PROCEEDINGS OF THE
THIRD LUNAR INTERNATIONAL
LABORATORY (LIL) SYMPOSIUM

RESEARCH IN PHYSICS AND CHEMISTRY

Organized by the
International Academy of Astronautics
at the XVIIIth International Astronautical Congress
Belgrade, 28 September 1967

Edited by

FRANK J. MALINA
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PREFACE

THE Third Lunar International Laboratory (LIL) Symposium was organized for the International Academy of Astronautics by its Lunar International Laboratory (LIL) Committee. The Committee was established by the Academy at Stockholm in 1960, upon the initiative of the Editor, to study the technical problems related to the construction of a manned research center on the Moon and to consider the fields in which research should initially be undertaken.

The LIL Committee at the time of the organization of the Third LIL Symposium consisted of the following members of the Academy: Dr. C. A. Berry (U.S.A.); Prof. N. Boneff (Bulgaria); A. C. Clarke, Esq. (U.K.); Prof. A. Dollfus (France); Prof. M. Florkin (Belgium); Prof. K. Y. Kondratyev (U.S.S.R.); Prof. Z. Kopal (U.K.); Prof. Sir Bernard Lovell (U.K.) (*Vice-Chairman*); Prof. L. Malavard (France); Dr. F. J. Malina (U.S.A.) (*Chairman*); Prof. H. Oberth (Ger. Fed. Rep.); Dr. W. H. Pickering (U.S.A.); Prof. L. I. Sedov (U.S.S.R.); Dr. S. F. Singer (U.S.A.); Prof. L. Spitzer (U.S.A.); Dr. H. Strughold (U.S.A.); Prof. H. C. Urey (U.S.A.) and Prof. F. Zwicky (Switzerland). It is in order to point out here that the Academicians on the Committee do not represent countries or organizations. They contribute their personal efforts in the spirit of international cooperation.

The First LIL Symposium, held at Athens in 1965, was devoted to research in the fields of the geosciences and astronomy. The proceedings were published for the Academy in 1966 by Springer-Verlag, Vienna.

The Second LIL Symposium, held at Madrid in 1966, was devoted to life sciences research and lunar medicine. The proceedings were published by Pergamon Press Ltd., Oxford, in 1967.

The papers dealing with research on the Moon in the fields of physics and chemistry that were presented at the Third LIL Symposium are contained in this volume. The Symposium was held on 28 September 1967 during the XVIIIth International Astronautical Congress at Belgrade.

The two half-day sessions of the Symposium were chaired respectively by Prof. Z. Horak of the Technical University of Prague and Prof. W. Jost of the University of Göttingen. The LIL Committee was especially gratified by the efforts made by the authors to discuss problems that up to the present time had not received very much attention when research on the Moon has been considered. The discussion that took place during the Symposium has not been included in order to speed up publication of the Proceedings.

The Fourth LIL Symposium, devoted to applied science research and utilization of lunar resources, will be organized by the LIL Committee for the Academy during the XIXth International Astronautical Congress at New York City in October 1968.

On behalf of the LIL Committee and of the contributors to the Symposium, I wish to express to Dr. C. S. Draper, President of the Academy, and to the Secretariat of the Academy great appreciation for their aid in organizing the Symposium; to the International Astronautical Federation and to the Jugoslovensko Astronauticke i Raketno Drustvo for making it possible for the Symposium to be held at Belgrade; and to the publisher, Pergamon Press Ltd., Oxford, for friendly co-operation in publishing the Proceedings.

Boulogne-sur-Seine, France
23 December 1967

CONTENTS

PHYSICS AND CHEMISTRY ON THE MOON

F. Zwicky†

Abstract—Résumé—Резюме

Three tasks await physicists and chemists on the Moon. These are:

1. A survey of the physical and chemical properties of the Moon, with particular stress on the surface and the various types of particles and rays impinging upon it.
2. The mobilization of all of our knowledge and equipment in physics and chemistry for the creation of living and working conditions on the Moon.
3. The initiation of pure and applied research in physics and chemistry in laboratories on the Moon or "field work" on its surface.

