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ABSTRACT

The design and function of solar cells as a source of electrical power for unmanned space vehicles is described in this pamphlet written for high school physical science students. The pamphlet is one of the NASA Facts Science Series (each of which consists of four pages) and is designed to fit in the standard size three-ring notebook. Review questions, suggested activities, and references are included. (PR)

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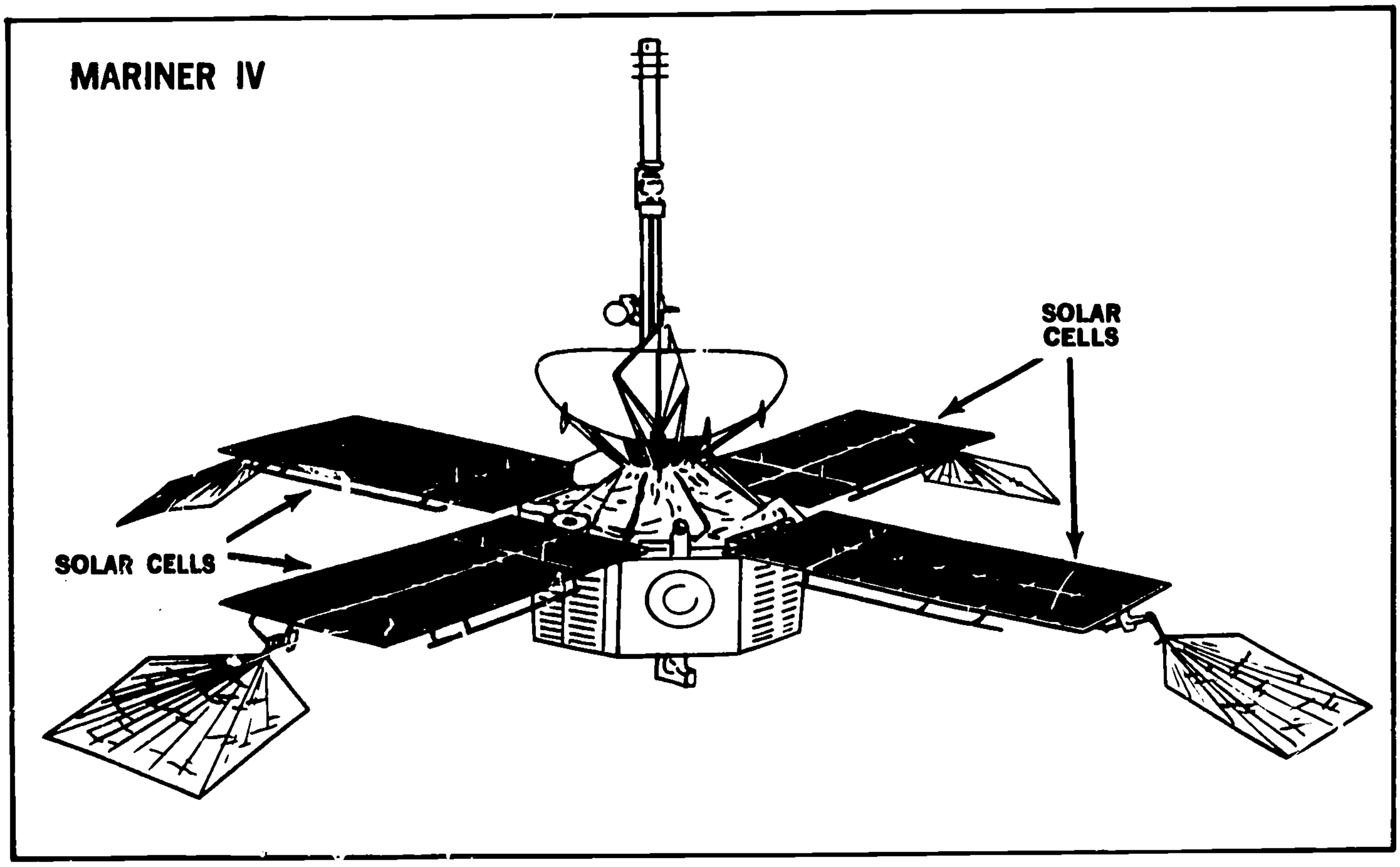
Solar Cells



