Research in Outer Space

The basic objectives of a continuing program of satellite research are outlined.

Technical Panel on the Earth Satellite Program,
U.S. National Committee for the IGY,
National Academy of Sciences

The International Geophysical Year marks the beginning of man's exploration of outer space. There have been previous rocket firings into the fringes of the earth's atmosphere, but the expanded rocket-sounding program on an international scale and the advent of artificial earth satellites represent by far the largest steps taken towards the scientific exploration of outer space and the planets.

The interests of human progress and our national welfare now demand that a long-term program of space exploration be formulated and pursued by the United States with the utmost energy. Although there will inevitably be benefits of a very practical nature from such a program, the basic goal of this exploration must be the quest of knowledge about our solar system and the universe beyond.

The scientific program proposed here has been formulated with the following ideas in mind:

1) The technology of space flight will probably develop gradually. Therefore, the payloads and distances traveled will be relatively small at first, and the scientific experiments and observations will be correspondingly modest in the early stages.

2) The scientific program should be designed to give information at each stage which will help in the planning of later flights.

3) Manned space flight will occur in the course of the program, but before this occurs certain crucial experiments, which are aimed specifically at the design of a manned vehicle, must be performed.

4) In the quest for outer space we must not lose sight of the tremendous implications which the occupation of space will have for life on earth.

The experimental program proposed in this study represents concepts and views of many scientists but particularly those involved in the current IGY satellite effort. Of the latter group, the Technical Panel on the Earth Satellite Program of the U.S. National Committee for the International Geophysical Year and its three Working Groups have in one way or another contributed to the thoughts expressed in this article (*1*).

Sounding Rockets

Sounding rockets have provided so much information about the upper atmosphere and its effects on incoming radiation of various kinds that they will continue to be useful in this area. A continuing program in which such rockets are used should be aimed at determining the distribution, in the vertical, of such quantities as (i) atmospheric composition; (ii) atmospheric pressure, temperature, and density; (iii) winds in the upper atmosphere; (iv) atmospheric ionization; (v) the absorption of electromagnetic radiation penetrating the atmosphere and the intensities of sources of such radiation in the atmospheric layers; (vi) the absorption of cosmic ray or solar particles and the secondary effects of these particles; (vii) the geomagnetic field (also covered in the section on satellites); (viii) electric current systems in the atmosphere; (ix) experiments requiring recovery of packages.

With a sufficiently intense program, it will be possible to detect latitudinal, diurnal, and seasonal changes of these quantities, and also the ways in which they are modified during periods of solar activity and magnetic storms.

Until the techniques for the recovery of packages from a satellite have been worked out in more detail and demonstrated, there will be a class of experiments requiring the return of various kinds of samples for which the vertical rocket is required. These may involve (i) film samples: photographs, spectrographic data, cosmic ray packets, or data recordings where the quantity of information is too great to be telemetered back to the earth; (ii) biological samples.

Experiments for which sounding rockets will probably *not* be suitable in the future, with the availability of earth satellites of progressively larger payloads, are solar or astrophysical observations, particularly those in which time changes are sought. Clearly, a satellite vehicle is superior for such observations.

Earth Satellites

An earth satellite is considered, for these purposes, to be a vehicle which is on an orbit controlled primarily by the earth's gravity. Such a vehicle will orbit at a distance of something less than 1 million miles from the earth and with insufficient velocity to carry it further. Even when the technology of space flight has progressed far beyond the ability to put satellites on orbit, and vehicles are being directed on heliocentric and interplanetary missions, the earth satellite will surely continue to be a base for fruitful observations.

Fundamentally, a satellite well outside the earth's atmosphere can be used for observation of only three kinds of things —namely, photons, particles, and fields.

The photons, since they represent electromagnetic radiation, may range from x-radiation and ultraviolet radiation to

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An earlier study of the panel in this area was prepared by R. W. Porter, J. A. Van Allen, H. E. Newell, W. W. Kellogg, and Lyman Spitzer, in January 1957. The present proposed program, based on the earlier report but considerably extending the scope of experimental possibilities, was prepared by W. W. Kellogg in collaboration with the Panel and the Working Group on Internal Instrumentation.

radio waves. In general, when one is dealing with photons coming from remote sources in the sun or beyond, the purpose of a satellite is to observe the wavelengths which do not penetrate the earth's atmosphere. This implies that the radiation of primary interest is at wavelengths below the ozone cutoff in the ultraviolet (about 0.32 microns) and at wavelengths above the ionospheric cutoff in the radio-wave region (about 30 meters, or 10 megacycles). Most of the radiation in between these limits penetrates the atmosphere and can therefore be observed on the ground or from balloons, except for some important, but limited, regions in the infrared where water vapor, carbon dioxide, and ozone cause absorption.

In addition to its use in observing these highly significant radiations from above, the satellite will be of great value in observing the earth, its changing cloud patterns, its infrared radiation, and so on.

The particles which can be observed from a satellite are solid meteoroids of various sizes and atomic nuclei with great energy emanating from the sun and from beyond (auroral particles and cosmic rays). Both types of particles are of great significance to the development of manned space vehicles, for the solid particles constitute a hazard to the vehicle, due to their ability to puncture its skin, and the atomic particles may be a hazard to the man inside.

The fields which are measurable from a satellite are the field of gravity and the magnetic field. Gravity is related to the masses and shapes of the earth and moon, and satellite observations promise to improve greatly the precision of our knowledge of these quantities. Magnetic field measurements not only tell about the magnetization of the earth and moon but also tell about the electric current systems in the vicinity of the earth.

Since a great deal has already been written about the uses of an artificial satellite, the experiments discussed below are presented in outline rather than in detail. First are those which could be carried out in Vanguard-type satellites—a statement based on the assumption that such satellites have a growth potential in payload to 50 or 75 pounds and that there will be a wider choice of orbits than there is under the IGY program. With larger payloads and more advanced techniques, more elaborate experiments could be performed—experiments which require stable platforms, high transmission power, large information bandwidth, recovery of packages, and so forth. Finally, there will be manned satellites.

Light-Weight-Satellite Experiments

Creation of visible objects. There are a number of reasons for wishing to have an easily visible satellite. In particular, precise determinations of orbit will probably be made optically, and it is clearly desirable to have a satellite which reflects or emits a considerable amount of light. At night, a flashing light with a brightness of 10^5 candle power or more would be just visible at a range of about 1000 miles, provided the duration of the flash was about 0.1 second or more. An alternative method for making the satellite visible is by using a large reflecting object such as a balloon or erectable corner reflector. Such an object, to be seen optically or visually, must be near the twilight zone of the earth, so that the observer can see the sunlit reflector against a darkened sky. Under such conditions a 100-square-foot diffuse reflector appears like a first-magnitude star at about 200 miles (if the angle between the sun and the observer is just right) and can still just be seen by the naked eye at a range of about 2000 miles. Naturally, with telescopes, one can do much better, but one must then know ahead of time where to look for the satellite.

