement will be correspondingly augmented (4, 5, 6).

These eye movements will have profound visual effects. Ask the "astronaut" to describe his visual experiences following rotation. In which direction does he report his visual field to be moving (clockwise, counterclockwise, horizontal or vertical)? This apparent movement of the visual field is termed *vertigo.*

Record the data as to: direction of rotation, direction of vertigo and other "astronaut's" reactions.

To what extent should nystagmus and vertigo affect the astronaut's performance in space?

Repeat the rotation as before, and following rotation ask the "astronaut" to toss a ball into a wastebasket placed five feet

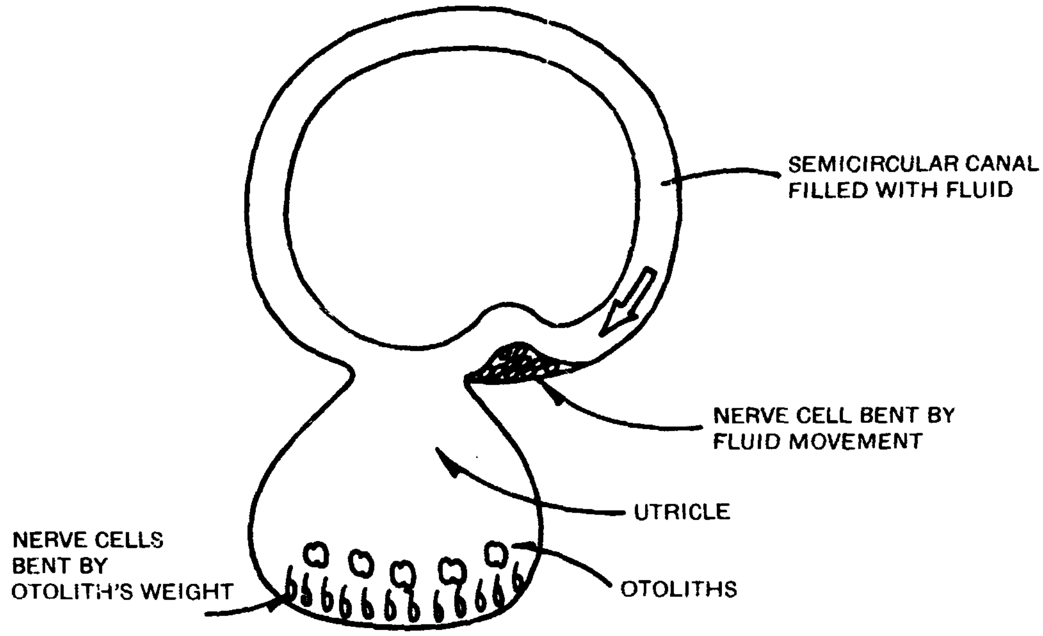


FIGURE 1. *Schematic illustration of the auditory labyrinth.*

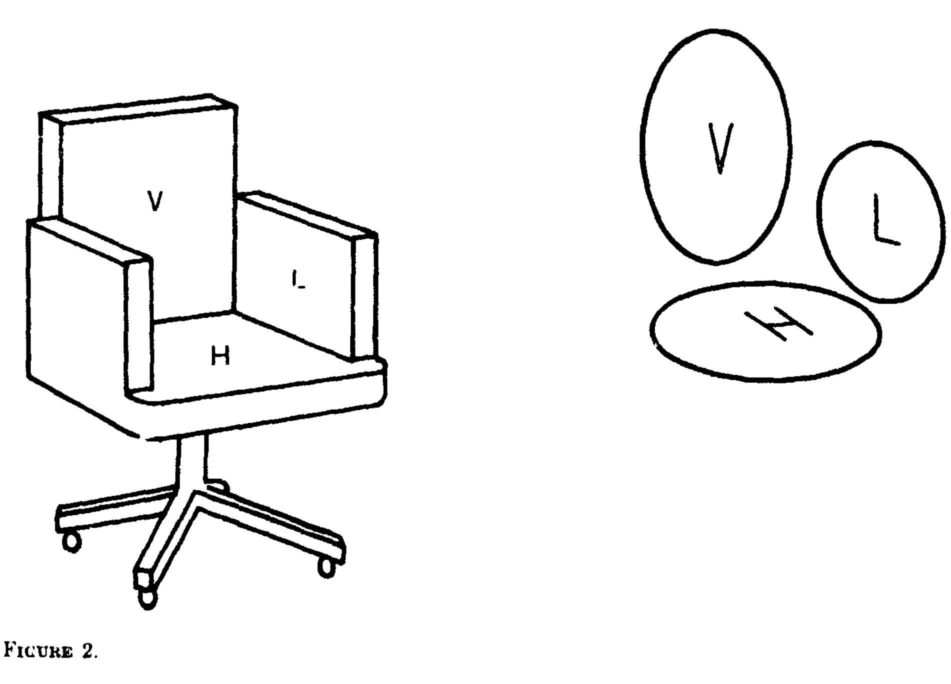


FIGURE 2.

directly in front of him. Describe his response and offer an explanation for his reaction in terms of nystagmus and vertigo.

There are three semicircular canals for each ear—the lateral, horizontal and vertical. These are arranged in planes similar to a chair with arms. The plane of the arms would correspond to the plane of the lateral canal; the plane of the seat would correspond to the plane of the horizontal canal; and the plane of the chair back would correspond with the plane of the vertical canal (Figure 2). In the above experiment, fluid movement was produced in which canal?

Fluid movements in the other canals can be studied and the above observations repeated. For fluid movement in the vertical canal, ask the "astronaut" to press his chin to his chest by bending his head down. In this way, his vertical canal will be in the plane of rotation and fluid within it will be affected by rotation. Simply lay the head on the shoulder to involve the lateral canals. Observe nystagmus, vertigo and ball tossing coordination following fluid movement in each of the semicircular canals (3, 6).

Additional Subjects for Consideration

1. What are the nystagmus and vertigo observations following rolling and head-over-heels tumbling as might occur in extravehicular activity? (5).

2. What factors might influence the time period of vertigo (fatigue, hunger, lighting, etc.)?

3. How is man's ability to manipulate, maneuver and walk affected by rotation? (4).

4. To what extent is man's coordination related to fluid movement in the semicircular canals (try walking a straight line with your head held in different positions) (3).

5. Study the effects of rotation on skilled performance.

LITERATURE CITED

1. Gernandt, B. E. 1963. Vestibular mechanisms, p. 549–564. *In* Handbook of physiology, Section 1, Neurophysiology, Vol. 1. American Physiological Society, Washington, D. C.

2. Graybiel, Ashton. 1952. Oculogravic illusion. AMA Archives of Ophthalmology 48:605–615.

3. Graybiel, A. and B. Clark. 1962. Perception of the horizontal or vertical with head upright, on the side and inverted under static conditions and during exposure to centripetal force. Aerospace Medicine 33:147–155. Aerospace Medical Association, Washington, D. C.

4. Graybiel, Ashton and Walter H. Johnson. 1962. A comparison of the symptomatology experienced by healthy persons and subjects with loss of labyrinthine functions when exposed to unusual patterns of centripetal force in a counter-rotating room. USN–SAM and National Aeronautics and Space Administration Joint Report No. 70. U. S. Naval School of Aviation Medicine, Pensacola, Florida.

5. Guedry, F. E., Jr. 1964. Orientation of the rotation axis relative to gravity; its influence on nystagmus and the sensation of rotation. USN–SAM and National Aeronautics and Space Administration Joint Report No. 96. U. S. Naval School of Aviation Medicine, Pensacola, Florida.

6. Guedry, F. E., Jr. and A. Graybiel. 1964. Compensatory nystagmus conditioned during adaptation to living in a rotating room. Journal of Applied Physiology 17:398–404.

section 3

PSYCHOLOGICAL ASPECTS

PROBLEMS OF ISOLATION AND CONFINEMENT

Conditions of Isolation and Confinement

The very spacecraft and life support system which man must take into space with him for his physical protection will contribute to conditions of isolation and confinement. Such conditions will be important psychological stresses during long-term space travels. Adequate protection must be provided for the astronaut against these factors which may affect both his physiological and psychological performance.

Isolation itself refers to the condition resulting from removal or separation of an individual from a portion of his usual environment. There are various degrees of isolation for an individual, both in regard to permanence and severity, and also in regard to the types of barriers which cause the isolation (10). All orbital, lunar and interplanetary flights, for example, involve isolation from the earth. If radio and television contact with earth is cut off, the isolation immediately becomes more complete.

Frequently occurring with isolation is confinement, a condition involving the physical restriction of the movement of an individual. In space flight, such confinement may be produced by the wearing of a cumbersome pressure suit or it may, in effect, be produced by mandatory means such as social or military restrictions (6).

Thus, during space flight, astronauts would be both isolated and confined. Various degrees and conditions of isolation and confinement may occur. For example, an astronaut may be subjected to social, cultural and perceptual isolation while encapsuled in his space vehicle with his crew on a long space flight.

Isolates may be volunteers, captives or victims of situational events such as shipwrecks or disasters (27). Chambers (10) has noted that there are over a thousand published reports concerned with isolation, confinement, sensory alteration and related conditions. These conditions have been experienced by prisoners, isolated explorers, shipwrecked sailors, pilots, astronauts and volunteers in flight simulation experiments. The vast majority of these are personal reports of extreme hardship, isolation and confinement. A much smaller number are controlled laboratory studies involving humans.

Early accounts of personal isolation experiences include those of Christine Ritter (26) alone in the Arctic at the turn of the century; Admiral Richard Byrd (7, 8) alone in the Antarctic; Joshua Slocum (30) and Alain Bombard (5) on extended ocean voyages in small vessels. Chambers (10) has summarized the primary symptoms of the extreme changes in behavior of such isolates. These symptoms are listed below:

1. Perceptual distortions
2. Visual illusions and vivid imagery
3. Bizarre hallucinations
4. Dramatic changes in attitude and temperament
5. Marked changes in motivation
6. Extensive emotional reactions
7. Deterioration of ability to remember, think and reason.

Sensory Alteration

There are several aspects of isolation including psychological feelings of separation from other people (aloneness); by physical distance; from society (cultural isolation); and from familiar surroundings (11). Most experimentally produced aspects of isolation, however, deal particularly with changes in the quantity and variety of sensory and perceptual input while the subject is confined within a small space. The purposes of such experimentation have been, in addition to those related to man in space, primarily to learn more of the functioning of the central nervous system and find possible applications in treatment of mental disturbances and to learn more of the process of "brainwashing."

In the last decade, a great number of studies dealing with sensory alteration have been made. Most of these involve sensory deprivation, or at least a reduction of the sensory stimulation to which an individual is subjected. This may involve 1) a single modality in which one sensory channel is blocked; 2) multimodality in which vision, hearing and touch channels are blocked; or 3) a decrease in input patterning by the use of such means as permitting only diffuse white light to reach the eye or "white noise" masking tones to reach the ear (6). Actually, it may be impossible to totally deprive a subject of sensory stimulation. Auditory sensations, for example, may still be experienced even in a completely soundproof room, due to sounds produced within the person's own body.

One well-known series of early sensory deprivation studies took place in the laboratory of Dr. D. O. Hebb, McGill University, Montreal (4). Subjects were placed in a small, lighted, partially soundproof room wearing gloves, cardboard tubes over their arms and translucent goggles. A "white noise" was produced by an air conditioner. They were allowed to leave the room to visit the bathroom. Two-way communication was provided and meals could be brought in upon request. The subjects experienced visual hallucinatory experiences and had difficulty in concentrating and in organizing their thinking. Some effects even persisted for days after release from their two or three day confinement. Later it was found that an increase in susceptibility to propaganda was exhibited while in the decreased sensory environment (18, 31).

Another series of sensory deprivation experiments was begun at Princeton University in 1956 (37, 36). In these studies, the subjects were isolated in dark, lightproof, soundproof rooms. Food and toilet facilities were available in the room and a "panic button" was provided for use if the subject wished to terminate the experiment. Various attempts were made during these studies to observe the relationship of total darkness and patterned and non-patterned illumination to the occurrence of hallucinations.

Lilly and Shurley (22) suspended subjects in a tank of slowly flowing warm water for periods of up to three hours. The only actual contact came from the straps suspending the subject and from a closely fitting, lightproof head mask which was fitted with a breathing tube. An initial period of recalling recent events was followed by a stage in which the subject intently concentrated upon what little stimulation was available to him. This gave way eventually to fantasies which were followed by hallucinatory experiences. Positive, enjoyable results were obtained at times when all disturbing stimuli were minimized.

A wide variety of techniques and procedures have been employed in sensory deprivation studies. These have been reviewed by Cameron, et al. (9), Chambers and Fried (11), Chambers (10) and Weinstein (38). The duration of isolation in these isolation and deprivation studies has varied from periods of less than one hour to fourteen days (25, 1, 39). Humans participating in such experiments have exhibited a great variety of personality and emotional disturbances including hallucinations, anxiety, frustration, apprehension and perceptual and thought distortion.

It is felt by many investigators that these sensory deprivation studies, while they are highly interesting, have only a limited relevance to actual space flight. During space flight, a great number of stimuli may be provided by ground communication and by other crew members. By carefully selecting and training crewmen and further resolving the problems of reduced sensory input, extended manned space operations should not be deterred (21, 2, 11, 17).

Cunningham (14) has suggested that the space explorer is likely to find self-preservation itself a powerful incentive to maintaining his mental equilibrium.

Sensory overloading may not only be more likely to occur than sensory underloading during spaceflight, but it may produce an equally serious psychological problem. Such overloading may be brought about by having to react to information from many dials and monitoring screens, various auditory signals, physiological stress and other sensory inputs—all simultaneously! This high work-load stress, as it is sometimes called, could be serious in that it could result in severe performance impairment when the astronaut's limit for organizing and responding to a sequence of events has been reached (23, 16).

Performance Degradation

Several experimenters have utilized space cabin simulators for studies of proficiency, vigilance, spatial discrimination and perceptual judgment. Hauty (17) found that when subjects were required to perform monitoring and corrective tasks over a time span of 30 hours, they reported a variety of aberrant experiences. These often involved such illusions as seeing gauges turning into faces or believing that a monitoring screen had turned brown and was ready to explode (34, 17).

Fatigue and the monotony of unchanging environments (leading to boredom) may produce serious threats to long-term space travel (28). Christensen (12) has indicated the importance of designing a spacecraft system that will require and use crew members in jobs which are both essential and challenging enough to prevent the occurrence of monotony and boredom. The possibility of switching jobs or varying the tasks might also be considered in an attempt to counteract boredom on long flights. Fatigue also represents a serious threat to the maintenance of performance reliability and vigilance.

Precautions must be taken to prevent performance decrements, disorientation and visual and perceptual distortions which often accompany the condition of sleep deprivation. Sleeplessness occurs often in small, isolated groups in the Antarctic and could produce problems on long flights (27). Chambers (10) has reviewed some of the studies of sleep deprivation and has pointed out the need for wakefulness during times of prolonged monitoring and vigilance while on extended space voyages.

An astronaut on such a long flight may find it necessary to detect infrequent visual or auditory signals of a low-attention value. Remaining vigilant during such prolonged monitoring tasks may be difficult (3). Hauty (17) and others have studied task attentiveness during simulated space flights of many days. Their reports indicate that over a long period of time, vigilance performance may become degraded. Nuclear submarine cruises have shown that problems of fatigue, boredom and vigilance can be minimized by providing carefully designed equipment layouts and appropriate activity tasks and work-rest schedules. Confinement has not been found to cause any significant effects upon intellectual functioning (24).

Several other potentially hazardous, but as yet poorly understood, problems are associated with isolation and confinement. "Fascination" is the condition in which an experienced pilot fails to respond to clearly defined stimuli. In reviewing this and related phenomena such as "freezing" and "voodoo death," Chambers (10) has expressed concern that these problems may exist, as space travel becomes longer and more complex.

A feeling of complete physical separation or detachment from the earth has often been experienced by men while flying at high altitudes. The "break-off" phenomenon, as this contact-severance is usually termed, was found by Clark and Graybiel (13) to be associated with long solitary high altitude flights where a minimum of effort was needed to pilot the aircraft. To some, the "break-off" was an exhilarating experience, but others reacted with feelings of depression and loneliness. Whether this phenomenon has any significance for astronauts during space travel has not yet been demonstrated adequately

Personality and Emotional Behavior

The performance of man in space may be profoundly influenced by the effect of stress upon his emotional behavior. Confinement during prolonged space flights might possibly produce restlessness, irritability, aggravation, hostility, or regressive behavior in one or more crew members. Such emotional behavior may endanger his equipment or even other members of the crew. Confined group living with its intercrew-interteam relationships and crew discipline must be considered on long flights.

Extended space travel will interfere with gratification of such human needs as erotic and emotional satisfaction. Other emotional and behavioral problems associated with isolation and confinement in space flight might include anxiety over prolonged exposure to extreme psychological or physiological hazards, fright or fear of the unknown, psychoses and painful shifts of emotion. Flinn (15), Slager (29), Chambers and Fried (11) and others have listed various qualities desirable in an astronaut.

The problems posed by investigations in the field of isolation and confinement are numerous and difficult and solutions to all of them have not yet been found. Many of these solutions can be found in actual manned space missions, others can be obtained from studies such as the ambitious one presently underway for NASA at the Albert Einstein College of Medicine, New York City, under the direction of Dr. Sidney Weinstein.

In this study, sensory deprived individuals are being compared with motor activity deprived individuals and those lacking patterned stimuli. Brightness, loudness and touch sensitivity thresholds, three-dimensional spatial organization, the effects of intrinsic guidance upon the individual's ability to respond to a "rearranged" environment, various physiological and neurophysiological effects and emotional responses are all being measured. This research has been initiated to help answer: a) What are the abilities relevant to space flight which are impaired after restriction of motion and relatively unchanging stimulation such as would occur in long space flights? b) What characteristics of individuals make them less susceptible to the effects of such restrictions? c) What type of stimulation is required to offset the effects of motor and sensory deprivation? (38).

By means of on-the-ground investigations such as the studies just itemized and by carefully selecting and training men for space flight, the potentially detrimental effects of isolation may be minimized (10, 31).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Among the rather limited number of laboratory-oriented experiences involving isolation and confinement suitable for use with high school students and classes, those dealing with sensory alterations are likely to evoke the most response from students. Such studies do not necessarily require the sophisticated equipment used by the professional investigators in the field. The sensory deprivation studies at Princeton, for example, took place in a darkened, lightproof room which had soundproofing such that a pneumatic hammer could not be heard from within (36). The subjects were paid and were in some cases confined for periods of ninety-six hours. Studies involving such procedures may be neither practical nor appropriate at the high school level. Short-term partial sensory deprivation experiments involving one or two sensory modalities, however, may be feasible if carefully planned.

1. The design of such partial deprivation experiments might utilize the techniques similar to those used at McGill University (4) or at New York University (19). At New York University, subjects spent eight hours on a comfortable bed in a lighted room. To provide visual deprivation, halved table tennis balls were rubber cemented over their eyes, thus permitting only diffuse white light to enter. To provide visual deprivation, other investigators have darkened the room or placed either opaque or semitranslucent goggles or masks over the subjects' eyes. Moleskin, a cloth-like mastic similar to adhesive tape, also has been used to fasten these devices over the eyes. One study utilized a "Panelescent" night light attached as a mask in front of the eyes.

2. In the New York University experiments, a random noise generator produced a "white" noise which was transmitted to the ears by means of padded earphones in a helmet worn by the subject. Others have used air conditioners or electric fans which produced a source of mixed frequency noise to mask any unwanted sounds. U-shaped foam rubber cushions surrounding the head also helped provide auditory deprivation.

3. Studies involving tactual isolation of the entire body surface are much more difficult but some researchers have achieved partial tactual deprivation by using fur-lined gloves or mittens and rolls of heavy cloth or cardboard tubes which cover the head, forearm and elbow. Others have employed cigar-box-shaped containers to keep the fingers relatively isolated from each other and from other objects. Weinstein (38) has mentioned several studies in which tactual sensitivity was improved by deprivation. This involved varying the distances between two points applied to the skin of the arm and measuring the distance at which the subject is able to discriminate two points from one. Enhancement of this ability has been found to last several days after deprivation was completed.

4. A study in which sensory-deprived subjects had been told to expect hallucinations and were given placebos (substances having no pharmacological effect; "sugar pills") to help bring them on, served to emphasize that the possible influence of suggestion should be taken into consideration in the design of sensory deprivation experiments (20, 35). Nearly all of the subjects reported unusual sensations during the one-hour sensory deprivation situation. This type of study might be very interesting to pursue with high school students. It should be noted that the time involved was only one hour in contrast to other sensory deprivation studies lasting one or more days.

5. Because of their rather serious psychological implications, all studies involving the isolation or confinement of students should be carefully planned. The safety of the students, psychologically as well as physiologically, should always be considered. This is especially true of any situation which exposes the student to conditions of sensory underload. It is advisable to include such persons as parents, family physician, school nurse, school district psychologist and department chairman or principal during the planning and performance of experimental sensory alteration studies in which students are participants. This is particularly desirable if this type of experiment is to last for several hours or more. It should also be pointed out to students that merely observing a partially sensory-deprived subject to "see what happens" does not constitute a valid experiment. Answers to specific questions should be sought and hypotheses tested.

Several other problems dealing with aspects of isolation and confinement might be investigated by students as individual or group research. These might include attempts to defeat boredom as it might pertain to monitoring tasks in a space vehicle or to semi-leisure activities. Information concerning the design of a viewing box into which a sensory-deprivation subject could look as often as he pleased, is found in Vernon (36). Such a box might contain a simple design or picture which could help to relieve boredom or provide needed stimulation to a subject in confinement.

Digit span, mental arithmetic and number retention tasks were studied as part of the psychological testing and psychosociological evaluation during a 30-day simulated space station mission. Reaction time, eye-hand coordination and vigilance were measured by testing. All of these tests involved elaborate electronic equipment, but several could be performed by students with much less complicated equipment of their own design.

NASA Educational Brief No. 1004–B entitled "Measures to Overcome the Problems of Postural Hypotension" (available from NASA Manned Spacecraft Center, Houston, Texas), deals with isometric contraction, inflatable cuffs and the bungee cord exerciser. Not only are these useful in overcoming loss of adequate circulation, but can be used to provide relief from boredom. Students may be interested in constructing a bungee cord exerciser. Try a regimen of isometric exercises during the school day to discover whether or not such activity reduces postural weariness due to sitting long hours in the class.

LITERATURE CITED

1. Arnhoff, F. N. and H. V. Leon. 1962. Sensory deprivation: its effect on human learning. Science 138:899-900.

2. Beech, H. R. 1961. Psychological problems of solitude and confinement, p. 59-74. *In* N. W. Pirie (Ed.), The biology of space travel. The Institute of Biology, London.

3. Bergum, Bruce O. and Donald J. Lehr. 1963. Vigilance performance as a function of task and environmental variables. George Washington University, Washington, D. C.

4. Bexton, W. H., W. Heron and T. H. Scott. 1954. Effects of decreased variation in the sensory environment. Canadian Journal of Psychology 8:70-76.

5. Bombard, Alain. 1953. The voyage of the *Heritique.* Simon and Schuster, New York.

6. Burns, Neal M. and Douglas Kimura. 1963. Isolation and sensory deprivation, p. 168-192. *In* Neal M. Burns, Randall M. Chambers and Edwin Hendler (Eds.), Unusual environments and human behavior. The Macmillan Company, New York.

7. Byrd, Richard E. 1930. Little America. G. P. Putnam's Sons, New York.

8. Byrd, Richard E. 1938. Alone. G. P. Putnam's Sons, New York.

9. Cameron, D. E., Leonard Levey, Thomas Ban and Leonard Rubenstein. 1961. Sensory deprivation: effects upon the functioning human in space systems, p. 225–237. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

10. Chambers, Randall M. 1964. Isolation and disorientation, p. 231-297. *In* James D. Hardy (Ed.), Physiological problems in space exploration. Charles C Thomas, Publisher, Springfield, Illinois.

11. Chambers, Randall M. and Robert Fried. 1963. Psychological aspects of space flight, p. 173-256. *In* J. H. U. Brown (Ed.), Physiology of man in space. Academic Press, New York.

12. Christensen, Julien M. 1963. Psychological aspects of extended manned space flight, p. 308-346. *In* George W. Morgenthaler (Ed.), Advances in the astronautical sciences, Volume 15,

Exploration of Mars. Western Periodicals Company, North Hollywood, California.

13. Clark, B. and A. Graybiel. 1957. The break-off phenomenon. A feeling of separation from the earth experienced by pilots at high altitude. Journal of Aviation Medicine 28:121-126.

14. Cunningham, Cyril. 1962. The effects of sensory improvements, confinement and sleep deprivation, p. 25-27. *In* G. V. E. Thompson (Ed.), Space research and technology. Gordon & Breach Science Publishers, London.

15. Flinn, Don E. 1961. Psychiatric factors in astronaut selection, p. 87-95. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

16. Hartman, Bryce O. 1961. Time and load factors in astronaut proficiency, p. 278-308. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

17. Hauty, George T. 1964. Psychophysiological problems in space flight, p. 196-224. *In* Karl E. Schaefer (Ed.), Bioastronautics. The Macmillan Company, New York.

18. Heron, W., B. K. Doane and T. H. Scott. 1956. Visual disturbances after prolonged perceptual isolation. Canadian Journal of Psychology 10:13-18.

19. Holt, Robert R. and Leo Goldberger. 1961. Assessment of individual resistance to sensory alteration, p. 248-262. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

20. Jackson, C. W. and E. L. Kelly. 1962. Influence of suggestion and subject's prior knowledge in research on sensory deprivation. Science 135:211.

21. Lansberg, M. P. 1960. A primer of space medicine. Elsevier Publishing Company, Amsterdam, The Netherlands.

22. Lilly, John C. and Jay T. Shurley. 1961. Experiments in solitude, in maximum achievable physical isolation with water suspension of intact healthy persons, p. 238-247. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

23. Miller, James G. 1961. Sensory overloading, p. 215-224. *In*

Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

24. Ormiston, Donald W. and Beatrice Finkelstein. 1961. The effects of confinement on intellectual and perceptual functioning. Technical Report No. 61-577. Aerospace Medical Research Laboratories, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

25. Petrie, A., W. Collins and P. Solomon. 1958. Pain sensitivity, sensory deprivation and susceptibility to satiation. Science 128:1431-1433.

26. Ritter, Christine. 1954. A woman in the polar night. E. P. Dutton and Company, New York.

27. Rohrer, John H. 1961. Interpersonal relationships in isolated small groups, p. 262-271. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

28. Simons, David G. 1963. Psychophysiological approach to the study of fatigue in space flight, p. 581-583. *In* Proceedings of the 12th International Astronautical Congress, Volume 2. Academic Press, New York.

