Deadline for Nominations: 15 September 1977
AAAS–Newcomb Cleveland Prize: Contest Year Is Nearly Over

The deadline for nominations of papers for the AAAS–Newcomb Cleveland Prize is fast approaching. Readers are invited to nominate papers published in the Reports section of *Science* from 3 September 1976 to 26 August 1977. The prize of $5000 and a bronze medal is now given annually to the author of an outstanding paper that is a first-time publication of the author's own research.

Nominations must be typed and the following information provided: the title of the paper, issue in which it was published, author's name, and a brief statement of justification for nomination. Nominations should be submitted to AAAS–Newcomb Cleveland Prize, AAAS, 1515 Massachusetts Avenue, NW, Washington, D.C. 20005. Final selection will rest with a panel of distinguished scientists appointed by the Board of Directors.

The award will be presented at a session of the annual meeting at which the winner will be invited to present a scientific paper reviewing the field related to the prizewinning research. The review paper will subsequently be published in *Science*. In cases of multiple authorship, the prize will be divided equally between or among the authors; the senior author will be invited to speak at the annual meeting.

Reports

Mining the Apollo and Amor Asteroids

Abstract. *Earth-approaching asteroids could provide raw materials for space manufacturing. For certain asteroids the total energy per unit mass for the transfer of asteroidal resources to a manufacturing site in high Earth orbit is comparable to that for lunar materials. For logistical reasons the cost may be many times less. Optical studies suggest that these asteroids have compositions corresponding to those of carbonaceous and ordinary chondrites, with some containing large quantities of iron and nickel; others are thought to contain carbon, nitrogen, and hydrogen, elements that appear to be lacking on the moon. The prospect that several new candidate asteroids will be discovered over the next few years increases the likelihood that a variety of asteroidal resource materials can be retrieved on low-energy missions.*

O'Neill (*1*) has suggested that it is possible, using existing technology, to construct large communities in a stable high Earth orbit. These communities would be built from factories that would process materials launched by an electromagnetic mass driver from the shallow gravitational potential well of the lunar surface (*2*). This concept has since been expanded to include the manufacturing of satellite solar power stations in high orbit, and offers a favorable benefit-cost ratio for the delivery of terrestrial electrical power in less than 20 years (*3*). Small asteroids have also been suggested as resource candidates because of their zero gravity fields and the possible availability of metals and other materials (*4*).

Comparing the cost of retrieving resources from competitive sources involves the study of a number of variables. Perhaps the single most important parameter is the total energy required to retrieve those resources at the most convenient opportunities. To a first approximation, the energy of retrieval is proportional to the mass and thus to the cost of the propulsion system required to move materials through the velocity increment to the locations of their end use. The energy per unit mass of resources retrieved is proportional to the square of the velocity increment, Δv, and so the evaluation of Δv for sample missions provides a useful data base for the economics of nonterrestrial mining.

Mascy and Niehoff (*5*) have outlined a mission profile for a sample return from the Amor asteroid 433 Eros. Niehoff (*6*) has evaluated the opportunities of a mission to the recently discovered Apollo asteroid 1976 AA and to the Amor asteroid 1943 (1973 EC). He concluded that a 1-kg sample could be returned to the surface of Earth in a 3-year round-trip mission to asteroid 1943 launched in 1992 by one space shuttle containing a supply of propellants and a recoverable upper stage. Other investigators (*1*, *4*) have discussed bringing material in from the asteroid belt, about 2.5 astronomical units (A.U.) from the sun. Table 1 compares lunar missions with favorable missions to various asteroids, broken down in short-thrust velocity increments from low Earth orbit to a heliocentric Hohmann transfer orbit (Δv_{esc}), from transfer orbit to rendezvous with the asteroid (Δv_{rend}), from departure from the asteroid to the vicinity of Earth (Δv_{dep}), and from injection into a high Earth orbit (Δv_{heo}).