With the sort of precise determinations of orbit which can be obtained with optical tracking, it is possible to do a number of important things. (i) Air drag at high altitudes, from which atmospheric density can be derived, can be determined. A possible complication here is the effect of an electrostatic charge on the satellite and the interactions between this charge, the ions present in the ionosphere, and the earth's magnetic field. (ii) Geodetic measurements on the size and shape of the earth can be made. (iii) Lunar mass can be measured from observation of satellites whose orbits pass near the moon. (iv) Ion densities can be determined when data from a satellite are coupled with certain precision radio techniques.

Total atmospheric thermal and visible radiation measurements. A satellite is in an ideal position to measure the total flux of radiation in and out of the top of the atmosphere. The incoming radiation, being primarily from the sun, is largely in the visible part of the spectrum, while the outgoing radiation from the atmosphere is infrared radiation plus the solar radiation which is scattered and reflected upward. These various fluxes can be sampled by a set of omnidirectional bolometers with coatings which are designed to absorb selectively a certain part of the spectrum. For example, a bolometer which is white in the visible but black in the infrared beyond about 4 or 5 microns will respond to the thermal radiation from the earth and atmosphere, while one with the reverse spectral characteristics will measure the direct and reflected sunlight. Further, a directional detector of visible radiation pointed toward the sun would, of course, monitor the incoming solar radiation alone. (Such a scheme is included in one of the IGY earth satellites.)

The purpose of this set of measurements is to determine the radiational heat budget of the earth and atmosphere. It is known that an excess of radiational energy is added to the atmosphere in low latitudes and that there is generally a net loss of energy from the polar regions. An understanding of this energy imbalance is basic to an understanding of the general circulation of the atmosphere. Furthermore, such a set of radiation measurements, provided that there were a reasonably fast response, would give a rough indication of the thermal inhomogeneity of the atmosphere and earth. It is likely that a measure of this inhomogeneity would provide an indication of the strength of the cyclonic and anticyclonic circulation. During periods of strong meridional transport of energy by the atmosphere there are rapid migrations, north and south, of warm and cold air masses, and these could probably be distinguished by their thermal characteristics.

Mapping of the cloud cover. On the sunlit side of the earth the contrast, in the visible and near-infrared, between clouds and ground or open water is considerable, and it has been demonstrated dramatically by the use of rocket and balloon photography that the existing weather can be traced by the large-area cloud patterns. These cloud patterns can be determined from a satellite by various means. A first approach, in which the scanning of the surface by photocells is performed by the uncontrolled rotation of the satellite, is being developed for the IGY program. In this case the reconstruction of the picture is complicated, however, and the data-handling capacity of the telemetering link places an upper limit on the amount of coverage and the degree of resolution.

The purpose of such an observation would be to show the cloud patterns over a large area of the earth with a degree of completeness not obtainable with present surface observation networks. For research in meteorology, this will throw new light on the way in which storm systems start and develop, on the broad pattern of flow, on the effects of mountain barriers, and so on. If techniques are refined to the point where the observations can be made available to meteorologists immediately, this would represent one of the greatest advances ever made in the gathering of meteorological data and would surely improve short-term forecasting and the prediction of hurricanes.

Mapping of the night airglow and aurorae. The upper atmosphere in the 70- to 150-kilometer region continuously emits ultraviolet, visible, and infrared radiation. In middle and low latitudes this emission, called the "night airglow," is relatively steady but displays moving patterns. As is well known, the aurorae of the polar regions are tremendously variable. A world-wide survey, on the dark side of the earth, of this radiation, made in the general manner of the cloud-cover experiment but with greater sensitivity and less angular resolution, would provide a map of the activity of the emitting layers. The brightest lines of the upper air emission spectrum are the familiar 5577- and 6300-angstrom lines of atomic oxygen, the 5893-angstrom doublet of sodium, the OH bands in the ultraviolet and infrared, and the O_2 "atmospheric bands" in the infrared. The last mentioned may be the brightest of all when observed from outside the atmosphere.

The airglow and aurorae present moving, complex patterns which must be related to the meteorology of the 70- to 150-kilometer region. A map of the emission in various wavelengths, from the ultraviolet into the infrared, would therefore be an invaluable aid in the study of the behavior of this important part of the atmosphere. It is significant that changes in solar emission are undoubtedly first signaled by changes in the circulation patterns in this same region of the atmosphere and that these changes probably then work downward to affect the lower atmosphere.

Time fluctuations of solar ultraviolet and x-radiation. Solar ultraviolet and x-ray intensities are quite variable and appear to depend greatly on solar activity. Both x-rays and the ultraviolet are enhanced during a solar flare, in some wavelength regions by an order of magnitude or more. These fluctuations have corresponding effects in the earth's atmosphere. Increased output of hard x-rays, for example, causes a pronounced D-layer and an associated interference with radio communications. An increase in the intensity of near-ultraviolet solar light could contribute to the marked temperature excursions that have been noted in the ozone layer, and such temperature excursions undoubtedly interact with the surrounding wind patterns.

Since solar ultraviolet light and x-rays have such a pronounced effect on the atmosphere, and since their fluctuations are associated with important related effects, it should be very fruitful to monitor these solar wavelengths over a long period of time, say for a year, for the purpose of correlating the ultraviolet and x-ray intensity–time curve with weather, radio propagation, the ionosphere, airglow, winds, and so forth. Because these solar radiations are absorbed by the atmosphere, the logical place to monitor them is from above the appreciable atmosphere. This could be done from an artificial satellite orbiting entirely above 200 miles of altitude. By the use of suitable windows and gas fillings, photon counters and ionization chambers can be constructed to respond only to radiation within a restricted band. (Such a photon counter, sensitive to Lyman-alpha radiation, is to be flown on an early IGY satellite.) With such detectors, various bands from the near-ultraviolet down to the hard x-rays could be monitored. Payloads on the order of 50 pounds should be adequate to permit coverage of a number of important wavelength bands in a single installation having indefinite duration of operations.

Distribution of hydrogen in space. The density of hydrogen in interplanetary and interstellar space has been a subject of much interest and speculation. On the basis of astrophysical observations, the current estimate is about 1000 atoms per cubic centimeter in interplanetary space and about 1 atom per cubic centimeter in interstellar space, but the basis for these estimates is uncertain.