29. Slager, Ursula T. 1962. Space medicine. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

30. Slocum, Joshua. 1956. Sailing alone around the world. Grosset and Dunlap, Inc., Publishers, New York.

31. Solomon, Philip. 1961. Motivations and emotional reactions in early space flights, p. 272-277. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

32. Solomon, Philip, P. E. Kubzansky, P. H. Leiderman, J. H. Mendelson, R. Trumbull and D. Wexler (Eds.). 1961. Sensory deprivation. Harvard University Press, Cambridge.

33. Space station system simulation. results of a 4-man/30-day mission simulation program. 1964. Document 64SD679. General Electric Company, Valley Forge Space Technology Center, Philadelphia, Pennsylvania.

34. Steinkamp, George R. and George T. Hauty. 1961. Simulated space flights, p. 75-79. *In* Bernard E. Flaherty (Ed.), Psycho-

physiological aspects of space flight. Columbia University Press, New York.

35. Stern, Robert M. 1962. Suggestions and sensory deprivation. Science 136:596-597.

36. Vernon, Jack A. 1963. Inside the black room. Clarkson N. Potter, Inc., Publisher, New York.

37. Vernon, Jack A., Theodore Marton and Ernest Peterson. 1961. Sensory deprivation and hallucinations. Science 133:1808-1812.

38. Weinstein, Sidney. 1964. Sensory, perceptual and physiological aspects of sensory deprivation. Conference on the Role of Simulation in Space Technology, August 17-21, 1964. Virginia Polytechnic Institute, Blacksburg, Virginia.

39. Zubek, J. P., G. Welch and M. G. Saunders. 1963. Electroencephalic changes during and after 14 days of perceptual deprivation. Science 139:490-492.

section 3

PHYSIOLOGICAL ASPECTS

CIRCADIAN RHYTHMS

Tacitus, first century Roman historian, observed that "in all things, there is a sort of law of cycles." Today, in the twentieth century we are finding that, indeed, almost all life processes do occur in cycles or rhythms. Modern research into biological periodicity has, in the past fifteen years, been a subject of steadily increasing interest to more and more scientists. Much of this increased interest in biological rhythms has been brought about by the manned space effort. The question of how man's firmly established rhythms will be altered in an extraterrestrial environment and how this might affect his performance and success is intriguing, as well as significant.

The area of biological periodicity is replete with unanswered and incompletely answered questions. How, for instance, will such factors as an erratic photic environment, changed work-rest schedules, and the physiological nature of the astronaut interact to determine the pattern in which his biological clock will run? How will the travel time of extended space flights influence these interactions?

The rhythmic changes occurring in an organism's physical environment are much better known to man than those periodicities exhibited by the organisms themselves. It has long been known, for instance, that the 23° inclination of the axis of the earth in conjunction with the 365-day period of revolution about the sun accounts for the periodicity of the seasons. Equally well-known is the monthly cycle of slightly over 29.5 days (synodical month) exhibited in the synchronization of the rising and setting of the sun and the moon. Other periodicity is demonstrated by the rotation of the earth in relation to the moon as observed during each 24 hour and 50 minute lunar day. The rotation of the earth in relation to the stars produces a period of about 23 hours and 56 minutes (sidereal day). Our sun rotates on its axis about once in every 27 days. Most of us take for granted the rotation of the earth on its axis that provides us with the 24-hour periodicity known as a solar day. The physical environment of an organism is abundantly supplied with a multitude of interacting rhythms.

It is the 24-hour periodicity of earth that has such great importance biologically. Biological rhythms with periods of about 24 hours in length are known as circadian rhythms, or circadian cycles.[1] If the periods vary somewhat from exactly 24 hours, the peaks of a given rhythmic function will occur correspondingly earlier or later each day (15, 17). Such circadian rhythms are firmly established in man as well as in many other organisms.

Aschoff (1) recognizes two forms of circadian periodicity: a) exogenous periodicity which exists while the factors in the environment show a periodicity, but ceases or diminishes when the environmental conditions are kept constant; b) endogenous periodicity which continues even if the environmental conditions are kept constant.

It is currently believed that the cause of periodicity is to be found within the organism itself and that the rhythmic nature of the environment acts to provide synchronizers (also known as entraining agents, clues, timegivers or zeitgebers). This "biological clock" is likely to be a temperature-corrected, continuous, environment-regulated chemical system rather than some particular structure within the body of the organism (2).

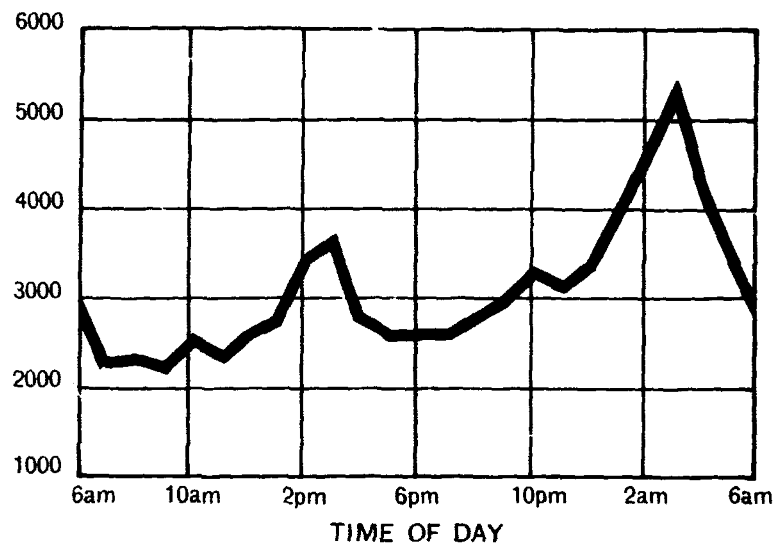
Strughold (40) has discussed the photic environment as a possible synchronizer of the biocycle of astronauts especially during interstellar flight and on celestial bodies. Research with chickens to determine the effects of light on parts of the body other than the eye is currently being carried out at the NASA Ames Research Center, Moffett Field, California, under the direction of Dr. Charles Winget et al. (43, 44, 45).

Much recent research in biorhythmics has involved the feasibility of shifting the external timing relation of a rhythm. For example, phase-shifting by means of alternating periods of light and darkness has been reported (15, 16, 17). These involve various metabolic parameters of mice. Such studies of rhythms during phase-shifting may have great significance in space biology.

The time shift of the circadian cycle in man requires a certain period for accommodation. Kleitman (28), using body temperature as an indicator, found that subjects were able to adapt to work-rest periods of both 18 hours and 28 hours if given sufficient time for readjustment. These studies, of course, did not include the effects of weightlessness, nor did they involve more than one of the 24 geographical time zones of the earth.

[1] Latin: *circa* = around or about; *dies* = day.

The study of phase-shifting requires a consideration of the normal fluctuations in physiological cycles in man. One such early study was of the frequency of errors in a large number of routine checkings of gas meters in Sweden over a nineteen-year period. The point of lowest efficiency at 3 a.m. was found to be very distinct (Figure 1) (32).



Errors made in 175,000 checkings of gas meters, from 1912–1931. (After Bjerner, Holm, and Swensson.)

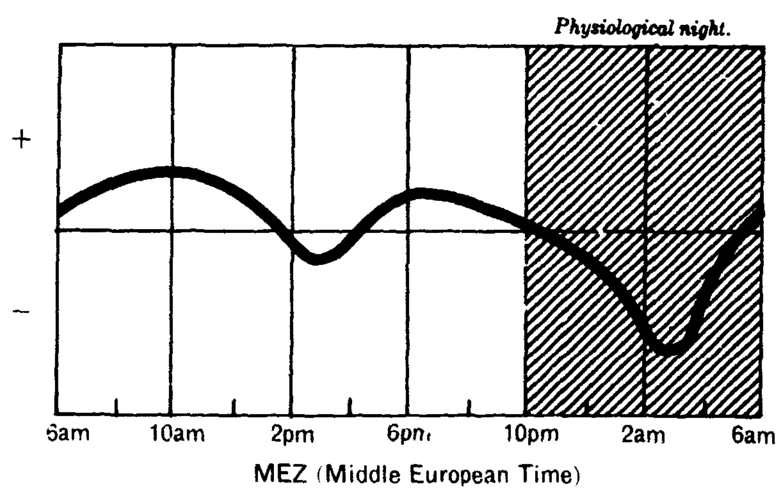


FIGURE 1. *Smoothed curve of human readiness to work over the day.*

It has been known for some time that the work output of experienced factory workers increases until about 10 a.m., decreases at noon, increases somewhat in the afternoon and then gradually and continually decreases. Nighttime further decreases the efficiency and work output (15, 32).

Time for readjustment is required in work shifts in such places as factories, hospitals, public emergency facilities, mines, military watches, all-night radio facilities and observatories. As part of this shift work, a person often must alternate morning, afternoon and night periods. Because it takes four or five days to adjust to new work periods, many workers, if shifts are changed too often, are nearly always in a state of readaptation (32).

In all of these examples, the time zone is not changed, only the work activities of the individual. Some interesting problems are presented by the reverse of this situation. That is, where the individual does not change his work-activity-rest pattern, but travels to another time zone (39).

Travel by jet plane illustrates some of the complexity of the circadian rhythm factors. A trip from Paris to New York at the speed of 700 mph would require five hours. Yet if a traveler left Paris at noon he would find that it was still lunch time when he arrived in New York. His biological clock, however, would indicate that it was evening and time for dinner (41).

The physiological or metabolic clock of a traveler does not coincide with the local time. Many people who have recently changed their residence from one part of the country to another several time zones away experience physiological discomforts such as becoming hungry, sleepy or awake at unusual hours that do not agree with local time. Many large corporations and governments do not allow their important representatives or executives to take part in major policy making decisions for several days after transoceanic flights due to this cycle asynchrony. Commercial airline pilots with seniority rights often prefer north-south routes because of the metabolic phase shift problems of east-west flights.

Body temperature has been found to vary in relation to the 24-hour fluctuation in performance and alertness (30, 46). Other studies of temperature have been made during such activities as the 12-hour cycle of the submarine crew watch-standing routine, four hours on duty, four hours off duty, and a seven-hour day with a 5:3 work rest ratio (25, 24). Kleitman (29), on the basis of temperature level studies, suggests possible use of schedules for astronauts consisting of an eight-hour daily duty divided into two- or three-hour watches.

A biosatellite experiment, under the direction of Dr. Colin S. Pettindrigh, Princeton University, has been scheduled to study the influence of biorhythms in various metabolic systems of the laboratory rat. Eight adult female rats are to be instrumented with transducers inserted in their abdominal cavities to provide telemetered body temperature and gross motor activity data. The lighting regimen will be controlled in intensity and in period. The resulting phases of rhythmicity will be studied and compared with ground controls to determine any possible differences affected by removal from terrestrial influence (33). It is hoped that evidence will be obtained to help answer the question of whether circadian biorhythms are environmentally induced or whether they are inherent (27).

When organisms are deprived of all the usual environmental influences (such as sound, light-dark relations and temperature fluctuations), desynchronized circadian rhythms (which are called "free running" cycles) are observed in a variety of biological processes (31, 14, 16). Might extraterrestrial travel help to determine what it is that influences these non-24-hour circadian rhythms (6)?

Cosmonauts Titov, Nikolayev and Popovich, while orbiting the earth, slept while it was night over Russia and Gemini 5 astronauts Cooper and Conrad did not sleep according to their planned schedule. Such data have increased speculation about the consequences of the desynchronization of man's circadian rhythms.

Only through actual extended manned space operations can answers to many of the questions of extraterrestrial biorhythms be found. It is certain, however, that their answers will be important in determining the success of man's space efforts.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

A number of studies and experiments might be undertaken to help give students an appreciation of biological rhythms inasmuch as current evidence indicates that such rhythms can be found in nearly all organisms (34, 11, 18, 9).

Some of these studies might be undertaken as classroom laboratory experiences by the entire class, while others might better be pursued by teams as demonstrations or as individual student research problems

1. Several variables could be investigated to increase awareness of physiological cycling in man. One such variable that can be measured in humans without expensive equipment or time-consuming methods is the rhythms of body temperatures.

   The student should be reminded to use caution in shaking the mercury down to 95° Fahrenheit and to leave the thermometer under the tongue for three minutes to insure an accurate reading, to cleanse the thermometer thoroughly after reading, and to record both temperature and the time of observation.

   The data should be plotted as a graph. It would be useful to continue the study for several days, plotting each day's readings on the graph or to plot the average of the readings for each time interval. It would be hoped that some students would wish to continue with such temperature recordings (at least during hours of wakefulness) for longer periods of time.

   Several questions may be raised in regard to the data. What factors could account for the differences or fluctuations of the body temperature of one individual during 24 hours? How does one individual's temperature curve compare with that of the rest of the class or with several classes? What is a "normal" temperature and how do you suppose it was determined? Why is each person's "normal" body temperature not the same?

   It has been found that simply lying down and relaxing results in a measurable drop in body temperature and that wakefulness during hours that are usually allotted to sleeping may cause the body temperature to rise a degree above that during sleep (30). These findings may suggest an investigation to some student or perhaps an excuse to stay up late at night.

   Evidence has been found of a correlation between body temperature and performance. Systematic investigation of the variation in performing such tests as reaction time, hand steadiness, multiplication of large numbers or naming colors are all possibilities for further investigations (29).

   A student may be interested in comparing his body temperature curve for the same time period with that of another warm-blooded mammal, perhaps a cat or dog. Since it would probably be necessary to obtain rectal temperatures of the dog or cat, the student may need to consider the dangers of broken thermometers, the problems of thorough cleansing of the thermometer and how to compare rectal and oral temperature readings. This could provide useful data for comparison with that of man.

2. A second group of experiments might involve studies of the effects of altered day-night cycles in plants and animals (photoperiodism). One way of obtaining data is to record the activity rhythms of the organisms.

To record small movements which take place over a period of time, many expensive and sophisticated devices have been used by investigators. These often include cages equipped with running or exercise wheels, revolution counters and automatic recorders (19). Directions for inexpensively modifying a standard kymograph recorder so it will revolve once every twenty-four hours may be found in deRoth (10).

Excellent directions for the construction of a very useful and inexpensive recording drum have been given by Harbeck (21). This versatile device makes use of a discarded spring-driven or electric clock and a one-pound coffee can (Figure 2). The clock mechanism is taken out of its case, the hands and face removed and the mechanism mounted on a vertical support. A length of stiff steel wire passes through and is soldered to the coffee can as the axle. The axle is suspended from notches cut out of the upper edge of a vertical metal drum support.

It is the connection between the axle and the clock shafts which determines the speed at which the drum will rotate. If connected to the center shaft, the drum will turn once an hour; if connected to the outer shaft it will rotate once every twelve hours. The center shaft on clocks which have a sweep second hand will allow a complete turn once a minute.

A hardware-cloth and coffee-can cage can be constructed for a mouse or rat and arranged so that it is suspended by springs over the recording drum (Figure 3). This "jiggle cage" can then be used to relate the activity of the animal to vertical movement of the cage. By careful calibration, this activity can be expressed in millimeters of vertical movement per unit of time. A ball point pen, soft lead pencil or bamboo-tip marking pen positioned in the center of the cage bottom produces marks on the recording drum paper in proportion to the amount of movement of the animal. Many variations and refinements of this basic design are possible, and will occur to students. In the design of another clock-motor type activity recorder, a smoked cardboard disc is attached to the clock's hour hand (after the other hands have been removed). One end of a wire lever is attached to an animal while the other end is arranged so that it rests upon the disc. Activity is determined by counting the number of scratches made on the smoked disc during a known time interval. Although this recorder was designed to record the activity patterns of such animals as hermit crabs,

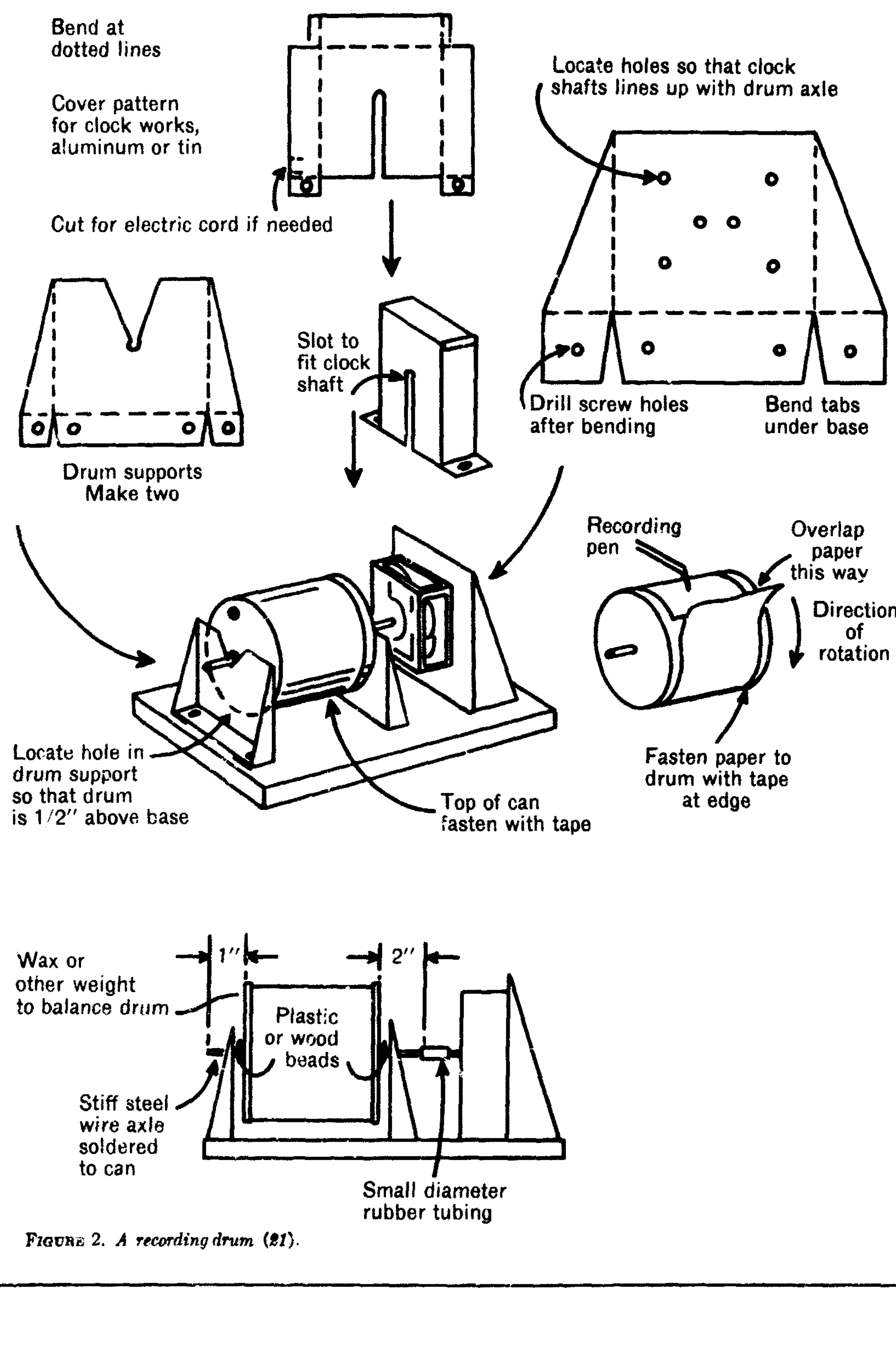


FIGURE 2. *A recording drum (21).*

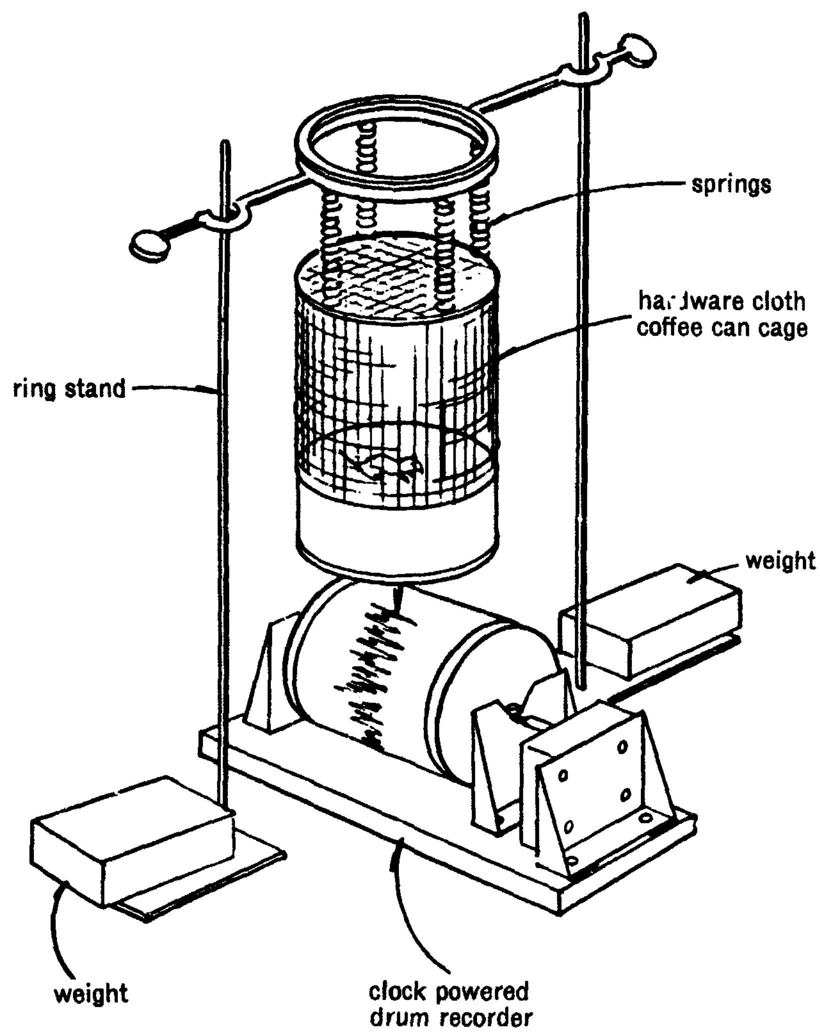


FIGURE 3.

crayfish and snails, it could be positioned vertically so as to record leaf movements in plants (42).

This technique has been used successfully to study the effect of a sudden reversal in the 24-hour light-dark cycle on the biological clocks of mice (35). The entire apparatus can be enclosed and a light provided when necessary. Care should be taken not to introduce other variables such as heat. It may be interesting, also, to change the intensity of the light, use a timer to control the lighting regimen, or to study the length of the accommodation or transition times of the animals. Various native rodents (e.g. *Peromyscus*) might be compared with laboratory animals (Figure 4).

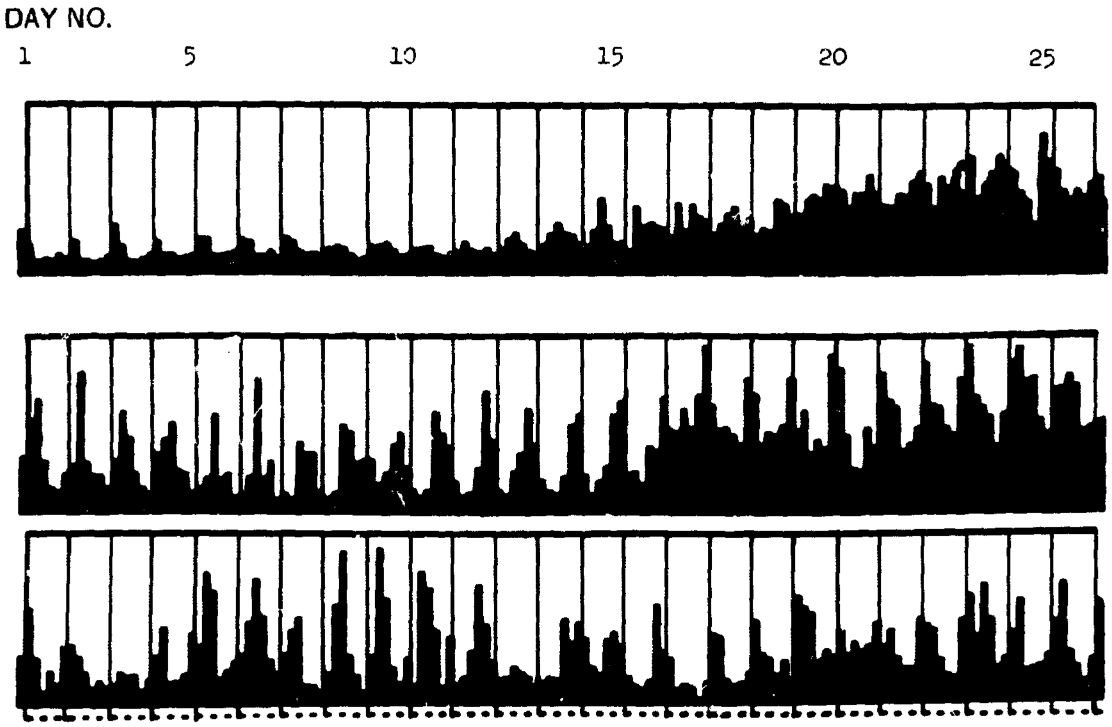


FIGURE 4. *Activity rhythm of three mice kept in light for four hours alternating with four hours of darkness. Activity in arbitrary units. Note circadian periodicity free-running from the 24-hour clock (24 hours shown by the vertical lines) (14).*

Dr. Robert Bolles, Hollins College, Virginia, is currently investigating the extent to which activity cycles in rats can be changed by using conditions of constant environmental stimulation in an environment providing supporting adiurnal cues.

Modification of the "jiggle cage" could be made so that smaller animals might be compared—lizards, snakes, amphibians and insects such as large ground beetles, darkling beetles or Jerusalem crickets. The biorhythms of cockroaches are being studied by various investigators including Dr. Franz Halberg, University of Minnesota, Dr. Colin S. Pettindrigh, Princeton University and Dr. Robert Lindberg, Northrop Aviation Corporation, Los Angeles. Dr. J. E. Harker (22, 23) has been investigating circadian rhythms of the cockroach for many years. Interesting rhythmic behavior exhibited by headless cockroaches and cockroaches in parabiosis (connected blood streams) are described by Beck (2).

Students may be interested in studies of *Drosophila* emergence rhythms and the sensitivity of fruit flies to brief periods of exposure to light (2, 3).

The activity patterns of land snails may be studied by feeding them lettuce colored with methylene blue and then allowing the snail to travel, thus producing a blue trail. The length of the trail per unit of time is an indication of the activity. The student may be able to devise ways to keep the snail from "retracing" its path and ways to prevent the snail from resting instead of moving.