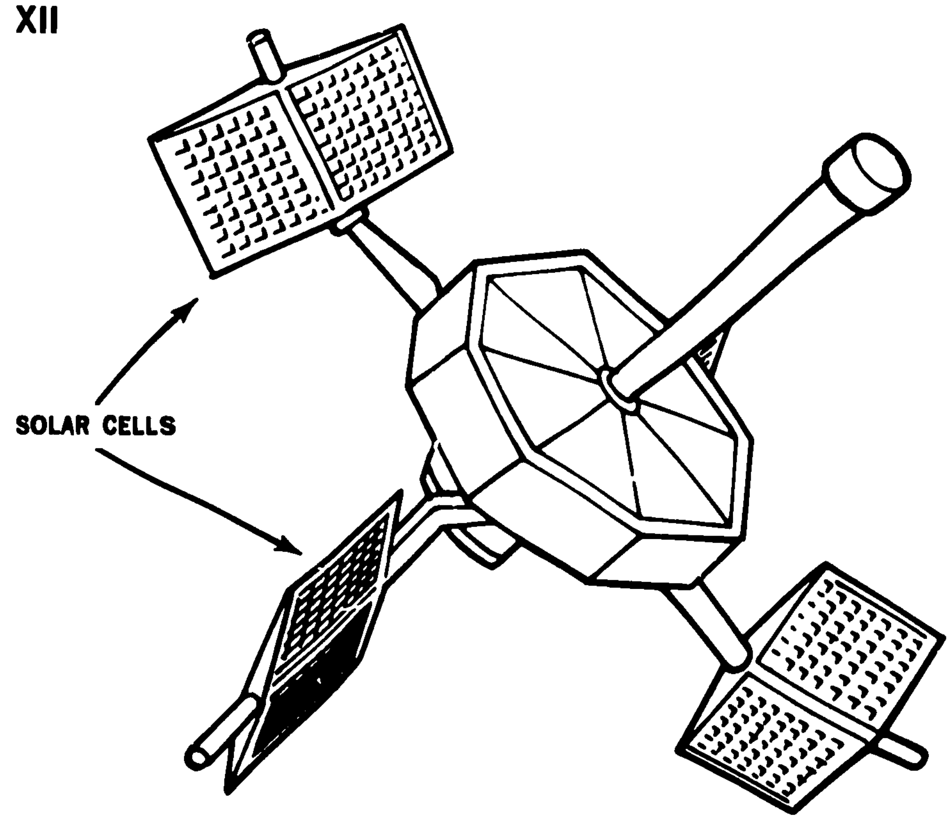
A reliable electrical system is necessary to provide on-board power for a spacecraft in orbit, or in a location, such as on the surface of the moon, where external power is not available. At present, the most common source of such power is the solar cell, a silicon crystal which converts sunlight directly into electrical energy.

Solar cells have provided primary electrical power for the majority of unmanned space missions conducted by the National Aeronautics and Space Administration. Among spacecraft using solar cells for on-board electrical power have been photographic missions to the moon of Ranger, Surveyor, and Lunar Orbiter; the Mariner flights to Venus and Mars; and numerous weather, communications, and scientific satellites.

Thousands of solar cells are required to generate even small amounts of electrical power. Mariner IV, which took and returned to earth the first photos of Mars, carried 28,224 solar cells. Their maximum power output near earth was 670 watts. The power output decreases when the intensity of illumination decreases. Therefore at Mars, much further from the sun, this output diminished to 320 watts.

All solar cells in use today are made from silicon, although there are a few other materials which could be used. But pure silicon, properly treated, makes an excellent solar cell. Oddly enough, the

EXPLORER XII



treatment involves the addition of impurities such as phosphorous and boron.

A solar cell is composed of a solid piece of silicon consisting of two electrically different regions, or "battery plates." Just as the plates of ordinary batteries behave in accordance with the materials and impurities of which they are composed, the regions of the solar cell behave differently, since one contains phosphorous and the other boron.