The density of hydrogen in space could be determined by observing the hydrogen Lyman-alpha radiation received from space and comparing it with direct solar Lyman-alpha radiation. Hydrogen ions in space would emit a more or less steady background of Lyman-alpha radiation as they captured electrons. Hydrogen atoms would fluoresce under irradiation by solar Lyman-alpha radiation, and this fluorescence would fluctuate directly with the solar curve. By analyzing the total intensity of Lyman-alpha radiation into the steady and solar-dependent components, one could determine the relative densities of hydrogen ions and atoms. With suitable calibration, the absolute densities could be determined.

The ionization chambers to be used to study solar Lyman-alpha radiation from an IGY satellite could also be used as the detectors for the hydrogen density experiment.

A valuable refinement of this type of observation would be the measurement of the contour of the Lyman-alpha line with high resolution. For this purpose, possibly, a very high order of reflection from a ruled grating combined with photoelectric scanning would be used. With such a technique it would be possible to obtain a resolution of a few hundredths of an angstrom, which is adequate to reveal the existence of an absorption core in the center of the line. Continuous measurements of this type from the satellite would reveal any temporal variation in the depth of the core of the line, and such measurements could give information about variations in the total neutral hydrogen content in the space between the satellite and the sun, and about the temperature of interplanetary hydrogen.

Survey of celestial sources in the far ultraviolet. Exploratory measurements made with rockets reveal a picture of stellar magnitudes in the far ultraviolet very different from that in the visible. Not only do the stellar emissions show anomalies in the ultraviolet but intense emission from ionized gas clouds has also been observed.

A satellite equipped with ionization gauges or photon counters with high sensitivity and restricted view could scan the sky with better aspect control than is possible with rockets and would provide a rough map of the ultraviolet "hot spots." Subsequent satellites with better orientation control could then survey these sources in more detail.

Extragalactic light. Among the many radiations which strike the top of the earth's atmosphere, the light from sources beyond our own galaxy is one of the most interesting, insofar as it contributes to our understanding of the astrophysical nature of the universe. The intensity of this extragalactic radiation is already known to be quite weak in comparison with the light from our own galaxy, and its spectral character is known to be heavily shifted to the red. These facts alone are subject to an immediate cosmological interpretation—namely, the expanding nature of the universe.

The hypothesis of the expanding universe can be submitted to a more specific test by detailed measurements of the spectrum of extragalactic light and by determination of the distribution of its intensity with respect to galactic latitude.

It is impossible to make such observations with ground-based or balloon-borne apparatus because of the great overburden of other radiations originating in the earth's upper atmosphere. One might suppose that they could be made with vertically fired rockets which surmount the major emitting layers of the atmosphere, but the intensity is judged to be so weak that the several minutes of a rocket's flight provide an inadequate period of time for significant measurement. A satellite, with its flight of longer duration, appears to be necessary for the accumulation of significant data.

The proposed apparatus consists of several high-sensitivity, photoelectric telescopes equipped with a variety of spectral filters—all operating in the visible region of the spectrum. This experiment seems properly classified as an exploratory one. Results are not assured, but if they are obtained they will be of very far-reaching and profound significance.

Cosmic ray observations. The objectives of a cosmic ray experiment would be: (i) to make comprehensive observations on the total intensity of the cosmic radiation as a function of latitude, longitude, altitude, and time; (ii) to determine whether the nuclei of lithium, beryllium, and boron are present in the primary cosmic ray beam and, if they are present, to measure their intensities; and (iii) to study, as in (i), the intensity of the heavy nuclei separately from the total intensity. Interpretation of the results of (i) and (iii) should yield a crucial test of the theory of the deflection of charged cosmic ray particles approaching the earth through the geomagnetic field and should yield new information on the nature and importance of interplanetary magnetic fields. The data of (ii) should settle one of the leading questions on the astrophysical origin of cosmic rays and on their propagation to the earth. The data from (i) and (iii) should provide a greatly improved understanding of the systematic and sporadic fluctuations of the primary radiation, the astrophysical causes of these fluctuations, and their consequences, as reflected in the rate at which secondary cosmic ray phenomena occur within the atmosphere. A special question is whether the solar sources of cosmic rays yield the same distribution of nuclear species as the usual primary beam.

Primary auroral particles. The polar aurorae ("northern lights" and "southern lights") are caused by the interaction of energetic charged particles with the upper atmosphere. Due to their charges, these particles are deflected by the earth's magnetic field and are focused on the polar regions. It has been established that the intensity of these streams of auroral particles changes rapidly, apparently as a result of changes in the sun.

In order to observe these particles it would be necessary to have a satellite on a high-inclination orbit, since the flux is concentrated toward the poles. By means of simple satellite-borne detectors it will be possible to map out the impact zones of the primary auroral particles on the top of the earth's atmosphere and to observe their changes (local and worldwide) with time to a degree not ever likely to be approached by ground observatories. It will be possible to compare rapidly the northern and southern zones of incidence and to study efficiently the ways in which the position and configuration of these zones are influenced by and correlated with geomagnetic field disturbances.

The temporal variations of the incidence of auroral radiations can be comprehensively correlated with observable activity on the sun to an extent not presently conceived to be possible by any other method. In addition, the nature of the primary auroral radiations (that is, protons, electrons, heavy particles, and so on) can be comprehensively studied, as can their intensities and energy spectra. A comparison of these data with those from ground observatories should be very fruitful in establishing the physical processes which are induced in the earth's atmosphere.

These auroral observations are closely related to observations of the geomagnetic field. Indeed it would be desirable, in order to obtain mutually supporting sets of data, to have two satellites aloft simultaneously—one carrying a magnetometer and the other carrying auroral radiation detectors. Eventually it may be possible to have a single satellite carry both types of apparatus.

Micrometeorites. There are various estimates of the number of micrometeorites striking the earth's atmosphere, but few actual measurements. For the IGY it is planned to count such particles in one or two satellites. The limited instrumentation and limited time of operation of the equipment will, however, leave unanswered such questions as: What is the mass spectrum? What is the energy spectrum? What are the fluctuations in total intensity? How are these particles related to visible meteor showers? By use of a satellite capable of operating over a period of a year, equipped with calibrated microphones, thin diaphragms with photocells to observe punctures, electrostatic analyzers, and the like, most of these questions could be answered.

Magnetic field. The earth's magnetic field is mainly caused by the magnetization of the earth's mantle and the electric currents flowing in its liquid core; this main part of the field can be quite accurately measured by ground-level surveys or aerial reconnaissance. However, the variations in this main field that are of external origin, amounting to as much as 7 percent, say, are due to a variety of current systems in the ionosphere and above. (There are current systems induced in the earth also, but these are presumably secondary effects caused by phenomena at great altitudes.) A major source of geomagnetic variations are the direct current systems in the lower part of the E-region, which are below the satellite altitudes. However, at much greater distances, perhaps an earth radius or more, there may be another highly variable current system known as the "ring current."