Rhythmic activity in plants may also be studied easily by students. A drum recorder can be used to automatically record the so-called "sleep-movements," in which the leaves of many plants droop at night and elevate by day (20). Such changes in leaf movements persist even when no change in temperature or light is involved. A thread or wire is attached from a leaf to a counterweight writing arm which records on a moving drum. This necessitates the orientation of a rotating drum apparatus so that an up and down motion of the leaves produces cycles on the drum's recording paper. A leaf movement recording system, using a strain gauge coupled to an amplifier and recorder, has recently been developed for use in biosatellite experiments testing the effects of light-dark cycles on the leaf movement of pinto bean plants (26). Bean seedlings have been intensively studied, especially in regard to their ability to "remember" some event such as having received brief exposure to light at some particular time in the sleep rhythm cycle (8, 4).

3. The sprouting eyes of potatoes, sealed in rigid containers and kept in constant darkness, show daily metabolic fluctuations, even to the point of "predicting" barometric pressure changes two days in advance of their occurrence (5). Dr. Donald L. Foster and Dr. Bruce Pine (13) of the Space/Defense Corporation, Birmingham, Michigan, have developed a life support system for maintaining a potato in a closed environment for a period of 90 days. A respirometer, capable of measuring oxygen consumption and carbon dioxide output of the potato to within twelve millionths of a cubic centimeter, is included as an integral part of a unit. Plans call for orbiting the "Spudnik" to try to discover whether its biorhythmicity is caused by outside forces or mechanisms within the cells.

Three easy-to-read sources of additional biorhythm investigations for students are to be found in Brown (7), Beck (2) and Farner (12). Three other recent, but more difficult, readings on biorhythmicity are by Reinberg and Ghata (36), Sollberger (37), and Stevens (38).

LITERATURE CITED

1. Aschoff, Jurgen. 1962. Timegivers of 24-hour physiological cycles, p. 373–380. *In* Karl E. Schaefer (Ed.), Man's dependence on the earthly atmosphere. The Macmillan Company, New York.

2. Beck, Stanley D. 1963. Animal photoperiodism. Holt, Rinehart and Winston, Inc., New York.

3. Brett, W. J. 1955. Persistent diurnal rhythmicity in *Drosophila* emergence. Annals of the Entomological Society of America 48:119–131.

4. Brown, Frank A., Jr. 1959a. Living clocks. Science 130:1535–1544.

5. Brown, Frank A., Jr. 1959b. The rhythmic nature of animals and plants. American Scientist 47:147–168.

6. Brown, Frank A., Jr. 1961. Extrinsic rhythmicality and the timing of the circadian rhythms, p. 28–31. *In* Circadian Systems, Report of the Thirty-ninth Ross Conference on Pediatric Research, Ross Laboratories, Columbus, Ohio.

7. Brown, Frank A., Jr. 1962. Biological clocks. AIBS–BSCS Pamphlet No. 2, D. C. Heath and Company, Boston, Massachusetts.

8. Bunning, Erwin. 1964. The physiological clock: endogenous diurnal rhythms and biological chronometry, second edition. Academic Press, New York.

9. Cloudsley-Thompson, J. L. 1961. Rhythmic activity in animal physiology and behavior. Academic Press, New York.

10. deRoth, Gerardus. 1965. A simple twenty-four hour recording device. Turtox News 43(8):194–195.

11. Ehret, C. F. 1960. Action spectra and nucleic acid metabolism in circadian rhythms at the cellular level, p. 149. *In* Cold Springs Harbor Symposia on Quantitative Biology, Volume 25. Long Island Biological Association, New York.

12. Farner, Donald S. 1964. Photoperiodism in animals. AIBS–BSCS (American Institute of Biological Sciences-Biological Science Curriculum Study) Pamphlet No. 15. D. C. Heath and Company, Boston, Massachusetts.

13. Foster, Donald L. and Bruce Pine. 1964. Respirometer and life support system for a potato in space environment. Second Quarterly Status Report, May 4–Aug. 14, 1964. Space/Defense Corporation, Birmingham, Michigan.

14. Halberg, Franz. 1961. Circadian rhythms: a basis of human engineering for aerospace, p. 166–194. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

15. Halberg, Franz. 1962. Physiologic 24-hour rhythms: a determinant of response to environmental agents, p. 48–99. *In* Karl E. Schaefer (Ed.), Man's dependence on the earthly atmosphere. The Macmillan Company, New York.

16. Halberg, Franz. 1964a. Physiological rhythms and bioastronautics, p. 181–195. *In* Karl E. Schaefer (Ed.), Bioastronautics. The Macmillan Company, New York.

17. Halberg, Franz. 1964b. Physiologic rhythms, p. 198–322. *In* James D. Hardy (Ed.), Physiological problems in space exploration. Charles C Thomas, Springfield, Illinois.

18. Halberg, Franz and R. L. Conner. 1961. Circadian organization and microbiology: variance spectra and periodogram on behavior of *Escherichia coli* growing in fluid culture. Proc. Minnesota Academy of Science 29:227–239.

19. Halberg, Franz E., C. P. Barnum and J. J. Bittner. 1959. Physiologic 24-hour periodicity in human beings and mice, the lighting regimen and daily routine, p. 803–878. *In* Robert W. Withrow (Ed.), Photoperiodism and related phenomena in plants and animals. American Association for the Advancement of Science, Washington, D. C.

20. Hammer, Karl. 1963. Endogenous rhythms in controlled environments, p. 215–232. *In* L. T. Evans (Ed.), Environmental control of plant growth. Academic Press, New York.

21. Harbeck, Richard. 1964. Project pointers. Science World Edition 1, 8(2):20–21.

22. Harker, Janet E. 1956. Factors controlling the diurnal rhythm of activity of *Periplaneta americana*. Journal of Exptl. Biology 33:224–234.

23. Harker, Janet E. 1960. The effects of perturbations in the environmental cycles on the diurnal rhythm of activity of *Periplaneta americana*. Journal of Exptl. Biology 37:154–163.

24. Hauty, G. T. 1962. Periodic desynchronization in humans under outer space conditions. Annals New York Academy of Sciences 98:1116–1125.

25. Hauty, G. T., F. G. Steinkamp, G. F. Hawkins and Franz Halberg. 1960. Circadian performance rhythms in men adapting to an 8-hour day. Federation Proceedings 19:54.

26. Hoshizaki, T. and K. Yokoyama. 1965. Recording leaf movements with a strain gauge. Nature 207:880–881.

27. Jenkins, Dale W. 1965. The National Aeronautics and Space Administration biosatellite program. Symposium on unmanned exploration of the solar system. American Astronautical Society. (Reprint No. 65–20.)

28. Kleitman, Nathaniel. 1952. Sleep. Scientific American 187: 34–82.

29. Kleitman, Nathaniel. 1961. Physiology cycling, p. 158–165. *In* Bernard E. Flaherty (Ed.), Psychophysiological aspects of space flight. Columbia University Press, New York.

30. Kleitman, Nathaniel. 1963. Sleep and wakefulness, second edition. University of Chicago Press, Chicago, Illinois.

31. Lawton, Richard W. 1963. The physiological effects of unusual environments, p. 3–31. *In* Neal M. Burns, Randall M. Chamber, and Edwin Hendler (Eds.), Unusual environments and human behavior. The Macmillan Company, New York.

32. Lehmann, G. 1962. Effect of environmental factors on biological cycles and performance of work, p. 381–389. *In* Karl E. Schaefer (Ed.), Man's dependence on the earthly atmosphere. The Macmillan Company, New York.

33. National Aeronautics and Space Administration, Ames Research Center. 1965. Biosatellite project experiments in review. Compiled by the staff of experiments and life systems for presentation to Fundamental Biology Study Session, Space Science Board, National Academy of Sciences-National Research Council on June 24, 1965. National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

34. Pettindrigh, Colin S. 1960. Circadian rhythms and the circadian organization of living systems, p. 159–184. *In* Cold Spring Harbor Symposia on Quantitative Biology, Vol. 25. Long Island Biological Association, New York.

35. Radford, George. 1964. Effects of altered light-dark cycles on mice.

36. Reinberg, Alain and Jean Ghata. 1964. Biological rhythms. Walker and Company, New York.

37. Sollberger, A. 1965. Biological rhythm research. American Elsevier Publishing Company, New York.

38. Stevens, Grover. 1966. Biological clocks. Reinhold Publishing Corporation, New York.

39. Strughold, Hubertus. 1952. Physiological day-night cycle in global flights. Journal of Aviation Medicine 23:464–473.

40. Strughold, Hubertus. 1962. Day-night cycling in atmospheric flight, space flight, and on other celestial bodies. Annals New York Academy of Sciences 98:1109–1115.

41. Strughold, Hubertus. 1963. The physiological clock in aeronautics and atronautics, p. 387–400. *In* Lectures in aerospace medicine, Feb. 4–8, 1963. School of Aviation Medicine, Aerospace Medical Division, Brooks Air Force Base, Texas.

42. Triner, Edward D. 1965. An inexpensive recorder for measuring activity cycles of organisms. American Biology Teacher 27:530–531.

43. Winget, C. M. and T. B. Freyer. 1966. Telemetry system for the acquisition of circadian rhythm data. Aerospace Medicine 37(8):800–803.

44. Winget, C. M., C. A. Mepham and E. G. Averkin. 1964a. Variations in intrauterine pH within a circadian rhythm (*Gallus domesticus*). National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

45. Winget, C. M., C. A. Mepham and E. G. Averkin. 1964b. Effects of a 17-spirola tone on a circadian rhythm and other physiological systems (*Gallus domesticus*). National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California.

46. Young, Donald R. 1963. Some metabolic aspects of extended space flight, p. 347–369. *In* George W. Morgenthaler (Ed.), Advances in the astronautical sciences, Volume 15. Western Periodicals Company, North Hollywood, California.

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section 4

EXOBIOLOGY

EXTRATERRESTRIAL BIOLOGICAL EXPLORATION

One of man's oldest and most fundamental interests has been an attempt to understand the universe. The time is rapidly approaching when man will begin the exploration of other planets. Biology will no longer remain an earthbound science.

The likelihood of extraterrestrial life is certainly probable when one considers that earth is but one of millions of planets, many of which must statistically possess the same molecular building blocks that form the living systems on earth.

The principal objective of extraterrestrial exploration will be to determine the state of chemical evolution in the absence of life, or the state of biological evolution if life is present. However, biology, unlike the physical sciences, is lacking in *universal* principles mainly because man has only been able to observe life on the planet earth. Exploration of other planets and observations of other living systems may lead to a universal concept of the origin and nature of such living systems.

Long before space technology will enable man to land on other planets, automated devices will be launched and soft-landed on extraterrestrial bodies. One-way trips to Mars will be available before round trips. In this regard, we must evaluate the necessity of man's presence in planetary exploration. Data collecting and analysis may well be accomplished more efficiently through instrumentation, which weighs less, presents fewer problems for space transportation and does not require life support systems.

One major problem is instrumentation. Ways must be found to be sure that any detected life is not simply that which is carried along from the earth by a vehicle. Thus, there is the necessity of finding ways of sterilizing the spacecraft and instruments to be used. The sterilization procedure must be effective, yet it must not be detrimental to the vehicle or instruments with regard to limiting their reliability.

Any information obtained from an extraterrestrial body concerning life on that body would cast at least some light on the origin and evolution of life. It could surely be one of the most important scientific discoveries of this century. Lack of evidence of life on any given planet would not resolve the question of extraterrestrial life or the origin of life, but would simply mean that we must look further (9).

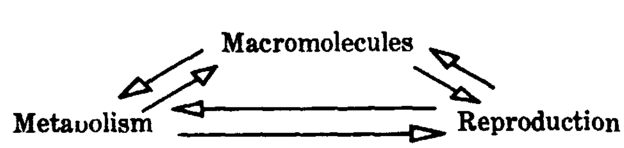
Problems Associated with Biological Exploration

The initial task of the exobiologist is to describe life in such a manner that tests can be devised which will demonstrate, unequivocally, the existence of extraterrestrial life. The manifestations of life most often listed are:

1. Growth
2. Movement
3. Irritability
4. Reproduction
5. Metabolism

Taken collectively, they indeed are indicative of life, but which are fundamental and which are not? (4).

The exobiologist sees certain of these criteria as having little value if one is dealing with microbes, as is suspected to be the case for Mars. A more modern definition of life is the concept of an information-storing and transferring system of macromolecules (nucleoproteins) under tight endogenous control. In order for this living unit to be maintained, two additional attributes of life are necessary —reproduction for the constant renewal of information and metabolism to provide the energy necessary for reproduction and synthesis of macromolecules. The concept of life can be summarized in the following manner:



One of the problems associated with understanding the extraterrestrial evolution of biological systems must be concerned with the detection of certain biologically significant molecules and the possibility of observing metabolic or reproductive processes. While it is possible that a single instrument—by itself—may be used to detect life, it is much more likely that a combination of techniques will be used. Several instruments based on these objectives have been developed and tested, and are listed below (5).

I. Methods for Detection of Extraterrestrial Macromolecules

GAS CHROMATOGRAPHY by Dr. Vance J. Oyama, Ames Research Center, Moffett Field, California.

This sensitive device is capable of rapid vapor analysis. Not only could extraterrestrial atmospheres be analyzed, but if solid samples were heat vaporized, the chromatograph could carry out detailed chemical assays. It could, through telemetry, transmit information about the presence or absence of organic material in soil samples. This information, coupled with other experimentation, should determine the status of chemical and biological evolution on extraterrestrial bodies (7).

SEARCH FOR OPTICAL ISOMERISM OR OPTICAL ACTIVITY by Dr. Vance J. Oyama, Ames Research Center, Moffett Field, California; and Drs. Lederberg and Halpern, Stanford University School of Medicine, Department of Genetics, Palo Alto, California.

There is a generic classification of compounds which is relatively independent of the detail of structure and yet which would pervade a biogenic chemistry. This is optical activity. It depends on the crucial role of the informational macromolecule in a definition of life and the use of tetravalent carbon in building such molecules. If the carbon has an asymmetric center, e.g., has a different chemical group on each of its four valences, then the atom is subject to stereo[optical] isomerism. The molecules thus have well-defined three-dimensional shapes and can be spoken of as having either left-handed or right-handed orientations. Except in the presence of biological systems, one would generally expect to find equal proportions of both such molecules. One can bring an optically active reagent in contact with the target molecule one is searching for. By this method, the ratio of left-handed and right-handed target molecules can be resolved by using gas chromatography (7).

OPTICAL ROTATION by Ira Blei, Melpar Company, Falls Church, Virginia.

One measurable property which has consistently been found in all living systems is optical rotation. A substance is said to possess optical activity when a "flat ribbon," or plane wave, of light (polarized) passing through this substance is twisted, or rotated, so that the flat ribbon of light emerges in a new plane.

This ability to rotate the plane of polarized light is associated with molecular structure in a unique manner, just as the absorption spectroscopic characteristics are unique. Not all materials are capable of rotating the plane of polarized light; however, nucleic acids, proteins, and carbohydrates, all associated with life, do.

An important feature of optical rotation is that it is thousands of times more sensitive near a spectroscopic absorption band of the substance than at wavelengths removed from it. Such biological molecules as nucleic acids and aromatic amino acids maximally absorb in the 2600 Å and 2800 Å regions, respectively. Organic compounds formed by chemical synthesis generally consist of mixtures which rotate light in opposite directions and thus neutralize each other. It is a characteristic property of living things to select and synthesize forms which rotate polarized light in one direction (5).

WET CHEMICAL ANALYSIS by Dr. Glenn E. Pollock, Ames Research Center, Moffett Field, California.

Investigations are being conducted into various micromethods of macromolecule analysis. Chemical methods for the separation and detection of proteins, carbohydrates and lipids are being reviewed for possible use in extraterrestrial investigations (7).

MICROFLUOROMETRY by Dr. Joshua Lederberg, Stanford University, Palo Alto, California, and Dr. Gerald Soffen, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

Specific ultraviolet absorption of particles is carried out by scanning microspectrophotometry. This specific absorption will establish a criteria for the selection of objects of interest within the microscopic field. Once this selection is made, microfluorometric techniques will be employed to detect the primary fluorescence of native compounds as well as the fluorescence due to products found by specific reactants. By this means of microchemistry, biologically significant molecules can be detected (2, 3, 4).

FLUOROMETRIC ORGANIC ANALYSIS (Martin Lander Experiment) by Dr. Joon Rho, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

Organic compounds can be partially or totally converted to volatile fluorescent materials by temperature-programmed pyrolysis under appropriate conditions. The volatile organic products produced by such pyrolysis of a sample of the planetary surface are to be condensed on a cool surface and their presence and amount determined by direct observation of their characteristic fluorescence (6).

AUTOMATED BIOLOGICAL LABORATORY (ABL) developed by Philco Corporation's Aeronautic Division for the Bioscience Programs Division of the National Aeronautics and Space Administration, Newport Beach, California.

The range of experimental techniques necessary to explore an extraterrestrial biological system and the severe limitations of any single criterion for the detection of life lead to the realization that the payload soft-landed on the planet must ultimately involve what has come to be called an Automated Biological Laboratory. The ABL involves provision for the multiplicity and diversity of chemical analytical techniques and biological assays that the goals of the investigation call for. It involves also the idea of an on-board computer by means of which a variety of programmed assay sequences can be initiated contingent on the results of prior steps. It also involves the idea of a sustained discourse between the computer and investigators on earth who would have the ability to completely reprogram the instrument to carry out new experiments not planned prior to landing (Figure 1).

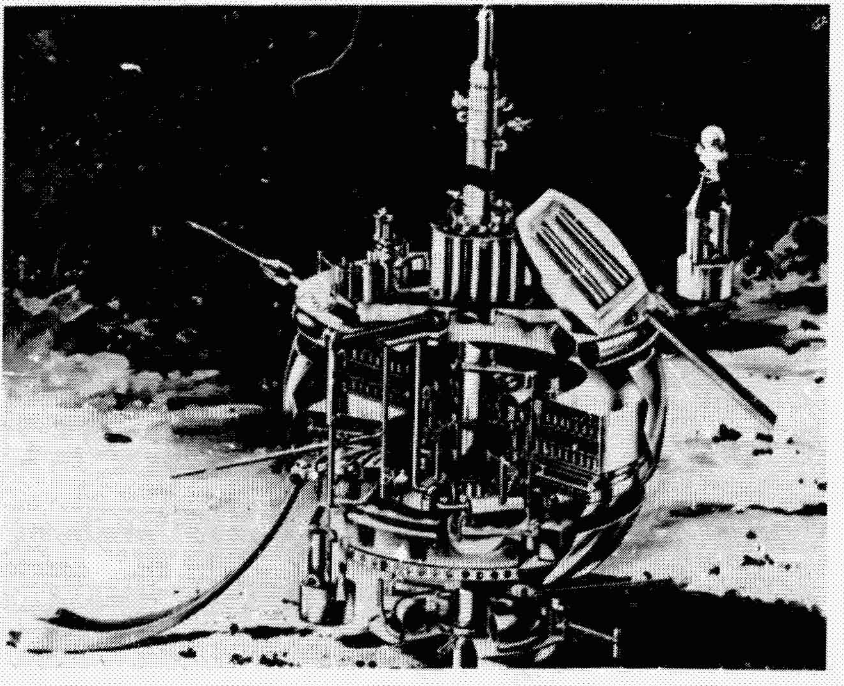


FIGURE 1. *SEARCH FOR LIFE—An artist's rendering shows how Philco Corporation's Automated Biological Laboratory (ABL) will seek the answer to one of the questions which has intrigued man for centuries: "Is there life on Mars?"*

VIDICON MICROSCOPE by Dr. Joshua Lederberg, Stanford University, Palo Alto, California and Dr. Gerald Soffen, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

An aerosol sample is injected into the plane of focus and the image is "stored" on the Vidicon television plate. The Vidicon picture will be telemetered to earth with resolutions up to 0.5 micron. It may be possible to identify various living or nonliving material (5).

MASS SPECTROMETER by Dr. Klaus Biemann, Massachusetts Institute of Technology, Cambridge, Massachusetts.

The material to be analyzed is vaporized by heat and the molecular fragments produced are accelerated onto an electron multiplier. The degree of acceleration is determined by the mass of fragments. Separation and identification of extremely small samples of material can be accomplished. The means of organic chemical analysis could provide crucial information about chemical evolution on extraterrestrial bodies (5).

J-BAND DETECTOR by Dr. R. E. Kay and Dr. E. R. Walwick, Philco Research Laboratories, Newport Beach, California.

A sample of material is mixed with the dye dibenzothiacarbocyanine and using a spectrophotometer, the light-absorbing characteristics for various wavelengths of light are determined. Uniquely, biologically significant macromolecules show a distinct increased absorption in the 650 mu range of the spectrum. This has been termed the J-Band after E. E. Jelly who described it in detail (5).

II. Detection of Extraterrestrial Metabolism

RADIOACTIVE CARBON DIOXIDE DETECTOR by Dr. Gilbert V. Levin, Hazelton Laboratory, Inc., and Dr. Norman H. Horowitz, California Institute of Technology, Pasadena, California.

This device has been named "Gulliver" after Swift's famous fictional traveler to strange places. Gulliver consists of a culture chamber that inoculates itself with a sample of soil. The chamber contains a broth whose organic nutrients are labeled with radioactive carbon. When microorganisms are put into the broth, they metabolize the organic compounds releasing radioactive carbon dioxide. The radioactive carbon dioxide is trapped on a chemically coated film on the window of a Geiger counter. The counter detects and measures the radioactivity; this information will be conveyed to a radio transmitter which will signal it to earth. Gulliver can detect growth, as well as metabolism, by virtue of the fact that the rate of carbon dioxide production increases exponentially (geometrically) in growing cultures. Exponential production of carbon dioxide would provide strong evidence for life on Mars and would make it possible to estimate the time required for doubling the number of organisms in the culture (5).

MICROCALORIMETRY by Dr. Glenn E. Pollock, Ames Research Center, Moffett Field, California.

Whenever metabolism is occurring, regardless of the size of the organism involved, heat involvement is always concomitant. Using extremely sensitive heat sensors, it is possible to detect the metabolic heat liberated by microorganisms (7).

PHOSPHATASE ACTIVITY DETECTION VIA FLUORESCENCE: THE MULTIVATOR by Dr. Joshua Lederberg, Stanford University, Palo Alto, California.

An instrument is designed to carry out functional tests for the presence of phosphatase and other enzymes. A phosphate substrate is mixed with a soil sample. Microbial metabolism utilizes the phosphate and releases a fluorescent residue which is detected by a sensitive photomultiplier light detector. This device is called a multivator. It is about a pound in weight and is designed to detect the presence or absence of microorganisms (5).

BIOLUMINESCENCE by Dr. Grace L. Picciolo, Goddard Space Flight Center, Greenbelt, Maryland.

The addition of ATP to a solution of luciferin and the enzyme luciferase results in visible light transmission which can easily be detected using photomultipliers. Since the biochemistry of all living organisms employs ATP, it will be possible to detect the presence of any ATP-containing organisms which might fall or be placed into the solution of luciferin by the resulting bioluminescence. Fireflies are the source of the enzyme.

III. Detection of Extraterrestrial Reproductions

TURBIDITY AND pH CHANGE DETECTOR by Dr. Wolf Vishniac, Yale University, New Haven, Connecticut.

This device, the Wolf trap, collects a specimen of soil and places it in a nutrient broth. The growth of microorganisms is detected through a change in acidity and by increased turbidity. These data will also enable growth rates to be calculated. However, the success of these analyses will be greatly dependent upon careful selection of growth media. How does one prepare nutrient media for organisms whose very existence is questionable? Dr. Richard S. Young, Chief of the Exobiology Division at Ames Research Center, is presently considering this problem. He is developing media required of bacteria grown in simulated Martian environments (5).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

1. The Survival of Earth Microbes in a Simulated Martian Environment.

   A selection of anaerobic and aerobic microbes could be subjected to the light-dark and freeze-thaw cycles of Mars (Table I). Their gaseous, water and nutrient environment could consist of molecules suspected to exist on Mars. Survival as indicated by growth characteristics, turbidity changes or actual organism counts could be evaluated.

2. Turbidity Changes Associated with Extraterrestrial Biological Exploration.

   The turbidity produced in broth cultures by microbes is monitored by a photoelectric cell and galvanometer circuit. A simple light meter could be used. The relationship between turbidity and organism population is easily determined by direct dilution counting of the organisms. Dry soil samples could simulate Martian soil for evaluation of this method of life detection.

3. Media Temperature Change Associated with Microbial Growth.

   The temperature of yeast cultures is monitored with a sensitive thermometer. Temperature changes could be correlated with the reproduction rate. Dilution counts could make it possible to directly relate temperature change with organism reproduction. Autoclaved or sterilized culture samples could be tested as negative controls.

TABLE 1—SURVIVAL AND GROWTH OF ORGANISMS IN SIMULATED PLANETARY (MARTIAN) ENVIRONMENTS (8)

Species	Survival Months	Moisture	Temperature °C	Atmospheric Pressure mm Hg	N_2 %	CO_2 %	Substrate
Conditions on Mars		14u±7u	−70 to +30 25±15, 11	85		3 to 30	
Anaerobic sporeformers Clostridia, Bacillus planosarcina	6	Low, ($CaSO_4$)	−60 to +20	76	95	5	Air-dried soil
Anaerobic nonsporef ers Pseudomonas, Rhodopseudomonas	6	Low, ($CaSO_4$)	−60 to +20	76	95	5	Air-dried soil
Anaerobes	Growth	Very wet	−75 to +25	760	100	(?)	Difco infusion broth
Aerobacter aerogenes, Pseudomonas sp.							
Clostridium, Corynebacteria "Thin short rod"	10	1% or less	−25 to +25	65	100	(?)	Soil
Bacillus cereus	2	0.5% soil	−25 to +25	65	94	2.21	Sandstone soil
Clostridium sporogenes	1 (growth)	8.4%	−25 to +25	65	94	2	Enriched soil
Clostridium botulinum	10	Lyophilized	−25 to +25	65	95	0 to 0.5	Lava soil
Klebsiella pneumoniae	6	Lyophilized	−25 to +25	65	95	0 to 0.5	Lava soil
Bacillus subtilis var. globigii	4	2%	−25 to +25	85	95	0.3	Media
Sarcina aurantiaca	4	0.5%	−25 to +25	85	95	0.3	Desert soil
Clostridium tetani	2 or less	1%	−60 to +25	85	95	0.3	Soil
Aspergillus niger	Over 6 hr	Very dry	−60 to +25	76	95.5	0.25	Glass cloth on copper bar
Aspergillus oryzae	Over 6 hr	Very dry	−60 to +25	76	95.5	0.25	"
Mucor plumbeus	Over 6 hr	Very dry	−60 to +25	75	95.5	0.25	"
Rhodotorula rubra	Over 6 hr	Very dry	−60 to +25	76	95.5	0.25	"
Pea, bean, onion, tomato, rye, sorghum, rice	0.3	Moist	+25	75	100	0	Filter paper
Winter rye	0.6	Moist	−10 to +23	76	98	0.24	Soil

4. The Nature of Fluorescence in Various Earth Microbes.

Cultures of microbes maintained on media containing fluorescent dyes are viewed under ultraviolet light. Point concentrations of the fluorescence would indicate microbial colonies. A systematic investigation of fluorescent dye retention in various microbes could be conducted.