The first step in the manufacture of solar cells is to prepare silicon crystals containing trace amounts of boron. The boron may constitute as little as 0.00002 percent of the crystal. Silicon has four valence electrons. Each atom forms covalent bonds with each of four adjacent atoms, forming four electron pairs. Boron has only three valence electrons. Therefore when a boron atom, added as an impurity, substitutes for a silicon atom, its three electrons can pair with the electrons of three neighboring silicon atoms. But the electron of the fourth silicon neighbor is paired with a *hole*. The absence of an electron is called a *hole* because it does in fact act like a vacancy. If an electron moves into the hole to complete this electron pair, a hole is left behind, into which another electron may move, leaving another hole. Thus a hole can travel through the crystal and be in effect a conductor of electric current.

Because a hole accepts a moving electron, it acts like a positive charge. Since the boron-containing silicon contains many positively charged holes, it is called P-type silicon. (P comes from "accePtor," but it is convenient to think of P for "positive.")

The P-type silicon crystals are cut into very thin square or rectangular slices about 0.008 inch to

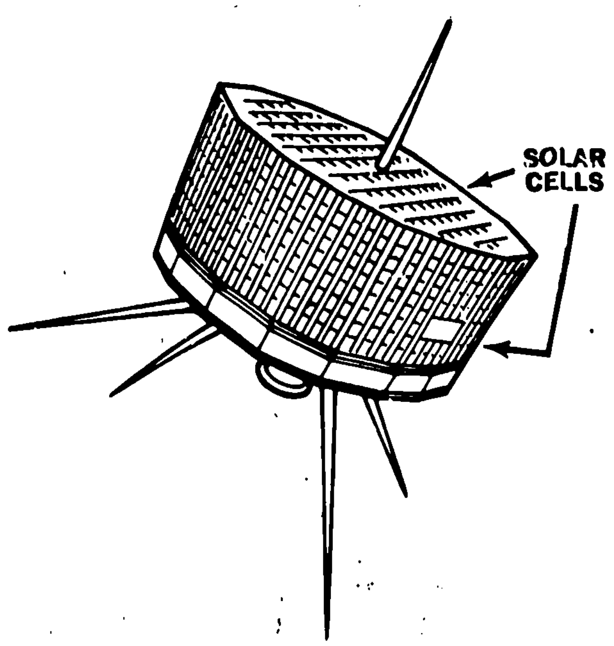
0.015 inch thick. The slices are then heated in an oven into which phosphorous vapor is introduced. The phosphorous penetrates the silicon to a depth of a few millionths of an inch. The phosphorous is then removed from one surface and the sides, leaving one surface coated. The concentration of phosphorous is about 100 times that of boron.

Phosphorous has five valence electrons. The fifth electron is not needed to complete the four covalent bonds with adjacent silicon atoms. This fifth electron is donated to the crystal and is free to move through it. Thus the phosphorous-boron-containing silicon is electron rich, with many free negative electrons. It is called N-type. (N comes from "doNor," but it's handy to think of N for "negative.")

The boundary between the P and N regions is called a P-N junction. The solar cell itself is referred to as an N-on-P cell, because it has an N region on top (toward the light) of a P region. When this boundary is first formed, there is a flow of electrons from the N region into the holes of the P region, with a corresponding movement of holes from the P region to the N region. This results in an internal voltage barrier, which makes it difficult for additional electrons to flow from the N region to the P region, since the holes that were there have in effect been filled.

