The continued and expanded study of Mercury is important to several aspects of planetary science. We first review the broad scientific objectives of such exploration and describe the methods by which such scientific objectives may be addressed. Groundbased optical, infrared and radar astronomy are discussed first, followed by Earth-orbital observations and in situ missions to Mercury. Several planned NASA missions, including the ASTRO Spacelab payload and the Hubble Space Telescope, have the potential for making important contributions to the study of Mercury. Sounding rockets can obtain ultraviolet spectroscopy when spacecraft lack such technical capabilities as extensive optical baffling. There are difficult performance requirements for getting spacecraft to Mercury, although technical solutions have been proposed to overcome these difficulties. A method that offers immediate potential to mount substantial Mercury missions with current launch vehicle inventory is the use of the multiple gravity-assist trajectories recently discovered by Yen. We discuss potential payloads for Mercury orbiters and the importance of eventually landing on the surface.

I. INTRODUCTION

Motivations for continued observation and exploration of Mercury are made clear by various authors in this book: Mercury’s atmosphere displays unique characteristics important to the understanding of satellite and cometary
atmospheres. Mercury’s geology is relevant to the general processes which affect terrestrial and satellite bodies. Mercury’s magnetosphere is complex and enigmatic: it represents the sole known example of a substantially magnetized small body and of a magnetosphere existing in the absence of an ionosphere. Additionally, Mercury’s evolution represents an end-member case because it formed—or at least is now located—at a temperature extreme in the solar system.

Although Mercury is an important object for study, its location near the Sun makes it a difficult object either to reach or observe. Fielding orbiter and lander missions is difficult because of the tremendous launch and orbit insertion energy requirements imposed by Mercury’s orbit close to the Sun. Additionally, the insolation environment imposes considerable constraints on spacecraft design, and hence mission cost. Mercury’s physical proximity to the Sun also makes the planet difficult to observe from the Earth, since solar elongation angles in excess of 28 degrees are never obtained.

Due in part to the intrinsic difficulty of reaching Mercury, potential missions have received low priority in planetary exploration plans. Neither NASA’s Solar System Exploration Committee nor the NRC’s Space Science Board have formally recommended high priority new missions to Mercury.

Faced with combined technical and programmatic difficulties, researchers interested in Mercury may for some time be faced with the prospect of adapting instruments and spacecraft designed for other purposes to observe Mercury remotely. Here, we examine the near-term avenues presently available for observing Mercury, both from the Earth and from space. We also discuss the scientific rationale and technical concepts for missions to Mercury. Before addressing these subjects, however, we first review the broad scientific questions which future observations must address.

II. KEY SCIENTIFIC QUESTIONS AND EXPERIMENTS

As described in this book, our knowledge of Mercury today stands at a point somewhat similar to our state of knowledge of Mars prior to Mariner 9. Although Mariner 10’s three successful flybys of Mercury provided sufficient information to develop pointed scientific questions, we still lack the data necessary to characterize the basic compositional make-up, phenomenological processes, and evolutionary history. Many of our questions require synoptic observations.

Simply put, the key scientific questions which must be addressed by the next generation of Mercury observations are:

1. What does the still unimaged hemisphere of Mercury look like and what are the inferred geomorphological and tectonic processes?
2. What is the chemical and mineralogical composition of the surface? What
are the textural properties of the surface? How do these vary among geologic units?
3. What is the full chemical composition of the atmosphere? How do the composition and pressure vary with location on Mercury and orbital phase?
4. By what processes are the Mercurian atmosphere generated?
5. By what process is the Mercurian magnetosphere generated and how does this magnetosphere interact with the time-dependent atmosphere and variable solar wind?
6. Does Mercury have a present-day liquid core and attendant dynamo? If so, how much of the core is molten?
7. What are the global geophysical properties of Mercury (gravity field, heat flow, and seismicity)?
8. What is the chronology of internal and external processes that have modified Mercury over time? Are there clues about how the planet formed?

Beyond these questions, Mercury observations also offer promise toward the general understanding of planetary magnetospheric, cratering and exospheric processes. Further still, Mercury provides a unique location for tests pertaining to general relativity and for the study of solar physics.