5. The Effect of Ultraviolet Radiation on Nutrient Synthesis.

Concentrations of various gases equivalent to the Martian atmosphere are mixed with small amounts of water in a closed glass chamber. The contents are sterilized thoroughly and irradiated with high intensity ultraviolet radiation for varying lengths of time. Pure cultures of microbes are aseptically introduced into the chamber and carefully studied for growth and reproduction. The high ultraviolet radiation may provide the energy necessary for recombination of the gaseous molecules into various macromolecules. These macromolecules so formed might form the nutrients for microbial colonies. A medical supervisor will be necessary to properly carry on this type of work.

Additional Subjects for Investigation

1. Study the growth of microorganisms in atmospheres other than the type found on earth, such as high carbon dioxide, hydrogen, methane and other atmospheres which resemble that of planets other than earth.

2. What changes in the hydrogen ion concentration are evident in the growth of microorganisms? Can pH be used as a positive proof of such growth?

3. Study survival of earth microbes in a simulated Martian environment.

4. Study the fluorescent properties of various microbes.

5. Study growth of microorganisms using various media.

LITERATURE CITED

1. First planning conference on biomedical experiments in extraterrestrial environments, 1961. Technical note (D-781). National Aeronautics and Space Administration, Washington, D. C.

2. Lederberg, J. 1960. Exobiology: approaches to life beyond the earth. Science 132:393-400.

3. Lederberg, Joshua and Carl Sagan. 1962. Microenvironments for life on Mars. Proceedings of National Academy of Sciences 48:1473–1475.

4. Lederberg, Joshua. 1965. Signs of life. Criterion-system of exobiology. Stanford University School of Medicine, Palo Alto, California. Nature 207(4992):9–13.

5. Quimby, Dr. Freeman H. (Ed.). 1964. Concepts of detection of extraterrestrial life. Special Publication No. 56. National Aeronautics and Space Administration, Washington, D. C.

6. Rho, J. H. 1963. Fluorometric measurements of growth: II. Fluorescence as a measure of bacterial growth of proteins. Jet Propulsion Laboratory, SPS 37–25, Pasadena, California.

7. Semiannual report. March-October 1964. Exobiology Division, Ames Research Center, NASA, Moffett Field, California.

   Fromhagen, Dr. L. H. Isolation and Identification of viruses and bacteria, p. 38.
   Oyama, Vance I. Prototype instrumentation development for life detection, p. 51.
   Oyama, Vance I. Research in the area of pyrolysis and of gas chromatography as a tool for the detection of life on Mars, p. 30.
   Oyama, Vance I. System for measuring respiration and metabolism, p. 42.
   Pollock, Glenn E. and Vance I. Oyama. Gas chromatography of stereoisomeric amino acids, p. 34.
   Pollock, Glenn E. Measurement of respiration and metabolism —detection of extraterrestrial microorganisms by microcalorimetry, p. 45.

8. Significant achievements in space bioscience 1958-64. January 1965. Special Publication No. 92. National Aeronautics and Space Administration, Washington, D. C.

9. Young, Richard S., Robert B. Painter and Richard D. Johnson. 1965. An analysis of the extraterrestrial life detection problem. Special Publication No. 75. National Aeronautics and Space Administration, Washington, D. C.

section 4

EXOBIOLOGY

DECONTAMINATION

Under some of the most rigid antiseptic techniques that man is able to devise, it has been proven that infections will and do occur. When one considers the sterilization of a space vehicle with its thousands of myriad parts created from all over the world, manufactured under a variety of conditions, assembled and tested, installed on the nose of a rocket booster and finally blasted upward through an atmosphere polluted with a multitude of contaminants, it seems amazing indeed that it should be possible to land a planetary or lunar probe that is sterile.

Using all the known and accepted techniques for the eradication of living organisms without destroying or reducing the reliability of the systems aboard the probe, we must finally accept a value something less than absolute that there are no organisms aboard; it is desirable that this level be of the order of 10^{-3} or preferably 10^{-4}. To lower the probability below this would increase the time of assembly and the resultant cost to a point where very likely no probes could be launched (3).

Before considering various sterilization methods and their effectiveness, it might be wise to elucidate the reasons for spending such large amounts of money on the research necessary to accomplish the sufficiently low level of contamination probability. The reasons can generally be classified within the limits of the following three statements:

1. To preserve clues to the origin of life and of the universe which may be found on the moon and other planets.

2. To protect the earth from reciprocal contamination by microbes found in space and extraterrestrial environments.

3. To prevent transfer of earth-life microbes to other worlds (13).

It is encouraging to note that in the interest of science the Russian and the United States scientific communities have agreed to cooperate in these objectives, in order that search for extraterrestrial life may be successfully pursued in a scientific manner. Contamination of the surface of Venus or Mars would surely wipe out the possibility of ever obtaining a clue as to the unique origin of life on earth. There is evidence in the form of microwave analysis of the surface of Venus that it is too hot there for the growth of organisms of earth origin. There is the possibility of error in these measurements and there may prove to be cooler regions in the atmosphere of Venus suitable for the growth of organisms. Research has shown, however, that organisms do not multiply in the free atmosphere. Apparently, a surface is required where the proper conditions of temperature, humidity and a suitable host are present (2).

Apparently, sterilization of probes launched toward the moon such as the American "Ranger" series and the Russian "Luniks" was not considered essential. Ranger IV was sterilized but likely there were some internal components that were not sterile. There is no information available on the sterile condition of the Russian probes which failed to function properly and crashed on the surface of the moon, releasing any contamination which may have been contained inside. Two authorities who state that there is no need for sterilization of a moon probe base their findings on the low probability of organic growth occurring under existing conditions of high vacuum, high radiation intensity and wide temperature extremes (11).

Dr. Joshua Lederberg of Stanford University, Stanford, California, holds a somewhat more conservative view. It is his belief that the moon should not be contaminated with living or dead organic life by space probes to the extent that it would be impossible for life scientists to determine whether organic substances found on the moon are native or were brought there from the earth. Calculations based on the surface area of the moon and the area that might be contaminated by each probe show that it would be undesirable to put down more than 4×10^{11} organisms from all of the planned unmanned shots. For a 40-shot unmanned program, this would mean on the average less than 10^{10} organisms per shot. If the average weight of a bacterium is taken as 10^{-12} grams, the total weight of viable or non-viable organisms should be limited to 10^{-2} grams per shot (5).

Tracking down a microbe on a space probe is a complex and expensive procedure. Florida State University has been granted a contract to study only the statistical aspects of the probability of contamination by space probe. Research contracts have been granted to study the manner in which organisms adhere to aluminum, copper, stainless steel, beryllium, glass, plastics, titanium and ceramics. Individual companies are conducting research from manufacturing plant to assembly in the final vehicle. Detection of the microbes is carried out by high speed radiation detectors counting tagged microbes as if they were atoms. It has been found that recording equipment, magnetic tape, certain semi-conductors, transistors and soldered connections are very difficult to free from contamination (14). What happens to the space vehicle after it is launched and comes in contact with micrometeoroids, retro-fire and cold gas attitude control jets is extremely problematical.

Methods of Sterilization

When a homogeneous population of microbes is exposed to a sterilizing agent under constant conditions, it is observed that the population falls exponentially with time. (This is analogous to a radioactive decay curve.) If the population is not homogeneous and the time of exposure is extended over a longer period, the curve tends to flatten somewhat. Exposure to heat, chemical agents and radiation treatment all apparently follow this same pattern of behavior. From this curve it is possible to predict just how long an exposure time is required to achieve the desired level of probability of viable organisms being present.

The most common method of sterilization, the steam autoclave, is similar to that found in the surgical room of hospitals and in dentist's offices. The steam is not able to penetrate sealed components. Delicate electronic devices such as radio transmitters may not function after this kind of treatment (12, 14). An alternative heat treatment consists of the use of dry heat at a temperature of 135° Centigrade extended over a 24-hour period (6). This has been found to lower the original number of resistant microbes by a factor of 10^{-12} according to G. W. Bruch of Wilmot Castle Company, Rochester, New York (personal communication). The use of dry heat has the advantage that it can be used over longer periods of time giving deeper penetration into assembled components without affecting performance levels of the items (1).

The use of radiation from a source such as the radioisotope Cobalt 60 or X-rays are excellent methods for sterilization and a great deal of experimental work has been carried out relative to the preservation of food without refrigeration after exposure to radioisotopes. Exposure to a dose of 5.0×10^{6} rad has been reported to reduce resistant microbial population to a factor of $10^{-6.3}$ of that originally present (7).

Increasing the dosage by one order of magnitude to 10^{7} alters the population level to $10^{-10.6}$ and a dose of 1.2×10^{7} rad gives a value of 10^{-13} (5). If each part of the probe was sterilized by radiation techniques and finally assembled into the complete spacecraft, the desired objectives would be achieved, provided equally sterile conditions prevailed during assembly.

Gas Sterilization

The gas most commonly used for the killing of microbes on exposed surfaces is ethylene oxide. When this gas is used on the completed craft, it does not reach sealed interiors, interiors of closed screw holes, flanges, gasket seats or electrical connectors. The gas is quite inert and it does not react with the components causing corrosion or other undesirable side effects. In actual practice, a shroud can be placed around the assembled gear. The gas is then introduced into the airtight container for a period ranging from 17 to 24 hours to achieve the desired level of sterilization (10).

Liquid Sterilization

The use of liquids does not seem to be as feasible as gaseous methods due to the surface tension of the liquid. For this reason, it does not reach into the corners and crevices as well as a gas and the effectiveness of a particular liquid seems to be erratic and sensitive to variations in its concentration, quantity, amount of evaporation, hydrolysis, polymerization, storage time, cleanliness of the substrate and the deposition of surface scum after removal (9).

It is quite obvious that each sterile piece of each sub-assembly must be integrated into a particular component and each major component into the final craft under completely sterile conditions. All of the adhesives, lubricants, gaskets, seals and every nut and bolt must be treated. Usually, during the checkpoint period, some component malfunctions and it is necessary to replace a particular part. Contact with a human being would destroy the integrity of the entire craft. Two solutions have been proposed to this problem. A large complex of air flow chambers has been constructed at the Jet Propulsion Laboratory, Pasadena, California, to study the effect of air flow and the control of microbe populations. Research indicates that this is a very effective method for the control of contamination, according to Dr. Joseph McDade (personal interview).

A second method is under study by the General Electric Missile and Space Division, Philadelphia, Pennsylvania. Under consideration is the construction of a full-scale facility measuring 69 ft. wide, 89 ft. long and 45 ft. high. It would be completely equipped internally with all testing equipment, autoclaves, and gas sterilizer at 850° Fahrenheit. It would have laminar air flow downward through the floor and tunnels leading from the outside enabling the workers to perform checks and replace components while completely isolated from the craft.

Once the craft has been completely checked out and is ready to fly, there is the problem of shipping and mating it to the rocket on the launch pad. Keeping the probe sterile during the countdown and during its passage through the earth's atmosphere presents additional engineering problems. The technology is at hand and, with the full cooperation of other nations, perhaps contamination of other planets and satellites can be avoided (15).

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

Earth Origin Microorganisms and Contamination of the Moon or Planets.

Introduction

Perhaps the most fascinating scientific problems confronting the biological scientist is the origin of life. There is a distinct possibility that life, in the form of microorganisms, may exist in the harsh climatic conditions of the moon or the planets Mars and Venus. Contamination of these environments by earth origin microorganisms could completely destroy this recorded history as well as nullify research on extraterrestrial organic matter.

Purpose

To investigate the growth of microorganisms after subjecting hardware to sterilization procedures.

Materials

Test tubes, 19 mm x 150 mm, 5
Peptone, 1 g
Beef extract, 0.6 g
Agar, 3 g
Distilled water, 200 ml
Beaker, 400 ml
Balance
Stirring rod
Graduated cylinder, 25 ml
Ring stand
Heat source
Pressure cooker, autoclave or some other sterilization technique
Petri dishes
Glass marking crayon
Used electronic components (e.g., 3 transistors and 2 condensers)
Pliers, 2
Cotton or aluminum foil for covering test tubes

Procedure

a. To prepare the sterile agar medium, add the peptone, beef extract and agar to the distilled water in the 400 ml beaker.
b. Mix thoroughly with the stirring rod, and heat until the mixture comes to a boil with continuous stirring.
c. Pour 15 ml of the nutrient agar into each of the test tubes and plug each lightly with cotton, or cover with aluminum foil cap.

d. Sterilize the tubes, petri dishes, transistors, condensers and pliers.
e. Place one sterile transistor in one petri dish and a condenser in another petri dish. Crush the second transistor with the pliers and place it in a third dish. Place the unsterilized transistor in a fourth dish.
f. Crush and break open the condenser with the second pair of pliers and place it in the fifth dish.
g. Pour the warm, sterile nutrient agar over each of the components from each of the test tubes.
h. Cover immediately and allow agar to solidify. When the agar has solidified, turn the dishes upside down and incubate them.
i. After three or four days of incubation, observe and record results.

Certain basic conclusions should be evident from this experiment:

Conclusions

a. Is it necessary to sterilize electronic components?
b. Can the interior of the electronic components give rise to growth of microorganisms when broken open?
c. Does external sterilization kill the microorganisms which might be found internally?
d. Is it possible that the manufacturing process destroys internal microorganisms?
e. Did the air in the room contaminate all the dishes before they were sealed?
f. How would you avoid air contamination?

Further Research

Can you make a transparent chamber into which you could place all the items needed to repeat the experiment? If so, then seal rubber gloves into armholes in the chamber and sterilize the chamber internally with an aerosol disinfectant, or germicidal lamp.

1. Remove covered petri plates through a trap door between the armholes and incubate. How do results compare? (Figure 1).

2. A second series of similar experiments could be conducted using typical spacecraft materials such as pieces of aluminum, copper, glass, plastic and ceramics subjected to sterilization procedures and then placed on culture media and incubated to see whether growth of microorganisms occurs.

3. An inexpensive transistor radio might also be used and scrapings from solder joints, corners, printed circuit board and case taken and incubated after gas sterilization procedures.

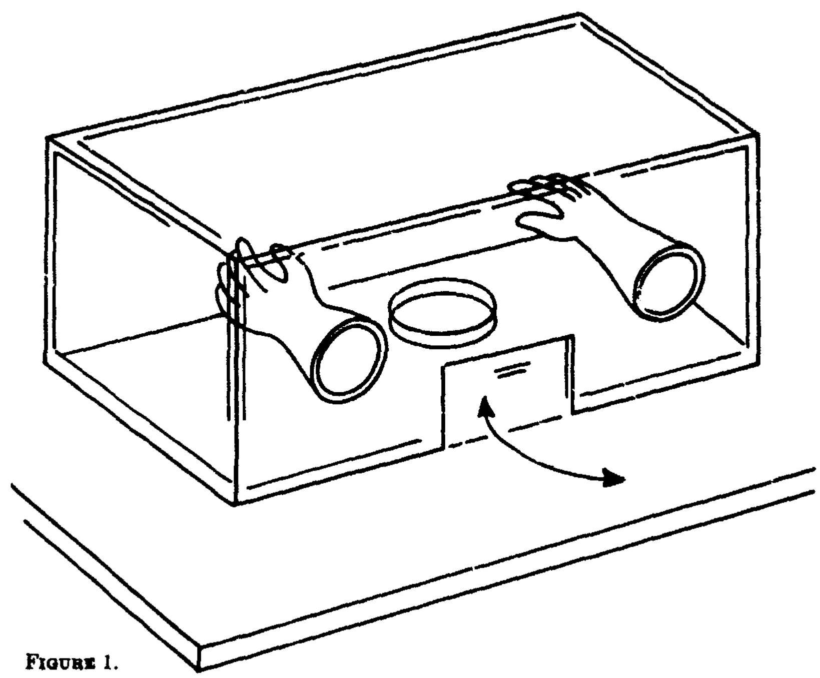


FIGURE 1.

4. Subject the transistor radio to dry heat sterilization procedure. Check for operational efficiency. Which electronic parts were or were not impaired by the heat?

5. What sterilization techniques are the most effective and most economical for spacecraft components?

LITERATURE CITED

1. Bruch, G. W. 1961. Dry heat sterilization of components for space probes. Status Reports 2 and 3 on National Aeronautics and Space Administration Contract #31. Wilmot Castle Company, Rochester, New York.

2. Gregory, P. H. 1961. Microbiology of the atmosphere. Interscience Publishers, New York.

3. Hobby, G. 1962. Sterilization criteria for marine spacecraft design. Internal Communication, Jet Propulsion Laboratory, Pasadena, California.

4. Imshenetsky, A. A. 1962. Prospects of the development of exobiology. Third International Space Science Symposium (COSPAR), Washington, D. C.

5. Jaffe, L. D. 1963. Sterilization of unmanned planetary and lunar vehicles—an engineering examination. Technical Report No. 32:325, Jet Propulsion Laboratory, Pasadena, California.

6. Koesterer, Martin G. 1965. Studies for sterilization of space probe components. NASA Contractor Report 191. National Aeronautics and Space Administration, Washington, D. C.

7. Lowe, H. N., W. J. Lacy, B. F. Surkiewicz and R. F. Jaeger. 1956. Destruction of microorganisms in water, sewage and sewage sludge by ionizing radiations. Journal of American Water Works Association 48:1363-1372.

8. National Academy of Sciences. 1957. Organic matter on the moon. Publication 757. National Academy of Sciences-National Research Council, Washington, D. C.

9. Opfell, J. B., C. E. Miller and P. L. Louderback. 1962. Evaluation of liquid sterilants. Semifinal Report to the Jet Propulsion Laboratory, Contract N2-150247. Dynamic Science Corporation, South Pasadena, California.

10. Phillips, C. R. 1961. Sterilizing properties of ethylene oxide. Sterilization of Surgical Materials. Pharmaceutical Press, London.

11. Sagan, C. 1960. Biological contamination of the moon. Proceedings of the National Academy of Sciences 46:393–401. National Research Council, Washington, D. C.

12. Sarkinen, John K. 1965. GG159 miniature integrating gyro sterilization exposure studies at 300° F. Final Report. Aeronautical Division, Honeywell, Inc., Minneapolis, Minnesota.

13. Sterilization for spacecraft, a bibliography. 1962. Access 16073. North American Aviation, Inc., Downey, California.

14. Stern, K. 1965. Capacitor sterilization test program. *In* Space Programs Summary 37–33, Vol. 4, p. 305–306. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

15. Voyager design study. 1963. Sterilization. Document G3SD801, Vol. 5. Missile and Space Division, General Electric Company, Philadelphia, Pennsylvania.

section 4

EXOBIOLOGY

THE CHEMICAL EVOLUTION OF LIFE

Where did life begin? Was it an event unique in our solar system, possible only on the planet earth with its abundant water and just the right intensity of solar energy? As the space probes reach out to the moon, Venus, Mars and the searching radar beams echo back, more and more evidence is mounting that indeed the advent of life may be unique on earth. If a space traveler swung by from one of the 10^{18} solar systems which exist with conditions very much like that of ours and looked down on earth, it is quite possible that he would not call it earth at all but hydrosphere, since three-fourths of the earth is covered by water. It could well be that it is this water which makes earth unique and capable of the origin of life.

Speculation about the creation of life and the conditions which might have existed at this fantastically complex and magnificent moment in history is one of the most important parts of the program of space exploration. The witches in Macbeth toiling over their steaming caldron, dropping in frogs' legs and other assorted tidbits, could not have possibly experienced the excitement and suspense which is shown by some of our scientific teams as they attempt to create the primitive building blocks of life, and possibly even life itself, from the primordial atmosphere assumed to be present when primitive life began. It is, indeed, hard to get people in the scientific community to agree on a definition of "life." One very simple definition says "Life is something which exists." Another says "Life is capable of reproducing itself in an exact pattern over and over again." Will science succeed in producing the first primitive cell which will metabolize food and reproduce itself? Will the members of the scientific community agree that the cell is alive and that the endless and constant vibrations within the atoms have been locked together in such a way as to produce pulsating life? (2, 5, 8).

A now famous letter by Charles Darwin, written in 1871, has been recorded by Francis Darwin as follows: "It is often said that all the conditions for the first production of a living organism are now present, which could have ever been present. But if (and oh, what a big if!) we could conceive in some warm little pond, with all sorts of ammonia and phosphoric salts, light, heat, electricity, etc., present, that a protein compound was formed ready to undergo still more complex changes. . . ." It is these conditions, described in this now famous letter, which make mother earth unique. Mariner IV findings indicate that the gaseous atmosphere on Mars contains argon with a molecular weight of 42 atomic mass units and a trace of carbon dioxide. The surface pressure there ranges between 5 and 7 millibars of mercury and if all the gas were packed into one layer of uniform density, it would be only 7 to 9 kilometers deep (scale height) at a temperature approximating 180° K or —90° Centigrade or —130° Fahrenheit. Equally formidable conditions for life apparently exist on the moon and Venus. If a manned mission or an unmanned biological probe brings us evidence that there is life of some sort, it might then be safely assumed that life statistically exists on some of the billions of other star-planet systems.

The search for extraterrestrial life is a prime goal of space biology and the attempt to create life under laboratory conditions is but one facet of the total picture. According to Fox (3), there are five stages in the chemical evolution of life:

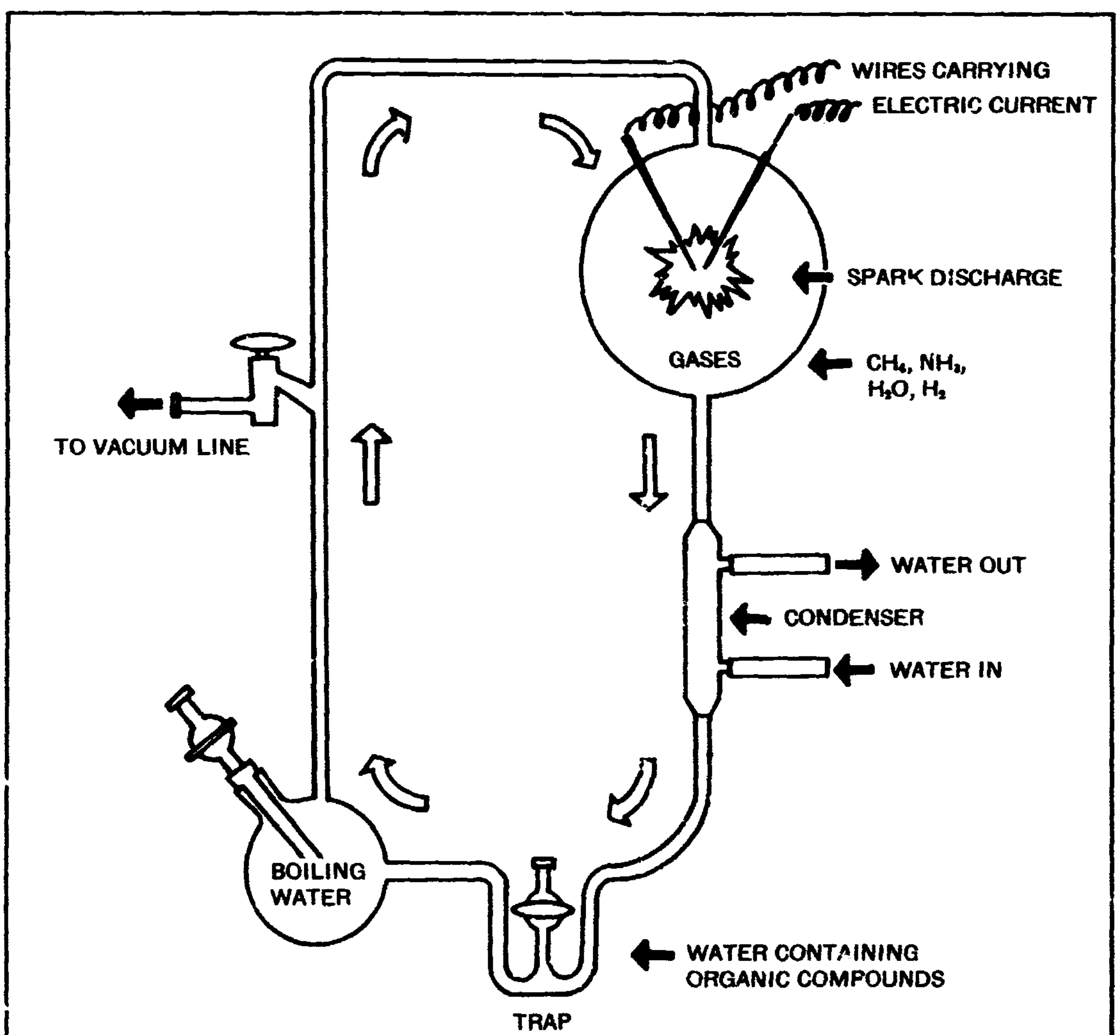
Stage 1: The synthesis of organic compounds
Stage 2: The synthesis of simple biochemical substances
Stage 3: The production of large molecules such as proteins
Stage 4: The appearance of organized cellular structure
Stage 5: The evolution of macromolecules and metabolism

All five stages coupled together form the basis for the creation of life from organic chemicals. Cyril Ponnamperuma, one of the leading scientists in the Exobiology Division of the NASA Ames Research Center, Moffett Field, California, feels that there are three distinct stages in the evolutionary process: inorganic, organic and biochemical. He states:

> In the first stage of chemical evolution, the primeval cloud of hydrogen gas by a series of reactions-implosion, fusion and fission, gave rise to the elements of the Periodic Table. This event occurred about twenty thousand million years ago. About fifteen thousand million years later, when the solar system was being formed, the highly reactive elements probably existed in their reduced form: methane, ammonia and water. When the planet earth was being born from the primitive dust cloud, four to five thousand million years ago, the rudimentary molecules which were the forerunners of the complex biological polymers of two thousand million years later were perhaps already in existence . . . Life, then, may be considered to be an inevitable process and bound to appear in the cosmos wherever conditions are favorable (7).