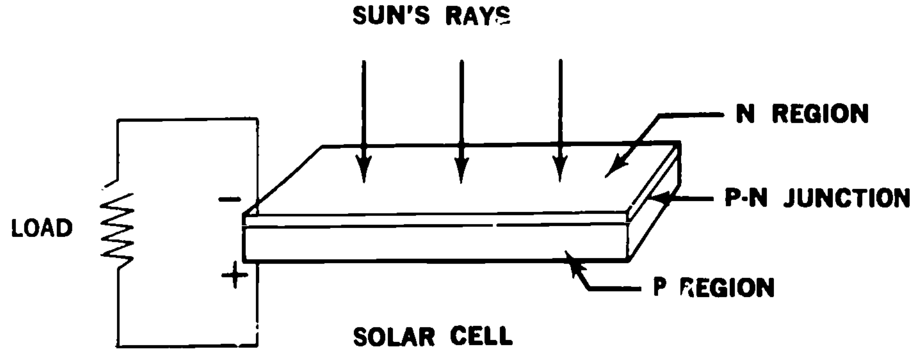
When the solar cell is exposed to sunlight, a photon of light penetrating the silicon in the N region will ionize an atom, which releases an electron, or, more properly, an electron-hole pair. This in effect charges the "plates" of the solar cell "battery." Since most of these light-generated electrons are repelled by the barrier at the N-P interface, they can more easily flow through a circuit outside the cell. Metallic contacts that have been made to the two regions of the solar cell carry the electrons through the external circuit, so that they constitute an electrical current to do useful work. When the cell is illuminated, electrons flow internally from P to N, and holes from N to P. The N region is negative with respect to the P region in an illuminated cell, as indicated in the accompanying drawing.

TIROS IV



Under the sunlight of outer space near earth, a solar cell measuring only one centimeter by two centimeters can produce a current of 60 milliamperes at four-tenths of a volt, delivering up to 25 milliwatts of power. Thus it is apparent that many thousands of the small cells are required to develop adequate electricity for spacecraft power systems. The cells are wired together in series to increase voltage and in parallel to increase current. As an added bonus, connecting them in parallel assures that if a few are damaged or malfunction in space, the remaining cells are able to continue their work without a critical loss in power.

The solar cells are mounted on a firm backing, or paddle, and will operate only when exposed to the sun. Several disadvantages of solar cells are apparent. Since the cells do not generate electricity when they are shaded from the sun, they are usually



accompanied by rechargeable batteries, which furnish power during dark periods. When in sunlight, the solar cells recharge the batteries in addition to furnishing operating power for the spacecraft. Assembling the cells takes much meticulous hand labor. The cells are fragile, and the paddle device on which they are usually mounted adds costly weight to a spacecraft. Mariner IV's four separate solar-cell paddles each weighed 18.7 pounds – about 13 percent of the spacecraft's total weight of 575 pounds.

An important problem facing the designer of solar-cell power systems intended to operate in space is radiation damage to the cells. This problem has been attacked in two ways. The past procedure was to protect the cells with a thin window of quartz or sapphire. But such a procedure made the power system extremely heavy. A better solution is to use more radiation-resistant cells. The new N-on-P cells are superior in this respect to the older P-on-N cells.

Although large silicon solar-cell arrays can provide ample power for more ambitious space missions, they are heavy, complex, and costly. Lighter, simpler, and cheaper solar cells are needed. An array of flexible cells, for instance, which could be rolled up like a window shade during launch and then unrolled for use in space might be a solution.

Considerable progress on flexible cells, called thin-film solar cells, has been made. These are produced by evaporating a thin film of semiconductor material, such as cadmium sulfide, onto a metallized plastic. Flexible film cells develop more power per pound than presently-used silicon cells. Unfortunately, the thin-film cells are less efficient than silicon cells, since they require more area and suffer degradation under cycles of temperature change. They have not been adequately tested for durability in the hostile space environment.

There are, of course, other power systems such as fuel cells, batteries, and various nuclear systems in use or under study for applications where solar cells cannot be used effectively. However solar cells, which are extremely reliable, will continue to provide primary on-board electric power for most unmanned satellites.

ACTIVITY:

Many hobby shops sell silicon solar cells at reasonable prices. These were originally manufactured for space applications but failed to meet the rigorous efficiency requirements. Obtain such a cell and test its voltage output in the dark, in sunlight, and under artificial light, using a high-impedance voltmeter. Connect the cell to a 10-ohm load and observe the change in voltage as you vary light intensity.

QUESTIONS:

1. Silicon is a member of what group in the chemist's periodic table?
2. Elements from what group are used as P-type additives? As N-type additives?
3. If a one centimeter by two centimeter cell has an efficiency of 9 percent and delivers 25 milliwatts at the earth's distance from the sun, what is the intensity of sunlight in watts per square centimeter? In watts per square foot?

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