In the present review some of the details of these three tasks are discussed as far as one can foresee them.

Survey of the Moon

Work on this project has now been successfully started but some of the most important data are still lacking. Suggestions are made as to the character of these as yet unknown facts about the Moon and as to methods to learn more about them.

Realization of living conditions

Solar furnaces and magnetohydrodynamic generators of electric power are among the most promising devices for the effective decomposition of rocks on the Moon and the generation of oxygen, water, nitrogen and the production of foodstuffs, propellants and all sorts of construction materials. These devices are described.

Scientific experimentation on the Moon

Taking advantage of the low gravitational and magnetic fields on the Moon, the absence of any atmosphere, the sterility of its surface, the availability of the full influx of light from the Sun and all other radiations, a great number of experiments can be devised which are either not possible on the Earth at all or which are much easier executed on the Moon. A number of these experiments are described and it is shown that we may hope to decide, on the Moon, some fundamental scientific issues very quickly.

In order to remain objective and not to squander funds and efforts uselessly, it must nevertheless be remembered that experimentation on the Earth with the aid of balloons, Earth-launched rockets and unmanned Earth satellites, and space ships, all have their particular merits. We must therefore choose devices which can give us the desired results in the most effective way, without attempting to do all of the intended experiments exclusively on the Moon.

The members of the International Academy of Astronautics will be interested in studying the projects described in friendly international co-operation.

Physique et chimie sur la lune. Trois tâches attendent physiciens et chimistes sur la Lune. Ce sont:

1. Un examen des propriétés physiques et chimiques de la Lune mettant l'accent sur la surface et les différents types de particules et de rayons qui la frappent.
2. La mobilisation de toutes nos connaissances, de tous nos équipments en physique et en chimie pour créer des conditions de vie et de travail sur la Lune.
3. La mise en œuvre de recherches pures et appliquées en physique et en chimie en laboratoire sur la Lune ou de "travail sur le terrain" à sa surface.

Cette mise à jour discute certains détails de ces trois tâches aussi loin que nous pouvons les prévoir.

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† Mount Wilson and Palomar Observatories, Carnegie Institute of Washington and the California Institute of Technology, Pasadena, California, U.S.A.

Examen de la Lune

Sur ce projet, le travail a maintenant débuté, avec succès, mais certaines des données les plus importantes font encore défaut. Nous faisons des suggestions sur le caractère de ces faits encore inconnus concernant la Lune et sur les méthodes permettant d'en apprendre davantage à leur sujet.

Réalisation de conditions de vie

Les fours solaires et les générateurs magnétohydrodynamiques d'énergie électrique sont parmi les dispositifs les plus prometteurs qui permettront de décomposer les roches sur la Lune et de créer de l'oxygène, de l'eau, de l'azote, de produire des aliments, des propergols et des matériaux de construction de toute sorte. Ces dispositifs sont décrits.

Expérimentation scientifique sur la Lune

Profitant du champ de gravitation et du champ magnétique faibles sur la Lune, de l'absence de toute atmosphère, de la stérilité de sa surface, du fait que l'on dispose de tout le flux lumineux du Soleil et de tous les autres rayonnements, on peut projeter un grand nombre d'expériences qui, soit ne sont pas du tout possibles sur la Terre, soit sont beaucoup plus faciles à exécuter sur la Lune. On décrit un certain nombre de ces expériences et on montre qu'on peut espérer résoudre sur la Lune, très rapidement, certaines questions scientifiques fondamentales.