An early notable experiment in this field of research was carried out by Melvin Calvin and his associates who, in 1951, subjected water and carbon dioxide to bombardment in the cyclotron at the University of California, Berkeley, and were able to prove that there was a significant yield of formic acid and formaldehyde (1). Stanley Miller, a graduate student in Harold Urey's laboratory at the University of California, San Diego, in 1953 took a mixture of water, methane, ammonia and hydrogen in concentrations assumed present in the primeval atmosphere of the earth and exposed them to electrical discharge simulating lightning (Figure 1). Amino acids and other organic compounds present in living systems were found. Sydney Fox, of Florida State University, Tallahassee, Florida, and John Oro, of the University of Houston, Houston, Texas, have each made notable contributions along similar lines of research. Fox's work centered on the origin of proteins and Oro has synthesized adenine and a number of biochemical inter-

FIGURE 1. *Diagrammatic representation of apparatus used by Stanley Miller for the synthesis of amino acids by electric discharge (6).*



mediates of purines (3) (Figure 2). Cyril Ponnamperuma and his associates at the NASA Ames Research Center Laboratories, Moffett Field, California, have subjected primitive earth environment gases to electron bombardment, electrical discharge and shock wave impact and they have found that one of the primary products appears to be hydrogen cyanide and a second major product is formaldehyde (6). This bears out the work done by other experimenters, and by starting with these substances and exposing them to ultraviolet light, a remarkable series of compounds have been formed. Adenine, guanine and urea have been identified. Urea is an important biochemical intermediate and the adenine and guanine are the two purines in the nucleic acid chains. It was found that the reaction with the hydrogen cyanide proceeded without an external source of energy. It progressed spontaneously at —10° Centigrade converting into more complex organic compounds. At present, twenty-three amino acids have been isolated from proteins and several of these acids have now been synthesized by applying simulated primitive earth conditions to simple constituents of the primordial atmosphere.

SUGGESTIONS TO THE TEACHER FOR DEVELOPMENT:

The development of the concept of the chemical evolution of life should be presented by the teacher so as to make this topic interesting for the student.

1. Give each student a handful of dirt and ask him to prove that there is life in the dirt by using all the tools at his command in the school biology laboratory. Detailed microscopic inspection will very likely fail to reveal living organisms. As a second step, take agar and make a culture of some of the moist soil. Ordinary untreated soil should produce colonies of microorganisms. Try checking the acidity using pH paper. Add moisture and place it in a warm area sealed off from the atmosphere, but exposed to the natural sunlight to see whether germination occurs. Sterilize some soil and check for microorganisms as a control.

2. This experiment would be a decided challenge and would be very much akin to the problem faced by our space scientists as they try to develop mechanisms for the detection of life by remote means via instruments landed on a distant planet. In setting up this experiment, it should be possible to impart to the student the excitement and challenge of such a scientific problem. Secure five or more samples of rich humus from various locations. Also secure sand, clay, swamp mud, sterilized soil and possibly manure. Place

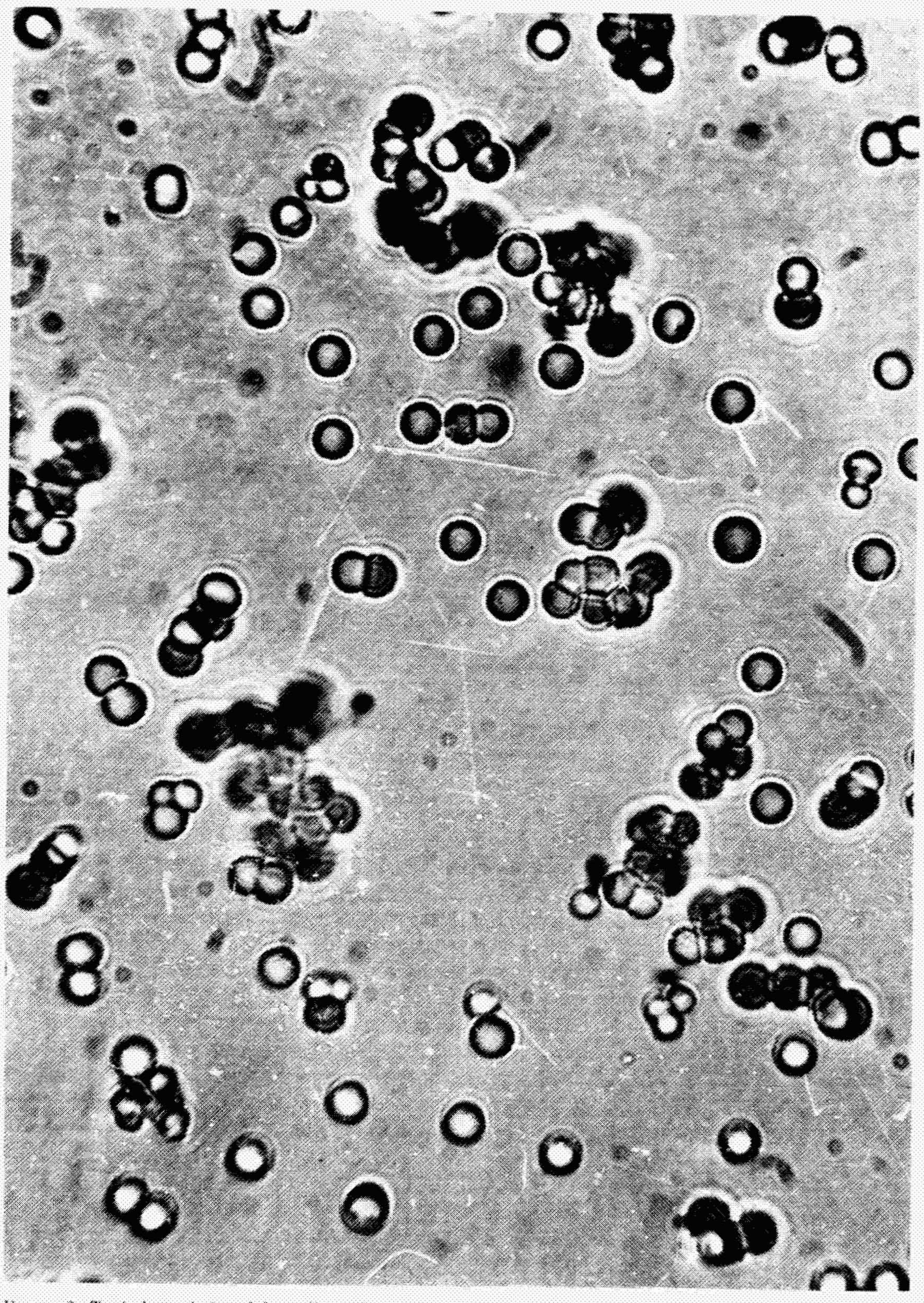


FIGURE 2. *Typical population of thermally produced microspheres (After S. W. Fox) (3).*

one sample of each soil type in its own individual metal container (i.e., an ordinary soup can). It would be wise to sterilize each can before the experiment to standardize conditions. A metal cover should then be soldered to the can, sealing it airtight. Paint each can black so that they appear identical and number them consecutively, 1, 2, 3, etc. Place these cans before the students and ask them to devise means whereby they can prove that life in some form might exist in these containers without actually removing and subjecting the contents to tests.

Procedures

a. Drill a hole in the cover of each container large enough to hold a rubber stopper about ½ inch in size. Using a one-hole stopper and glass tubing, connect the can to a flask of clear limewater which is protected from exposure to the air. Check periodically for clouding of the limewater—indicating that carbon dioxide is being generated by the contents, $CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$, and that life possibly exists in the can (Figure 3).

b. A manometer might be connected to one or more of the cans (Figure 3) and this can sealed off with wax from air pressure variations. If this device was connected to a can in which fermentation was taking place or organic matter was present, a marked change in the level of the manometer would indicate increased gas pressure inside the can.

c. A measured amount of distilled water might be added to one or more of the cans, using a dropper, via the one-hole stopper (Figure 3, Step 3). After a period of one day, some of the water may be withdrawn from the can without letting any of the soil escape by careful pouring from the original hole or using a stopcock drain sealed into place near the bottom of the can. This water could then be placed in sterile culture dishes with agar medium and then incubated to determine the presence or absence of organic matter.

d. Some of the water obtained in step c above could be tested with pH paper or a pH meter to determine the acidity of the sample. In this experiment, it might be wise to test samples of the water each day over a period of one week to determine possible increase in the pH of the water. Any continued change in pH would lead to the conclusion that some biological change was taking place due to organic life. Check the culture with a microscope for microorganisms.

e. A fifth test might involve the sense of smell. Odors from a soil sample are often indicative of living organic matter. Odor would not be a positive test, but coupled with the other tests, it would be one more clue.

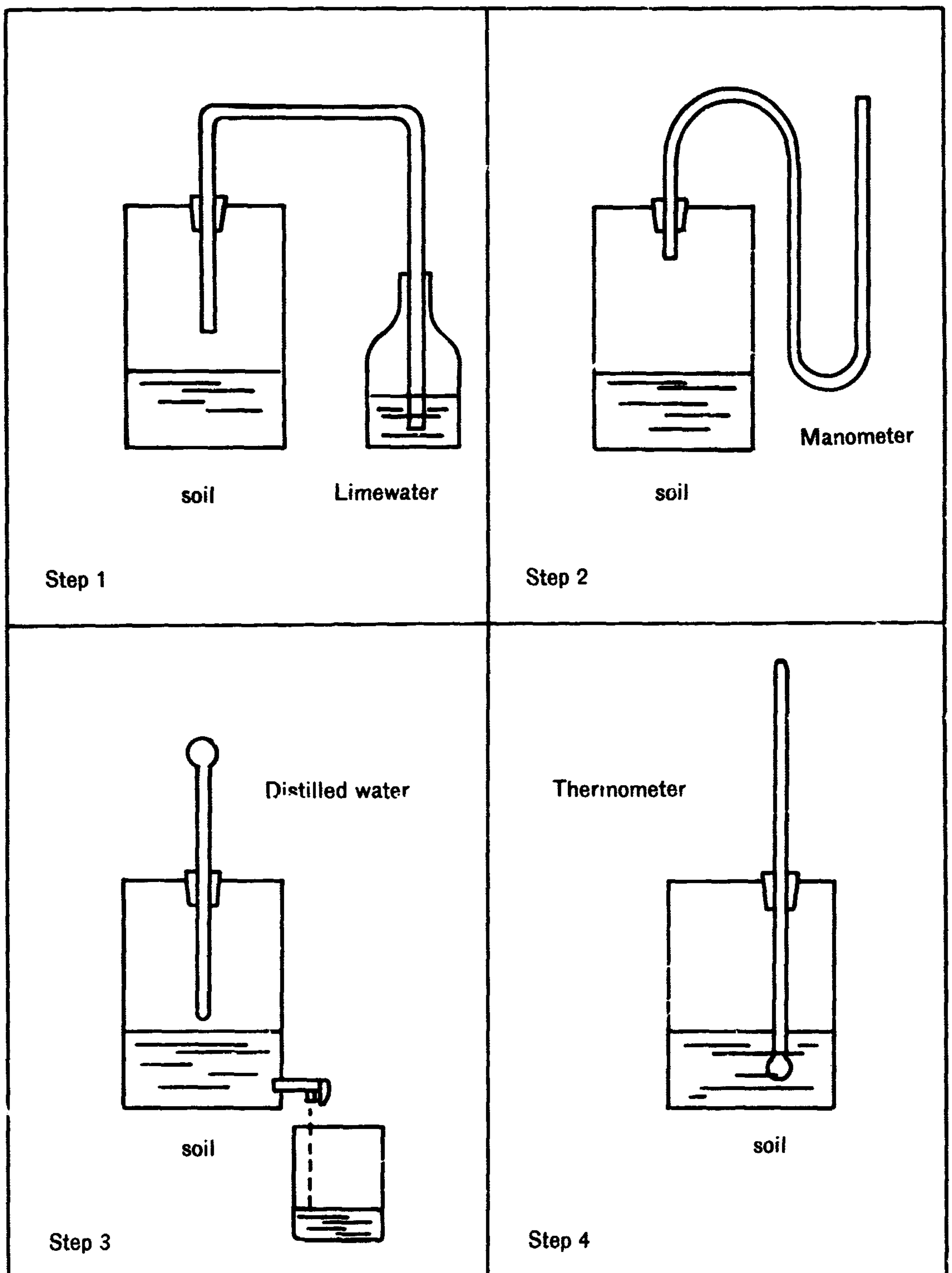

soil
Limewater
Step 1
Manometer
soil
Step 2
Distilled water
soil
Step 3
Thermometer
soil
Step 4

FIGURE 3.

f. The insertion of a sensitive laboratory thermometer through a one-hole stopper into several cans would be another check for the presence of life. Keep each can under the same external temperature conditions and if one or more of the cans indicates a higher internal temperature, this might indicate organic activity (Figure 3, Step 4).

NASA scientists and laboratories under contract to NASA are devising their own "black box" experiments for the detection of life by some very sophisticated mechanisms functioning thousands of miles from the earth and transmitting the information back to computers which digest the information and furnish answers to the dreams of scientists.

3. The B.S.C.S. Blue Version exercise, "Formation of Coacervates," is especially appropriate for use in introducing students to this topic. It involves the use of gum arabic, gelatin and hydrochloric acid in forming organized droplets, called coacervates, which exhibit some of the properties of life.

An Additional Suggestion for Investigation

A number of additional experiments could be carried out by selected advanced students under careful supervision following the lines of research by Dr. Ponnamperuma and others at the Chemical Evolution Branch, Exobiology Division, NASA Ames Research Center, Moffett Field, California. For background material, it is recommended that the student first read all the literature cited at the end of this discussion and then proceed to set up apparatus under the guidance of the teacher or other qualified scientist (Figure 1). To avoid the expense of glass blowing, a special three-neck boiling flask apparatus (e.g., Kontes Glass K 60600) might be used in place of the apparatus used by Miller. Such a flask is, however, very expensive. Perhaps loan could be obtained from a local chemical industry (Figure 4). The right and left necks would be for the insertion of two tungsten electrodes to stimulate lightning discharge and provide the energy for reaction. Details for evacuation of the flask to remove oxygen, and methods of introducing CH_4, NH_3 and H_2O should be well planned by the student. Various concentrations of ammonia, methane and water must be tried for various periods of prolonged high voltage discharge conditions. One may begin with 25 cc CH_4, 25 cc NH_3 and 100 ml H_2O with a discharge lasting 24 hours. The reaction should be carried out under a fume hood and shielded from the experimenter with a plastic or shatterproof glass barrier. All safety precautions should be well planned and executed. The high voltage discharge can be provided by using standard leak testing high voltage probes (e.g., Cenco No. 80730). Running for long periods of time will overheat the device and it is recommended that the body of the probe be drilled with ⅜-inch holes over the entire area of the plastic case and cooled by a fan blowing air into the holes while it is in use. The copper lead wires must be well insulated. The reaction mixture will turn a dirty brown color and, as reported earlier in this article, it should contain a high percentage of hydrogen cyanide (perhaps 18%), even though the actual amounts may be measured in terms of microliters.

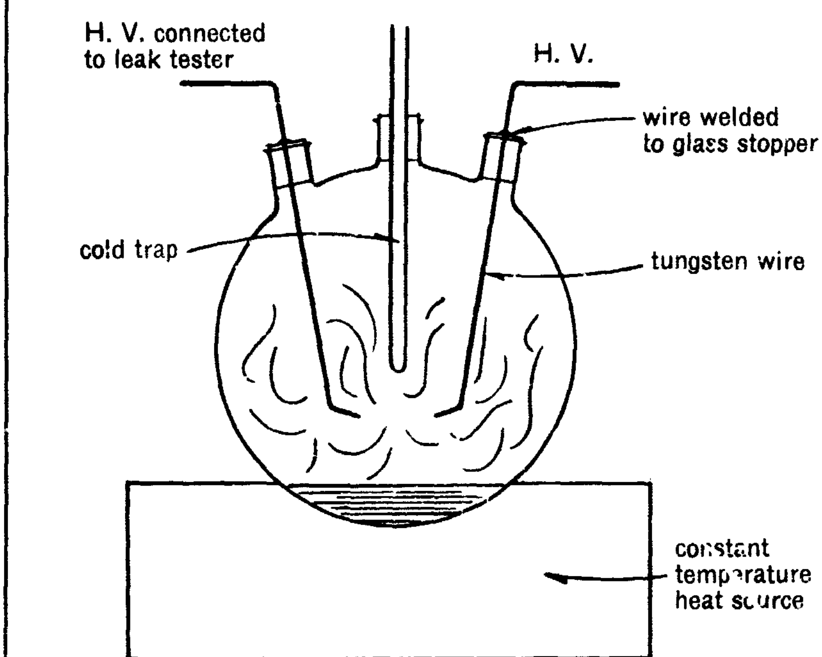


FIGURE 4.

Special laboratory precautions must be taken with the HCN due to its highly toxic nature. It is a colorless liquid or gas with a specific gravity slightly less than that of water 0.921 g/L. It becomes a gas at 26° Centigrade and melts at —14° Centigrade, thus the freeze-out method can be used to rid the solution of the cyanide. From this point on, the experimenter is faced with the identification of the products which have resulted from the high voltage bombardment of the gases. A very acceptable method for this identification is the use of thin layer chromatography (4, 9, 10). The development of the starch chromatogram is very fast, appearing in approximately 45 minutes when 10 microliters from a pipette are used for spotting. A mixture of five known amino acids, the same as those one might expect from the experimental run, could also be spotted and a comparison of the spots would lead to identification of the unknowns.

The directions and suggestions given here are not detailed sufficiently to be followed in "cookbook fashion" by a student and it is expected that he will do much reading and planning before attempting such an experiment. It is hoped that through the performance of some of these experiments and exposure to the background reading material that the student will begin to realize the majesty of the creation of life and gain appreciation of the methods that are being used to probe ever deeper into what is undoubtedly the greatest riddle of mankind. From their ranks will certainly come the individuals who may some day answer this question.

LITERATURE CITED

1. Calvin, M. 1961. Chemical evolution. University of Oregon Press, Eugene, Oregon.

2. Florkin, M. 1960. Aspects of the origin of life. Pergamon Press, New York.

3. Fox, S. W. 1957. The chemical problem of spontaneous generation. Journal of Chemical Education 34:472–479.

4. Mizell, M. and S. B. Simpson, Jr. 1961. Paper chromatography separation of amino acids. Journal of Chromatography 5:157.

5. Oparin, A. I. and V. Fesenkov. 1961. Life in the universe. Twayne Publishers, Inc., New York.

6. Ponnamperuma, Cyril and Norman W. Gabel. 1967. Current status of chemical studies on the origin of life. Exobiology Division, NASA Ames Research Center, Moffett Field, California. 64 p.

7. Ponnamperuma, Cyril and Richard S. Young. 1964. Early evolution of life. American Institute of Biological Sciences. D. C. Heath and Company, Boston, Massachusetts.

8. Rutten, M. G. 1962. The geological aspects of the origin of life on Earth. American Elsevier Publishing Company, New York.

9. Saifer, A. and I. Oreskes. 1956. Color reactions of amino acids with alloxan, isatin and ninhydrin in circular paper chromatography. Analytical Chemistry 28:501.

10. Wolfe, M. 1957. The quantitative determination of amino acids by paper chromatography. Biochimica et Biophysica Acta 23:186.

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APPENDIX A SPACE BIOLOGY RESEARCH CENTERS VISITED BY STAFF

During the preparation of this syllabus many research centers were visited; scientists were interviewed; and their work discussed in some detail. Many experts submitted abstracts of their work. Numerous experiments suitable for performance in high schools were unearthed in this manner. The following is a listing of research centers visited.

THE ALBERT EINSTEIN COLLEGE OF MEDICINE
The Bronx, New York

GENERAL ELECTRIC COMPANY, MISSILE AND SPACE DIVISION, SPACE SCIENCES LABORATORY
Valley Forge, Pennsylvania

INSTITUTE FOR BEHAVIORAL RESEARCH
Silver Spring, Maryland

LOCKHEED MISSILES AND SPACE COMPANY RESEARCH LABORATORIES
Palo Alto and Sunnyvale, California

NASA AMES RESEARCH CENTER
Moffett Field, California

NASA MANNED SPACECRAFT CENTER
Houston, Texas

CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena, California

JET PROPULSION LABORATORY
Pasadena, California

UNIVERSITY OF CALIFORNIA
Berkeley, California

UNIVERSITY OF CALIFORNIA, WHITE MOUNTAIN RESEARCH STATION
Bishop, California

SPACE SCIENCES LABORATORY
Berkeley, California

RICHMOND STORAGE AND SERVICE FACILITY
Richmond, California

UNIVERSITY OF CALIFORNIA, LAWRENCE HALL OF SCIENCE
Berkeley, California

UNIVERSITY OF CALIFORNIA
Los Angeles, California

AEROSPACE MEDICAL RESEARCH LABORATORIES, WRIGHT-PATTERSON AIR FORCE BASE
Dayton, Ohio

STANFORD UNIVERSITY
Palo Alto, California

STANFORD UNIVERSITY SCHOOL OF MEDICINE
Palo Alto, California

HINE LABORATORIES, INC.
1099 Folsom Street
San Francisco, California

APPENDIX B FILM AND AUDIO TAPE SOURCES

Excellent films pertaining to space biology subjects are available but are not abundant. In the conduct of this study numerous films were reviewed; those evaluated as "excellent" or "good" in terms of their appropriateness to this volume are listed below.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION FILMS

Requests for free loan of NASA films should be addressed to the NASA film library nearest to you. Complete addresses for each of the NASA film libraries appear below.

If You Live In:	Address Your Request To:
Washington, Oregon, Idaho, Montana, Wyoming, northern California (Monterey, Fresno, and Mono counties, and North), Alaska	NASA AMES RESEARCH CENTER Film Library Moffett Field, California 94035
Arizona, southern California (San Luis Obispo, Kings, Kern, Tulare, Inyo counties, and South), Hawaii, Nevada, and Utah	NASA NASA PASADENA OFFICE Public Information Office 4800 Oak Grove Drive Pasadena, California 91103
Texas, Oklahoma, Kansas, Nebraska, New Mexico, Colorado, North Dakota, South Dakota	NASA MANNED SPACECRAFT CENTER Public Affairs Office Code—AP 2 2101 Webster Seabrook Road Houston, Texas 77058
Alabama, Mississippi, Tennessee, Louisiana, Missouri, Arkansas	NASA MARSHALL SPACE FLIGHT CENTER Public Affairs Office Community Services Marshall Space Flight Center, Alabama 35812
Ohio, Indiana, Illinois, Wisconsin, Michigan, Minnesota, Iowa	NASA LEWIS RESEARCH CENTER Office of Educational Services (4-4) 21000 Brookpark Road Cleveland, Ohio 44135

If You Live In:	Address Your Request To:
Virginia, Kentucky, North Carolina, South Carolina	NASA LANGLEY RESEARCH CENTER Public Information Officer Mail Stop 154 Langley Station Hampton, Virginia 23365
Florida, Bermuda, Georgia, Puerto Rico, Virgin Islands	NASA JOHN F. KENNEDY SPACE CENTER Photographic Operations Code—SOP-323 JFK Space Center, Florida 32899
Maryland, Delaware, West Virginia, Pennsylvania, New Jersey, District of Columbia	NASA GODDARD SPACE FLIGHT CENTER Photographic Branch, Code 253 Greenbelt, Maryland 20771
Latin America and overseas, Canada (and films not available from Regional Centers)	NASA HEADQUARTERS Code—FAD-3 Washington, D.C. 20546
New York, Maine, Vermont, New Hampshire, Connecticut, Massachusetts, Rhode Island	NASA ELECTRONIC RESEARCH CENTER Educational Programs Office 575 Technology Square Cambridge, Massachusetts 02139

MEDICAL EXPERIMENTS FROM MANNED SPACE FLIGHT. (MSC-65-274) 29 minutes, color, 1966. A detailed description of the effects of prolonged weightlessness on flight crews. It explains the methods, techniques, instrumentations, recordings, and analytical equipment. The film depicts physiological studies of demineralization, orthostatic hypotension, the heart, hematology, metabolism, pulmonary function, otology stress, circadian rhythm in weightless conditions. Rating: Not rated in this study.

THE FOUR DAYS OF GEMINI 4. (HQa-134) 28 minutes, color, 1965. This is a documentary film covering the spectacular Gemini-Titan IV mission of Astronauts James A. McDivitt and Edward H. White. It includes a beautiful color sequence of the pre-launch and launch activities, Astronaut White's spectacular "space walk" and many other experiments conducted on the four-day mission. Included in the description of the experiments are photographs of the earth. Narration includes the actual voice communications of the astronauts inside the spacecraft. The film also depicts the pre-flight training of McDivitt and White, and takes a detailed look at White's EVA suit and "space gun." Rating: Good.

LIVING IN SPACE

Part I	— (HQ–131 A)	A Case for Regeneration, 12 minutes, color, 1966
Part II	— (HQ–131 B)	Regenerative Processes, 20 minutes, color, 1966
Part III	— (HQ–131 C)	A Technology for Spacecraft Design, 12 minutes, color, 1966

This is a series of three films which depict various problems man must face in planning and carrying out long-duration manned spaceflights. Part I illustrates the basic requirements for oxygen, water, food, and waste disposal which must be incorporated in a regenerative or recycling system. Part II presents a more comprehensive view of the physics, chemistry, biology, and technology involved in a life support system, and possible solutions to problems of bathing, shaving, eating, and sleeping in a weightless environment. Part III shows the development of the orbital lab concept and regenerative system for extended future spaceflights. These films show a prototype manned orbital space lab being utilized at the NASA Langley Research Center, Hampton, Virginia. (A NASA FACTS publication entitled "Living in Space" is available for use with these films.) Rating: Not rated in this study.

THE NASA BIOSATELLITE PROGRAM (BETWEEN THE ATOM AND THE STAR). (HQ–107) 28 minutes, color, 1965. What are the effects of gravity on basic life processes? What will be the effect of prolonged weightlessness or a no-gravity atmosphere upon living organisms, particularly upon man? These are but a few of the questions that will be investigated in the NASA Biosatellite Program. Leading biologists in the country are designing experiments that will be conducted in an earth-orbiting satellite. Rating: Excellent, A.

RETURNS FROM SPACE. (HQa–156) 27 minutes, color, 1966. Some of the varied "spin-off" benefits and products of space research are illustrated and demonstrated in this film. These include the use of sensors for monitoring hospital patients; devices which enable the handicapped to operate wheelchairs, TV sets, and similar mechanical devices; the development of freeze-dried foods for the use of campers; and other medical and manufacturing aids. Rating: Not rated in this study.

A series of interviews with leading space scientists originally part of a 1966 NASA television series. The following subjects are available as 16 mm. black and white, 28-minute films:

SCIENCE REPORTER SERIES

FOOD FOR SPACE TRAVELERS. (HQK–SR3) A television interview with dietitians who plan and prepare meals for astronauts to eat during space flights. Various types of space foods and the methods of preparing them are demonstrated. Rating: Good, informative film.