With a satellite-borne magnetometer flying over a monitoring magnetometer on the ground, the two making simultaneous measurements of the magnetic field, it is possible to determine the horizontal flow of current between the ground and the satellite. The same technique can be used with two satellite magnetometers as they pass over each other. Thus, it is possible to map the electric current systems out through the region of the ring current.

The use of vertical rockets to do this same thing has already been mentioned. In some ways a rocket is superior to a satellite for magnetic measurements, since it can make a vertical profile from the ground up, and thereby determine where the electric currents lie. However, these currents are highly variable, and a satellite makes it possible to determine how they vary in time, how they are related to solar activity, and how they may vary in the horizontal. The ideal approach would be to use rockets and satellites in combination, thereby obtaining a more complete map of the geomagnetic field in three dimensions and in time.

Ionospheric observations. The ionized layers of the ionosphere (D, E, F_1, F_2) generally lie at altitudes of between 80 and 300 or 400 kilometers. They are therefore mostly below the altitude of the satellite. A number of effective methods have been suggested for measuring the total free electron density between the satellite and the ground, one being a measure of the difference between the angle of incidence of the radio tracking signal and the optical line-of-sight as the satellite passes over a tracking station. The difference is very small and barely measurable for the radio frequencies best suited for tracking and telemetering. In order to insure accurate tracking, the USNC–IGY satellites transmit primarily at 108 megacycles. However, a 40-megacycle transmission is also planned for some USNC–IGY satellites (one of the frequencies used in the Soviet satellites), and at this lower frequency more bending and dispersion of the radio waves will occur. The use of some of the techniques of radio astronomy would be appropriate for measuring this effect. The transmission of two or more frequencies simultaneously would give added meaning to the results. Another observation yielding total electron densities is the rotation of the plane of polarization of the radio wave, due to the Faraday effect. Such an observation requires the use of a high-gain antenna with a dipole, to sense the plane of polarization, and a knowledge of satellite orientation.

Another class of satellite radio experiments would make use of the satellite as a known source of radiation to measure certain aspects of the fine structure of the ionosphere. It is observed that radio stars fluctuate, and these fluctuations are in part due to ionospheric inhomogeneities of various sorts, some of which are in the E-region and some in the F-region. A satellite would permit these horizontal inhomogeneities (sometimes known as "ionospheric lenses") to be mapped, both in the horizontal and in the vertical. Since the satellite may at times be in or below the F-region, it will be possible to separate out the various effects of the two regions of inhomogeneity. An especially interesting aspect of the irregularities in ionization of the upper atmosphere is the pattern of the auroral clouds, streamers, draperies, and so on, which extend from the E-region upward to great heights. These patterns are marked by visual radiation, as is well known, but they are also regions of intense local ionization. The radio signal from a satellite in the auroral zone would be influenced by the auroral ionization, and presumably a study of the fluctuations would tell a great deal about the character and distribution of the ionization in this region.

It should be borne in mind that the gross structure of the ionized layers can be measured from the ground continuously with ionospheric recorders, and that the general features of the ionosphere are already quite well understood. Furthermore, as was pointed out above, the fine structure of the ionospheric layers can probably best be determined by a rocket which penetrates rapidly through the ionosphere, recording successive changes in "radio depth" as it goes. However, it is certain that valuable ionospheric experiments can be made by means of satellite radio transmissions, and the experiments described above will be possible with any satellite which provides a more or less steady signal with stable frequency and known polarization.

To date, no experiment has been proposed which can measure the free electron distribution above the top of the ionosphere from a single satellite without serious difficulties due to the dominant effects of inhomogeneities in the ionosphere itself and uncertainties in the orbit, which tend to mask any second-order effects at the satellite altitude. However, the distribution of free electrons above the ionosphere would be of great significance. The use of two satellites, with a two-frequency transmission link between them, offers an apparently feasible solution. Another possible technique would be the use of a miniature-sweep frequency ionospheric sounder in the satellite, directing its pulses downward.

Biological experiments. Biological experiments should be instituted at the earliest opportunity in the satellite program, since they will be crucial to the eventual attainment of manned space flight. There appear to be two main areas of concern: the biological effects of prolonged exposure to the radiation in space (cosmic rays and the various solar emissions), and the subtle and complicated effects of prolonged weightlessness.

With regard to the first, a program of exposure of biological samples and live animals to cosmic radiation at high altitude in balloons has been under way for some time, and at the altitudes attainable by balloons (over 100,000 feet) the cosmic radiation is essentially the same as at satellite altitudes. There are other kinds of radiation, such as solar ultraviolet and x-rays, which do not penetrate to balloon altitudes, but these can be reproduced conveniently in a laboratory. Thus, the use of a satellite for the study of radiation effects on biological specimens does not appear to be very rewarding.

For the study of prolonged weightlessness, on the other hand, there is no known substitute for a vehicle floating freely in space. Biological specimens and live animals have been successfully flown and recovered from high-altitude rockets, having been exposed for a few minutes to a situation of weightlessness. The second Soviet satellite carried a dog, thereby lengthening the duration of the period of weightlessness *ad mortuum.* The USNS–IGY satellite program includes a biological sample (yeast). These first attempts to study weightlessness will have to be greatly expanded in the future.

Advanced Satellite Experiments

Selective and directional thermal radiation measurements. Since certain constituents of the atmosphere, such as water vapor, ozone, and carbon dioxide, have strong absorption lines in the infrared region of the spectrum, a detector looking downward which is sensitive only in these regions does not "see" the earth's surface. Instead, it detects the radiation emitted upward from the upper levels of the constituent, the radiation from the layers below having been absorbed by the atmosphere. Thus, for example, a detector looking down at around 9.6 microns (in a strong ozone band) would receive the thermal emission from the top of the ozone region at about 10 to 30 kilometers of altitude; a detector looking down at around 6 microns (in a strong water-vapor band) would receive the emission from the top of the troposphere at 8 to 10 kilometers, above which there is relatively little water vapor. A quantitative measurement of the thermal radiation in one of these narrow spectral intervals gives a measure of the temperature (and, to a second order, density) of the emitting layer. A more detailed analysis of the variation of this emission with zenith angle can give the vertical distribution of temperature in the emitting layer. This experiment would require great detector sensitivity and a considerable degree of orientation control, particularly for the measure of the "limb darkening" just described. To be most meaningful, the record for an entire satellite circuit should be complete, probably requiring storage of data and retransmission over a telemetering station.