Pour rester objectif et pour éviter de gaspiller sans résultat argent et efforts, il faut néanmoins se rappeler que l'expérimentation sur la Terre à l'aide de ballons, de fusées tirées à partir de la Terre et de satellites terrestres inhabités, de vaisseaux spatiaux, chacune de ces méthodes a ses mérites particuliers. Nous devons donc choisir des dispositifs qui peuvent nous donner les résultats cherchés de la manière la plus efficace, sans tenter de faire toutes les expériences projetées exclusivement sur la Lune.

Cela intéressera les membres de l'I.A.A. d'étudier les projets décrits en amicale coopération internationale.

Физика и химия на Луне. — Физиков и химиков ожидают на Луне следующие три задачи:

1. Обследование физических и химических свойств Луны, уделяя особое внимание поверхности и различным типам попадающих на нее различных частиц и лучей;
2. Мобилизация всех наших знаний и оборудования в области физики и химии для создания жизненных и рабочих условий на Луне;
3. Начало проведения чистых и прикладных исследований в области физики и химии в лабораториях на Луне и в «полевых условиях» на ее поверхности.

В настоящем обзоре рассматриваются некоторые подробности этих трех задач, насколько мы их можем предвидеть.

Обследование Луны

Работа над этим проектом успешно началась, однако все еще не хватает некоторых наиболее важных данных. Будут высказаны предположения относительно характера этих еще неизвестных фактов о Луне и методов их изучения.

Создание жизненных условий

Солнечные печи и магнитогидродинамические генераторы электрической энергии относятся к наиболее перспективным приспособлениям для эффективного разложения лунных пород и производства кислорода, воды, азота и пищевых продуктов, топлива и всевозможных строительных материалов. Будет дано описание этих приспособлений.

Научные опыты на Луне

Благодаря низкому гравитационному и магнитному полю, отсутствию атмосферы, стерильности поверхности, наличию полного солнечного светового потока и других радиаций, на Луне можно провести множество опытов, которые либо совсем невозможны на земле, либо гораздо легче провести на Луне. Будут рассмотрены некоторые из этих опытов и будет показано, что мы можем надеяться весьма быстро разрешить на Луне некоторые фундаментальные научные проблемы.

Чтобы быть объективным и не расточать понапрасну средства и усилия, следует все же помнить, что эксперименты на земле с помощью воздушных шаров, ракет, непилотируемых спутников земли и космических кораблей имеют свои особые достоинства. Поэтому мы должны выбирать приспособления, которые могут дать нам желаемые результаты наиболее эффективным образом, не пытаясь проводить все предполагаемые эксперименты исключительно на Луне.

Членам Международной академии астронавтики будет интересно изучить проекты в духе дружественного международного сотрудничества.

A. INITIAL ORIENTATION

As a purely mental exercise, one might immediately start to speculate about possible experiments and researches in physics and chemistry on the Moon, with special emphasis on those tests that cannot be performed on the Earth at all, or at any rate those that can be carried out on the Moon with relatively much greater ease. Such an undertaking, however, would be unrealistic, since we must first use our present knowledge in the natural sciences to plan for decisive tests which will give us information about the exact physico-chemical conditions to be dealt with on the Moon, once we get there. Precipitous planning of basic research on the Moon disregarding the actual boundary conditions can only result in disappointments and in a great waste of effort and available means. Furthermore, as to funds to be solicited, we must be quite clear as to how they are going to be spent most effectively. Although we are space enthusiasts, we must at all times take care not to overshoot our goals and thus have our projects discredited in the public eye.

All possibilities must be considered in their proper perspectives.(1) The controversies which have been raging in scientific, governmental and parliamentary circles, as well as among the general public, indicate clearly that it is our first duty to evaluate all of the means at our disposal and to choose those which will produce the desired results most effectively, cheaply and safely. As to some of the possible means I mention, earthbound research still occupies first place. In addition, we now can use high-flying balloons, earthbound test rockets, artificial satellites, interplanetary space vehicles and finally installations on the Moon, Mars or other suitable members of the solar system.