Table 1 shows that a round trip of minimum energy to a main belt asteroid of very low inclination and eccentricity would require energies (Δv^2 per unit mass) several times those for selected Apollo and Amor asteroids. The Earth-approaching asteroids become even more economical candidates than main belt asteroids when solar energy is used for transport. The main belt asteroids are in a region of solar flux five to ten times less than that at Earth, whereas the Apollo and Amor asteroids are in a region of solar flux one to three times less than that at Earth. Thus a transportation system utilizing solar energy, with a power plant subtending a fixed area exposed to sunlight, would yield five times as much energy at a selected Apollo or Amor asteroid as at a main belt asteroid. When factored in with the comparisons in the energy of transfer orbits (Table 1), it is possible to gain a factor of $\gtrsim 30$ in throughput for the transportation of material if a selected Apollo or Amor asteroid is used instead of a convenient main belt asteroid. These considerations are obviously vital in discussing initial investments in space manufacturing.

Optimized round-trip missions to some Apollo and Amor asteroids require energies comparable to those to the lunar

Table 1. Estimated parameters for missions of low energy transfer and short-duration thrust from low Earth orbit to several asteroids and the lunar surface, rendezvous, and return to high Earth orbit.

Object	Launch date	Round-trip-time	Velocity intervals (km/sec)				
			Δv_{esc}	Δv_{rend}	Δv_{dep}	Δv^{*}_{heo}	Δv_{total}
433 Eros	1977 (1993)†	3 years	4.7	1.8	1.7	1–5	9–13
1976 AA‡	1993	1 year	6.1	3.0	4.5	3–5	17–20
1943‡	1992	3 years	4.6	0.9	1.6	1–5	8–12
1943‡	1996	1 year	4.3	4.3	4.6	1–5	14–18
Convenient main belt asteroid		3 years	8	5	5	3–5	21–23
Moon		Days	3.2	2.4–3	2.4	0–1	9

*Estimated, depending on orbit height, conditions of injection, and possible gravity assist (minimum of 1 km/sec for lunar distance). †Eros has a synodic cycle of 16 years, and so a similar low-energy mission could be flown in 1993 (5). ‡See (6).

Table 2. Approximate chemical composition (percentages) of meteorites and lunar soil samples.

Component	Ordinary chondrites	Carbonaceous chondrites	Lunar samples
Silicates	75–86	76–90	98–100
Water	0.2–0.3	1–21	0
Free metals	8.3–19	0.1–3.5	0–1
Carbon	0	0.1–3.8	0
Nitrogen	0	0.01–0.3	0

surface (Table 1). But the gain from the use of Earth-approaching asteroids is greater for several reasons: (i) it may be possible to tap resources scarce on the moon; (ii) there is the prospect of discovering, in the next few years, Apollo and Amor asteroids with more favorable mission opportunities than those shown in Table 1; (iii) such missions would enable investigators to explore the asteroids (7, 8); and (iv) greater flexibility in mission design and propulsion systems would appreciably reduce the cost of space industrialization, particularly during its early phases. The requirement of soft landings on the moon, the half-time availability of solar energy on the lunar surface, and the logistics of transporting lunar material into free space and subsequently transferring it to a convenient space manufacturing site increase the cost of lunar mining as compared to asteroidal mining.

In recent years, some excellent and extensive work has been done in classifying the chemical composition and identifying the mineralogy of asteroids on the basis of Earth-based visible and near-infrared spectrophotometric and polarimetric observations (9–11). These observations have been compared with the results of laboratory studies of the optical properties of meterorites whose chemical abundances and mineralogy are well known (12). In this way, it has been possible to deduce that a generic relationship may exist between some asteroids and meteorite classes. In the main belt, the matches are particularly close between one class of asteroids and stony and stony-iron meteorites (sloping spectra, higher albedo) and between a second class of asteroids and carbonaceous chrondrites (flat spectra, low albedo). More than 90 percent of those minor planets observed thus far have been classified in one or other of these two broad spectral compositional groups, silicaceous and carbonaceous (9). Moreover, narrow-band spectrophotometry has revealed information about the chemical composition of the surfaces of 70 asteroids (13).