The purpose of such a set of measurements would be to map the effective temperature of various layers high in the atmosphere. Some of these layers are inaccessible to conventional sounding balloons, and even those which are accessible can only be sampled at a few points. As meteorologists have obtained progressively more information about the synoptic conditions in the upper atmosphere (using balloons and occasional rockets, to date), they have gained more insight into the behavior of the atmosphere, and their ability to forecast the weather has gradually improved. However, balloons cannot penetrate the part of the atmosphere which is affected by solar ultraviolet radiation below about 0.3 micron (the ozone cutoff). It seems reasonably certain now that short-term changes in solar radiation have an immediate effect on parts of the upper atmosphere and that these effects propagate slowly downward in a complicated and as yet unexplained way. A synoptic satellite observation of the kind described would probably provide a direct measurement of the immediate effects of a solar disturbance on the thermal structure of the atmosphere. It would, therefore, be a key to the development of a physical basis for long-range weather prediction.

Selective and directional ultraviolet and x-ray measurements. As already pointed out, ultraviolet and x-radiation from the sun below about 3000 angstroms does not reach the surface, but is absorbed and scattered by various constituents of the upper atmosphere. In some wavelengths this radiation is absorbed in a relatively limited region. Thus, if one scanned the sunlit atmosphere from above, using a number of ultraviolet detectors, one would be able to obtain a vertical profile of several of the constituents. For example, by scanning with photon counters sensitive to 1400 to 1100 angstroms, it is possible to survey the vertical distribution of O_2 from the 100-kilometer level to the top of the ionosphere. At around 2500 angstroms one could determine the distribution of O_3 below 100 kilometers. Similar measurements in x-ray wavelengths would monitor density variations in the E and F_1 regions of the ionosphere.

These types of measurements have been proved in rocket experiments. With sufficient payload available, more refined spectroscopic surveys of the earth's atmosphere in the far ultraviolet should be possible; with the sun as a light source, its attenuation might be measured, or characteristic reasonance lines of the various constituents studied.

Astronomical spectrograms. A spectrograph mounted in an artificial satellite would be able to photograph the sun, planets, and stars completely free from interference by the atmosphere, thus extending the sensitivity far into the ultraviolet end of the spectrum and permitting a much more detailed study of these bodies than is now possible.

Spectrographs to do this job are, in essence, available. Suitable light collectors would have to be designed. A pointing control would be necessary. Such a control could probably be worked out along the lines of those now used in rockets, with a total weight of less than 30 pounds. To retrieve the film, it would be necessary to work out techniques for recovery of a capsule from the satellite orbit (or of the satellite itself); however, such techniques have already been proposed and are considered to be feasible within the expected weight limitations.

An alternative to the recovery of film is, of course, the electronic processing and telemetering of these observations. This is discussed further in the next section.

Ultraviolet photographs of the sun. Much of the photochemical and dynamical activity in the sun is associated with the emission of ultraviolet radiation. Photographs of the sun in various regions of the ultraviolet should permit localization of regions associated with the respective wavelength emissions and would be an important aid to understanding solar activity.

Suitable filters and ultraviolet-sensitized films are available for making such photographs. If necessary, pointing controls similar to those already used in rockets could be constructed for directing a camera at the sun. It would probably be desirable (but not necessarily essential) to recover the film after the pictures had been taken; however, as indicated above, it is believed that suitable techniques could be developed for the recovery operation.

In this type of experiment the use of photoelectronic recording and telemetering should certainly not be overlooked, however. Such a technique would be of great advantage, for example, if a more or less continuous picture was needed. A variety of approaches can be considered for obtaining photoelectronic pictures of the sun in the ultraviolet or x-ray region. For example, it is entirely possible to measure the distribution of Lyman-alpha radiation over the sun's disc by means of a photon counter with narrow field of view, sensitive to this line only. By using a simple scanning motion, it is even possible to obtain a crude picture equivalent to a television scan of about 20 lines' resolution in a rocket experiment, and the longer time available in satellite measurements would permit such scans to be made with more resolution and at other interesting wavelengths, such as the helium resonance lines at 584 and 304 angstroms, the MgX line at 625 angstroms, and various x-ray wavelengths.

Planetary spectrograms. A variation of the experiment on ultraviolet and x-ray measurements would be the measurement of the spectra of the various planets in the ultraviolet and infrared. All of the central planets have visible atmospheres, but the composition of these atmospheres is difficult to observe spectrographically from the ground, due to the presence of the same or similar gases (in differing proportions) in our own atmosphere. For example, the solar ultraviolet radiation reflected from these planets is completely absorbed by our atmospheric ozone, and large segments of the infrared radiation which is emitted are absorbed by water vapor, carbon dioxide, and ozone, plus other trace constituents such as methane and nitric oxide. A satellite would have a clear view of these planets.

The radiation from them is very weak, however, and would require quite accurate positioning of the spectrograph in order to provide long exposures with limited angular fields (in order to minimize the cosmic and stellar background). Moreover, it would probably be most desirable to recover the spectra in the form of exposed plates, though it is possible to telemeter the information to the ground.

An experimental test of the general theory of relativity. One of the predictions of the general theory of relativity is that the fundamental time scale of atomic phenomena (for example, frequency of emitted spectral lines) is influenced by the gravitational potential in which the emitting system is located. This prediction has received, thus far, only a very few observational verifications, and even these remain in a somewhat controversial state. It is conceivable that it may be possible to mount a so-called cesium or thalium "clock" in a satellite and a similar one at a ground station and intercompare the rates of these two clocks over an extended period of time. In accordance with the general theory of relativity, it is expected that there would be a systematic difference in the rate of running of these two "atomic clocks," because of the known difference of gravitational potential to which they are subjected.

The effect is a small one, and it appears that accumulated observation over a period of the order of a month may be required to surmount reasonable experimental errors in location of the position of the satellite and in ionospheric conditions. (Both effects, of course, influence the transit time of the transmitted intercomparison signal from the satellite to the ground station.)

A proposal is known to be currently under consideration for a similar intercomparison between clocks, one of which is located on a mountain and the other in a neighboring valley. However, if the technical problems can be adequately solved, it may be desirable to utilize a satellite for a more sensitive test of this very profound theoretical hypothesis under different conditions.

Solar (cosmic) radio noise in the high-frequency and low-frequency spectrum. High-frequency radio waves below about 5 megacycles cannot penetrate the ionosphere, and even radio waves at 20 megacycles are sometimes totally absorbed. Thus, it is not possible to observe from the ground the lower frequency end of the radio noise which comes from the sun and beyond.

A satellite would, of course, not suffer from ionospheric absorption, but the signal levels in this region are low, and the antennas required to obtain much gain have to be large. However, by the use of long wires, or large erectable reflectors or lenses to concentrate the signals and to obtain directionality, measurements could be made on high-frequency signals below the ionospheric cutoff.