Among all of the methods of review, planning, evaluation and systematic construction the morphological approach appears to me to be the most promising. This universal and powerful approach has been highly developed during the past few decades. It has been extensively and successfully applied to discovery, invention and research in many fields of science and technology, as well as to a multitude of human activities.(2) Particularly successful use of it was made in astronomy,(3) jet propulsion,(4) the formulation of justice in the space age,(5) the evaluation of individuals and of organizations, multilanguage teaching(6) and education in general. It has also been used for the study of the aberrations of the human mind, which are responsible for the continued dire state of the world, and, of course, for the solution of many special problems. For those who are interested in establishing the proper relations of their own specific interests and endeavours to all human activities in general, it will be desirable for them to familiarize themselves with the principles and the philosophy of the morphological approach and with the various morphological methods, even though they might not intend to make extensive use of them.

As to the prospects for scientific research in space and on the Moon, in particular, the author has on several occasions suggested that a group of experts among the members of the International Academy of Astronautics collaborate in composing a comprehensive monograph on *Science on the Earth and in Space* which would deal with the following topics:

1. A brief enumeration of experiments and observations in biology, medicine, astronomy, physics, chemistry and other fields which can basically and successfully be carried out only in extraterrestrial locations.[1]
2. Experiments in the fields mentioned which can be performed with high-flying balloons, with test rockets launched from the Earth and returning to it, and finally on Earth-orbiting observatories.
3. Experiments and observations which are possible both in space and on the Earth should be conducted on the latter whenever possible, except when cross-checks in space are needed.
4. Finally the human implications of all intended projects should be thoroughly analysed and all aspects should be clearly communicated to an interested and sufficiently educated public.

It is of interest in this context to emphasize the disconcerting fact that, after thousands of years of research in astronomy and innumerable successes in the practical application of the results achieved, we astronomers are still frequently being asked what our science is really good for. For this reason, in addition to the general study proposal made above, it will be desirable also to write a monograph on the impact of astronomical research on the thoughts and actions of men. Astronomy has, in particular, succeeded in dispelling many fatal superstitions and aberrations of the human mind and it is to be credited with the invention of methods and devices, both scientific and practical, without which modern life would, literally, come to a standstill.

After scientific tests will have given us enough information about the Moon and the space surrounding it, we must begin to plan for the construction of devices which will enable us to *establish* ourselves on the Moon.[7] These devices must be built and fully tested on the Earth. Once we have them well in hand, they can be transferred to the Moon and used there for the installation of living quarters and experimental stations for the first astronauts. Later on necessary apparatus will have to be produced on the Moon itself.

Right from the start the grave question arises of whether to give preference to the construction of many settlements on the Moon for the purpose of accommodating "immigrants" or to limit their number and give priority to scientific laboratories, observatories, the necessary accessory installations and living quarters for the working staffs. This problem will have to be dealt with in particular by the legal-scientific committee of the International Academy of Astronautics and the various cognizant government agencies. The Academy of course has manifested a vital interest in all problems of space law ever since its foundation.

B. EXPLORATION OF THE CONDITIONS TO BE ENCOUNTERED ON THE MOON

In connection with our intention of venturing into space and establishing ourselves on extraterrestrial bodies it is useful to study the methods of planning used by successful explorers here on the Earth: that is, the great original navigators of the seas and of the ocean depths (for instance the Piccards, father and son), the pioneers of the polar caps (Nansen, Amundsen and others), and of the atmosphere and the stratosphere (again Auguste Piccard) and, last but not least, the wisest among the great mountain climbers. The compilation of a monograph entitled *The Morphology of Spatial Exploration* should prove a most stimulating task for a good writer and would no doubt make fascinating reading for a large public.