The compositions of six Apollo or Amor asteroids have been studied. The spectrophotometry of 1685 Toro (14) showed a close match to some common chrondritic meteorites. Extensive observations of 433 Eros during its 1974–1975 apparition have led to a possible identification of its surface composition with H-type ordinary chrondrites (15); large quantities of metallic particles, perhaps 10 to 30 percent iron, are present (16). In addition to the high metal content, the inferred composition of Eros was most similar to that of other Earth-approaching asteroids such as 1685 Toro. The results of studies of four other Apollo or Amor asteroids, 1976 AA, 887 Alinda, 1566 Icarus, and 1620 Geographos, also are consistent with the surfaces of ordinary chrondrites (11, 17).

The average chemical compositions of ordinary and carbonaceous chrondrites (18) and of lunar samples (19) are shown in Table 2. If most Apollo and Amor asteroids have the composition of ordinary chrondritic materials, the raw materials from these nearby asteroids are richer in metallic iron and nickel and poorer in aluminum and titanium oxides than the moon. It is possible in the future that some Apollo and Amor asteroids will be identified as parent bodies of the aluminum-rich meteorites, that is, meteorites containing eucrites, howardites, and aubrites. Perhaps most significant is the presence of water (about 0.3 percent) in ordinary chrondrites.

A carbonaceous asteroid would be of immense value in supplying space habitats with abundant carbon, nitrogen, and hydrogen, which have been found in only trace amounts in lunar samples (Table 2). It is likely on the basis of recent photometric, polarimetric, and radiometric observations (20) that some of the main belt carbonaceous asteroids have been perturbed into orbits approaching Earth. One such possibility is the Amor asteroid Betulia.

The increasing rate of discovery of Apollo and Amor asteroids over the last few years should make it possible to compile a list of several resource candidates and to examine retrieval opportunities. Astronomers at the California Institute of Technology (8, 21) have initiated a systematic photographic program to search for asteroids that cross the orbits of Earth and Mars. Using the 18-inch (46-cm) Schmidt camera at Mt. Palomar with sensitive emulsions, they can detect the close approaches of asteroids to absolute magnitude 18 (diameter, 1 km). From photographs of 200 to 300 sky fields per year, they expect to find two to three new Apollo or Amor objects each year to add to the known list of 20 Apollo and 17 Amor asteroids. Using avilable mass-frequency data on asteroids and meteoroids that cross the orbit of Earth, they have calculated a total population of 1600 ± 800 Apollo and Amor asteroids of diameter greater than 1 km (their cutoff in detection), with the number of asteroids increasing approximately as the inverse square of the radius. A concerted effort based on the use of the Palomar 48-inch Schmidt telescope would increase the discovery rate to approximately ten objects per year larger than 1 km and $\gtrsim 25$ objects per year larger than 100 m, the detection cutoff for that telescope. A space-borne Schmidt telescope of moderate aperture in 1 year could take $\sim 20,000$ pictures from which it is likely that $\gtrsim 100$ Apollo or Amor asteroids could be discovered and their orbits determined.

In all, there are $\sim 10^5$ asteroids larger than 100 m in diameter which, over time, pass close to Earth. Almost certainly, many of these objects will have orbits that are more favorable in energy transfer than those of currently known asteroids. It will be only a matter of time before asteroids will be discovered for which the energy transfer requirements for a mission are lower than for travel to the lunar surface (*22*). The scientific and prospecting motivations argue strongly for a step-up in the search program and in the follow-up work of orbital determination, compositional classification, and mission analysis.

The criteria for choosing any mission to transport asteroidal material back to Earth or to a manufacturing site in high Earth orbit would include low technical risk, minimum mass launched from Earth's surface to the asteroid, and the availability of propellants and energy at the asteroid. The overall goal is to minimize the cost of retrieval per unit of resource mass received at the space manufacturing facility or location of end use.