SUITED FOR SPACE. (HQK–SR5) This television film explores the history of space suits from Mercury through Gemini and Apollo, and the life support system which an astronaut must wear on the moon. Rating: Good, informative film.

SPACE MEDICINE. (HQK–SR8) Dr. Charles Berry discusses and shows the medical progress and problems of sending a human being into space and concludes that, so far, there are no serious problems. Rating: Good general interest film. Interview and demonstrations.

THE SEARCH FOR EXTRATERRESTRIAL LIFE. (HQK–SR 13) Dr. Richard Young and his associates at the NASA Ames Research Center explain and illustrate their advanced study for determining forms of life which may exist on other planets, and the instruments which are being designed to explore the surface of other planets. Rating: Good, informative.

TRIAL BALANCE (HQK–123) 27 minutes, color, 1965. A fascinating and colorful film. Through the use of new graphic techniques, it shows how NASA has contributed to the growing body of scientific knowledge. Explores such fields as meteorology, communications, the study of planets, and the search for extraterrestrial life. The film departs from the use of animation only briefly to include dramatic photos of the surface of the sun and moon. Although suited for educational purposes, it is nontechnical and has an appeal to general adult audiences. The film features narration by actor Albert Dekker, and a musical score especially composed for the film. Rating: Good, interesting approach.

CREW SYSTEMS DIVISION. (MSC–63–142) 24 minutes, color, 1963. Documents the achievements of the Crew Systems Division in developing environmental control systems for spacecraft, personal equipment for crew members, protection from radiation, requirements for life support and physiological instrumentation.

It also describes briefly how some of the developments will have application in fields other than manned space flight. Rating: Good.

THE JOHN GLENN STORY. (HQa-90) 31 minutes, color, 1963. An inspiring biography of Astronaut John Glenn, narrated by TV-film star Jack Webb. The film depicts his boyhood in Ohio, his distinguished record as a Marine Corps pilot in World War II and the Korean War, his historic mission as the first American to orbit the earth, and his welcome home and address before Congress. President John F. Kennedy introduced the film with a personal message. The film stresses American ideals as exemplified by the heroism of Astronaut Glenn. Rating: Good, inspirational for youth groups.

EDUCATION: SPRINGBOARD TO SPACE. (MSC-65-255) 14 minutes, color, 1965. Demonstrates a need for educated people in the space program. It relates how astronomy, chemistry, physics, mathematics, engineering, medicine, and other academic areas will pioneer the way to creativity and comprehension in conquering the unknown. The film continues by showing how this knowledge is applied to research in various phases of the space program. Rating: Good, but better for general science.

GEMINI: THE TWINS. (MSC-65-260) 14 minutes, color, 1965. Describes the astronaut's role in the Gemini Program. It shows engineers and astronauts working together to solve the difficulties with the spacecraft and pressure suits. The film continues with astronaut training in the Translation and Docking Simulator, the Gemini Part-Task-Trainer, and the Gemini Mission Simulator. It concludes with highlights of the GT-III and GT-IV missions. Rating: Good.

EXTRAVEHICULAR ACTIVITY—GEMINI IV—JUNE 3, 1965. (MSC-65-286) 13 minutes, color, 1965. Highlignts the activities of the historic space walk by Astronaut Edward White. The film continues with preflight preparations, including a description of the material used in the Gemini extravehicular suit for the stroll in space. Onboard cameras record the extravehicular activity while Pilot White describes his adventures in space. Rating: Good.

MANNED SPACE FLIGHT—MANNED SPACECRAFT TECHNOLOGY. (MSC-65-269) 21 minutes, color, 1965. Reports on the hardware development and reliability of the Gemini and Apollo spacecraft. It shows various test facilities to insure the reliability of the spacecraft. The film illustrates the major differences in the Mercury, Gemini, and Apollo spacecraft. It continues with the Apollo propulsion system, crew system, biomedical and instrumentation equipment, and landing system. The film concludes with preflight checkout of Apollo and Gemini spacecraft. Rating: Good.

GEMINI SCIENCE PROGRAM. (MSC–65–279) 50 minutes, color, 1966. Explains the fourteen science experiments in the Gemini program. Dr. Homer J. Newell introduces the Space Science Applications Program; Dr. Gerathewohl, Dr. Young, and Dr. Beder describe the gravitational biology experiments; Dr. Duntley relates the visual acuity experiments; Drs. Gill and Lowman trace the synoptic terrain experiments; Dr. Work, Dr. Saudy, Mr. Nagler, and Mr. Soules tell of the synoptic weather experiments; Dr. Gill and Dr. Ney describe the dim-sky phenomena; Dr. Henize relates the ultraviolet spectra experiment; Dr. Trombka, Dr. Shapiro, Dr. Fichtel, Dr. Medved and Dr. Hemenway explain the purpose of the space physics experiments. Rating: Good, but long for high school use.

THE NASA MANNED SPACECRAFT CENTER—A NATIONAL RESOURCE. (MSC–64–242) 28 minutes, color, 1966. An interesting and informative report on activities at the NASA Manned Spacecraft Center. The film relates the responsibility of the Administrative Directorate, including project and program management. It shows the Flight Crew Operations involved in various astronaut training activities. The Engineering and Development Directorate is responsible for crew systems, biomedical studies, simulation laboratories, vibration chambers, thermochemical test facilities, structure and material facilities, and advanced mission planning. The film concludes with the Flight Operations Directorate, showing activities in the Mission Control Center, Real Time Computer Complex, Display Area, Worldwide Tracking Networks, and recovery forces. Rating: Good.

MANNED SPACECRAFT CENTER PROGRESS REPORT—JANUARY THROUGH JUNE 1966. (MSC–66–329) 29 minutes, color, 1966. Reports on the operation of the centrifuge, Chamber A, and acoustical testing facilities. The film highlights the Gemini IX missions. It reports on the AS–201 mission and continues with Apollo manufacturing and development. Referenced are astronauts' selection and crew announcements. Also included in the report are the 500 F vehicle movement to Launch Complex 39, the moon landing by Surveyor I, and biological studies at Ames Research Center. Rating: Good.

MANNED SPACE FLIGHT: GEMINI RENDEZVOUS MISSIONS. (MSC–65–252) 18 minutes, color, 1965. Explains the rendezvous and docking method in the Gemini and Apollo Programs. Animation shows the rendezvous and docking phase in Project Apollo. The film continues by depicting the six rendezvous concepts in the Gemini program, which are the Radar Computer Method, the Radar Optical Sight Method, the Optical Sighting Technique, the Direct Ascent Method, the LEM Rendezvous Simulation, and the LEM Abort Simulation. Rating: Good.

GEMINI VISUAL ACUITY EXPERIMENT. (MSC-65-282) 30 minutes, color, 1966. Starts with the scientific quantitative data on visual acuity in space. Dr. S. Q. Duntley defines acuity. The sightings by Astronaut Gordon Cooper during the MA-IX space mission were the historical basis for the origin of the experiment. As the film continues, Dr. John Taylor explains how studies were conducted to establish the validity of the sightings. The film includes the selection, preparation, and instrumentation of the ground sites, development of in-flight equipment, and flight crew training. It documents the significant visual acuity experiment on each mission, including photographic coverage, on-board tapes, and animation. The film concludes with an analysis of the experimental data. Rating: Good, shows details necessary in experimental procedures.

APOLLO LUNAR MISSION PROFILE. (MSC-65-245) 31 minutes, color, 1965. Relates the thrust needed to power man toward the moon. It delineates the three Apollo spacecraft modules in animation. The film continues with an explanation of the launch facilities and the Mission Control Center. A lunar mission profile is portrayed in animation with preflight preparations, launch, earth parking orbit, lunar trajectory, repositioning of the Apollo modules, mid-course corrections, entering lunar orbit, crew transfer, descent, lunar exploration, ascent, rendezvous and docking, earth trajectory, mid-course corrections, reentry, and parachute deployment. Rating: Good.

STEP INTO SPACE. (MSC-65-259) 11 minutes, color, 1965. This film is representative of astronaut activities in training, engineering modifications, and pressure suits. It shows astronaut training in the classroom, in flight, and with docking simulators, Gemini trainer, survival, contingency egression, geology, weightlessness, navigation and recovery. The film continues with astronaut evaluation, spacecraft modifications and pressure suits. Finally, the film shows how astronaut training proceeds for a specific mission. Rating: Good.

PROJECT APOLLO MANNED FLIGHT TO THE MOON. (HQ-83) 13 minutes, color, 1966. This film shows the principal steps that will be taken by NASA to place men on the moon and get them back safely within this decade. It shows the principal features of the Gemini spacecraft, the modified Titan booster, and the type of operations to be carried out under the Gemini program. Finally, the complete sequence of events from the manned lunar landing from earth launch to return is shown using the Saturn V launch vehicle and the Apollo spacecraft. It also shows the principal features of the Apollo spacecraft, the Saturn I, I-B, and V boosters and types of launch to be accomplished by each. Rating: Good.

LEGACY OF GEMINI. (HQ–160) 28 minutes, color, 1967. This is a documentary review of the major accomplishments in the Gemini Program and the relationship of those accomplishments to the Apollo manned spaceflight program. The film emphasizes astronaut training for Gemini flights, especially the development of work capabilities in a weightless environment. The twelve Gemini flights are shown as a single composite flight from launch to recovery, with photography of rendezvous and docking, station keeping, and experiments conducted by the astronauts. The film includes the best of Gemini photography of space and earth terrain. Rating: Not rated in this study.

ATOMIC ENERGY COMMISSION FILMS

Requests for the free loan of Atomic Energy Commission films should be addressed to the library nearest you. Complete addresses for each of the libraries appear below.

If You Live In:	Address Your Request To:
Alaska, Oregon, Washington	Film Library Information Division U. S. Atomic Energy Commission Richland Operations Office P. O. Box 550 Richland, Washington 99352
California, Hawaii, Nevada	Public Information Office U. S. Atomic Energy Commission San Francisco Operations Office 2111 Bancroft Way Berkeley, California 94704
Arizona, New Mexico, Texas, Oklahoma	Film Librarian Information Division U. S. Atomic Energy Commission P. O. Box 5400 Albuquerque, New Mexico 87115
Montana, Utah, Idaho	Mack C. Corbett, Director Office of Information U. S. Atomic Energy Commission Idaho Operations Office P. O. Box 2108 Idaho Falls, Idaho 83401
Colorado, Wyoming, Nebraska, Kansas	Neilsen B. O'Rear, Public Information Officer U. S. Atomic Energy Commission Grand Junction Office Grand Junction, Colorado 81502

If You Live In:	Address Your Request To:
North Dakota, South Dakota, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Michigan, Indiana, Ohio	Ruth Jones Information Office U. S. Atomic Energy Commission Chicago Operations Office 9800 South Cass Avenue Argonne, Illinois 60439
Arkansas, Kentucky, Tennessee, Louisiana, Mississippi	Peggy McConnell, Film Librarian Public Information Office U. S. Atomic Energy Commission Oak Ridge Operations Office P. O. Box E Oak Ridge, Tennessee 37830
Pennsylvania, New York, Vermont, New Hampshire, Maine, Massachusetts, New Jersey, Rhode Island, Connecticut	Beatrice Martinelli Public Information Service U. S. Atomic Energy Commission New York Operations Office 376 Hudson Street New York, New York 10014
Delaware, Maryland, Virginia, District of Columbia, West Virginia, Canada	Sid L. Schwartz Audio-Visual Branch, Division of Public Information U. S. Atomic Energy Commission Washington, D. C. 20545
North Carolina, South Carolina, Alabama, Georgia, Florida	Film Librarian U. S. Atomic Energy Commission Savannah River Operations Office P. O. Box A Aiken, South Carolina 29802

WHO MAY BORROW

Residents of the United States and Canada who are bona fide representatives of educational, civic, industrial, professional youth activity, and government organizations are invited to borrow films from the AEC Motion Picture Library which services their area. Because of wear and tear that results from repeated projections, films are loaned for *group* showings, and *not* for screening before individuals or in homes. Because custody of the films involves both legal and financial responsibility, films cannot be loaned to minors.

ATOMS FOR SPACE. 28½ minutes, color, 1962. This film describes the development and use of compact nuclear power sources for space under the Atomic Energy Commission's Systems for Nuclear Auxiliary Power (SNAP) program. The film features the first use of atomic power in the nation's space effort and briefly covers the uses of SNAP devices on land and sea. By means of animation and models, the two basic concepts of the SNAP program are shown. In one approach, the energy of decay from radioactive isotopes is used to generate electricity directly without moving parts. This method is being developed for the AEC by the Martin Company, the aerospace division of the Martin Marietta Corporation. A SNAP isotopic-power generator was launched on board the Navy's TRANSIT navigation satellite in June, 1961, marking the first use of nuclear power in space. The other SNAP approach uses the heat from a compact nuclear-fission reactor to generate electricity by a turbogenerator system or by direct conversion. Rating: Good. For General Information, General Science.

NUCLEAR REACTORS FOR SPACE. 17 minutes, color, 1961. The SNAP program—Systems for Nuclear Auxiliary Power—is an AEC program to develop long-lived auxiliary power from nuclear power for use in satellites and space vehicles. Compact atomic reactors being developed by Atomics International for use in SNAP systems are shown in this *semitechnical* film. Safety characteristics of the SNAP reactor during fabrication, testing, transport, installation, launching, and use in space are described. Detailed sequences filmed at Atomics International on fabrication and testing show the simplicity and compactness of the reactors. Safety features are described in scenes that illustrate shipping and launch-site activities. Launch of the reactor during re-entry into the atmosphere is shown in a detailed animation sequence. Many beneficial uses of SNAP in the U.S. national space program are illustrated. Produced by Atomics International. Also available from Atomics International, P. O. Box 309, Canoga Park, California. Rating: Good. Physics and Electronics classes.

RADIATION IN BIOLOGY: AN INTRODUCTION. 13½ minutes, color, 1962. The purpose of this film is to explain to junior and senior high school students in biology, general science, or physics the meaning of high-energy radiation and to show how this radiation is used in biological research. To accomplish its objectives, this film briefly reviews light from the sun (wave radiation), radio waves, X-rays, etc. It also touches on the various sources of radiation (X-ray machines, nuclear reactors, cosmic rays, the sun, etc.). Radioisotopes are defined, and their life is traced from production through their use as tools in the study of radiation damage. The effect of radiation on living cells is demonstrated by comparisons of plants grown from irradiated and non-irradiated seeds and mice that had been irradiated with those that had not been irradiated. The film also shows the effects of radiation on bone marrow, on the protective lining of the intestine, and on chromosomes (mutations). The use of radioisotopes to trace chemical processes in plants (the absorption of nutrients) is also covered. Autoradiographs are explained, and the function of a Geiger counter is outlined. The film was made under the technical direction of Dr. Harvey Patt, Division of Biological and Medical Research at AEC's Argonne National Laboratory (ANL), and photographed at ANL. Produced by Coronet Instructional Films. Rating: Good.

UNIVERSITY OF CALIFORNIA

University of California Extension
Film Library
Berkeley, California

How to order library films:

1. a. Before ordering, please read the following regulations carefully. Placement of the first order indicates acceptance of these terms.

   b. Select films only from the current University Extension bulletin and subsequent supplements which will follow. Earlier catalogs should be destroyed.

   c. Use University Extension Order Blanks (available upon request) to save time and expedite booking. Orders by letter, purchase order, or telephone are acceptable, but should conform to these regulations.

   d. Orders must include:
   1) The name and address to which the film and confirmation should be sent.
   2) The name and address to which the invoice should be sent. (Do *not* send payment with order.)
   3) The exact film number and its title together with the date or dates it is to be used. List alternative dates if possible.

   e. Order well in advance to allow for confirmation or for any necessary changes.

   f. When the confirmation form is received, note and follow the "use" and "due back" dates. Read confirmation carefully. Write immediately if changes are desired.

   Educators should order for the entire school year or semester if possible, to assure the availability of films. (Please note your vacation periods and avoid booking for these dates.)

2. a. Do not send payment until you receive invoice listing service fees and transportation charges.
   b. The service fee is for one-day use. Service fees subject to change without notice.
   c. Borrower pays transportation costs both ways. The invoice includes cost of shipping the film to the user, plus a ten-cent handling charge for each package. Borrower will prepay and insure return shipments to the Film Library. There is no charge for transportation time to and from the borrower.
   d. A film order may be cancelled at any time prior to shipping date. Charges will not be cancelled if the shipment has left the Film Library or if the film has been packaged for messenger pick-up at the Library.
   e. The borrower will be held responsible for damage beyond normal wear and for any loss of films in his possession or during transit back to the Film Library. NOTE: Minimum Parcel Post Insurance does not provide an insurance number for tracing lost films.

   A special rate reduction applies to many films if reserved in advance for two or more consecutive days; the full service fee is charged for the first day of use and half the service fee for each additional day the film is booked. Invoices will include the reduced rate where it applies.

   A "late charge" equal to the one-day use fee will be made for each extra day a film is held without permission.

MAN IN SPACE. (3221) 35 minutes, color (rental price: $12.50) A vivid depiction of rocket development from ancient Chinese weapons to modern missiles sets the stage for a provocative film production showing how man may conquer outer space and establish a small artificial satellite 1,075 miles above the earth. But how will mortals react to space travel? To answer this vital question, an animated cartoon character personifying Dr. Heinz H ber, aviation medicine authority, comments on the problems of "weightlessness" and other new experiences our hero will meet. Dr. Wernher von Braun, world-famous rocket engineer, presents the next step in man's assault against the space barrier. He illustrates the mechanics of the four-stage rocket necessary to accomplish interplanetary travel. This leads into a graphic, animated cartoon visualization of man's first successful rocket journey to outer space. (Walt Disney Productions.) Restricted to one or two days' use. Rating: Good, Disney stylizing.

MAN AND TH. MOON. (3222) 20 minutes, color (rental price: $10.00) This film describes the work of weather stations today for forecasting weather and possible future use of satellites to control weather and divert destructive storms and hurricanes. This film presents a realistic and believable trip to the moon in a rocket ship as it may occur in the foreseeable future. (Walt Disney Productions.) Restricted to one or two days' use. Rating: Good, general science, Disney stylizing.

MARS AND BEYOND. (3225) 30 minutes, color (rental price: $15.00) In solving the enigma of the red planet, Mars, man may find a key that opens the first small door to the universe. Carried forward on the wings of modern science, man in the years that follow may discover the miracle of life as it exists in all its countless forms throughout an infinite creation. This film presents some factual material as well as fantastic speculation relative to Mars. It will serve to stimulate thought and study of the planets and develop greater interest in the future of space travel. This film discusses the temperature and atmosphere on the planets and conditions necessary for life. It portrays man's earliest concepts of the planets, particularly Mars. It pictures the possible surface of Mars and the ways in which plant and animal life may have adapted to conditions there. It describes an imaginary flight to Mars in an atom-powered spacecraft. (Walt Disney Productions.) Restricted to one or two days' use. Rating: Good, Disney stylizing.

UNITED STATES AIR FORCE

Many films dealing with space biology are available to schools from the U.S. Air Force. They may be requested from base film libraries which are located at most Air Force bases in the United States. If you do not live near such a base, requests may be mailed to:

Air Force Film Library
8900 South Broadway
St. Louis, Missouri 63125

Alaska residents should mail requests to:

Air Force Film Library
Elmendorf AFB, Alaska

A complete film catalog (Air Force Manual 95–2, Vol. II) and "Request for Film Forms" (AF Form 253c) are available from the Air Force Film Library Center.

THE AEROSPACE MEDICAL DIVISION. (SFP 1313) 14 minutes, color, 1965. Reviews progress in aerospace medicine. Reveals extensive nature of aerospace medical research conducted in AFSC laboratories. Relates this research to clinical medicine, education and training. Rating: Good.

G-FORCES. (TF 1–8194) Limited prints. 30 minutes, color, 1962. Explains the law of gravity and its effects on man and man's efforts to explore space. Clearly defining linear, radial and angular acceleration, film points out their effects on the human body in terms of positive, negative and transverse G-forces. Research and development scenes depict some of the immeasurable time and effort devoted to the study of gravitational problems primarily involving weightlessness, acceleration endurance in three-stage rocket flights, buffeting, tumbling, and deceleration. Rating: Good.

HYPOXIA. (TF 1–8195) 22 minutes, color, 1963. Deals with hypoxia, one of the hazards of high altitude flight and space travel involving oxygen shortage in the respiratory system under low barometric pressure environment. Explains terms hypoxic, stagnant and methods of prevention peculiar to each type. Also discusses hyperventilation and its causes and effects. Rating: Good, preview before showing to class.

RESPIRATION AND CIRCULATION. (TF 1–8187) 26 minutes, color, 1961. Limited prints. Explains and illustrates the functions of the circulatory and respiratory systems within the human body and shows how they work together under the direction of the brain through reflex chemoreceptor control. Animated illustrations depict the relationship of these complex systems with the physiological problems of flight. Rating: Very Good.

AEROSPACE MEDICAL RESEARCH AT HOLLOMAN AFB. (SFP 1020) 27 minutes, color, 1961. Portrays the intensive biodynamic research conducted at Holloman AFB to assure man's safe journey to outer space. At Holloman, trained volunteers ride the captive missile track to test man's tolerance to varying G-forces. Others participate in weightlessness studies or ascend to fantastic altitudes to test man's reaction to cosmic radiation. Expertly trained and cared for animals also contribute to extensive tests that guarantee man's survival in a hostile environment. Rating: Very Good.

MAN AND SPACE. (SFP 1120) 23 minutes, color, 1963. This comprehensive review of the Air Force Systems Command's bioastronautics life sciences program shows how professional staffs representing nearly every scientific area conduct intensive research and coordinate operational medical support to assure man's safety in all manned space exploration. Rating: Fair to Good.

OXYGEN—IN-FLIGHT REQUIREMENTS. (TF 1-5038a) 23 minutes, color, 1956. Describes the effects of oxygen on the pilot and crew at various altitudes. Explains dangers of hypoxia and "bends" and shows decompression chamber tests. Rating: Good, preview before showing to class.

BREAKTHROUGH—SEARCH FOR KNOWLEDGE. (SFP 1225) 20 minutes, color, 1964. Reports on the Air Force's basic research program and its contributions to the space program. Illustrates how this program, under the jurisdiction of the Office of Aerospace Research (OAR), provid[illegible]ndless source of knowledge to further our space efforts and [illegible] insure national security and aerospace supremacy. Visits to several of OAR's many in-house laboratories show the wide range of research projects under development. Also points out OAR grants to universities and research centers. Film illustrates the never-ending cycle of searching for knowledge. Rating: Good.

PRIVATE COMPANIES

McDonnell Aircraft Corporation
Box 516, Dept. 92, Room 167, Bldg. #1
St. Louis, Missouri 63166

PROJECT GEMINI. 13½ minutes, color, 1964. A fully animated public relations film portraying a typical Gemini rendezvous mission. Non-technical in content, it includes such scenes as Gemini maneuvering into the Agena's orbit, the astronauts performing the docking maneuver, their fiery return to earth, as well as some of Gemini's potential applications during later flights, e.g., satellite repair, crew transfer. Rating: Good, animation technique.

WHAT IT'S LIKE OUTSIDE. 12 minutes, color, 1965. You'll take a dramatic journey into space aboard Gemini IV and see breathtaking color pictures of Major White maneuvering outside the spacecraft with his space gun, spectacular views of California, the Nile Delta region, Florida and acres of the Midwest. You will listen to Major White give you a personal description of these events. Film concludes with scenes of the successful recovery and the congratulatory message of Mr. Dave Lewis, president of McDonnell, to all members of the Gemini team. Rating: Good.

JOURNEY INTO SPACE. 12½ minutes, color, 1961. A fully animated film illustrating the complete sequence of a successful orbital flight of a manned Atlas-Mercury vehicle, taking into account flying of the Atlas missile, orbit and re-entry. A good teaching film on mechanics of the system. This film won two Industrial Photography awards. Rating: Good.

Lockheed-Georgia Company
Motion Picture Film Library
Zone 30, B-2 Building
Marietta, Georgia 30062

THE HUMAN FACTOR. 7 minutes, color. Discusses human physiological needs and necessity of taking an Earth environment into space. It raises such questions as:

1. How many tasks can be performed efficiently at one time?
2. How may man achieve the highest performance in relation to duty and rest periods?
3. How long can he sustain the performance?
4. What criteria are to be used in selection of space crews?

This film is concerned with the basis of human performance in a space environment as it is carried over from earth environment. Rating: Good.

North American Aviation, Inc.
Atomics International Division
Public Relations Department
8900 De Soto Street
Canoga Park, California 91304

ATOMS FOR SPACE. 28 minutes, color. Shows the development and use of compact nuclear power sources for space under AEC's SNAP program. It shows the two basic concepts of the SNAP program: the radioactive isotope approach and the nuclear reactor approach. The first use of nuclear power in the nation's space effort is featured. Rating: Good, physics.

North American Aviation, Inc.
Space and Information Systems Division
Public Relations Department
12214 Lakewood Boulevard
Downey, California 90241

APOLLO MISSION. 12 minutes, color. Animated flight of Apollo spacecraft to the moon and back. Rating: Good.

Society for Visual Education, Inc.
1345 Diversey Parkway
Chicago, Illinois 60614

Filmstrips available for purchase:

LEAVING THE WORLD. No. A–484–1. 41 frames. This filmstrip pictures man-made satellites recently launched and explains rocket-powered thrust and speed of release. It also defines perigee, apogee, period and ellipse. Suitable for elementary school and junior high school.

CURRENT EVENTS IN SPACE. No. A–484–2. 47 frames. This filmstrip explains the functions of satellites and the information they collect. It covers the first successful moon shot and shows the launching of a satellite. Suitable for junior high school through ninth grade biology.

MAN IN SPACE. No. A–484–3. 47 frames. This filmstrip shows how men are being trained for outer space trips. It includes obstacles such as weightlessness, acceleration, temperature extremes and radiation. Suitable for junior high school.

SPACE TRAVEL A.D. 2000. No. A–484–4. 52 frames. This filmstrip deals with the nature of space, facts of astronomy, relationship of time and distance to space travel, new forms of power, atomic engines, plasma and proton power. Suitable for elementary school and junior high school.

APPENDIX C TEACHING FROM RESEARCH PAPERS

An Approach to Teaching Science as a Process
by Howard B. Baumel and J. Joel Berger, *Science Teacher*, April 1965

In the past 30 years, leaders in the field of science education have continually called attention to the need for, and importance of, emphasizing scientific methods and attitudes in teaching procedures. Brandwein, Watson and Blackwood[1] report that a survey of 42 syllabuses, from 37 states for all secondary school science courses, reveals one common element—all propose to teach scientific methods.