Having myself made a number of first ascents of difficult mountains, I still vividly recall the multivaried aspects involved. A thorough study of these aspects immediately suggests the adoption of conceptually analogous, but of course in detail quite different, tests for our march into space. While some of the conditions in climbing an unscaled mountain, such as estimated duration of the climb, temperature and wind environment, altitude, i.e. pressure of the atmosphere, general rock, snow and ice formations, stone falls, avalanches, explosive snow boards, etc., can be moderately accurately predicted, others remain largely unknown, although one may observe one's mountain from a distance with telescopes for a long time.

In spite of all caution taken, there have been tragic accidents whose causes remained unknown even after the event. While writing this I notice a news item about the recent tragedy on Mount McKinley, for instance. The leader, Mr. J. F. Wilcox, comments as follows: "At the present time no one knows what happened—it may well be that no one will ever know. The summit team was very strong and equipped much better than most groups. They had the combined experience of climbing on every continent of the world and their leader was a cool-headed veteran of two Antarctica expeditions. I find their loss only a little short of unbelievable. It is interesting to note that all fatal accidents on Mount McKinley have involved very experienced climbers. Mountaineers should be aware that infrequent situations do occur that probably no one can cope with."

This means that in space unforeseen circumstances and disasters must be expected with still greater probability. In any case great care will have to be exercised to choose men of great versatility, dexterity and ample equipment to be prepared for all conceivable and inconceivable eventualities. The experiences and habits of mountain climbers, arctic explorers and other hardy pioneers are worth studying for the purpose.

As in climbing mountains, exploring Antarctica or the ocean depths and the interior of the Earth one must in the first place discuss all problems with congenial and technically competent fellow enthusiasts. These we hope to find within the International Academy of Astronautics and the groups associated with it.

We all remember the sad times during the past twenty-five years, and even as recently as a few years ago, when our occupation with space research was not only considered useless by some of our scientific colleagues, but they even acted as if we were not quite respectable or of sound mind. This attitude has caused us a lot of difficulties and delays and has retarded the march into space by at least a decade. Although enormous funds are now being expended in preparations for space travel, the basic outlook among the great moguls of science and politics is still uncertain and often steepled in antiquity, such that truly universal and imaginative minds are not really listened to. For this reason, some of the simplest tests concerning our uncertainty about vitally important conditions on the Moon have not yet been performed. I describe some of these tests below:

1. *Tests for the Presence of Hydrogen in the Materials of the Moon's Surface*

Water will obviously be a prime necessity, if we are going to establish ourselves permanently on the Moon. The following alternatives suggest themselves:

(a) Water or ice as such exists at some depth.
(b) H_2O is incorporated as crystal water in the minerals of the rocks of the Moon, as it is found for instance on the Earth in granites in a proportion of one to several percent. Since this solidly bound water could have been bombarded out of the surface layers by impinging cosmic rays, tests must be carried out to some reasonable depth.
(c) Hydrogen may occur in the various minerals of the Moon in the form of hydrides or other more complicated compounds.

If hydrogen should not be found within accessible depths below the Moon's surface, there remain only the two alternatives of either carrying water there from the Earth or producing it by nuclear fission on the spot; neither have very attractive prospects as far as the present state of the art is concerned. Immediate tests for the existence of hydrogen on the Moon are therefore of the greatest urgency.

I have suggested such tests ever since my first attempt at launching artificial meteors into interplanetary space from a high-flying V-2 rocket at White Sands Proving Grounds, New Mexico, U.S.A., on December 17, 1946. After this first experiment failed, for more or less accidental and minor reasons (see Appendix A and Ref. 4), no further support was forthcoming for eleven years. A second attempt could be made only on October 16, 1957 when we successfully launched a pellet from a shaped charge mounted on an Aerobee rocket as the first man-made object into interplanetary space, free from the gravitational pull of the Earth (see Appendix B).