In order to address the scientific goals of future Mercury studies, multiple observational techniques must be employed: Question (1) requires high-quality imaging and altimetry of the entire planet. Question (2) requires multi-spectral imaging, orbital X-ray and gamma-ray fluorescence measurements, and surface geochemistry experiments. Questions (3) and (4) cannot be answered definitively without high-resolution synoptic spectroscopy (particularly in the ultraviolet), as well as in situ charged-particle measurements, and in situ mass spectroscopy. Questions (5) and (6) await in situ magnetic field and charged-particle environment observations extending over time scales at least as long as the Mercurian year (88 days). Complete answers to Question (7) require surface exploration. Question (8) involves a synthesis, and will therefore rely upon information obtained from all of the aforementioned techniques, and others.

This recounting of the key scientific questions and the methods by which these questions can be resolved provides two insights. First, without future spacecraft missions to Mercury, even our first-order questions cannot be fully answered. Second, however, synoptic Earth- and space-based remote sensing can clearly still contribute important findings, particularly in terms of improved imaging, altimetry and spectroscopy. In the remainder of this chapter, the specific projects and programs which can improve our knowledge of Mercury are reviewed.

III. FUTURE GROUNDBASED STUDIES

Mercury must always be observed from the Earth at small solar elongation angles. At its maximum, Mercury never strays farther than 28° from the
FUTURE OBSERVATIONS AND MISSIONS

Sun. Such close proximity makes observations difficult at best. However, as evidenced by the recent discovery of sodium and potassium in Mercury's atmosphere by Potter and Morgan (1985a, 1986a), ground-based work can still make important contributions.

Among the priorities for future ground-based work are: (1) expanded atmospheric composition and abundance studies, particularly as a function of Mercury's orbital position; (2) surface composition studies by the technique of spectrophotometry; and (3) radar observations. In addition, related activities such as radar and spectrophotometric observations of asteroids, satellites, and the Moon as well as laboratory studies of meteorites will contribute to our understanding of Mercury by placing it in the larger context of planetary studies.

Several key projects remain concerning Mercury's atmosphere. Most important is the study of spatial and temporal variations in the atmospheric abundance of sodium, potassium and any other as-yet-undiscovered constituents of the Mercurian atmosphere. The measurement of such variations over Mercury's orbital and rotational periods is vital for understanding the mechanisms(s) responsible for the generation of this tenuous atmosphere (cf. Chapter by Hunten et al., and references therein). Temporal variations in Mercury's atmosphere are particularly important to understand in light of the well-known convolution of true abundance and observed abundance caused by the high radial velocities of the planet in its elliptical orbit. In addition to spectroscopy, stellar occultation opportunities (Mink 1987) could potentially provide measurements of the vertical composition, pressure, and temperature structure of Mercury's atmosphere.

Ground-based spectrophotometric observations of Mercury's surface should unlock significant information about Mercury's formation conditions. Resolving the question of the presence of Fe$^{2+}$ in the surface mineralogy (Chapter by Vilas) would provide information about volatiles in the surface materials, and by extension, address questions concerning the extent of the feeding zone which Mercury sampled during its formation. Mercury's silicate composition could be probed with a search for the Restrahlen bands at thermal infrared wavelengths.

New ground-based instrumentation allows telescopic observations to be made across extended spectral ranges, and facilitates compensation of the effects of high airmass and bright sky background. The correlation of compositional variations with geologic units identified in Mariner 10 images, and the extension of such research to the as-yet-unimaged hemisphere of Mercury, is of particular interest.

Ground-based observations are also useful for studying surface properties and composition. However, as with atmospheric studies, such observations are complicated by Mercury's small size and its proximity to the Sun. However, spectrophotometry (Chapter by Vilas) and polarimetry (Gehrels et al. 1987) each continue to be profitable. Of particular interest would be the correlation of compositional variations with the specific geologic units mapped...
by Mariner 10 (Rava and Hapke 1987), and the extension of such research to the prediction of the as yet unmapped portions of Mercury.

Radar and radio observations can provide information about topographic slope and altitude, surface electric properties, surface thermal properties, spin-axis orientation, and the ephemerides of Mercury (R. Landau, personal communication). Indeed, it was by radar techniques that Mercury’s 2:3 orbital-to-rotational resonance was discovered.

