hence the density tracings justifiably may be treated as intensity profiles. Of course, the errors in the equivalent widths are much larger with the weak spectra.

Measurements of the equivalent widths and estimates of their uncertainties, together with the corresponding number densities, are shown in Table 1. These values are consistent with the Lyman-α widths of about 9 Å found in δ and ζ Orionis by an earlier Princeton rocket observation[2]. The photometric quality and improved resolution of the new spectra provide much more confidence in the initial results.

Table 1. THE INTERSTELLAR LYMAN-α ABSORPTION LINE

Star	Equivalent width W_λ (Å)	Column density N (cm^{-2})
δ Ori	$8\cdot2\pm1$	$1\cdot3\times10^{20}$
ε Ori	$8\cdot5\pm1$	$1\cdot4\times10^{20}$
ζ Ori	$9\cdot3\pm1$	$1\cdot6\times10^{20}$
η Ori	12 ± 6	3×10^{20}
ι Ori	9 ± 3	$1\cdot5\times10^{20}$
σ Ori	12 ± 3	3×10^{20}

The lack of conspicuous variations in line width from one star to the next suggests that the distribution of hydrogen is not markedly irregular. The average density of hydrogen is about 0·1 atom cm^{-3} over an assumed distance of 450 parsec[8] to the Orion stars. In contrast 21 cm emission measurements[9,10] in the Orion region have indicated values around $1\cdot3\times10^{21}$ atoms cm^{-2}, which exceed the densities in Table 1 by a factor of ten. Likewise, 21 cm absorption in the continuum of the Orion Nebula[11–13] suggests that column densities in the order of $1\cdot5\times10^{21}$ atoms cm^{-2} should be present in front of the nebula. One would not expect a substantial portion of the hydrogen seen in emission to lie beyond the Orion region, which is already about 130 parsec out of the galactic plane.

It is perhaps easier to account for our disagreement with the absorption measurements by saying that most of the hydrogen seen could be associated with the nebula or by assuming that the excitation temperature of the hyperfine transition is a great deal lower than the commonly quoted value of 125° K. Although a direct comparison with the radio data may be confused by such factors as the existence of small scale spatial or temperature inhomogeneities, it should, none the less, be evident that the difficulty in accounting fully for the discrepancy in the measurements may lead to exciting conclusions on the physical nature of the interstellar medium.

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PLANETARY SCIENCE

Life in the Clouds of Venus?

WHILE the surface conditions of Venus make the hypothesis of life there implausible, the clouds of Venus are a different story altogether. As was pointed out some years ago[1], water, carbon dioxide and sunlight—the prerequisites for photosynthesis—are plentiful in the vicinity of the clouds. Since then, good additional evidence has been provided that the clouds are composed of ice crystals at their tops[2,3], and it seems likely that there are water droplets toward their bottoms[4]. Independent evidence for water vapour also exists[5]. The temperature at the cloud tops is about 210° K, and at the cloud bottoms is probably at least 260–280° K (refs. 4 and 6). Atmospheric pressure at this temperature level is about 1 atm.[7]. The observed planetary albedo falls steeply in the violet and ultra-violet[8], which accounts for the pale lemon yellow colour of Venus. The albedo decline would not be expected for pure ice particles, and must therefore be caused by some contaminant. Dust, ozone, C_3O_2 and other gases may possibly explain these data but, whatever the explanation, the ultra-violet flux below the clouds is likely to be low. If small amounts of minerals are stirred up to the clouds from the surface, it is by no means difficult to imagine an indigenous biology in the clouds of Venus. What follows is one such speculation.

A macroscopic organism living in the clouds of Venus must be regulated to live at an essentially fixed altitude. If it is carried, for example by convective downdraughts to the lower atmosphere, it will encounter uncomfortably high temperatures, and if it is carried to the cloud tops it will encounter very little moisture and very low temperatures. We therefore imagine an isopycnic organism constructed as a float bladder[9]. Because the atmosphere is primarily carbon dioxide and nitrogen, a float bladder filled with hydrogen would be very effective. Molecular hydrogen can be produced from water by photosynthesis, as is known in purple bacteria[10]. Although the observed cases are for aerobes there is no reason why photosynthetic production of hydrogen by anaerobes should not occur. We consider such an isopycnic organism near the 0·5 atm. pressure level; the atmospheric density here will be about 7×10^{-4} g cm^{-3}, depending somewhat on composition. The organism is essentially a spherical hydrogen gasbag with outer radius R_1, and inner radius R_2. For the organism to have a mass equal to the displaced mass of atmosphere, we require

$$5\times10^{-5}\,R_2^3 + \rho(R_1^3 - R_2^3) = 7\times10^{-4}\,R_1^3$$

where ρ is the density of the outer membrane. For $\rho \simeq 1\cdot1$ g cm^{-3}, $(R_1 - R_2)/R_1 \simeq 2\times10^{-4}$. If the minimum skin thickness is about 1μ, as in terrestrial organisms having a dermal layer one cell thick, the gasbags have a minimum diameter of about 4 cm, about the size of a pingpong ball. Much larger organisms would also be possible. If the skin were a unit membrane thick (about 75 Å), the organism could conceivably be as small as 75μ in diameter; but this is clearly a lower limit—it is unlikely that the requisite metabolic processes could be contained within a unit membrane.

The postulated photosynthetic organism would reside just below the Venus clouds, or in the lower cloud deck. Water would be collected either as rain or by contact with the droplets, and minerals blown up from the surface would be captured on the sticky underside of the organism, and ingested by pinocytosis. The mineral requirements would be modest, and the ash content would be a very small fraction of the dry weight. Metabolic schemes can be worked out using known terrestrial biochemistry. Much smaller non-isopycnic organisms can also be envisaged. If the Stokes–Cunningham fallout times to reach moderately high temperatures are less than the replication times and if updraughts exist, a stable population of microorganisms may be possible[1]. Life at the Venus clouds can be envisaged which operates entirely on known terrestrial principles.