Subsequently I proposed to eject a slug from a larger shaped charge directly against the Moon, an experiment whose feasibility was theoretically confirmed by calculations carried out by different competent groups. A small ultrafast missile, made up in part of reducing elements such as aluminium for instance would, upon penetration of the Moon's rock, hydrolyse the crystal water, if such were present, and explosively liberate gaseous hydrogen under tremendous pressure and high temperature. Calculations showed that the resulting high-flying dust clouds could have been observed from the Earth for several minutes. In addition, the flash of the Balmer emission lines of atomic hydrogen could have been easily recorded by means of the prime focus spectrograph of the 200-in. Palomar Hale telescope (equipped with a transmission grating mounted in the parallel beam of the zero corrector, in order to have a wide angle arrangement, and, thus, not to miss the flash because of the uncertainty of the location of the point of impact). Although funds were actually made available from private sources for this experiment, governmental approval could not be obtained in the United States of America for this test.

In parenthesis, it should be mentioned that test particles ejected from shaped charges, especially those equipped with coruscative inserts are a most effective means for the exploration of a multitude of physico-chemical conditions and phenomena within the Earth's atmosphere, and the electromagnetic fields within it and surrounding it (Fig. 1). But they have only seldom been used.

In continuation of my original suggestions, I have repeatedly proposed during the past few years that particles be launched against the Moon from shaped charges mounted on lunar vehicles such as the "Surveyor" or the "Orbiter". The effects of such ultrafast pellets on the Moon's surface materials could have been televised from these vehicles back to the Earth. And finally, shaped charges could now be fired directly from probes placed on the Moon. All of these proposals have so far fallen on deaf ears, with the result that we have no knowledge as yet about the vital question of whether or not hydrogen will be readily available for extraction from the Moon's surface materials.

2. *Tests for the Availability of Oxygen on the Moon*

If H_2O is found as crystal water in the rocks, the supply of oxygen for living would appear to be assured. Means to extract it with the aid of a solar furnace for instance, or by electrolytic processes will be described further on. Even if H_2O should not be readily available, oxygen certainly must be present in the form of oxides, carbonates, silicates, etc., since we know that the Moon's surface can hardly be a composite of pure chemical elements, such as the various metals, carbon, silicon, sulphur, etc., with the exclusion of bound oxygen, fluorine, chlorine, etc. Tests for the presence of oxygen can also be made through the observation of the impacts of fast particles ejected from shaped charges, equipped with either neutral or with coruscative inserts. On impact of such ultrafast pellets, temperatures are generated which are capable of dissociating most oxygen bearing minerals and chemical compounds. The hot oxygen liberated can be recognized through observations of its atomic or molecular emission spectrum.

3. *Tests for the Presence of Other Elements on the Moon*

In addition to hydrogen and oxygen, the availability of nitrogen, helium, neon or argon are of prime importance. It has indeed been found that man cannot indefinitely breathe pure oxygen.[7] One of the inert gases mentioned must be added in the right proportion. Since these can be largely recovered, it would, of course, not be impossible to carry an initial supply in concentrated form from the Earth to the Moon. Nevertheless, it would be far more convenient to extract them from the Moon's materials. Adequate tests as to their presence there are therefore also of the utmost importance. Again, pellets from shaped charges shot at the rocks can be used for the purpose. Inert and noble gases are of course also of importance for many of the scientific experiments I shall mention later on as well as for the construction of high grade thermal power plants using the Sun's radiation as the energy source, such as the closed cycle gas turbine (for instance the AKA turbine of the Escher-Wyss Company in Zürich, Switzerland).

For construction materials, reagents of all sorts and particularly for the fabrication of propellants and rockets on the Moon a number of additional elements such as lithium, aluminium, iron and fluorine and chlorine (for the activation of terrapulse and generally terrajet engines) are of importance. In parenthesis it should be mentioned that already in 1964 I built and ran a hybrid motor using lithium threaded aluminium cylinders and water as the propellants. Such motors with a specific impulse of about 210 sec would serve ideally on the Moon. There is, of course, no question as to all of the elements mentioned being available on the Moon in sufficient abundance.