Many definitions of the objectives related to scientific methods and attitudes have been developed. It appears that all of the definitions have a great deal in common.[2] Recently, however, the idea of the existence of any single, definable scientific method has been questioned and viewed as a gross oversimplification and distortion of the methods of scientific inquiry.

Thus, while there is a genuine concern on the part of scientists, science educators and science teachers that students develop insights into methods of science, it is generally believed that the presentation of the "scientific method" as the well-known sequence of steps is an approach that is all too often completely unsuccessful in inculcating a conception of what science is about, how science works, and what the real character of the scientific enterprise is.

An approach that attempts to combine the character of science with its content through the involvement of students with the research papers of scientists appears to have great potential in teaching

[1] *Paul F. Brandwein, Fletcher G. Watson and Paul E. Blackwood. Teaching High School Science; A Book of Methods. Harcourt, Brace and World, New York, 1958. p.11.*

[2] *National Society for the Study of Education, Fifty-ninth Yearbook, Part One, Rethinking Science Education. University of Chicago Press, Chicago, Illinois, 1960. p. 47.*

science as a process. Among the many rewards to be gained from the students' firsthand contact with original scientific writings are the genuine excitement in seeing fundamental discoveries through the eyes of their discoverers, the humanizing enrichment in becoming acquainted with the personalities of great scientists, and the possibility that youngsters will "catch" the climate of accuracy, the carefully detailed work, and the essential honesty of their scientific efforts.

The authors have been using this approach in their respective science classes for the past four years. Only those research papers which involved content similar to that studied at the time, which could easily be understood by the students, and which reflected significant contributions to the development of scientific knowledge were selected. There are many sources available from which suitable research papers may be chosen. The selected papers were duplicated for distribution to the students. Explanations were included for any terms which might not have been clear.

A series of questions which attempted to focus student attention upon important aspects of scientists and experimentation was prepared for each selected research paper.

These questions required the students to:

1. Recognize and state problems.
2. Select, evaluate, and apply information in relation to problems.
3. Recognize and state hypotheses.
4. Recognize and evaluate conclusions, assumptions and generalizations.
5. Identify remarks, attitudes, procedures or conclusions in the research paper that involve or illustrate aspects of scientists or experimentation.

The following sample questions may serve as a guide to any paper selected:

1. What problem was the scientist studying?
2. What information did the scientist have at hand when he investigated the problem?
3. What hypothesis did the scientist probably have in mind as he planned his investigations?
4. What was the outcome of the experiment?
    a. Observationally?
    b. In relation to hypothesis?
5. What conclusion was reached?
6. Is the conclusion justified?
7. What simple experiments could you plan that make it possible to confirm the scientist's conclusions?

8. What have you used in your experimental plan that was not available to the scientist?

In addition, questions which involved an understanding of the specific science content in the paper were also included in the guide.

The students received copies of the papers to be considered and the accompanying questions approximately two days prior to class discussion. In class the students had before them both the paper and the completed questions. The teacher then gave a brief description of the historical background pertinent to the paper being analyzed. The answers of individual students to each of the questions served as the framework around which discussion of the significant aspects of the papers proceeded.

The regular use of these research papers does not diminish student achievement in terms of subject matter. Baumel[3] found that students who studied biology in classes where research papers were used performed as well, on a standardized biology achievement test as did students who had spent full time in covering the usual course content.

Those students who read and analyzed the research papers were invited to express their reactions anonymously to this technique in a free response type of questionnaire. Many of the students believed that their conceptions of science and scientists had changed as had some aspects of their behavior. A typical comment was "I got to feel as if I was in the scientist's shoes, making all the experiments and decisions."

The experience of the authors in using research papers in secondary school biology and chemistry classes indicates that this is an approach which appears to be on the right track toward the development in students of the attitudes, appreciations, and understandings inherent in the ways scientists work.

[3] *Howard B. Baumel. "The Effects of a Method of Teaching Secondary School Biology Which Involves the Critical Analysis of Research Papers of Scientists on Selected Science Education Objectives." Doctor's thesis. New York University, New York, N.Y. 1963.*

APPENDIX D IMPORTANT SOURCES OF AEROSPACE LITERATURE

Technical aerospace literature produced by NASA research and development activities, its contractors and grant holders, related U.S. Government agencies, and U.S. and foreign research organizations, grows at the rate of more than 75,000 titles per year. It is important that the high school biology teacher become aware of how to gain access to this storehouse of knowledge. The following publications will be very helpful to the teacher in this regard:

HOW TO USE NASA's SCIENTIFIC AND TECHNICAL INFORMATION SYSTEM, 1967. Scientific and Technical Information Division, National Aeronautics and Space Administration, Washington, D. C. 20546. This is a 24-page booklet whose purpose is to acquaint interested individuals who lack prior knowledge of it, with NASA's scientific and technical information system and tell them how to use it. This publication is highly recommended for high school biology teachers and is available for twenty cents from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402.

SCIENTIFIC AND TECHNICAL AEROSPACE REPORTS (STAR). The basic and most widely available guide to NASA's storehouse of knowledge is STAR. It is a comprehensive journal of abstracts and indexes covering worldwide report literature on the science and technology of space and aeronautics. This semimonthly publication is the most important single aid to the person seeking to find out what kinds of technical information NASA has accumulated.

Abstracts in each issue are arranged in 34 subject categories, including Biosciences and Biotechnology. Each issue of STAR contains five indexes: Subject, Corporate Sources, Personal Author, Report Number and Accession Number. Cumulative Indexes are published quarterly and include the same five indexes plus a listing of contract numbers.

Annual subscriptions fo the semi-monthly issues and cumulative index issues of STAR, or individual copies of both, may be obtained from: Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. Annual subscription rates for the semi-monthly issues are $33 while individual copies are $2.25 each. Annual subscription rates for the cumulative issues are $30 while individual copies of the cumulative index issues vary in price according to the number of pages. It may also be consulted at some 50 public and university libraries in various parts of the United States.

The publication "How to Use NASA's Scientific and Technical Information System" provides many valuable details as to the use of STAR and includes sample abstracts, sample indexes and a sample table of contents. Documents announced in STAR are available from the Clearinghouse for Federal Scientific and Technical Information (CFSTI) for $3.00 per printed copy and 65 cents per microfiche copy.

INTERNATIONAL AEROSPACE ABSTRACTS (IAA). International Aerospace Abstracts is published by special arrangement between NASA and the AIAA. It complements STAR by providing worldwide coverage of scientific and trade journals, books, and meeting papers in the field of aerospace science and technology. IAA uses the same subject categories and publishes the same types of indexes as STAR. STAR and IAA are issued during alternate weeks. Annual subscriptions to IAA are available at $25.00 from Technical Information Service, American Institute of Aeronautics and Astronautics, Inc., 750 Third Avenue, New York, N. Y. 10017.

PHOTOREPRODUCED DOCUMENT SERVICE

This service is available through:

Technical Information Service
American Institute of Aeronautics and Astronautics, Inc.
750 Third Avenue, New York, N. Y. 10017

Paper copies of accessions announced in International Aerospace Abstracts (IAA) and of other published articles in the Technical Information Service library will be furnished at $3.00 per document, regardless of the number of pages.

Paper copies of accessions announced in Scientific and Technical Aerospace Reports (STAR) and of similar unpublished reports in the TIS library will be supplied at the rate of $0.25 per page, minimum order $3.00. Microfiche of documents announced in IAA will be available at a nominal rate. Documents available in this manner are identified by the symbol # following the accession number in the Abstracts Section and in the Report Number and Accession Number Indexes.

NASA PRINTED BIBLIOGRAPHIES

NASA publishes several bibliographies in well-defined fields including "Aerospace Medicine and Biology—A Continuing Bibliography and Indexes" (NASA SP–7011). This is a continuing bibliography of selected abstracts from both STAR and IAA, as well as abstracts of journal articles made available by the Library of Congress. "Aerospace Medicine and Biology," in its subject coverage, concentrates on the biological, physiological, psychological and environmental effects to which man is subjected during and following simulated or actual flight in the earth's atmosphere or in interplanetary space. References describing similar effects on biological organisms of lower order are also included, as are those describing related topics.

Aerospace Medicine and Biology, and NASA's other bibliographies, are available from the Government Printing Office, or from: Clearinghouse for Federal Scientific and Technical Information (CFSTI), Springfield, Virginia, 22151. The cost of Aerospace Medicine and Biology is $1.00 per issue.

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

NASA issues six formal series of publications in which it reports significant advances in knowledge that have resulted from its own laboratory research and exploration of the atmosphere and space and from the work of its contractors and grant holders.

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies. A NASA Special Publications catalog is issued semiannually and is available from: Scientific and Technical Information Division, NASA, Washington, D. C. 20546.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include: Tech Briefs; Technology Utilization Reports; Technology Utilization Notes; and Technology Surveys.

NASA EDUCATIONAL PUBLICATIONS

These are primarily non-technical publications, informational/educational in nature, and designed to meet the needs of schools, colleges and universities in space science and technology. There are a number of booklets, folders, and bibliographies in this series, including the following publications which may be especially useful to the high school biology teacher:

SPACE, THE NEW FRONTIER
HISTORICAL SKETCH OF NASA
THIS IS NASA
A REPORT FROM MARS
7 STEPS TO A CAREER IN SPACE SCIENCE AND TECHNOLOGY
LIFE SCIENCE IN A SPACE AGE SETTING

Single copies of these publications, as well as a complete list of NASA Educational Publications, and a booklet describing the NASA services and programs which are available to teachers and students, may be obtained without cost from: FGE-1, Educational Publications, NASA, Washington, D. C. 20546.

NASA FACTS

NASA FACTS describes NASA programs, with photographs and diagrams of the spacecraft and launch vehicles. Sheets are designed for 8 x 10½ looseleaf notebook insertion. Examples of NASA FACTS issues which are especially useful in high school biology are:

Vol. II, No. 8	Manned Space Flight: Project Apollo
Vol. II, No. 10	Biosatellites
Vol. III, No. 1	Manned Space Flight: Project Apollo
Vol. III, No. 5	Living in Space

NASA FACTS will be mailed, on a continuing basis, without cost to those who request it from FAD-2, Educational Publications, NASA, Washington, D.C. 20546.

EDUCATIONAL BRIEFS

NASA Educational Briefs are a series of two- to eight-page information sheets designed to disseminate to classroom teachers educational materials concerning advances in science and technology resulting from the Nation's aerospace program. They are produced by the NASA Manned Spacecraft Center.

The series is coded by subject category:

001–999 Series	—Educational Programs and Services
1000	— Life Sciences
2000	— Earth Sciences and Astronomy
3000	— Chemistry
4000	— Physics
5000	— Mathematics
6000	— Technical Trades and Crafts
8000	— Measurements
10,000	—General Space Program Information

Examples of issues especially useful in high school biology include:

No. 1003	Foods for Use in Space
No. 1004–A	Circulatory Problems Resulting from "Weightlessness"

No. 1004–B	Measures to Overcome the Problems of Postural Hypotension
No. 10012	Astronaut Selection Requirements

Educational Briefs are available without cost from the Manned Spacecraft Center, Houston, Texas.

NASA SEMIANNUAL REPORT TO CONGRESS

Each NASA Semiannual Report to the Congress of the United States covers in detail six months of accomplishment. The reports include details on activities and accomplishments in several areas including: Manned Space Flight; Scientific Investigations in Space; Satellite Applications; Advanced Research and Technology; Nuclear Propulsion and Power Generation; Tracking and Data Acquisition; International Programs; Grants and Research Contracts Activities; Informational and Educational Programs; Personnel, Management, Procurement and Support Functions. A number of useful appendices, tables and illustrations are also included in each report. There is often a several-month lag between the end of the fiscal report period and actual publication of the report. Reports are for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. The 17th Semiannual Report covers June–December 1967, and costs $1.00.

ADDITIONAL SELECTED NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LITERATURE

GPO = available from Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402
CFSTI = available from Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151

A SELECTED LISTING OF NASA SCIENTIFIC AND TECHNICAL REPORTS FOR 1965. (NASA SP–7024) Annotated listing of NASA reports and journal articles announced during 1965 in *Scientific and Technical Aerospace Reports* (*STAR*). Included are Special Publications, Technical Reports, Technical Notes, Technical Memorandums, Technical Translations, and Contractor Reports. 1966 1400 pp. GPO $7.00. *Similar listings available for 1964 and 1963:* NASA SP–7018 (1132 pp. GPO $5.25), and NASA SP–7005 (236 pp. CFSTI $3.00).

GUIDE TO THE SUBJECT INDEXES FOR SCIENTIFIC AND TECHNICAL AEROSPACE REPORTS. (NASA SP-7016) Third revised edition. 1966 440 pp. CFSTI $3.00

PLANETARY ATMOSPHERES, A CONTINUING BIBLIOGRAPHY. (NASA SP-7017:01) A selection of annotated references to unclassified reports and journal articles introduced into the NASA information system during the period February 1965–May 1966. A large number of these references were produced as a result of the Mariner II and Mariner IV probes of the atmospheres of Venus and Mars. A limited number of references to the atmospheres of Jupiter, Mercury and Saturn are also included. 1966 440 pp. CFSTI $3.00. *Previously issued under the same title:* NASA SP-7017, containing references acquired from January 1962 to February 1965 (142 pp. CFSTI $3.00).

AEROSPACE MEDICINE AND BIOLOGY, A CONTINUING BIBLIOGRAPHY. (NASA SP-7011:24) Monthly annotated bibliography concentrating on the biological, physiological, psychological, and environmental effects on man during and following simulated or actual flight in the earth's atmosphere or in interplanetary space. References describing similar effects on biological organisms of lower order are also included. Among related topics covered are sanitary problems, pharmacology, toxicology, safety and survival, life-support systems, exobiology, and personnel factors. This most recent supplement contains references to NASA acquisitions during April 1966. Subject, corporate source, and author indexes. 1966 76 pp. CFSTI $3.00. *Previous 1966 issues under the same title:* SP-7011(23), containing selected references acquired in March 1966 (68 pp. CFSTI $3.00); SP-7011(22), February 1966 (80 pp. CFSTI $3.00); and SP-7011(21), January 1966 (52 pp. CFSTI $3.00).

CUMULATIVE INDEX TO NASA TECH BRIEFS, 1963–1965. (NASA SP-5021:02) A guide to technological innovations derived from the NASA space program, containing citations and abstracts of all *NASA Tech Briefs* published through 1965. Subject index and two indexes relating *Tech Brief* numbers to originating sources. 1966 41 pp. CFSTI $3.00

GEMINI MIDPROGRAM CONFERENCE. (NASA SP-121) This report contains 46 papers presented at the Gemini Midprogram Conference held at the Manned Spacecraft Center, Houston, Texas, February 23–25, 1966. The first group of 30 papers describes the spacecraft and launch vehicle, flight operations, and mission results, and includes accounts of the Gemini VI-A and VII rendezvous and the astronauts' reactions to the flight; the second group reports on in-flight experiments. 1966 444 pp. GPO $2.75

INVOLUNTARY HYPOHYDRATION IN MAN AND ANIMALS: A REVIEW. *By John E. Greenleaf* (NASA SP–110) This review summarizes the literature pertaining to delay in rehydration following water loss and associated factors influencing water intake by man and animals. 1966 34 pp. GPO $0.30

DEVELOPMENT OF A SMALL ANIMAL PAYLOAD AND INTEGRATION WITH A SOUNDING ROCKET. *Larry J. Early, Ed.* (NASA SP–109) A report on the results of Phase I of the Bio-Space Technology Program, describing the design, development, and integration with a modified Atlas launch vehicle of a small-animal payload. Included are discussions of a trajectory and performance, vehicle aerodynamic analysis, payload and recovery systems design, biological bench tests, payload flight-qualification testing, and flight tests and results. 1966 98 pp. GPO $0.60

PROCEEDINGS OF A CONFERENCE ON THEORETICAL BIOLOGY. (NASA SP–104) A series of discussions on de novo cell synthesis and population ecology held in Princeton, N. J., November 22-24, 1963, under the sponsorship of NASA and the American Institute of Biological Sciences. 1966 188 pp. GPO $1.00

HUMAN RESPONSE TO SUSTAINED ACCELERATION. *A Literature Review by T. M. Fraser* (NASA SP–103) A critical review of the open literature in the field, this report deals with the natural history and physiological effects of sustained acceleration, and with human tolerance and performance during acceleration stress. 1966 136 pp. GPO $1.00

PHILOSOPHY OF SIMULATION IN A MAN-MACHINE SPACE MISSION SYSTEM. *By T. M. Fraser* (NASA SP–102) An examination of the philosophy of simulation as it pertains to manned space activities, with particular orientation to research in the life sciences. 1966 107 pp. GPO $0.50

SIGNIFICANT ACHIEVEMENTS IN SPACE BIOSCIENCE, 1958–1964. (NASA SP–92) A summary of certain aspects of the space biology program that brings together some results of NASA and NASA-sponsored research in this new scientific field. Information from many other sources, especially the U. S. Air Force, is included. 1966 128 pp. GPO $0.55

MEDICAL ASPECTS OF AN ORBITING RESEARCH LABORATORY. (NASA SP–86) A report by the Space Medicine Advisory Group (SPAMAG), a group of consultants representing varied disciplines in the life sciences. Recommendations fall in three broad categories: (1) life support; (2) experiments to test the response in the space environment; and (3) research laboratory design and operation. 1966 144 pp. GPO $1.00

BIOENERGETICS OF SPACE SUITS FOR LUNAR EXPLORATION. (NASA SP-84) *A Literature Review by Emanuel M. Roth* This report discusses the new problems in optimal space-suit system design presented by the potential for severe physical exertion outside the spacecraft and on the surface of the moon and other celestial bodies. Subjects covered include the metabolic load imposed on humans by exertion, the mechanics of locomotion under varied terrain and gravity conditions, mobility restriction in space suits, and problems of thermal control. 1966 140 pp. GPO $1.00

PROCEEDINGS OF THE FIFTH NATIONAL CONFERENCE ON THE PEACEFUL USES OF SPACE. (NASA SP-82) Papers presented at the meeting held May 25–28, 1965, in St. Louis, Mo., to review space accomplishments and their global impact. 1966 200 pp. GPO $1.50

SHORT GLOSSARY OF SPACE TERMS. (NASA SP-1) Brief definitions of frequently used space terms, selected from the *Dictionary of Technical Terms for Aerospace Use* (NASA SP-7). Second edition. 1966 52 pp. GPO $0.25

EXTRATERRESTRIAL LIFE: A BIBLIOGRAPHY. PART I, REPORT LITERATURE. PART II, PUBLISHED LITERATURE. (NASA SP-7015) A comprehensive collection of annotated references on the general subjects of extraterrestrial life and exobiology, including such related topics as the origin of life on earth and terrestrial contamination of spacecraft. Part I consists of references to selected domestic and foreign reports prepared during the period 1962 through July 1964; Part II lists journal articles and books published in the period 1900–1964. A limited selection of 1965 sources is also included. The first volume is indexed by subject, author, corporate source, and contract number. The subject and author indexes of the second volume also cover information contained in Part I. 1965 Part I 76 pp. GPO $0.45; 1965 Part II 335 pp. GPO $2.00

THE INTERNATIONAL SYSTEM OF UNITS—PHYSICAL CONSTANTS AND CONVERSION FACTORS. *Compiled by E. A. Mechtly* (NASA SP-7012) This document defines the basic units of the Système International, adopted officially by the 1960 Eleventh General Conference on Weights and Measures, and tables for converting from U. S. customary units. 1965 20 pp. GPO $0.20

MEDICAL AND BIOLOGICAL APPLICATIONS OF SPACE TELEMETRY. (NASA SP-5023) A description of the biotelemetry systems developed for, or employed in, the space effort and in civilian biomedical applications. It is directed toward expediting more widespread use of such devices and toward accumulation of information useful in further design and applications. Glossary. 1965 66 pp. GPO $0.45

SPACE MEDICINE IN PROJECT MERCURY. *By Mae Mills Link* (NASA SP-4003) This volume examines the development of NASA's fund of space-medicine information and experience. It also shows how NASA was able to draw upon the vast and rich resources of the Air Force, the Navy, other Government agencies, industry, and academic and private research institutions to develop life-support systems to protect man against the stresses of launch, orbit, reentry, and impact throughout the Mercury program. Index. 1965 198 pp. GPO $1.00

NASA 1965 SUMMER CONFERENCE ON LUNAR EXPLORATION AND SCIENCE. (NASA SP-88) Results of the conference on lunar exploration, held in Falmouth, Mass., July 19-31, 1965, including the conclusions and recommendations drawn from it. An overall lunar-mission summary is given, together with the working-group reports from which the summary was obtained, in the disciplines geodesy/cartography, geology, geophysics, bioscience, geochemistry (mineralogy and petrology), particles and fields, lunar atmosphere measurement and astronomy. 1965 422 pp. GPO $1.50

NASA UNIVERSITY PROGRAM REVIEW CONFERENCE. (NASA SP-85) A review conducted at a conference in Kansas City, Mo., March 1-3, 1965, by university professors and administrators of the programs sponsored by NASA through grants and research contracts with universities throughout the country. Included are papers on X-ray and gamma-ray astronomy and biological research, as well as on the effect the grants and contracts have had on research at particular universities. 1965 400 pp. GPO $1.50

SUMMARY REPORT ON THE NASA UNIVERSITY PROGRAM REVIEW CONFERENCE. (NASA SP-81) Summary of the conference held in Kansas City, Mo., March 1-3, 1965, including a discussion of background objectives and policies of the NASA University Program from the point of view of a university professor. 1965 37 pp. CFSTI $3.00

PROGRESS IN DEVELOPMENT OF METHODS IN BONE DENSITOMETRY. (NASA SP-64) Proceedings of a conference held in Washington, D. C., March 25-27, 1965, under the joint sponsorship of NASA, the National Institute of Arthritis and Metabolic Diseases (NIH), and the American Institute of Biological Sciences. The report covers various methods of studying and measuring bone demineralization, a problem anticipated for astronauts as a result of weightlessness and decreased activity during prolonged space missions. 1966 204 pp. GPO $1.50

SYMPOSIUM ON THE ANALYSIS OF CENTRAL NERVOUS SYSTEM AND CARDIOVASCULAR DATA USING COMPUTER METHODS. *Lorne D. Proctor and W. Ross Adey, Eds.* (NASA SP-72) Proceedings of a conference held in Washington, D. C., October 29–30, 1964, at which Government and university authorities discussed use of computer techniques in collecting and analyzing data on the central nervous and cardiovascular systems. 1965 600 pp. CFSTI $3.00

THE ROLE OF THE VESTIBULAR ORGANS IN THE EXPLORATION OF SPACE. (NASA SP-77) A collection of 34 papers, presented at a conference in Pensacola, Fla., January 20–22, 1965, which comprises a state-of-the-art report on the experiments and observations of the effect space travel may have on the vestibular organs of man. Includes animal studies, oscillation studies, use of drugs, and so forth. 1965 392 pp. GPO $2.25

AN ANALYSIS OF THE EXTRATERRESTRIAL LIFE DETECTION PROBLEM. *By Richard S. Young, Robert B. Painter and Richard D. Johnson* (NASA SP-57) Guidelines and ground rules for a cohesive study of the solar system and beyond for evidences of life—past, present, or future. The study includes a section on "The Attributes of Life" and is mainly concerned with a discussion of conditions on Mars. 1965 33 pp. CFSTI $3.00

SECOND SYMPOSIUM ON PROTECTION AGAINST RADIATIONS IN SPACE. (NASA SP-71) Papers of a conference held at Gatlinburg, Tenn., October 12–14, 1964, and sponsored by AEC, NASA, and USAF. Four disciplines are represented: The Radiation Environment, Biological Effects, Effects on Materials, and Shielding. 1965 551 pp. GPO $3.25

DICTIONARY OF TECHNICAL TERMS FOR AEROSPACE USE. *William H. Allen, Ed.* (NASA SP-7) This first edition of a dictionary for space scientists and technologists contains more than 6000 carefully chosen and precisely defined terms. It does not attempt, however, to include every aspect of space terminology. 1965 314 pp. GPO $3.00

BIBLIOGRAPHY RELATED TO HUMAN FACTORS SYSTEM PROGRAM (JULY 1962–FEBRUARY 1964). *By Richard J. Potocko* (NASA SP-7014) Bibliography divided into 18 categories covering the areas of human research and performance, man-systems integration, and life-support and protective systems. Also relevant listings under the categories of biology, physiology, and psychology. Each listing includes information for locating an abstract in either Scientific and Technical Aerospace Reports (STAR) or International Aerospace Abstracts (IAA). 1964 242 pp. CFSTI $3.00; NASA SP-7011(20), 721 pp. CFSTI $3.00; and "A Cumulative Index to the 1964 Issues of a Continuing Bibliography on Aerospace Medicine and Biology," NASA SP-7011(07), 554 pp. CFSTI $3.00. Monthly issues may also be purchased individually from CFSTI for $3.00 per copy.