Collection of micrometeoritic samples. If techniques can be worked out for recovery of the satellite or of small capsules from the satellite, a long-period collection of micrometeorite particles could be made. These samples could be collected in containers filled with something like silicone grease, which could be opened while the satellite is on orbit and then closed just before the recovery operation is begun.

The recovery of a representative sample of meteoric material would be of value for a number of reasons: It would throw light on the relative abundance of elements in the solar system; it would help to resolve the questions concerning the scattering effect of this dust, observed as the zodiacal light; it would supplement the previously mentioned satellite observations of the impact effects of meteors; and so forth.

Manned satellites. Later in this article manned space flight is discussed briefly, and it is pointed out that man will inevitably venture into outer space sooner or later. Whether the presence of a man in the vehicle will contribute to our knowledge of the universe is beside the point. Such an achievement should, perhaps, be considered as an end in itself—the ultimate biological experiment.

Lunar Investigations

One of the major justifications for building and launching a rocket to the moon is the knowledge which would be obtained about our nearest neighbor in space. The emphasis of the long-range program described here is on an orderly progression of technical development and scientific research into problems of outer space. In this context, the investigation of the moon is but a step to the investigation of the planets.

There are several potentially fruitful experiments and observations on the moon now being considered, some of which could be made by impacting the moon directly (the impact velocity would be about 9000 feet per second for a vehicle taking 2 to 3 days for the trip), some of which could be made by a satellite in a circumlunar orbit (this would be a special kind of satellite), and some of which would require the lowering of instruments to the surface. Ultimately there will be manned vehicles capable of landing on the moon.

The experiments which should take priority are, in general, those which give information about the moon as a whole, rather than about the particular point of impact—those that will reveal the most about the processes by which the moon was formed, its past history, and so forth, and that will be most useful in the planning of subsequent experiments. The three quantities to be measured which pertain to the moon as a whole are the lunar gravity or mass, the moon's magnetic field, and its atmosphere. Of these, probably the last is the only one which requires a landing on the moon. A further experiment, described more fully below, is the determination of the internal structure of the moon by seismic prospecting techniques; this will certainly require the landing of an instrumented package.

Measurement of lunar mass and gravity. Present estimates of the moon's mass, based primarily on observations of the motions of asteroids and of the motions of the earth's polar axis, have a possible error of about 0.3 percent. So great an uncertainty as this would affect any calculation of the trajectory of a moon rocket, since calculations must take into account the moon's mass. It is therefore desirable that one of the early moon experiments be devoted to a more precise measurement of this quantity.

There are two possible ways of going about this. The best way is to track the rocket as it approaches the moon and to deduce from the path which the rocket takes, and from the instant of its arrival, the force of the moon's pull at each point. This is entirely practical in principle, but it requires considerable accuracy in the tracking. The accuracy requirements almost certainly could not be met by an electronic tracking system on the earth. A radar altimeter and Doppler drift measurement from the lunar vehicle itself might provide sufficient accuracy for such a determination. The use of ballistic cameras which could position a large diffuse reflector or a flashing light on the vehicle against the star background is also a promising possibility for accurately determining the motion of a vehicle relative to the moon.

An alternative method would be to measure the lunar gravity from the surface of the moon directly, after the rocket had landed. This kind of measurement is relatively simple and can be performed by measuring the displacement of a known mass suspended from a carefully calibrated spring, by measuring the time-of-fall of a body in a known distance, by measuring the period of swing of a pendulum of known length, and so on. By any one of these techniques the gravity of the moon could be measured with an error considerably less than one part in a thousand.

A measurement of the lunar gravity at some point on the surface is not sufficient to determine the lunar mass, however. The other parameter is the square of the distance between the measuring point and the moon's center. The average radius of the moon is about 1740 kilometers. Some of the mountains of the moon have been determined to be more than 1.3 kilometers high. There are escarpments more than a kilometer high separating plateaus from low-lying plains or *maria,* and the crater bottoms are at a different level from the surrounding land. In fact, the variations between various parts of the moon's surface, since the so-called "continental" or "sea" areas are at different heights above the mean level, make a determination of the size and shape of the moon somewhat uncertain. According to Baldwin, the lunar bulge is 2200 meters (in the direction of the earth), and the uncertainty in this quantity is about ±200 meters. This alone corresponds to a possible error in height above the moon's center of 1/10,000, and a corresponding error in the lunar mass determination of 0.02 percent. It would appear, therefore, that this may be the limiting factor in determining the lunar mass from an observation of lunar gravity on the moon's surface, but such an observation would still reduce the present uncertainty by an order of magnitude.

Direct measurement of the lunar magnetic field. At present there is apparently no evidence at all that the moon has a magnetic field. It must have one, however, since it could hardly have existed for so long in close proximity to the earth without experiencing some effect of the geomagnetic field. Furthermore, the lunar magnetic field would depend on the method of formation of the moon and on the magnetic field in which it existed during its formation.

If we consider that an approximate lower bound to the lunar magnetic field is the strength of the earth's magnetic field at a distance of 386,000 kilometers, then we would be faced with the problem of measuring a field of about 0.14 gammas. (The magnetic field at the surface of the earth is about 0.5 gauss, or 50,000 gammas.) Familiar techniques exist for measuring magnetic fields down to a few gammas, but this remnant of the earth's field may, by itself, be too small to be measured. Thus, the first measurement of the lunar magnetic field should be considered to be exploratory and should be made with as much sensitivity as possible.

It may be that the moon's field is much stronger than this, due, perhaps, to internal circulations while it was cooling; or it may be that the moon's magnetic field does not align itself with the extension of the earth's field. If either of these possibilities is found to be true, it would be a matter of considerable theoretical interest, since it might reveal something about the way in which the moon was formed and about the history of the earth-moon system.

If the lunar magnetic field is larger than the foregoing calculation indicates, another likely cause would be the retention of the larger magnetic field in which the moon was embedded at the time of solidification. It has been held that the moon was closer to the earth when it solidified, and so it may have been in a stronger field at this time.

Mass spectrographic measurements of the lunar atmosphere. It is customary to think of the moon as having no atmosphere at all. Astronomical observations have given no sure indication of a lunar atmosphere. Theoretical calculations on the persistence of any remnant of an atmosphere show that even the heavier gases, such as krypton, xenon, and perhaps CO_2, would slowly escape from the hot, sunlit side of the moon.

Nevertheless, there is a possibility that enough gas is trapped in the crust of the moon so that there is a steady leakage of this gas. The heavier gases would stay on the surface for awhile, so there would be a very tenuous but constantly replenished atmosphere. A measurement of the constituents of this atmosphere would reveal information about the rate at which these gases are being released by the crust. This would be of considerable help in understanding the constitution of the crust and the way in which the moon was formed.