Radar work has demonstrated that Mercury’s surface may be less lunar-like than once suspected. In particular, some radar data have indicated that Mercury is comparatively smooth from an rms-slope standpoint, but anomalously rough on small scales (1–10 cm). Studies by a variety of groups (see, e.g., Chapters by Clark et al. and Harmon and Campbell) have demonstrated that radar-derived roughness and slope data appear to correlate with terrain units imaged by Mariner 10. Over the next decade, radar system improvements at both Goldstone and Arecibo, as well as increased latitudinal coverage will significantly improve the radar data base on Mercury, and provide our only means of actively probing the planet without mounting a space mission.

Radio and infrared observations can also contribute to studies of the thermal, mechanical and electric properties of the surface regolith.

IV. OBSERVING MERCURY REMOTELY FROM EARTH ORBIT AND DEEP SPACE

Remote observations of Mercury from space offer certain advantages over Earth-based studies. They can achieve broader spectral coverage and diffraction-limited resolution and also can circumvent solar-elongation difficulties with appropriate baffling systems. In this section we demonstrate the desirability of adapting future satellite platforms for observations of Mercury from Earth orbit.

It is important to recognize that a few “proof-of-concept” observations of Mercury have already been carried out from Earth orbit. Included among these are serendipitous observations by the Skylab ATM and Solar Maximum Mission coronagraphs. Additionally, one simple Space Shuttle payload (CHAMPS) had planned to observe Mercury during orbital twilight periods to obtain low-resolution ultraviolet spectra; CHAMPS was destroyed with the Orbiter Challenger on its tragic last mission.

While thermal and telescope baffling constraints have precluded observations of Mercury by recent orbiting observatories, including Copernicus, IRAS and IUE, several possibilities exist for near-term space-based observations of Mercury. Among the possibilities, however, only one spacecraft is actually planning to make observations—the Hubble Space Telescope (HST). While HST was not originally believed capable of observing at small solar elongation angles, a study (LMSC 1984) conducted by the manufacturer (Lockheed Missiles and Space Company) has demonstrated that imaging ob-
servations can indeed be made during orbital twilight periods when the Sun is occulted by the disk of the Earth.

It is estimated that HST will be able to achieve 30 to 60 km resolution at Mercury. This will permit the as yet unmapped hemisphere to be imaged, thereby revealing the full pattern of global geology for the first time. At a spatial resolution of 30 to 60 km, basins, large craters, scarps and other large-scale constructs may be recognizable. The question of hemispheric geologic asymmetries may also be addressed. Sufficient observations are planned to map the entire planet (except for certain polar regions) at 1:150,000 scale. Because HST's imaging systems include extensive filter wheels, multispectral imaging will also be possible.

While Space Telescope can make images of Mercury, it cannot obtain Mercurian spectra. This limitation derives from engineering constraints on the spacecraft's navigational capabilities. In short, HST must navigate to and guide on Mercury by means of gyroscopes because its star trackers cannot operate in close angular proximity to the Sun. Using gyroscopes limits the ability of the Space Telescope to place accurately its extremely small spectroscopy slits on Mercury. By contrast, the imaging apertures are quite large. Thus, while one confidently expects to obtain albedo and large-scale topographic maps from HST, it is beyond HST's capability to obtain Mercury spectra.

Concerning ultraviolet observations, it is particularly important to note that the important spectral region from 1800 to 3200 Å remains wholly unexplored at Mercury. The Mariner 10 spacecraft did not include this capability (Broadfoot 1976). This portion of the ultraviolet is diagnostic both to atmospheric studies (Barth 1969) and to mineralogical investigations (Wagner et al. 1987). Ultraviolet spectra of Mercury cannot be obtained by Space Telescope for the technical reasons cited above.

High-resolution ultraviolet spectra of Mercury and its atmosphere are of considerable scientific import. They would (1) permit diagnostic surface mineralogy bands to be observed (including the iron-oxide absorptions at 2600 Å), (2) establish the presence or absence of currently undiscovered constituents of Mercury's atmosphere such as Mg and Mg+ , (3) permit the time-dependent measurement of atmospheric composition, temperature and pressure profiles, (4) document the ultraviolet albedo curve of Mercury, and (5) search for aurora. Given the importance of ultraviolet spectroscopy, we now examine how such data might be obtained in the essence of missions to Mercury.