C. CONSTRUCTION OF THE NECESSARY APPARATUS AND DEVICES ON THE EARTH

As I have mentioned, the use of fast particles ejected from shaped charges provides a most useful tool. Since these particles may be overoxidized in composition or they may contain a surplus of reducing elements, not only their mechanical impact on the Moon's materials is involved but also their chemical reaction with the targets as well. For instance, ultra-fast particles of aluminium will reduce almost any oxide or oxygen bearing compound. Fluorine, on the other hand, may act as an oxidizer replacing oxygen and release the latter in gaseous form.

Just how many preliminary tests of the types described have already been made by the various agencies working on the preparations for the exploration of extraterrestrial space is not known to me in any detail. I therefore mention here only a few which I and some of my associates have carried out. Some of these include the following.

1. Impacts of ultrafast reducing pellets shot against rocks such as granite were observed. Using aluminium or boron particles for instance, the crystalline water contained in the various minerals was explosively hydrolysed and gaseous hydrogen detonatively released.
2. The fast melting, evaporation and sublimation of various rocks in the focus of a solar furnace was observed and studied. In the laboratory we used for convenience an arc image furnace. Experiments of this type were, for instance, carried out under my direction at the Aerojet General Corporation in Azusa, California, where I was engaged for many years as director of research and as chief research consultant. In these tests both H_2O and CO_2 were liberated explosively at temperatures of between 2000° and 2500°C. No tests for nitrogen or trapped noble gases were made. It should, however, be mentioned that some information on this subject is available from the extended investigations of meteorites, which were concerned both with the trapped and the chemically or physically bound gases as well as with the "frozen-in", pseudostable configurations and metastable molecules and molecule ions. (Experiments of this sort were in particular carried out by Professor Houtermans and his group at the University of Berne in Switzerland.)

It goes without saying that it will be most desirable to vastly expand the programs just sketched. As to the distribution of the work involved, I should, in particular, like to advise small countries and groups of alert inventors and experimenters in all countries to occupy themselves intensively with these matters, which seem to have been neglected by many of the large cognizant governmental organizations and large industrial concerns. Such investigations and efforts by independent investigators and inventors would fill many of the gaps which the "big" ones have left untouched and which, if not dealt with in time, actually may become a source of serious delays and disasters. Also, in the spirit of the International Academy of Astronautics, we must do everything to liven up the competition and collaboration between many of the interested groups in all countries. Cooperative work on universal projects will help to establish and to strengthen the *bonds between man and man*, bonds which have been so sadly disrupted by recent tragic events, prejudices and insistence upon sterile ideologies.

D. THE PHYSICAL CONDITIONS ON THE MOON

About the physical structural conditions on the Moon we know of course considerably more than about the chemical and mineralogical composition of its surface layers and, particularly, about the more specific questions of whether or not and in what form we shall find hydrogen, nitrogen, water and so on. Already from astronomical observations during the past few decades much could be inferred about the structure of the Moon's surface, its physical properties such as thermal and electrical conductivity, optical and radio albedo, stability, granulation and so on.[8] The long standing controversy about dust or rocks, as well as about the relative firmness of the ground has largely been resolved through the photographs and contact tests made and relayed to the Earth by the various lunar probes.

Two most important aspects, however, are still to be investigated. These concern, first, suspected semi-volcanic activities and associated frequencies of tremors and quakes. And, secondly, of great importance will be the knowledge about the possible existence of deep fissures, cracks, gorges and caves which would be of value for the fast construction of shelters. Even at that we shall of course not be spared the labor of digging deep here and there on the Moon to establish safe living quarters. In this connection it is therefore to be regretted that the author's long standing suggestion for the production of terrajet engines and terrapulse devices in particular, as well as other earth boring propulsive power plants, activated by Earth reacting chemicals, that is terrafuels, has not been seriously accepted and practically realized. Even though the mechanical design of these engines should not prove too difficult, the problem of producing terrafuels and terrapropellants cheaply and in large enough quantities should not be underestimated. Fast Earth-opening devices would be useful on the Earth for many purposes also. On the Moon they may prove indispensable, if we wish to establish ourselves there permanently and speedily.