The conditions in the lower clouds of Venus resemble those on Earth more than any other extraterrestrial environment now known. It is possible that life arose under more moderate conditions on the surface of Venus in its early history; for example, the planet may then have been appreciably less degassed than it is today, with an atmospheric greenhouse much less effective than the contemporary one. Outgassing advanced, surface temperatures rose, and the surface became more inclement. Organisms may have then emigrated to the clouds, and may there be awaiting the first biological experiments to be performed in the vicinity of the Venus clouds.

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Lunar Diurnal Atmospheric Tide

Haurwitz and Chapman[1] have recently described the discovery, analysis and distribution of the lunar semidiurnal air tide. There is, in addition to lunar semidiurnal excitation, a smaller lunar diurnal gravitational excitation. Although there must be some atmospheric response to this excitation, it has not yet been found in the data.

The diurnal component of the lunar gravitational potential is given by Bartels[2] as

$$\Omega = \lambda \sin\theta \cos\theta \, e^{il} \qquad (1)$$

where the physical quantity corresponds to the imaginary part of the expression; and $l = 2\pi(\tau - 2S) + \varphi$, θ is the colatitude, φ is the longitude, τ is the time in sidereal days, $S = \tau$/lunar month, and $\lambda = -19{,}706$ cm^2/sec^2. There is in addition to Ω another lunar diurnal component the period of which is one sidereal day. The closeness of the sidereal and solar days would make the separation of this lunar component in the data very difficult.

The approximate analysis of the response of the atmosphere to the diurnal component of lunar gravitational potential is simple, and shows why the response has not yet been detected. It also suggests how one may now proceed to find it. The analysis for a thermal excitation with the same latitude dependence as (1) has been given by Lindzen[3]. If we ignore the difference between τ and $\tau - 2S$, as it affects the solution of Laplace's tidal equation, then the extension of the analysis to gravitational excitation is immediate and yields

$$u = -\frac{i\lambda}{a\omega} \, e^{il} \qquad (2)$$

$$v = \frac{\lambda}{a\omega} \cos\theta \, e^{il} \qquad (3)$$

$$\delta p = \delta\rho = \delta T = \omega = 0 \qquad (4)$$

where u is the northerly velocity oscillation, v is the westerly velocity oscillation, a is the radius of the Earth, ω is the rotation rate of the Earth, δp is the pressure oscillation, $\delta\rho$ is the density oscillation, w is the upward velocity oscillation, and δT is the temperature oscillation.

An estimate of the geomagnetic oscillation resulting from u and v, as given by (2) and (3), may be obtained from the following approximate equation derived by Baker and Martyn[4]

$$\frac{\partial^2 R}{\partial\theta^2} + \cot\theta \, \frac{\partial R}{\partial\theta} \, \frac{1}{\sin^2\theta} + \frac{\partial^2 R}{\partial\varphi^2}$$
$$= \frac{aK_3}{\sin\theta}\left(\frac{\partial}{\partial\varphi}(u H_z \sin\theta) + \frac{\partial}{\partial\varphi}(v H_z)\right) \qquad (5)$$

where R is the electric current function, K_3 is some time and space averaged Cowling conductivity, and H_z is the vertical component of the Earth's magnetic field.

From Chapman and Bartels[5]

$$H_z \cong C\{\cos\theta + \tan\theta_0 \sin\theta \cos(\varphi - \varphi_0)\} \qquad (6)$$

where $C \cong -0{\cdot}6$ gauss, θ_0 is the colatitude of "equivalent" central magnetic dipole's N-pole $\cong 11°$, φ_0 is the longitude of "equivalent" central magnetic dipole's N-pole $\cong 70°$ W. Substituting equations (2), (3) and (6) into equation (5) and solving for R one gets

$$R = -\frac{iK_3 C\lambda}{2\omega}\{\sin\theta e^{il} - \tan\theta_0 \cos\theta \, e^{i(l-\varphi+\varphi_0)}\} \qquad (7)$$

The current intensity is given by

$$U = \frac{1}{a\sin\theta}\,\frac{\partial R}{\partial\varphi} = \frac{K_3 \lambda C}{2a\omega} \, e^{il} \qquad (8)$$

$$V = -\frac{1}{a}\,\frac{\partial R}{\partial\theta} = -\frac{iC\lambda K_3}{2a\omega}\{\cos\theta \, e^{il}$$
$$+ \sin\theta \tan\theta_0 \, e^{i(l-\varphi+\varphi_0)}\} \qquad (9)$$

where U is the southward (northerly) intensity, and V is the eastward (westerly) intensity. The associated variation in magnetic potential is given by

$$\Phi = -\frac{8}{3}\pi R \qquad (10)$$

where differences between the distance from the Earth's centre to the dynamo layer and the radius of the Earth have been ignored. From Φ, the magnetic field variations are obtained as follows

$$Y = -\frac{1}{a\sin\theta}\,\frac{\partial\Phi}{\partial\varphi} \cong \frac{8}{3}\pi U \qquad (11)$$

$$X = \frac{1}{a}\,\frac{\partial\Phi}{\partial\theta} \cong -\frac{8}{3}\pi V \qquad (12)$$

Due to the obliquity of the Earth's magnetic field there is, in addition to the component of R following the Moon, another component of R which is stationary. The same is, of course, true for the fields derived from R. Schematic representations of the velocity, current and magnetic fields are shown in Fig. 1. From Fig. 1 we see that the lunar diurnal tide may well be the simplest global dynamic system.