One way ultraviolet observations could be made is by using the recently proposed Earth-orbiting Planetary Telescope mission. Such a satellite, as now envisioned, would employ extensive solar baffling specifically to permit synoptic, long-term imaging and spectroscopy of Mercury and Venus, comets approaching perihelion, and certain asteroids. Both visible and ultraviolet detectors have been suggested for the payload. However, this mission is not yet approved and is therefore, at best, years away.
Another proposal for obtaining exploratory high-resolution Mercury ultraviolet spectra involves one or more flights of an ultraviolet telescope/spectrometer aboard a sounding rocket (cf., Table 1). As has been pointed out (Stern et al. 1986), a typical 300 rocket flight observation using a 16-inch telescope with modern digital array detectors could obtain A-class surface spectroscopy in the mid-ultraviolet. The detection and equivalent-width measurement of a variety of suspected but unobserved atmospheric atoms and ions, including magnesium, could be carried out by a sounding-rocket mission. Such an experiment would also provide the ultraviolet surface albedo curve to high accuracy (<1% rms).

Similar sounding rocket experiments have successfully obtained spectra of Venus, Jupiter and bright comets. The advantages of a rocket experiment (Fig. 1) include its low cost, its rapid-response time scale (12–18 months) and its independence from the oversubscribed Shuttle and ELV manifests. By combining a twilight solar occultation and optical baffling, extremely high off-axis light rejection capabilities can be obtained. After an initial “survey” flight, reflights could (a) employ echelle resolution spectroscopy to measure resonance-line profiles, (b) perform surface spectroscopy of the opposite hemisphere, and (c) explore the orbital-phase dependence and time dependence of atmospheric composition and magnetospheric structures.

In addition to dedicated sounding rocket or satellite missions, ultraviolet spectra of Mercury could also be obtained by adapting the ASTRO Spacelab payload. Were the ASTRO observatory to incorporate a more extensive solar baffle, it could obtain a wealth of data about Mercury and its atmosphere. ASTRO carries three meter-class ultraviolet telescopes with imaging, spectroscopic and polarimetric capabilities.

It may also be possible to observe Mercury and its environment remotely if the proposed CRAF cometary spacecraft travels inside 1 AU (thereby being able to make Mercury observations at higher elongation angles than are available from Earth, hence reducing the need for extensive solar baffles).

**TABLE I**

<table>
<thead>
<tr>
<th>Scientific Rationale for Observing Mercury's Ultraviolet Spectrum from a Sounding-Rocket Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Obtain a Mid-UV Survey Spectrum of Mercury: 1800–3000 Å is completely unexplored</td>
</tr>
<tr>
<td>2. Surface Science Objectives:</td>
</tr>
<tr>
<td>Albedo as f(X)</td>
</tr>
<tr>
<td>Diagnostic mineralogy, including silicate and FeO absorption bands</td>
</tr>
<tr>
<td>3. Atmospheric Science Objectives:</td>
</tr>
<tr>
<td>Identification of emissions from potential neutral and ionic constituents which could include: Mg, Si, Al, Fe, S</td>
</tr>
</tbody>
</table>
In a similar vein, we also point out that the Pioneer Venus Orbiter has been used on several occasions to observe bright objects (e.g., comets) unobservable from Earth due to poor geometry. Although this spacecraft is spin-stabilized, the Pioneer Venus Orbiter Ultraviolet Spectrometer (PVOUVS) experiment can detect Mercury Lyman-α emissions at the level detected by Mariner 10's ultraviolet spectrometer in a 12-hour integration (A. I. Stewart, personal communication). The routine monitoring of Mercury's hydrogen envelope (which is not possible from within the Earth's geocorona) would provide a unique data set in the absence of an in situ Mercury mission. The PVOUVS can also measure Mercury's ultraviolet albedo.

V. MISSIONS TO MERCURY

As we have pointed out, certain key questions about Mercury can be answered only by sending spacecraft to observe the planet closely and to sample its surface and its environment. Although the planetary science community has not formally endorsed missions for the study of Mercury in the past decade, the objectives for such a mission have been assessed (Jet Propulsion Laboratory Publ. 77-51, 1977).