Of the various candidate transportation systems that have been studied in recent years, the electromagnetic mass driver (*1, 3, 23*) appears to best satisfy these criteria. A recent study (*24*) has considered the case of the retrieval with a mass driver of an Apollo or Amor asteroid 200 m in diameter (10^7 metric tons) through a Δv of 3 km/sec from its current orbit to a space manufacturing site in high Earth orbit for manufacturing about ten satellite solar power stations rated at 10,000 Mw each. Asteroidal material would be used as reaction mass. Aside from development costs common to space applications of mass drivers, the total investment in such a mission would be approximately $1 billion (1976 dollars) with the main costs being Earth-to-orbit transportation of the mass driver (1700 tons at $240 per kilogram), mass driver cost (at $400 per kilogram), and power plant cost (at $1000 per kilowatt). The estimated costs (in 1976 dollars per kilogram) of the retrieval of materials to a high Earth orbit are as follows: from Earth, $240; from the moon, $1 to $2; from a convenient main belt asteroid, $5 to $10; and from a convenient Apollo or Amor asteroid, 10¢ to 60¢. For all these missions it is assumed that there will be an upgraded space shuttle for Earth launch, mass drivers for interorbital transportation, and a 10-year amortization period. Other assumptions are discussed in (*24*). It is clear from these figures that the economic case for utilizing the Apollo and Amor asteroids is compelling. Since the cost for the retrieval of these asteroids may be less than for the lunar case by a factor of ~ 10, the total initial cost of space manufacturing (*1, 3, 25*) can be reduced by half.

A satellite solar power station manufactured from the first asteroidal delivery could, at a later time, supply the power to retrieve larger asteroids by mass driver. For example, a 10,000-Mw model could harvest a 1-km (10^9-ton) asteroid which could provide enough material for the world's energy supply for decades to centuries from satellite solar power as well as an abundance of raw materials for space habitats and space-processing facilities. Further analysis will be required to determine whether the costs and risks of using asteroidal materials for space industrialization are as low as those suggested here. It may be that both lunar and asteroidal approaches will be desirable and could be complementary. The exploitation of one or more of the Apollo or Amor asteroids should cause no great concern for the long-term ecological integrity of the solar system because most of these objects are doomed to collide with Venus, Earth, or the moon within a relatively short time frame, less than 10^8 years (*26*), and thousands of them exist.

BRIAN O'LEARY

Department of Physics,
Princeton University,
Princeton, New Jersey 08540

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Antibody-Induced Antigen Redistribution and Shedding from Human Breast Cancer Cells

Abstract. *Cell surface antigens of human breast cancer cells undergo a rapid redistribution when bound by antibodies from cancer patients. The subsequent shedding of these antigen-antibody complexes and free antigen may be instrumental in tumor survival.*

Tumor-specific cell surface antigens are potent sources of tumor protection from host defense mechanisms and may be intimately involved in the metastatic process. Surface antigens that are shed by tumor cells may compete with the tumor for the effector processes of the immune system, thereby allowing tumor survival (*1*). In the present study we show that antibodies from breast cancer patients induce the redistribution and subsequent shedding of cell surface antigens from cultured BOT-2 human breast cancer cells (*2*). To our knowledge, this is the first demonstration of this phenomenon in epithelial tumors in humans, although similar shedding of membrane antigens from human melanoma cells (*3*) and 7*S* IgM from Burkitt lymphoma cells has been reported (*4*).