About the gravity, the magnetic and electric fields on the Moon (possibility of a plasma around it), as well as the various types of radiations and particles impinging on its surface we are tolerably well informed so as to enable us to plan reasonably, both as to how to exploit these various conditions and phenomena as well as how to guard against any ill effects to man, animals and plants in shelters.[7]

E. SOLAR FURNACES, MAGNETO-HYDRODYNAMIC GENERATORS AND OTHER DEVICES

Two types of installations have been proposed by the writer (and have partly been experimented with), which promise to be most useful for establishing ourselves on the Moon. The purpose of both of them is to liberate hydrogen, water, carbon dioxide, nitrogen, oxygen, noble gases and any of the chemical elements needed from the solid surface materials. In addition to the production of the gases mentioned, the solid materials available must be acted upon by evaporation, fractional distillation and electrolytic separation so as to yield, if necessary, elements like lithium, beryllium, boron, carbon, fluorine and, especially, aluminium and iron for purposes of construction and later on for scientific experimentation. If found, precious elements will of course also be produced for scientific, technical and medicinal purposes, as well as for use as catalysers for all sorts of chemical reactions, including the synthesis of food stuffs.

1. *Solar Furnaces and Condensation Traps*

Temperatures approximating that of the Sun (5800°K) can be obtained on the Moon with the aid of reflecting mirror type solar furnaces as shown schematically in Fig. 2. At such temperatures all of the solids available will be easily melted or partly evaporated, sublimated, dissociated or even ionized. Hydrogen, water, carbon dioxide, oxygen, nitrogen and the noble gases can thus be readily produced, if contained in the rocks; and there will even be a small yield of various gaseous radicals and ions of atoms and molecules. In condensors of successively lower temperature H_2O, CO_2, O_2, N_2, H_2 and the various noble gases can be trapped and separated. This procedure has been described in other places.[4, 9]

Very primitive solar furnaces can also be used for welding operations, for instance, for the manufacturing of bricks for building purposes, glazing and proper

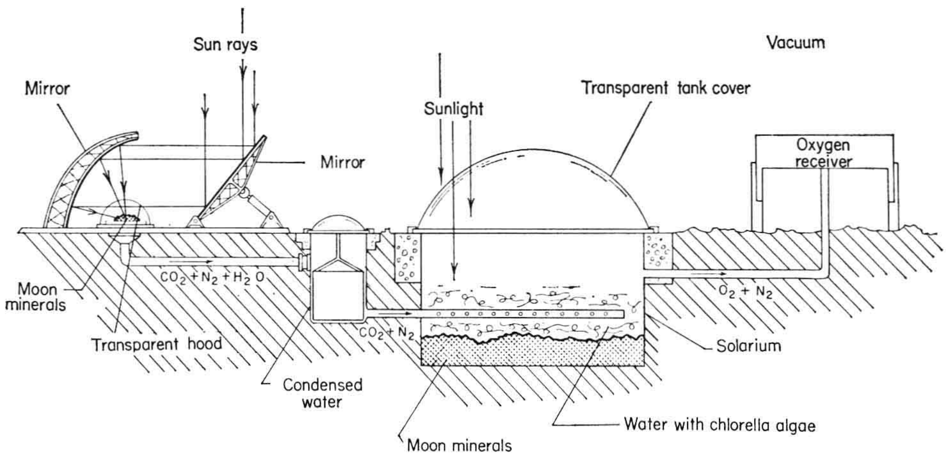

FIG. 2. Reflecting type solar furnace installation for the production of water, carbon dioxide, oxygen, nitrogen and molten slags for the electrolytic separation of elements on the Moon.