Because the first-order questions about Mercury can only be fully answered by long-term measurements, flyby missions to Mercury are not scien-
tically preferable. We therefore restrict our attention in this chapter to orbiter and lander missions.

As noted, the launch and orbit insertion energy requirements necessary to mount orbiter and lander missions are severe (Yen 1985). This is due to a combination of Mercury's position deep in the solar gravitational well, the planet's small mass which reduces its gravitational braking potential, and its lack of a substantial atmosphere which could be used for aerobraking. Additionally, the spacecraft design requirements for Mercury missions are complicated by the hot near-Sun environment.

In the past, a number of technology-driven techniques for achieving the $\Delta V$ performance necessary to mount Mercury missions have been studied. Included in these studies were: extremely large launch vehicles (Friedman 1978), solar-sail propulsion systems (French and Wright 1986), and solar-electric propulsion systems (Friedlander and Feingold 1977). Unfortunately each of these techniques suffers a common weakness: they are technology driven. Neither Saturn-class launch vehicles, nor solar sails, nor solar-electric propulsion systems are available today; they are not even under development by NASA. Given Mercury's past lack of priority in the queue of potential planetary space exploration missions, we regard those missions requiring the development and flight test of new high-performance propulsion systems to be substantially less likely to occur. Since an available and less costly alternative has recently been discovered, we will not consider technology-driven approaches further; the interested reader is instead referred to the references cited above.

How might Mercury be reached using available launch vehicles and propulsion systems? Recently, Yen (1985) has discovered a family of multiple Venus-Mercury encounter trajectories which, through successive gravity assists, reduce mission performance requirements to levels deliverable by available systems, such as Titan-Centaur, Atlas-Centaur and Shuttle/ITOS.

Venus gravity assists have long been known to reduce the launch requirements necessary to reach Mercury; in fact, this technique was employed by Mariner 10 to conduct its pioneering mission to Mercury in 1974. While such trajectories are useful for flybys, they are not adequate for orbiters and landers. This is because of the large orbit inject propulsion requirements at Mercury resulting from the high heliocentric approach velocity of the Venus/Mercury transfer orbits. Yen's contribution has been to find trajectories that employ repeated Mercury encounters to dramatically reduce the braking requirements for Mercury orbit injection.

For example, a single launch in July of 1994 using a Titan-Centaur combination could place a 1477-kg payload into orbit around Mercury. A schematic of a sample EV3M trajectory is shown in Fig. 2. Numerous launch windows capable of supporting the Yen-multiple gravity assist technique are available between 1991 and 2004; each opportunity offers several distinct en-
route trajectories which trade transit time against injected payload mass (see Table 1).

Given this remarkable set of Shuttle and ELV compatible trajectories to Mercury, it now becomes possible to "field" substantial Mercury missions almost as easily as Mars and Venus missions. We therefore next consider the candidate experiments which would be most valuable on a return to Mercury. Of course, many of the important Mercury observations are similar in nature to those proposed for the study of other solid bodies including Mars and asteroids, and most particularly the Moon.

While it is generally regarded important that a close correspondence between future lunar and Mercury payloads be maintained, the breadth of Mercury studies is greater than that of lunar studies. This is because Mercury has an atmosphere, which the Moon has not, and because Mercury is magnetized, which the Moon is not. Further, Mercury's close proximity to the Sun provides a unique vantage point for measurements of the possible time variations in the gravitational constant, for frame-dragging tests important to general relativity theory (Committee on Gravitational Physics, 1981), and for precise measurements of (or at least constraints on) the solar quadrupole moment (Committee on Solar Space Physics, 1980). Given these differences between the Mercury and lunar science objectives, it is clear that additional instruments, such as an

![Image of trajectory diagram]

Fig. 2. Proposed EV2M4 gravity-assisted trajectory necessary to put a 1464-kg payload into 300 km circular orbit around Mercury. The payload, launched using a Titan 34D7/Centaur G', requires 4.5-yr flight time from the Earth to Mercury (figure from Yen 1986).
ultraviolet spectrometer and precise radio-science instrumentation should be included on future missions to Mercury.