MEASUREMENT OF THE HEARTBEAT OF BIRD EMBRYOS WITH A MICROMETEORITE TRANSDUCER. *By Vernon L. Rogallo* (NASA SP-5007) This report describes a new ultrasensitive momentum transducer that has been successfully adapted as a ballistocardiograph to measure the heartbeat of avian embryos. Experiments have demonstrated that life can be detected as early as 4 days in the incubation period. The technique appears to open new avenues of investigation in such areas as vaccine production and drug research. 1964 10 pp. CFSTI $3.00

THE MEASUREMENT OF BLOOD PRESSURE IN THE HUMAN BODY. *By C. R. Smith and W. H. Bickley.* (NASA SP-5006) Survey presenting a state-of-the-art summary prepared from the open literature for nonmedical scientists and engineers. 1964 34 pp. GPO $0.30

BIOASTRONAUTICS DATA BOOK. *Paul Webb, Ed.* (NASA SP-75) This publication is for designers of aerospace vehicles and equipment. It contains carefully selected applied research data from the life sciences in consistent engineering units, accompanied by metric scales. Index. 1964 400 pp. GPO $2.25

CONCEPTS FOR DETECTION OF EXTRATERRESTRIAL LIFE. *Freeman H. Quimby, Ed.* (NASA SP-56) The devices and instruments described in this illustrated booklet are among those planned for inclusion in vehicles designed to land on planets such as Mars. They constitute techniques for detecting growth and metabolism, for determining the presence of biologically significant molecules, and for actual visual observation of microorganisms and the planetary terrain. 1964 53 pp. GPO $0.50

PROCEEDINGS OF THE FOURTH NATIONAL CONFERENCE ON THE PEACEFUL USES OF SPACE. (NASA SP-51) Thirty papers delivered at a conference held in Boston, Mass., April 29–May 1, 1964. Eight sessions: Space and the Nation, Congress and Science, Men in Space, the Future, Machines in Space, Practical Uses of Satellites, Living in Space, and Working for Space. 1964 225 pp. GPO $1.50

SPACE CABIN ATMOSPHERES. PART I: OXYGEN TOXICITY (NASA SP-47); PART II: FIRE AND BLAST HAZARDS. (NASA SP-48) *Literature Review by Emanuel M. Roth.* The first volume of this review deals with toxicity of oxygen at pressures below 1 atmosphere and the relation of oxygen to other factors of concern in space cabins, such as radiation effects and lung blast. Part II discusses environmental factors in space cabin fire hazards, including flammability of fabrics, gases, liquids, and vapors, electrical fire hazards, and hazards from meteoroid penetration; problems of fire prevention and extinguishing in space cabins are also examined. 1964 Part I 51 pp. GPO $0.40; 1964 Part II 119 pp. GPO $1.00

RESULTS OF THE PROJECT MERCURY BALLISTIC AND ORBITAL CHIMPANZEE FLIGHTS. *James P. Henry and John D. Mosely, Eds.* (NASA SP-39) This publication presents a full account of the flights of the Project Mercury chimpanzees, from program-planning through launch and recovery operations. It gives a detailed account of training techniques, in-flight measurements, and post-flight evaluation procedures. These flights verified the feasibility of manned space flight. The suborbital ballistic flight of "Ham," on January 31, 1961, was the prelude to Astronaut Alan B. Shepard's suborbital space flight, while the orbital flights of "Enos," on November 29, 1961, preceded the comparable flight of Astronaut John H. Glenn, Jr. 1963 71 pp. GPO $0.45

CONFERENCE ON SPACE, SCIENCE, AND URBAN LIFE. (NASA SP-37) proceedings of a conference held at Oakland, Calif., March 28–30, 1963, on the applicability of the national space program, and the knowledge resulting from aerospace research, to the problems of urban growth. Index. 1963 254 pp. GPO $1.75

PROCEEDINGS OF THE NASA-UNIVERSITY CONFERENCE ON THE SCIENCE AND TECHNOLOGY OF SPACE EXPLORATION, VOLS. 1 AND 2. (NASA SP-11) State-of-the-art papers on NASA programs presented to the scientific and technical community at a conference held in Chicago, Ill., November 1–3, 1962. 1962 Vol. 1 429 pp. GPO $2.50; Vol. 2 532 pp. GPO $3.00 *These papers have also been published individually as follows:* "Geophysics and Astronomy in Space Exploration," NASA SP-13 (43 pp. GPO $0.35); "Lunar and Planetary Sciences in Space Exploration," NASA SP-14 (85 pp. GPO $0.55); "Celestial Mechanics and Space Flight Analysis," NASA SP-15 (41 pp. GPO $0.35); "Data Acquisition From Spacecraft," NASA SP-16 (59 pp. GPO $0.40); "Control, Guidance, and Navigation of Spacecraft," NASA SP-17 (54 pp. GPO $0.40); "Bioastronautics," NASA SP-18 (35 pp. GPO $0.30); "Chemical Rocket Propulsion," NASA SP-19 (55 pp. GPO $0.40); "Nuclear Rocket Propulsion," NASA SP-20 (62 pp. GPO $0.45); "Power for Spacecraft," NASA SP-21 (26 pp. GPO $0.25); "Electric Propulsion for Spacecraft," NASA SP-22 (37 pp. GPO $0.35); "Aerodynamics of Space Vehicles," NASA SP-23 (56 pp. GPO $0.40); "Gas Dynamics in Space Exploration," NASA SP-24

(51 pp. GPO $0.40); "Plasma Physics and Magnetohydrodynamics in Space Exploration," NASA SP-25 (77 pp. GPO $0.50); "Laboratory Techniques in Space Environment Research," NASA SP-26 (51 pp. GPO $0.40); "Materials for Space Operations," NASA SP-27 (46 pp. GPO $0.35); and "Structures for Space Operations," NASA SP-28 (46 pp. GPO $0.35)

RESULTS OF THE THIRD U.S. MANNED ORBITAL SPACE FLIGHT, OCTOBER 3, 1962. (NASA SP-12) Results of the MA-8 flight by Astronaut Walter Schirra, October 1962, including spacecraft and launch-vehicle performance, mission operations, aeromedical analysis of pilot performance, and pilot's flight report. 1962 120 pp. GPO $0.70

RESULTS OF THE SECOND MANNED ORBITAL SPACE FLIGHT, MAY 24, 1962. (NASA SP-6) Results of the MA-7 flight by Astronaut M. Scott Carpenter. 1962 107 pp. GPO $0.65

RESULTS OF THE FIRST U.S. MANNED ORBITAL SPACE FLIGHT, FEBRUARY 20, 1962. Results of the MA-6 flight by Astronaut John H. Glenn, Jr. 1962 204 pp. GPO $1.25

PROCEEDINGS OF THE SECOND NATIONAL CONFERENCE ON THE PEACEFUL USES OF SPACE. (NASA SP-8) Principal addresses, scientific papers, and panel discussions of a conference held May 8–10, 1962, in Seattle, Wash. 1962 282 pp. GPO $1.50

LIST OF SELECTED REFERENCES ON NASA PROGRAMS. (NASA SP-3) List of the selected NASA publications and releases issued during the 3 years following the agency's establishment in October 1958. 1962 236 pp. GPO $1.25

ADDITIONAL SELECTED SPACE SCIENCE BOOKS

Ahrendt, Myrl H. 1965. THE MATHEMATICS OF SPACE EXPLORATION, Holt, Rinehart and Winston, Inc., New York.

Berkner, Lloyd V. and Hugh Odishaw (Eds.). 1961. SCIENCE IN SPACE. McGraw-Hill Book Co., Inc., New York.

Bernardo, James V. 1968. AVIATION AND SPACE IN THE MODERN WORLD, E. P. Dutton & Co., Inc., New York.

Bourne, Geoffrey H. (Ed.). 1963 MEDICAL AND BIOLOGICAL PROBLEMS OF SPACE FLIGHT. Academic Press, New York.

Brown, J. H. U. 1963. PHYSIOLOGY OF MAN IN SPACE. Academic Press, New York and London.

Brunning, Erwin. 1967. THE PHYSIOLOGICAL CLOCK. Springer-Verlag, New York, N.Y.

Burns, Neal M., Randall M. Chambers and Edwin Hendler (Eds.). 1963. UNUSUAL ENVIRONMENTS AND HUMAN BEHAVIOR. The Free Press of Glencoe, London.

Caidin, Martin. 1962. WHY SPACE? AND HOW IT SERVES YOU IN YOUR DAILY LIFE. Julian Messner, New York.

Caidin, Martin and Grace. 1962. AVIATION AND SPACE MEDICINE. E. P. Dutton & Co., Inc., New York.

Corliss, William. 1965. SPACE PROBES AND PLANETARY EXPLORATION. D. Van Nostrand Company, Inc., New York.

Egan, Philip S. 1961. SPACE FOR EVERYONE. Rand McNally & Company, San Francisco.

Emme, Eugene M. 1965. A HISTORY OF SPACE FLIGHT. Holt, Rinehart and Winston, Inc., New York.

Faget, Max. 1965. MANNED SPACE FLIGHT. Holt, Rinehart and Winston, Inc., New York.

Flaherty, Bernard E. (Ed.). 1961. PSYCHOPHYSIOLOGICAL ASPECTS OF SPACE FLIGHT. Columbia University Press, New York.

Gardner, Marjorie H. 1965. CHEMISTRY IN THE SPACE AGE. Holt, Rinehart and Winston, Inc., New York.

Glasstone, Samuel. 1965. SOURCEBOOK OF THE SPACE SCIENCES. D. Van Nostrand Company, Inc., New York.

Goodwin, Harold Leland. 1965. THE IMAGES OF SPACE. Holt, Rinehart and Winston, Inc., New York.

Haggerty, James J., Jr. 1966. MAN'S CONQUEST OF SPACE. Vista of Science Series. National Science Teachers Association, Washington, D. C.

Hardy, James D. (Ed.). 1964. PHYSIOLOGICAL PROBLEMS OF SPACE EXPLORATION. Charles C Thomas, Publishers, Springfield, Illinois.

Henry, James P. 1965. BIOMEDICAL ASPECTS OF SPACE FLIGHT. Holt, Rinehart and Winston, Inc., New York.

Hunter, Maxwell W. 1965. THRUST INTO SPACE. Holt, Rinehart and Winston, Inc., New York.

Hymoff, Edward. 1965. GUIDANCE AND CONTROL OF SPACECRAFT. Holt, Rinehart and Winston, Inc., New York.

Jaffe, Leonard. 1965. COMMUNICATIONS IN SPACE. Holt, Rinehart and Winston, Inc., New York.

Kayser, Charles. 1961. THE PHYSIOLOGY OF NATURAL HIBERNATION. Pergamon Press, New York.

Lansberg, M. P. 1960. A PRIMER OF SPACE MEDICINE. American Elsevier Publishing Co., New York.

McLaughlin, C. H. 1963. SPACE AGE DICTIONARY. D. Van Nostrand Co., Inc., New York.

Meitner, John G. (Ed.). 1965. ASTRONAUTICS FOR SCIENCE TEACHERS. John Wiley and Sons, New York.

Miller, James W. (Ed.). 1962. VISUAL PROBLEMS OF SPACE TRAVEL. National Academy of Sciences-National Research Council, Washington, D. C.

Moffat, Samuel, and Elie A. Shneour. 1965. LIFE BEYOND THE EARTH. Vista of Science Series. National Science Teachers Association, Washington, D. C.

Naugle, John E. 1965. UNMANNED SPACE FLIGHT. Holt, Rinehart and Winston, Inc., New York.

Newlon, Clarke. 1964. 1001 QUESTIONS ABOUT SPACE. Dodd, Mead & Co., New York.

Pirie, N. W. 1961. THE BIOLOGY OF SPACE TRAVEL. The Institute of Biology, London.

Rush, Hanniford. 1962. MAN TO THE MOON. Rand McNally & Co., San Francisco.

Schaefer, Karl E. 1964. BIOASTRONAUTICS. The Macmillan Co., New York.

Sells, S. B. and Charles A. Berry (Ed.). 1961. HUMAN FACTORS IN JET AND SPACE TRAVEL. The Ronald Press, New York.

Slager, Ursula T. 1962. SPACE MEDICINE. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Stern, Phillip D. 1965. OUR SPACE ENVIRONMENT. Holt, Rinehart and Winston, Inc., New York.

Stine, G. Harry. 1962. MAN AND THE SPACE FRONTIER. Alfred A. Knopf, New York.

Sutton, Richard M. 1965. THE PHYSICS OF SPACE. Holt, Rinehart and Winston, Inc., New York.

Wells, Robert. 1961. ALIVE IN SPACE. Little, Brown and Co., Boston.

Widger, William K., Jr. 1965. METEOROLOGICAL SATELLITES. Holt, Rinehart and Winston, Inc., New York.

Wunder, Charles C. 1965. LIFE INTO SPACE. F. A. Davis Co., Philadelphia, Pennsylvania.

Young, Richard S. 1965. EXTRATERRESTRIAL BIOLOGY. Holt, Rinehart and Winston, Inc., New York.

GENERAL ELECTRIC COMPANY REFERENCES

Konikoff, J. J. 1960. ENGINEERING EVALUATION OF ALGAE FOR MANNED SPACE FLIGHT. (Reprint No. 80) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. 1961. A PARTIALLY CLOSED CYCLE LIFE SUPPORT SYSTEM FOR LONG-TERM SPACE FLIGHT. (Reprint No. 81) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. 1961. OXYGEN RECOVERY SYSTEMS FOR MANNED SPACE FLIGHT. (Reprint No. 82) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. 1961. SPACE FLIGHT ECOLOGIES. (Reprint No. 83) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. 1962. OXYGEN RECOVERY BY THE CATALYTIC DISSOCIATION OF CARBON DIOXIDE. (Reprint No. 84) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. 1963. CLOSED ECOLOGIES FOR MANNED INTERPLANETARY FLIGHT. (Reprint No. 201) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. and L. W. Reynolds. 1963. RESULTS OF SOME EXPERIMENTS IN BIOCHEMICAL ELECTRICITY. (Reprint No. 87) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J. and L. W. Reynolds. 1963. DEVELOPMENT OF WATER RECYCLING DEVICE WITH SPECIAL REFERENCE TO SPACE APPLICATION. (Reprint No. 202) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Konikoff, J. J., L. W. Reynolds and E. S. Harris. 1963. ELECTRICAL ENERGY FROM BIOLOGICAL SYSTEMS. (Reprint No. 203) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Okamoto, A. H. and J. J. Konikoff. 1961. STUDY OF THE PURIFICATION OF WATER FROM BIOLOGICAL WASTE. (Reprint No. 85) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

Reynolds, L. W. and J. J. Konikoff. 1963. A PRELIMINARY REPORT ON TWO BIOELECTROGENIC SYSTEMS. (Reprint No. 204) Space Sciences Laboratory, General Electric Co., Missile and Space Division, Philadelphia, Pennsylvania.

WRIGHT-PATTERSON AIR FORCE BASE LITERATURE

Bach, R. O., W. W. Boardman, Jr. and J. W. Robinson, Jr. 1965. APPLICATION OF LITHIUM CHEMICALS FOR AIR REGENERATION OF MANNED SPACECRAFT. AMRL-TR-65-106. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Benoit, R. J., F. Trainor and A. Bialecki. 1960. SELECTION OF AN ALGA FOR PHOTOSYNTHETIC GAS EXCHANGER. WADD Technical Report 60–163. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

DeSteiguer, D. and A. T. Pessa. 1963. A STUDY OF THE EFFECTS OF LONG-TERM INGESTION OF RECOVERED WATER: HUMAN INGESTION TRIALS. AMRL–TDR–63–70. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Dodson, John and Harold Wallman. 1964. RESEARCH ON A WASTE SYSTEM FOR AEROSPACE STATIONS. AMRL–TDR–64–33. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Gall, Lorraine S. 1964. DETERMINATION OF AEROBIC AND ANAEROBIC MICROFLORA OF HUMAN FECES. AMRL–TR–64–107. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Huey, Ronald S. 1964. STUDY OF AN INORGANIC SYSTEM FOR THE RECOVERY OF OXYGEN. AMRL–TDR–64–30. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Keating, Donald A. and Robert W. Roundy. 1961. CLOSED ECOLOGY. WADD Technical Report 61–129. Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.

London, Sheldon A. 1962. GASEOUS EXCHANGE IN A CLOSED ECOLOGICAL SYSTEM. AMRL–TDR–62–139. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Markowitz, Meyer M. and Eugene W. Dezmelyk. 1964. A STUDY OF THE APPLICATION OF LITHIUM CHEMICALS TO AIR REGENERATION TECHNIQUES IN MANNED, SEALED ENVIRONMENTS. AMRL–TDR–64–1. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

McGoff, M. J. 1965. POTASSIUM SUPEROXIDE ATMOSPHERE CONTROL UNIT. AMRL–TR–65–44. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Mickelson, William F. 1963. LIFE SUPPORT SYSTEMS EVALUATOR CONSTRUCTION TECHNIQUES. AMRL–TDR–63–43. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Miller, R. A. and S. Halpert. 1962. A FOOD REFRIGERATION AND HABITABLE ATMOSPHERE CONTROL SYSTEM FOR SPACE VEHICLES, DESIGN, FABRICATION AND TEST PHASES. AMRL–TDR–62–149. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Miller, R. A. and D. J. Withey. 1964. EMERGENCY BREATHING AND SUIT PRESSURIZATION SYSTEM. AMRL–TR–64–60. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Nevens, Thomas D., John A. Krimmel and David R. Jordan. 1965. FEASIBILITY INVESTIGATION OF VISCOUS SOLVENT REMOVAL OF TRACE CONTAMINANTS. AMRL–TR–65–100. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Nichols, Duane C. 1965. WATER RECLAMATION FROM URINE THERMOELECTRIC SYSTEM. AMRL–TR–65–29. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Nihart, G. J. 1964. COMPATIBILITY OF MATERIALS WITH 7500 PSI OXYGEN. AMRL–TDR–64–76. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Nuccio, P. P. and S. J. Lis. 1963. METHOD OF HEATING FOODS DURING AEROSPACE FLIGHT. AMRL–TDR–63–135. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Peters, Gavin H., James E. Aker and E. F. Morello. 1964. A SOLID CHEMICAL AIR GENERATOR. AMRL–TDR–64–71. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Pilgrim, A. J. and S. P. Johnson. 1962. INVESTIGATION OF SELECTED HIGHER PLANTS AS GAS EXCHANGE MECHANISMS FOR CLOSED ECOLOGICAL SYSTEMS. AMRL–TDR–62–127. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Presti, J. B. and H. Wallman. 1963. A LABORATORY MODEL OF AN INTEGRATED WATER RECOVERY SYSTEM. AMRL–TDR–63–88. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Reynolds, John M., Harry Y. Choi, Richard L. Mela and Mathew Hurwitz. 1963. DESIGN STUDY OF A LIQUID OXYGEN CONVERTER FOR USE IN WEIGHTLESS ENVIRONMENTS. AMRL–TDR–63–42. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Roth, Norman G., John J. Symons, Dave Cohen and Robert B. Wheaton. 1964. HUMAN WASTE COLLECTION AND STORAGE DURING AEROSPACE FLIGHT. AMRL-TDR-64-3. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Shoenberger, Richard W. and Charles S. Harris. 1965. HUMAN PERFORMANCE AS A FUNCTION OF CHANGES IN ACOUSTIC NOISE LEVELS. AMRL-TR-65-165. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Slonim, A. R., A. P. Hallam and D. H. Jensen. 1962. WATER RECOVERY FROM PHYSIOLOGICAL SOURCES FOR SPACE APPLICATIONS. AMRL-TDR-62-75. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Speckmann, E. W., K. J. Smith and K. M. Offner. 1965. PHYSIOLOGICAL STATUS OF MEN SUBJECTED TO PROLONGED CONFINEMENT. AMRL-TR-65-141. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Speckmann, E. W., K. J. Smith and J. E. Vanderveen. 1965. NUTRITIONAL ACCEPTABILITY OF A DEHYDRATED DIET. AMRL-TDR-65-33. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Wallman, H., J. L. Dodson, V. A. Speziali, R. J. Nickerson and B. J. Weissman. 1962. DESIGN AND DEVELOPMENT OF A PHOTOSYNTHETIC GAS EXCHANGER. AMRL-TDR-62-37. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Warner, Arthur W., Daniel L. Brown and Werner Glass. 1964. RECOVERY OF POTABLE WATER FROM URINE BY MEMBRANE PERMEATION. AMRL-TDR-64-73. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

Zeff, J. D., R. B. Neveril, M. W. Norell, D. A. Davidson and R. A. Bambenek. 1961. STORAGE UNIT FOR WASTE MATERIALS. ASD Technical Report 61-200. Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

ADDITIONAL REFERENCE LITERATURE

Adey, W. Ross. 1963. POTENTIAL FOR TELEMETRY IN THE RECORDING OF BRAIN WAVES FROM ANIMALS AND MEN EXPOSED TO THE STRESSES OF SPACE FLIGHT. Reprinted from "Bio-telemetry." Pergamon Press, New York.

Adey, W. R. 1964. DATA ACQUISITION AND ANALYSIS TECHNIQUES IN A BRAIN RESEARCH INSTITUTE. Annals of the New York Academy of Sciences, Vol. 15, art. 2, pages 844–866.

Adey, W. R., R. T. Kado and D. O. Walter. RESULTS OF ELECTROENCEPHALOGRAPHIC EXAMINATIONS UNDER THE INFLUENCE OF VIBRATION AND CENTRIFUGING IN THE MONKEY. Space Biology Laboratory, Brain Research Institute, University of California, Los Angeles.

Adey, W. R., W. D. Winters, R. T. Kado and M. R. Delucchi. 1962. ELECTROENCEPHALOGRAPHY AND CLINICAL NEUROPHYSIOLOGY. Elsevier Publishing Co., Amsterdam.

Adey, W. R., J. D. French, R. T. Kado, D. F. Lindsley, D. O. Walter, R. Wendt and W. D. Winters. April 1961. EEG RECORDS FROM CORTICAL AND DEEP BRAIN STRUCTURES DURING CENTRIFUGAL AND VIBRATIONAL ACCELERATIONS IN CATS AND MONKEYS. A study supported by Contract No. AF49 (638)–686 with the Office of Scientific Research of the United States Air Force and Grants B–1883, B–485 and B–611 from the United States Public Health Service.

Ammann, Elizabeth C. B. and Victoria H. Lynch. July 1965. GAS EXCHANGE OF ALGAE. I. EFFECTS OF TIME, LIGHT INTENSITY AND SPECTRAL-ENERGY DISTRIBUTION ON THE PHOTOSYNTHETIC QUOTIENT OF *CHLORELLA PYRENOIDOSA*. Applied Microbiology, Vol. 13, No. 4, pages 546–551.

Burton, Russell R. and Arthur H. Smith. January 1965. CHRONIC ACCELERATION SICKNESS. Aerospace Medicine, Vol. 36, No. 1.

Eley, James H., Jr. and Jack Meyers. 1964. STUDY OF A PHOTOSYNTHETIC GAS EXCHANGER, A QUANTITATIVE REPETITION OF THE PRIESTLEY EXPERIMENT. The Texas Journal of Science, Vol. XVI, No. 3.

Golueke, Clarence G. and William J. Oswald. 1958. REPORT ON PRELIMINARY STUDIES OF BIOLOGICAL CONTROL OF ENCLOSED ENVIRONMENTS. Sanitary Enginering Research Laboratory, Department of Engineering and School of Public Health, University of California, Berkeley, California.

Halpern, B., J. W. Westley, I. von Wredenhagen and J. Lederberg. 1965. OPTICAL RESOLUTION OF D, L AMINO ACIDS BY GAS LIQUID CHROMATOGRAPHY AND MASS SPECTROMETRY. Biochem. Biophys. Res. Comm., 20: 710.

Halpern, B. and J. W. Westley. 1965. HIGH SENSITIVITY OPTICAL RESOLUTION OF D, L AMINO ACIDS BY GAS CHROMATOGRAPHY. Chem. Comm., 12: 246.

Halpern, B., J. Ricks and J. W. Westley. January 1966. BIOCHEMICAL APPLICATIONS OF GAS LIQUID CHROMATOGRAPHY. Part I: The Stereospecific Hydrolytic Action of Acylase 1 (Hog Kidney). Journal of Analytical Biochemistry.

Lederberg, J. 1965. SIGNS OF LIFE. Nature 207: 9–13.

Lederberg, J. and C. Sagan. 1962. MICROENVIRONMENTS FOR LIFE ON MARS. Proceedings of the National Academy of Sciences 48(9): 1473–1475.

Levinthal, E. C., J. Lederberg and L. Hundley. 1964. MULTIVATOR—A BIOCHEMICAL LABORATORY FOR MARTIAN EXPERIMENTS. Life Sciences and Space Research II (COSPAR).

Lynch, V. H., E. C. B. Ammann and R. M. Godding. 1964. URINE AS A NITROGEN SOURCE FOR PHOTOSYNTHETIC GAS EXCHANGERS. Aerospace Medicine, Vol. 35, No. 11.

Myers, Jack. 1958. STUDY OF A PHOTOSYNTHETIC GAS EXCHANGER AS A METHOD OF PROVIDING FOR THE RESPIRATORY REQUIREMENTS OF THE HUMAN IN A SEALED CABIN. Air University, School of Aviation Medicine, United States Air Force, Randolph Air Force Base, Texas.

Oswald, W. J., C. G. Golueke, H. K. Gee and R. C. Cooper. 1961. MICROBIOLOGICAL WASTE CONVERSION IN CONTROL OF ISOLATED ENVIRONMENTS. First Annual Report. Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, University of California, Berkeley, California.

Oswald, W. J., C. G. Golueke, J. W. Brewer and H. K. Gee. 1962. MICROBIOLOGICAL WASTE CONVERSION IN CONTROL OF ISOLATED ENVIRONMENTS. Second Annual Report. Sanitary Engineering Research Laboratory, College of Engineering and School of Public Health, University of California, Berkeley, California.

Schenberg, Samuel (Ed.). 1958. LABORATORY EXPERIMENTS WITH RADIOISOTOPES FOR HIGH SCHOOL SCIENCE DEMONSTRATIONS. United States Atomic Energy Commission, Washington, D. C.

Summary and Conclusions of a Study by the Space Science Board. 1965. National Academy of Sciences-National Research Council, Washington, D. C. BIOLOGY AND THE EXPLORATION OF MARS.

Westley, J. W. 1965. A NEW FLUOROGENIC SUBSTRATE FOR PHOSPHATASE. Submitted to Journal of Analytical Biochemistry.

APPENDIX E CODE FOR USE OF ANIMALS IN HIGH SCHOOL BIOLOGY COURSES

Code for Use of Animals in High School Biology Courses, Formulated by the National Association of Biology Teachers

The first aim of demonstrations that involve animals in high school science courses is to achieve an understanding of life processes. Such studies lead to a sympathetic respect for life. A second aim of animal studies is to provide future citizens with some knowledge of the principles of health, disease, and medicine, and of some aspects of agriculture. In addition, by achieving these goals, some students are motivated to become the medical and biological scientists of the future.

Experiments which are useful for high school students are not necessarily the same as those which would be done in a university or medical school. Much can be learned about life processes from microorganisms and plants; invertebrates and cold-blooded vertebrates can be used for many animal studies in high schools, but birds and mammals are essential to the demonstration of certain concepts because of their closer similarities to man. The same guiding principle of respect for life in the use of animals for the welfare of man should apply in the study of all living objects, including the conservation of useful plants.

All observations on animals must be performed in a humane fashion and anesthetics used as appropriate for the kind of organism, the intactness of the animal, and the type of observation.

To guarantee that students acquire the spirit of humane treatment of animals, a qualified adult supervisor must assume primary responsibility for planning and conduct of demonstrations involving intact living animals. Such supervision must extend to both classroom and extracurricular projects.

Proper quarters and care must be provided at all times, including vacation periods. Students should be instructed in the principles of humane treatment of animals, and training in the proper handling of animals should be a part of the preparation of all high school biology teachers.

APPENDIX F

BIOSATELLITE II

Preliminary data from the 45-hour flight of Biosatellite II indicates that in a weightless condition: (a) the roots of wheat seedlings grew upward toward the shoots and curved outward, whereas in normal growth patterns the roots grow downward vertically or at specific angles to the vertical; (b) leaves of pepper plants curved downward, in some cases touching the stem instead of their normal growth which is horizontal to the earth's surface; (c) fertilized frog eggs underwent normal cleavage patterns. This appears to confirm data from a similar experiment carried aboard Gemini XII.

Other experiments involving the effects of radiation on living organisms in a weightless condition are being evaluated.

☆U. S. GOVERNMENT PRINTING OFFICE : 1969 O - 327-151