It is possible to design a lightweight mass spectrograph which could give an indication of both the atmospheric density and the atomic mass distribution of the lunar atmosphere—or at least an estimate of an upper bound of the amount of each gas present. The University of Michigan has proposed a design for such a gas analyzer; it would work on the principle of an "omegatron," could possibly be used in a satellite vehicle, and would operate down to pressures of the order of 10^{-10} millimeters of mercury. If it could function in a satellite, then it should be able to function on the moon. There does not seem to be any sure way at this time of estimating whether the trace of a lunar atmosphere could be detected by an instrument operating at this level of pressure, but the experiment certainly warrants a try (perhaps preceded by the observation of pressure described in the following paragraph).

Pressure and density of the lunar atmosphere. A measurement of the pressure or density of the lunar atmosphere alone would not be as useful as a measure of the individual constituents, as suggested in the previous section. The only advantage would lie in the fact that a pressure measurement is simpler to make, in principle, than a mass spectrographic measurement. If weight or complexity were a problem, then it might be desirable to make a pressure measurement first. Once the existence or nonexistence of a measurable atmosphere had been established, the decision to operate a mass spectrograph could be made on a firmer basis.

Seismic and microseismic observations of the lunar crust. There are probably two *natural* sources of motion in the moon's crust: that caused by shifting, sliding, or folding of the crust and that caused by the impact of meteoroids.

In order for the first to occur, the center of the moon would have to be plastic or molten, like the center of the earth, since there could hardly be much shifting of the moon's crust if the moon were a rigid sphere. Occasionally there might be a landslide, due to small-scale fracturing of a cliff subjected to the large monthly temperature variations, but a landslide would probably not register as a "moonquake." It is an open question whether the moon has a molten interior. In the geologic past there seems to have been volcanic activity, and the *maria* appear to have been laid down as a covering of molten material. However, since man has been observing the moon, there has been no clear case of an active volcano on the moon, and so it may be completely solidified by now. Listening for moonquakes would be one way to find the answer to this riddle.

There is, however, no doubt about the fact that meteoroids are continually impacting the moon. Most of the particles from interplanetary space are very small, with diameters of less than a millimeter. These would have almost no effect on the moon's surface during our period of observation and would not cause any measurable microseisms. However, there is a definite possibility that several large particles might hit somewhere on the moon during the period of observation. Depending on their energies and their distances from the instrument, the impacts would be detected as waves in the crust, just as the impulse from explosions on the earth's surface is picked up hundreds of miles away. In the case of the moon there does not seem to be any way of determining how far away from the recorder a meteoroid hit, but it might be possible to get some useful information from the character of the pulse.

If an explosion (or explosions) could be created at a known time and at a place some distance from the recorder, then one could make full use of the powerful techniques which have been developed for seismic prospecting. For studies of the lunar subsurface and core, this would certainly be preferable to depending on meteor impacts. In order to use seismic prospecting techniques, one must know the distance between the explosion and the recorder, and the recorder must be able to measure the time-of-travel, and the character, of the shock wave. Actually, after traveling a short distance in the lunar crust, the original shock wave would be broken up into a number of waves with different group velocities and modes of propagation, and the analysis would depend to a large extent on being able to sort out the various components of the wave. This would mean that the wave would have to be recorded with considerable time resolution, and the record would then be transmitted to the earth by a playback mechanism. This would allow one to expand the time scale of the record in order to accommodate the bandwidth of the telemetering link.

The source of the shock used in the seismic experiment, which must be at some known distance from the detecting instrument, could be a hydrogen or an atomic explosion, or possibly the impacting of another part of the vehicle system. For example, if a last stage similar to the Vanguard second stage, weighing about 800 pounds, empty, were used to start the instrumental section on its way, it would release an amount of energy on impact with the moon (at 9000 feet per second) equivalent to nearly the same number of pounds of TNT. Naturally, the instrument package would have to precede it and land before the impact of the booster occurred, but this would require only a small extra push to the package early in the flight.

A more elaborate experiment can be conceived, in which grenades could be ejected from the moon rocket, travel a known distance, and then explode on hitting the ground. This would give a pulse of known energy at a known distance from the seismograph. If this experiment were considered crucial enough, it could probably be performed, but considerations such as the weight of the auxiliary projectiles, the accuracy with which they could be aimed, the effects of rough terrain, and other problems make such an undertaking seem rather difficult.

Observations at the point of impact. As mentioned earlier, the most valuable experiments, at least in the initial stages of lunar exploration, are those which deal with the moon as whole. However, it is clear that there are a number of things concerning the surface on which the package landed which would be of great interest. Among the important properties which would lend themselves to measurements are: (i) temperatures of the surface and subsurface; (ii) surface hardness; (iii) chemical composition of the surface material.

The Soviets have suggested the use of mobile instrument carriers equipped with television links to the earth (called "tankette laboratories")—an interesting means of extending such local observations over a wider area.

Planetary and Interplanetary Investigations

The requirements for landing an instrument package gently onto the surface of the moon are roughly equivalent in difficulty to those for placing the same weight of instruments on a collision course with either Mars of Venus. The detailed problems to be solved are different, particularly with respect to guidance, but the propulsion requirements may actually be considerably less for the interplanetary flight. It should be noted that the velocity necessary to escape from the earth-moon system is less than 0.01 percent greater than the initial velocity required to just reach the moon.

To achieve a heliocentric orbit is in many respects easier than to achieve an interplanetary (that is, planet-to-planet) trajectory, since the propulsion requirements are about the same while the guidance accuracy required would probably be less, depending on what is expected of the orbit. For this reason, it is not unreasonable to treat interplanetary and heliocentric flights together, even though the scientific objectives may be quite different.

One of the major problems in unmanned interplanetary flight will be that of communications and tracking. For example, at the distance of Mars at closest approach (about 50,000,000 miles, on the average), it would require an astronomical telescope with a 20-inch aperture to see a sphere of 1 kilometer diameter with an albedo of 1 (a white surface). This suggests that very large inflatable balloons or corner reflectors will have to be used if the space vehicle is to be tracked optically, or it will have to carry a source of bright light. Tracking by radar is not out of the question, though powerful transponders would be required to allow the vehicle to be reached at such a range.

Communication over these great distances will obviously require a great deal of transmitted power. All other things being equal, the power required increases with the square of the range of the communications link. For example, it is claimed that an advanced narrow bandwidth (an effective predetection noise bandwidth of 10 cycles per second) telemetering system, called the Microlock system, can now be designed to reach 3000 miles with only one milliwatt of transmitted power. At the mean distance of Mars at closest approach, the power required for such a system would be about 200 kilowatts. There are undoubtedly other schemes which are better suited for this purpose, but the problem certainly requires attention.