The key measurements which a spacecraft could make from orbit about Mercury are: multispectral and fluorescence spectroscopy composition maps, complete surface mapping and altimetry, magnetospheric studies, atmospheric composition and dynamics observations, dust environment studies, radiometry observations, and the determination of the first few gravitational harmonics (by radio tracking). Although a Mercury orbiter would also be useful to gravitational physics, these relativity experiments are best suited to a small stable-orbit free-flying subsatellite which can be accurately ranged upon from Earth (Vincent and Bender 1988).

To exploit most fully the capabilities of an orbiting spacecraft, a high inclination (e.g., polar) orbit is required. In combination with high inclination, a circular low-altitude orbit is preferable for surface composition and geoid mapping experiments. For magnetospheric and atmospheric studies, however, a high-altitude (apoapsis $\simeq 3 \, R_M$) elliptical orbit is desired. This higher orbit is also preferable from the standpoint of spacecraft thermal design. A mission compromise would be to insert into high orbit for 88 to 176 days, and then to lower the orbit for the remainder of the mission.

In Table III, we list the components of a Mercury-orbiter payload designed by European investigators (Neukum 1985) to study surface geology and geochemistry, atmospheric composition and structure, the local particle and fields environment, and solid-body rotation dynamics. Experiments to address tests of relativity would augment this list (see Bender et al. 1986). We

### TABLE II

Sample Mercury Orbiter Mission Opportunities, 1990–2010

<table>
<thead>
<tr>
<th>Launch Date</th>
<th>Trajectory Type</th>
<th>Transit Time (yr)</th>
<th>Payload Configuration</th>
<th>Payload Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/30/91</td>
<td>EV7M$^4$</td>
<td>4.5</td>
<td>OSL$^3$</td>
<td>1347</td>
</tr>
<tr>
<td>7/23/94</td>
<td>EV7M$^4$</td>
<td>5.6</td>
<td>OSL$^3$</td>
<td>1610</td>
</tr>
<tr>
<td>7/05/96</td>
<td>EV7M$^4$</td>
<td>4.4</td>
<td>GS</td>
<td>499</td>
</tr>
<tr>
<td>7/10/96</td>
<td>EV7M$^4$</td>
<td>5.3</td>
<td>OSL$^3$</td>
<td>1325</td>
</tr>
<tr>
<td>7/25/99</td>
<td>EV7M$^4$</td>
<td>4.9</td>
<td>OSL$^2$</td>
<td>1027</td>
</tr>
<tr>
<td>9/07/02</td>
<td>EV7M$^4$</td>
<td>4.5</td>
<td>OSL</td>
<td>955</td>
</tr>
<tr>
<td>6/30/04</td>
<td>EV7M$^4$</td>
<td>4.3</td>
<td>GS</td>
<td>652</td>
</tr>
<tr>
<td>7/10/04</td>
<td>EV7M$^4$</td>
<td>5.6</td>
<td>OSL$^3$</td>
<td>1053</td>
</tr>
<tr>
<td>8/05/05</td>
<td>EV7M$^4$</td>
<td>5.6</td>
<td>OSL$^4$</td>
<td>1398</td>
</tr>
<tr>
<td>7/09/07</td>
<td>EV7M$^4$</td>
<td>5.2</td>
<td>OSL</td>
<td>951</td>
</tr>
</tbody>
</table>

$^a$Table adapted from Yen (1985).

$^b$O = 600 kg orbits; S = 500 kg subsatellite; L = 200 kg lander. Exponent on L indicates the number of landers.

$^c$Maximum mass carried into 300 km altitude circular orbit, after injecting a 500 kg subsatellite into a 300 km × 12 hr orbit.
### TABLE III