Antibody-induced redistribution and shedding of mammary tumor cell surface antigens were studied by living cell membrane immunofluorescence. The patient serum used for demonstration of antigen redistribution and shedding was known to have complement-dependent cytotoxicity to BOT-2 human breast tumor cells and was representative of a bank of 10 serums with identical reactions. This serum contained immunoglobins of the G class that bound the surface of BOT-2 cells as identified by a positive reaction with IgG specific antiserum. The immunofluorescence technique was applied to the living cell membrane by incubating for 1 hour at 4°C 5×10^6 tumor cells in 3.0 ml of patient serum from which the complement had been removed by heat. The cells were then rinsed for 1 hour in three changes of phosphate-buffered saline (PBS) at 4°C. The specimen was then coupled with fluorescein-labeled goat antiserum to human IgG for 30 minutes at 4°C and again washed for 1 hour in three changes of PBS at 4°C. This stage was considered 0 time and a sample was taken for microscopic examination. Four similar samples were taken, and in each of them the PBS was replaced with Eagle's minimum essential medium containing 10 percent calf serum. These samples were then incubated in an atmosphere of 5 percent CO_2 and air at 37°C for intervals of 2, 4, 6, and 8 hours. In a second series of experiments, BOT-2 cells were treated with patient serum at 4°C as above, incubated at 37°C for 26 hours, then reincubated in the same patient serum to determine if antigens were replaced. At the end of each incubation period, the samples were extracted from the medium as pellets by centrifugation at 1000*g* for 10 minutes and mounted in buffered glycerin. Specimens were photographed on an Olympus FLM-UV microscope fitted with an FITC interference filter and a Y-52 barrier filter. Controls consisted of (i) samples from which patient serums had been omitted and (ii) samples to which serums from normal human volunteers were added.

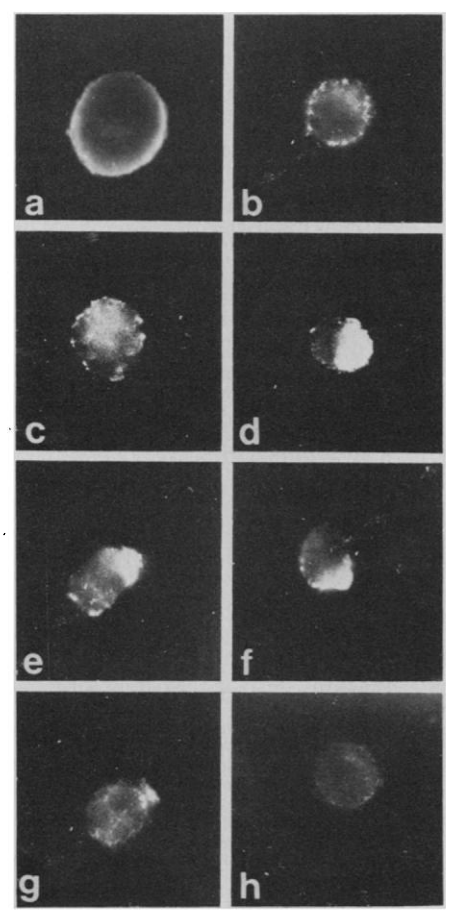

Fig. 1. Immunofluorescence of cell surface antigens. (a) Zero time. (b) After 2 hours. (c) After 4 hours. (d–f) After 6 hours. (g, h) After 8 hours. (Original magnification, ×400)

At 0 time, immunofluorescence of cell surface antigens bound by patient serum IgG appeared as a single bright halo on the tumor cell membrane (Fig. 1a). This type of localization remained unchanged up to 8 hours when the cells were maintained at 4°C. However, when the temperature was raised to 37°C a redistribution of antigens rapidly occurred. After 2 hours of incubation at 37°C the membrane antigens were redistributed into small aggregates that formed a uniform speckled pattern over the whole cell surface (Fig. 1b). Four hours of incubation at 37°C allowed further aggregation into large clumps irregularly distributed on the cell surface (Fig. 1c). After 6 hours of incubation, most cells had single fluorescent clumps with considerable fluorescent intensity (Fig. 1, d to f). After 8 hours of incubation at 37°C most cells had little or no fluorescence; however, between cells there was considerable highly fluorescent debris floating free (Fig. 1, g and h). In the second experimental series, where antibody-labeled cells were incubated an additional 26 hours, and then reexposed to the same patient serum, no binding occurred. At the end of this incubation period, almost 100 percent of the cells remained viable and could be plated for continued growth. Omission of breast cancer serum or the substitution of normal serum abolished all fluorescence.

The redistribution and shedding response of cell surface antigens to anti-