anticipates our arguments later regarding the meaning of richness, but by this stage of the analysis we had come to believe that more elaborate measures of diversity [see, for instance, R. P. McIntosh, *Ecology* **48**, 392 (1967) for a superb development of a diversity index], although formally gratifying, may have no particularly compelling biological meaning. The meaning of such indices may be more metaphoric than functional.
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Mission to an Asteroid

Hannes Alfvén and Gustaf Arrhenius

Importance of Studying Asteroids

As long as the asteroids were regarded as fragments of a broken-up planet, interest in them was limited. There are now good reasons to believe that the asteroidal belt represents an intermediate stage in the formation of planets. This links the present conditions in the asteroidal region with the epoch in which the earth and the other planets were accreting from interplanetary grains. Hence, in order to understand how the solar system originated it may be essential to explore the asteroids.

We have already tangible samples of the earth and of the moon. Furthermore, meteorites have been carefully investigated. It is important to study also bodies intermediate in size between the moon and meteorites. The asteroids are such bodies. In this respect a study of an asteroid is more important than the study of Mars or Venus.

The Apollo 11 results suggest that the chemical composition of the moon may be significantly different from that of the terrestrial planets, the meteorites, and the sun. It is also possible that these differ from each other. It is therefore important to obtain samples of other bodies in order to establish the range of variation in elemental abundance in the solar system. There are indications that the chemical abundance in different bodies depends on their distance from the sun. An examination of samples from Mars and from one or several asteroids would clarify this. The data from asteroids would be easier to interpret than those from Mars since the asteroids are less likely to be differentiated.

Since a manned landing on Mars will not take place until after 1980, it is of interest to discuss whether a sample of an asteroid may be obtained in an easier way, at an earlier time, and as a technologically intermediate step.

A few asteroids have diameters of the order of 100 kilometers, but most of them have diameters as small as a few kilometers; probably there are also large numbers of microasteroids covering the entire range below the observed sizes.

A sample from an asteroid could in principle be obtained in two different ways:

1) A spacecraft could land on a large asteroid. This would be easier than a lunar landing because of the fact that the escape velocity of the asteroid is negligible. On the other hand, an asteroid mission is more difficult because of the distance to the asteroids and their large relative velocity with respect to the earth when some of them come into our neighborhood. An asteroid landing would be much easier than a landing on Mars.

2) A small asteroid could perhaps be captured and brought back to the earth, and either landed on the earth's surface or stored in orbit around the earth for later investigations. This would require that the asteroid be very small (mass less than 100 kilograms). The spacecraft need not necessarily be brought up to the full speed of the asteroid if some device could be constructed which catches and slows down the asteroid. A major problem is to detect objects that small and to compute their orbits.

Asteroids Close to the Earth

We shall confine ourselves to discussing missions—manned or unmanned—to asteroids in our close environment. There are a number of asteroids which at regular intervals come close to the earth. A landing on such an asteroid would be of special significance to the investigation of the early history of the solar system. Since such asteroids have acted as probes registering events in the neighborhood of the earth's orbit, an analysis of them could make possible a reconstruction of the essential features of the earth, the moon, and the earth-moon system as they were in the past. One could also derive clues to the history of the sun.

Dr. Alfvén is professor at the Royal Institute of Technology, Stockholm, Sweden, and visiting professor at the Department of Applied Physics and Information Science, University of California, San Diego. Dr. Arrhenius is professor at Scripps Institution of Oceanography, University of California, San Diego.

Table 1. Asteroids having an inclination $<15°$ and coming closer to the sun than 1.2 astronomical units.

Orbital element							Close approach data			
Number	Name	Semimajor axis (A.U.)	Eccentricity	Inclination (deg)	Time (yr)	Diameter (km)	Time	Distance (A.U.)	Relative velocity (km/sec)	Position
433	Eros	1.458	0.223	10.83	1.7606	20	1975.06	0.15	2.5	At perihelion, in ecliptic plane.
1221	Amor	1.922	0.436	11.93	2.6652	<1				Closest 1972.2; distance >0.2 A.U.
1620	Geographos	1.244	0.335	13.33	1.3874	4	1976.42	0.26	>15	At perihelion 0.19 A.U. above ecliptic plane; Geographos is performing a loop around the earth with the latter in the center of the loop.
1627	Ivar	1.864	0.395	8.43	2.5453	8				No close approach before 1980.
1685	Toro	1.368	0.425	9.37	1.5998	11	1972.62	0.14	15	73° before perihelion; 0.13 A.U. above ecliptic plane.