**Proposed Mercury Science Payload**

<table>
<thead>
<tr>
<th>Instrument/Experiment</th>
<th>Scientific Objective</th>
<th>Est. Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma-Ray and Solar Neutron Spectrometer</td>
<td>Chemical abundance of K, U, Th, O, Mg, Al, Si, Ca, Fe, possibly Na, Ti, Cr, Cl. Measurement of solar and cosmic gamma ray lines and continuum, solar neutrons</td>
<td>13</td>
</tr>
<tr>
<td>X-Ray Spectrometer</td>
<td>Chemical abundances of Mg, Al, Si, Fe</td>
<td>8</td>
</tr>
<tr>
<td>Visual and Infrared Mapping Spectrometer</td>
<td>Mineralogical composition: olivine, pyroxene, plagioclase, Fe and Ti abundance</td>
<td>10</td>
</tr>
<tr>
<td>Multispectral Imager</td>
<td>Surface structure/morphology, spectral/compositional mapping</td>
<td>6</td>
</tr>
<tr>
<td>Infrared Radiometer</td>
<td>Thermal properties: thermal conductivity and temperature gradient in the regolith, additional information on composition of surface materials</td>
<td>4</td>
</tr>
<tr>
<td>Microwave Detector</td>
<td>Heat flow in combination with IR radiometer: thermal conductivity, thermal gradient</td>
<td>13</td>
</tr>
<tr>
<td>Altimeter</td>
<td>Topography: necessary for gravimetry experiment</td>
<td>10</td>
</tr>
<tr>
<td>Gravity Experiment</td>
<td>Internal structure, general relativity, gravitation</td>
<td>—</td>
</tr>
<tr>
<td>Ultraviolet Spectrometer</td>
<td>Composition of atmosphere: He, O, Xe, Ar, Ne</td>
<td>6</td>
</tr>
<tr>
<td>Magnetometer</td>
<td>Determination of the 3 elements of the magnetic field at different latitudes, longitudes, altitudes</td>
<td>2.5</td>
</tr>
</tbody>
</table>

*Adapted from Mercury Polar Orbiter proposal to ESA (Neukum 1985).

Note that the solar neutron spectrometer included for the purpose of surface compositional studies also has application to the study of solar flares and could also measure low-energy solar beta decay events unobservable from 1 AU (Cooper 1986). A detailed discussion of the science objectives of a Mercury Orbiter is given by Neukum (1985).

Finally, we point out the importance of landers and rovers on Mercury. The important measurements which landing vehicles could provide are: in situ surface composition, surface mechanical properties, internal activity (seismic and thermal), total atmospheric pressure and fractional abundance measurements, as well as local seismic profiling, and an assessment of the surface magnetic field and charged-particle environment. The emplacement of the lander’s radio beacon on Mercury would also permit the amplitude and period of the planet’s physical libration to be determined. By combining libration
data, with orbital measurements of the gravitational harmonics and spin obliquity, it is possible to determine definitively the size of Mercury's molten core (see Peale's Chapter). However, given the historically high cost of planetary landers, an attractive alternative for Mercury exploration might be the emplacement of a penetrator network (Friedlander and Davis 1976). Because they are impact landing devices, penetrators are inherently simpler, lighter and less costly than soft landers. A network of three or more penetrators could provide a capable magnetic, seismic and heat-flow array for geophysical studies of Mercury's interior.

VI. SUMMARY

Mercury occupies an important place in planetary science. At present, however, our knowledge of Mercury is perhaps more primitive than of any other planet save Pluto. Mercury is difficult to observe because of its perpetual angular proximity to the Sun, and difficult to reach because of its position deep in the solar gravitational well. Still, its study from the Earth and space is important.

Valuable remote observations remain to be performed from the Earth and from Earth orbital spacecraft equipped with suitable optical baffles. For the near term, two key projects appear to carry the greatest potential for the improvement of our knowledge about Mercury from space; these are:

1. High resolution ultraviolet spectroscopy;
2. Large-scale global structural and multispectral mapping.

Because ultraviolet observations hold high promise for Mercury, low cost adaptations of existing space instruments (e.g., ASTRO) or the commission of a sounding rocket program to explore Mercury's ultraviolet spectrum appears to be a key future requirement. Additionally, continued radar/microwave experiments and long-term spectroscopic monitoring of Mercury's atmosphere by ground-based observers will continue to provide important data.

For the longer term, spacecraft missions to Mercury must be undertaken if we are to understand the planet more fully. Flyby missions do not appear to be capable of providing the synoptic observations required to complete the exploration of Mercury. An observer-class polar orbiter, however, can satisfy the key objectives of a moderately comprehensive exploration program. Such missions are feasible with the current stable of launch vehicles.

Acknowledgments. Conversations and critiques which improved our manuscript were provided by M. Davies, L. Esposito, R. Landau, D. Siskind, H. Smith, A. Friedlander and W. Mendell. It is a pleasure to acknowledge A. Alfaro's assistance in the preparation of this manuscript.