SOLAR SYSTEM

Europa's oxygen atmosphere

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THE discovery of gaseous oxygen on Europa, reported on page 677 of this issue by Hall *et al.*[1], is the climax of a 23-year search for this gas on the three outer galilean satellites of Jupiter: Europa, Ganymede and Callisto. But the gas pressure is low, a mere 10^{-5} microbar.

In June 1972 Ganymede, the largest moon in the Solar System, occulted an obscure 8th magnitude star. Successful observations were obtained from Java and India; the shadow just missed Darwin, Australia[2]. The diameter obtained (5,270 km) was within 10 km of that found later by the Voyager spacecraft, and there was marginal evidence for an atmosphere with a surface pressure around a microbar.

A few years later, in preparation for the encounters of the Voyagers with the Jupiter system, Yung and McElroy[3] proposed that the gas might be O_2. The presence of water ice on the surface implies that the vapour is in the atmosphere at some very low pressure. It is rapidly dissociated by ultraviolet radiation from the Sun, and the hydrogen escapes, leaving the oxygen to build up until it is in steady state with its loss processes. The most important of these processes follows photolysis of O_2 near the top of the atmosphere by energetic solar photons (wavelength less than 202 nm). If a photon possesses more energy than is required to dissociate a molecule, the excess can appear as kinetic energy, shared equally between the two oxygen atoms. The one that is directed upward can escape if its energy exceeds 0.63 electronvolt. Yung and McElroy found that the surface pressure could be as large as 0.4 to 1 microbar, in agreement with the value deduced from the stellar occultation data. They pointed out that their model would apply equally well to any large jovian satellite with exposed ice, specifically Europa and Callisto.

Broadfoot[4] was therefore encouraged to use the ultraviolet spectrometer on Voyager 1 to observe another stellar occultation by Ganymede, in a spectral region especially sensitive to O_2. Nothing was detected, and the upper limit obtained for the surface pressure was 10^{-5} microbar. This is almost exactly the pressure now inferred for Europa. Why did the model of Yung and McElroy predict a much higher pressure?

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Europa — a moon with atmosphere.

The answer was pointed out a few years later in a review by Kumar and Hunten[5]. There are two possible states for such an atmosphere, differing in O_2 pressure by the remarkably high factor of 10^5; Yung and McElroy discussed only the high-pressure one, which seemed to describe the result from the 1972 occultation. In this state, the O_2 builds up to a level that partially shields the water vapour from photolysis, reducing the rate to a value that can be matched by the limited loss rate of oxygen atoms (the 'Urey self-shielding mechanism'). In the low state, the photolysis rate of water vapour is limited simply by the amount in the atmosphere, which in turn is controlled by the vapour pressure and any additional sources such as bombardment by ions from the jovian magnetosphere. In principle, small changes in the supply rate could switch a given moon from one state to the other, but the transition would take around 100,000 years.

The Europa observations[1] were made in the far ultraviolet with the newly repaired Goddard High Resolution Spectrograph on the Hubble Space Telescope. They show two spectral features of atomic oxygen in roughly equal intensities: the resonance triplet centred at 130 nm and the spin-forbidden line at 136 nm. Although the optical transition probability of the second line is small, both excited states are easily reached by impact of electrons on either oxygen atoms or O_2 molecules; the latter process involves simultaneous dissociation and excitation. The analysis by Hall *et al.*[1] shows convincingly that both the spectral features, at the intensities observed, can be accounted for by the O_2 source, although there could be a small contribution from oxygen atoms. The flux of electrons of energies in the range of a few tens of electronvolts is taken from the plasma experiment on Voyager. Because these electrons penetrate right through the atmosphere to the surface, the intensities give directly the number of O_2 molecules per unit area.

Remarkably, O_2 was also found just last year on Ganymede, but there it is trapped in the ice rather than being in the atmosphere[6]. Weak, broad absorptions at 577 and 628 nm have now been identified with transitions of two coupled O_2 molecules, each from the ground state to the first excited electronic state. The band at shorter wavelength is produced by a transition to an excited vibrational level of the upper state. Weak absorptions of this type have long been known in the Earth's atmosphere, and they are much stronger in liquid and solid oxygen. On Ganymede it appears that the O_2 molecules are trapped in the water ice, where they may be generated by charged-particle bombardment.

The half-dozen large satellites in the outer Solar System are worlds in themselves, most of them larger than Pluto and even Mercury. All but Ganymede and Callisto are now known to have atmospheres, and these two, like Europa, must surely have some O_2. Titan has a dense nitrogen atmosphere containing some methane; Triton and Pluto have tenuous nitrogen atmospheres and surfaces covered with nitrogen ice; and volcanic Io has drifts of sulphur dioxide ice and wisps of the same gas in its atmosphere. □

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