One may expect that such records of the history of the solar system would be more undisturbed on an asteroid than on any other celestial body. On planets like the earth, Venus, and Mars the traces of early events have been obliterated by geological processes. On the moon they are better preserved, but lunar samples will necessarily report more about the unique history of the moon than about the general conditions in interplanetary space. Moreover, all material in the moon's outer layers has been hit with at least the escape velocity, which is 2 kilometers per second. Fragile material in space is necessarily destroyed at such an impact.

Table 2. Properties of asteroids.

Body	Radius (km)	Density (g cm^{-3})	Gravitation (cm sec^{-2})	Escape velocity
Earth	6400	5.5	10^3	11 km/sec
Asteroid	6	3.0	0.5	7.8 m/sec
Asteroid	3	3.0	0.25	3.8 m/sec
Asteroid	2	3.0	0.16	2.5 m/sec
Asteroid	1	3.0	0.08	1.3 m/sec

Suitable Asteroids

Table 1, which was computed by J. Trulsen, gives a list of possible asteroids suitable for missions during the coming decade. The best opportunity seems to be offered by the opposition of Eros in 1975.

An asteroid mission is not necessarily confined to those bodies which are known today. The list from which Table 1 was computed includes only 1700 asteroids. A list of about 1000 new asteroids will be available very soon. Fifty thousand asteroids are estimated to be observable with the Mount Wilson or Mount Palomar telescopes. If all of these were cataloged, the number of available objects for a mission would be likely to increase by a factor of 20 to 30.

Asteroid Landing as an Intermediate Step toward Mars

In view of the fact that a manned mission to Mars is not likely to take place before 1980, one may seriously consider the possibility of a manned landing on an asteroid as an intermediate step in the exploration of the solar system. In addition to its scientific merit, such a project would give valuable experience of prolonged travel in translunar space. The distance to an asteroid is in some cases less than half the distance to Mars. One may even consider whether a station on an asteroid may be helpful for a later Mars mission.

The actual landing on an asteroid is simpler than the landing on the moon because of the almost negligible gravitation of the suggested objects (see Table 2). In fact, landing has the character of a docking operation and takeoff requires a minimum of power. If the spacecraft is brought to zero velocity relative to the asteroid at a distance of some kilometers from it, the gravitation of the asteroid will make it fall down. The speed with which the spacecraft hits the asteroid is of the order of a few meters per second, corresponding on the earth to a fall from a height of less than a meter.

The smallness of the asteroids will make man look big and feel great. Even in a clumsy space suit he will be able to jump about a kilometer high and return back smoothly after some 10 minutes. But there is no danger that he will be lost in space provided that the radius of the asteroid exceeds 1 or 2 kilometers. Hence, work outside a landed spacecraft can be performed without any tether between man and the craft. This constitutes an important difference between an orbiting observatory and an installation on an asteroid. As the gravitation on the asteroid is of the order of 10^{-4} of the earth's gravitation, a man weighs only a few grams. If the spacecraft has landed upside down, he can easily turn it right since the weight of a 10-ton craft on the asteroid is of the order of 1 kilogram. Consequently, a landing may be performed without any preparatory selection of suitable sites and no special landing module is needed.

On the asteroid no vehicle transportation is needed because a man can jump ahead half a mile at a time and become an around-the-globe traveler in about 2 hours. As a result it should be possible to systematically explore and sample the entire asteroid surface during one single mission. In contrast, the meaningfulness of lunar and planetary sampling is at the present seriously limited by the small radius of action permitted by present technology and by the difficulty and danger posed by large rocks and crevices.

