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Voyager 2 at Neptune and Triton

In this issue of *Science* investigators who participated in a great era of planetary exploration present results of their observations of Neptune and its related bodies. Many of the authors devoted parts of 17 years or more to designing and fabricating instruments and to subsequent observations, data reduction, and interpretation. The teams participated in exploitation of an opportunity that occurs only once in 176 years when a unique alignment of the outer major planets makes feasible a robotic visit to them. Voyagers 1 and 2 were propelled into space in 1977. Subsequently both visited Jupiter and Saturn. Voyager 2 went on to Uranus and Neptune. After each planetary encounter, *Science* published the first scientific reports of results obtained from 11 different instrument packages. It is a great testimonial to the skill of the scientists and engineers involved that the instrumentation survived 12 years in the harsh environment of space.

In the course of encountering the Neptune system, some 9000 images were obtained. Observations were conducted in the visible, infrared, and ultraviolet as well as at centimeter wavelengths. The magnetic field was probed, plasmas were studied, energetic particles were measured, and radio emissions from Neptune were noted.

In many instances the various instruments independently produced results that confirmed the validity of the findings or extended the range of observations. As a result, it was possible, for example, to study the atmosphere of Neptune over a range of pressures of more than 10^{12}. The upper regions of the atmosphere consist mainly of atomic and molecular hydrogen, together with about 0.15 mole fraction helium. The lower regions contain about a 3×10^{-5} mole fraction of methane and about 10^{-7} mole fraction of C_2H_2. Effective temperature at 10^5 Pa (which corresponds to 1 bar) is 59.3 K. Internal heat sources in Neptune contribute 2.7 times more energy to thermal emissions than does solar power. The density of Neptune is 1.6. Presumably that means that it has a core of chondritic composition that is heated by radioactivity. Most of the mass of Neptune is probably H_2O in various forms. The internal heat moves to the surface in a nonisotropic fashion. This leads to great surficial activity and high winds.

Neptune's magnetic field has an intensity of the same order of magnitude as that of Earth. However, the field can be represented as a dipole displaced far from the center of Neptune and inclined by 47° with respect to the rotation axis. Neptune also emits radio signals that disclose that it rotates with a period of 16.11 hours.

During the Neptune encounter Voyager 2 instruments detected six new satellites—chunks of dark rock 50 to 200 km in size.

Triton is a most interesting object. It is the one large moon in the solar system that orbits in a retrograde direction. Its orbital plane is tilted 20° to that of Neptune. Triton apparently was captured by Neptune billions of years after the solar system was formed. Triton's surface is not pock-marked with many impact craters. The density of Triton is about 2.08, indicating a substantial rocky core. The atmosphere, consisting mainly of nitrogen, has a pressure only about 10^{-5} that of Earth. The surface apparently consists largely of water ice covered by solid nitrogen, which highly reflects sunlight. Surface temperature is 38 K. A small amount of methane present in the atmosphere is photodegraded to form C_2H_2 and other hydrocarbons. The hydrogen escapes.

After Triton initially was captured by Neptune, tidal evolution probably produced significant heating and melting. On Triton, local topographic features include cliffs, ridges, pits, and craters with relief commonly exceeding 1 km. This implies a rigid material that will not flow at temperatures of 40 to 50 K during billions of years. Water ice almost uniquely represents the substance that satisfies the boundary conditions. Terraces on Triton are features that fit in with a picture of tidal melting and H_2O.

In spite of its 38 K surface temperature, Triton displays geyser-like activity. This was noted at the south polar region, which currently faces the sun. Presumably solar radiation penetrated into the solid nitrogen, causing greatly enhanced pressure and an eruption that carried any opaque material up to 8 km above the surface.

The Voyager program was a great success. We owe the teams that participated admiration and gratitude.—PHILIP H. ABELSON