Some of the scientific objectives of interplanetary flight—objectives which can only be attained by such an effort—are listed below. An attempt has been made to name the simpler experiments first, and it appears that these simpler ones would in every case yield information required for the planning of the succeeding flights.

Determination of the astronomical unit. The basic unit of length used in astronomy is the semimajor axis of the earth's orbit about the sun (the astronomical unit), now estimated to be 92,900,000 miles or 149,600,000 kilometers and known to only three or, at most, four significant figures. It is taken as the basic unit because the diameter of the earth's orbit is the longest baseline which terrestrial astronomers can ever achieve. The parsec, a derived unit of length which is commonly used to measure stellar distances, is the distance at which the astronomical unit subtends one second of arc. In order to relate the astronomical unit to our usual yardsticks, it is necessary to triangulate from the earth on interplanetary objects whose orbits can be observed and timed. The closest objects of this kind are the asteroids; but the closest asteroids are several million miles away, and so triangulation from a baseline on the earth on such an object cannot be carried out with great accuracy (as evinced by the uncertainties in the values given above for the astronomical unit).

The situation would be greatly improved if astronomers were provided with an "artificial asteroid," one which passed relatively close to the earth occasionally and which could be observed as it circles around the sun. Ways of making it observable will require further thought, as will the corrections which may have to be applied for solar radiation pressure, meteoric and coronal drag, the perturbations of the earth and planets, and so on. By the time this experiment is achieved there will probably be enough information available on interplanetary conditions to permit such corrections to be made quite precisely.

An improved value of the astronomical unit would reflect itself in improved precision in other fundamental constants.

For example, the constant of gravitation expressed in terms of the astronomical unit, the solar mass, and the mean solar day is known from astronomical observations to nine significant figures; the gravitational constant expressed in centimeter-gram-second units is known from laboratory measurements to only four significant figures. It is the low accuracy in the conversion factors between the two sets of units, especially the unit of length (astronomical unit to c.g.s.) which prevents astronomers from converting the more precise value of this fundamental constant to the c.g.s. system.

Determination of planetary masses. When the distances between objects in the solar system have been established more accurately, the next objective in astronautics would be the determination of the masses of these objects. It is necessary to know the mass of a planet in order to determine its effects on the path of a nearby space vehicle, so planetary masses will be an essential input in calculating interplanetary trajectories accurately.

It is just this relationship between planetary masses and trajectories which forms a useful basis for a mass determination. Space vehicles dispatched on paths close to the various planets would be accurately tracked (perhaps with auxiliary position sensors in the vehicles themselves, such as star trackers and radars). From a precise trajectory the planetary mass would be deduced.

Entry into planetary atmospheres. As noted above in connection with advanced satellite experiments, it will be possible to learn a good deal about the planets and their atmospheres from satellite observing stations. However, a logical prelude to an actual landing on a planet (though probably not a necessity in the case of Mars or Venus) would be the observation of the behavior of an instrumented "reentry body" as it plunged into the planet's atmosphere. From a knowledge of its approach trajectory and a time history of altitude, deceleration, and vehicle surface heating, the atmospheric data necessary for designing subsequent entry vehicles could probably be determined.

Of course, the planets differ tremendously. Present estimates indicate that it would be even easier for a satellite to penetrate the atmospheres of Mars or Venus, given a slanting approach, than to return to the earth. The atmosphere of Mercury is essentially nonexistent. It is for the larger outer planets that such atmospheric entry bodies, or probes, would be most useful. This is discussed further in the next section.

Landing on the planets. Clearly, each planet is unique in its characteristics, and so the objectives and techniques for a landing vehicle would be different for each planet. Mercury, small and sun-scorched, poses many of the same problems as our moon. Venus and Mars, the most intriguing planets as well as the closest, will undoubtedly merit attention first, and the problems associated with the placing of instruments on their surfaces are so similar to those involved in the placing of instruments on our earth's surface that development of landing schemes and experiments should be fairly straightforward, once the guidance and propulsion problems have been overcome. The large outer planets are altogether different from the inner planets, and there may be no such thing as "landing" on their inner cores, which very possibly are nowhere solid but may consist of a liquid center merging with a deep gaseous envelope. One might, instead, design a vehicle which would enter the atmosphere of such a planet and then settle to a certain density level, where it would float, like an inextensible balloon. As for Pluto, we can now only guess at what its atmosphere and surface are like.

To restrict the discussion to Venus and Mars, the significance of obtaining observations on the surfaces of these two planets is too obvious to require emphasis. Moreover, the number of things which one would wish to find out about these sister planets is overwhelming. The most compelling question is undoubtedly: What forms of life, if any, do these planets have?

For the purpose of paving the way for subsequent landings on these two planets by manned space ships, the following are probably the most important features to be determined: (i) atmospheric density and composition near the surface; (ii) the range of atmospheric temperatures and winds near the surface; (iii) gross terrain features, such as mountains, valleys, snow fields, and, at least in the case of Venus, possible rivers and seas. It must be remembered that the surface of Venus is unobservable in the visible or infrared, due to the continuous cloud deck, so one must both land to explore its surface and fly over it at relatively low altitude to map it by radar. Mars could probably be roughly mapped by aerial reconnaissance without penetration of its atmosphere, but it might be impossible to identify some features without a closer look; (iv) surface composition. One would expect the surfaces of these planets to be infinitely varied, as is the surface of the earth. Still, one would learn a great deal about the conditions to be encountered on landing if one had previous knowledge of the chemical composition of some representative soils, their hardness and depth, their moisture content, and so forth.

Manned Space Flight

Although it is impossible to predict how quickly man himself will follow his exploring instruments into outer space, the inevitable culmination of his efforts will be manned space flight and his landing on the nearer planets. It is clear that he can develop the ability to do these things, and it is hard to conceive of mankind stopping short when such a tempting goal is within reach.

The attainment of manned space flight, however, cannot now be very clearly justified on purely rational grounds. It is possible, at least in principle, to design equipment which will do all the sensing needed to explore space and the planets. Mobile vehicles could be designed to land and crawl across the face of each of these distant worlds, measuring, touching, looking, listening, and reporting back to earth all the impressions gained. They could be remotely controlled, and so could act like hands, eyes, and ears for the operator on earth. Moreover, such robots could be abandoned without a qualm when they ran out of fuel or broke down.

Though all this could be done *in principle,* there may be a point at which the complexity of the machine to do the job becomes intolerable, and at which a man is found to be more efficient, more reliable, and above all more resourceful when unexpected obstacles arise. It is, in a sense, an article of faith that man will indeed be required to do the job of cosmic exploration personally—and, furthermore, that he will *want* to do the job himself, whether required to or not.

With man's first venture into outer space, a new program of research and exploration will begin. The program described above will therefore be the prelude to the drama to follow.