Scientific Data Collection during an Asteroid Mission

In principle, an asteroid mission could be undertaken with an unmanned probe or a manned spacecraft. The choice between these modes should be determined by the role of such a mission in the larger framework of planetary, particularly martian, exploration. Among the data of fundamental scientific interest are those concerning the chemical composition and its variation over the asteroid. From these data it should be possible to establish the chemical uniqueness of the asteroids or their kinship with other bodies in the solar system. The successful remote-measurement techniques employed in the unmanned Surveyor experiments on the lunar surface should be useful on the asteroid, particularly for the light major elements. Recent technological advances in the field of energy-dispersion x-ray spectrometry make this a promising complementary technique for elements above atomic number 11, including critical minor elements.

The crystal structure of the material would provide information on temperature, pressure, and other variables during and after the formation of the asteroid; remote measurement of these properties is also within the capability of the Surveyor system, although it has not as yet been tested in space.

One of the fundamental questions concerns the competing rates of accretion and breakup. The temperature-pressure record in minerals would provide a basis for estimating the maximum size achieved during the past history of the asteroid. The extent of shock damage, evident from conventional x-ray and optical diagnostic investigations, should also throw light on the breakup question. For such investigations we need samples returned to the earth. Also of value would be manned or unmanned seismic experiments which would indicate to what extent the originally loose material has been compacted, and if the compaction has reached such magnitude as to suggest that the asteroid is a fragment from the interior of a planetary-sized body.

As in the lunar and martian exploration, determination of the age of the major events in the history of the asteroid is of fundamental importance; the necessary measurements can be achieved only on returned samples.

In general we see that the scientific problems associated with an asteroid mission are similar to those of the lunar missions and can be approached with instrumentation now existing and tested. By comparison with the moon and planets, the asteroids are even more promising sources of scientific information bearing on the history of the inner part of the solar system. From the point of view of space travel, journeys to the asteroids appear useful in providing the experience necessary for the more demanding voyages to the nearest planets. But there are also a number of other technological advantages to be explored, including the ease with which an underground shelter or an observatory can be constructed on an asteroid. If the asteroid is a result mainly of accretion, compaction by impact and gravitation would be low and the surface material loose. This, together with the low gravitational field, would make it simple to excavate and move soil for shielding against penetrating radiation and meteorite impact.

In Defense of Science

Alvin M. Weinberg

It is incredible, but true, that science and its technologies are today on the defensive. The attack, which is most noticeable in the United States, has been launched on four fronts. First, there are the scientific muckrakers, mostly journalists, who picture the scientific enterprise as being corrupted by political maneuvering among competing claimants for the scientific dollar. Second, there are thoughtful legislators and administrators who see a waning in the relevance of science to the public interest, especially as we address ourselves to grave social questions that are hardly illuminated by science. To deny connection between science and public affairs weakens one of the main arguments for public support of basic science: that out of basic science comes technology, which in turn improves our human condition. Third, there are the many technological critics who urge a slowdown, or at any rate a redirection, of technology because of its detrimental side effects. And finally, there are the scientific abolitionists: the very noisy, usually young, critics who consider the whole scientific-technological, if not rationalistic, mode of the past 100 years a catastrophe. To them technology is the opiate of the intellectuals (*1*); some of the more extreme would demolish human reason as the ultimate tool for achieving human well-being. The consequence, or perhaps a further symptom, of all this harassment is a reduction in society's support for science. The U.S. budget for science has fallen from 2.5 percent of the gross national product in 1965 to 2 percent in 1969.

It is appropriate at this 10th anniversary meeting of the Association of German Scientists to examine these attacks against science and its technologies. We who have devoted our lives to the use of science for human betterment cannot allow our underlying belief in the rational use of science to be undermined without reacting sharply and positively.

The Scientific "Muckrakers"

"Muckraking" is a word used by the American President Theodore Roosevelt, to describe a group of journalists who, at the turn of the century, found corruption in American society and exposed it. The scientific muckrakers, such as Daniel S. Greenberg, Spencer Klaw, and others, see corruption in the scientific-political system. Perhaps it would be more accurate to say their sensibilities are hurt by the existence of a scientific politics.

By scientific politics I mean the process, essentially political, by which pri-

The author is the director of the Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830. This article is adapted from an address given on 18 October 1969 at the 10th anniversary of the Association of German Scientists at Munich, Germany.