EPSPs in layers III and IV and those in layer II represent mono- and polysynaptic transmissions, respectively. A similar relation was found in IPSPs of layer II to IV cells, but with a greater slope  $(4.2 \pm 0.7 \text{ s per meter})$ and central delay ( $2.7 \pm 1.4$  ms), suggesting the polysynaptic nature of IPSPs. Besides the orthodromic responses, LGN stimulation produced antidromic spikes in about one-third of the infragranular layer cells (Fig. 2F).

The results of the intracellular responses were in agreement with those reported for adult VC (2) and LGN-VC transplant preparations (5), except that conduction velocity of the LGN axons was much slower (2, 18).

In summary, morphological and electrophysiological studies indicate that neural connections are mutually established between the cocultured LGN and VC, preserving laminar organization of afferent and efferent, and excitatory and inhibitory connectivity. Our findings indicate the existence of intrinsic mechanisms yielding appropriate axonal extension and synapse formation in LGN and VC.

#### **REFERENCES AND NOTES**

- 1. A. Peters and M. L. Feldman, I. Neurocytol, 5, 63 (1976); J. S. Lund, G. H. Henry, C. L. Macquenn, A. R. Harvey, J. Comp. Neurol. 184, 599 (1979); D. Gilbert, Annu. Rev. Neurosci. 6, 217 (1983)
- 2. K. Toyama, K. Matsunami, T. Ohno, S. Tokashiki, K. Hoyama, K. Matsunanii, T. Ohno, S. Fokasinki, Exp. Brain Res. 21, 45 (1974).
   R. W. Sperry, Proc. Natl. Acad. Sci. U.S.A. 50, 703
- (1963); P. Weiss, J. Exp. Zool. 68, 393 (1934); R. D. Lund and M. J. Mustari, J. Comp. Neurol. 173, **289** (1977); C. J. Shatz and M. P. Stryker, *Science* **242**, 87 (1988).
- Y. Komatsu et al., Dev. Brain Res. 22, 305 (1985). Hamasaki et al., Brain Res. 422, 172 (1987)
- S. M. Crain, in Cell, Tissue, and Organ Cultures in 6. Neurobiology, S. Fedoroff and L. Hertz, Eds. (Academic Press, New York, 1977), pp. 147–190; B. H. Gähwiler, J. Neurosci. Methods 4, 329 (1981).
- 7. The dissected block was confirmed to contain the entire LGN as well as a part of other thalamic nuclei (roughly one-third of the dissected block) in histological sections of the fetal brain from which the LGN block was dissected.
- G. Brunner et al., Dev. Brain Res. 2, 563 (1982). A small piece of HRP crystal was applied to a fine incision made in the connection between the LGN and VC explants. After 2 to 4 hours of incubation, the culture was fixed and reacted with diaminobenzidine.
- 10. A piece of DiI was placed on the surface of the LGN of coculture preparations fixed with formalin, and the cultures were kept for 3 to 7 days at room temperature to allow diffusion of the dye. This always yielded preferential anterograde labeling of LGN axons with very scarce labeling of VC cells [P. Godement, J. Vanselow, S. Thanos, F. Bonhoeffer, Development 101, 697 (1987)].
- 11. D. Ferster and S. LeVay, J. Comp. Neurol. 182, 923 (1978)
- 12. J. G. Parnavelas, E. J. Mounty, R. Bradford, A. R. Lieberman, ibid. 171, 481 (1977)
- 13. Y. Komatsu et al., J. Neurophysiol. 59, 124 (1988). Spontaneous discharges were not detected in the LGN and VC explants by extracellular recording. 14.
- 15. C. Nicholson and J. A. Freeman, J. Neurophysiol.
- 38, 356 (1975). 16. The critical latency was determined as a sum of conduction time of afferent impulses and the median value (1.5 ms) of the central delays for mono- and

polysynaptic EPSPs. The conduction time was calculated according to the conduction velocity of LGN impulses (0.33 m/s) and the distances between the stimulation and recording sites. The upper and lower halves of the supragranular

- layers and the granular layer were referred to as layer II, III, and IV, respectively.
- 18. Y. Fukuda, I. Sumitomo, C.-F. Hsiao, J. Neurophysiol. 50, 46 (1983).
- 19. We thank H. Fujisawa and S. Takagi for their useful advice and for permitting us to use their laboratory equipment, and Y. Komatsu and F. Murakami for their helpful advice. Supported by grants-in-aid for Scientific Research Projects 63770091 and 63112006 from the Japanese Ministry of Education, Science, and Culture

28 November 1988; accepted 8 May 1989

### **Technical Comments**

# Ultraviolet Levels Under Sea Ice During the **Antarctic Spring**

I. E. Frederick and H. E. Snell report (1) that the extended period of summertime ultraviolet (UV) radiation levels in the Antarctic during the period of ozone depletion may be harmful to indigenous life forms. It was pointed out that since the local life forms may have developed only the minimum defenses necessary to tolerate the UV levels in which they evolved, it is reasonable to consider the fractional increase in the local yearly dose as a measure of potential damage. It is therefore alarming that the presented estimates of the UV radiance during October and November at McMurdo Sound were as large as those in mid-summer.

The purpose of this comment is to point out that the spring UV enhancement will be exaggerated under the vast sea ice cover surrounding Antarctica, an environment rich in life. This conclusion follows from experiments (2-5) which clearly show that the ice is less turbid in early spring than later in the season. The increased turbidity in late spring results from the growth of weakly scattering brine inclusions as the ice warms and from the strongly scattering air channels left near the surface as brine drains into the bulk of the ice (4). To date, transmission measurements have been made only in the visible part of the spectrum, but modeling of the diffusive transport of light through sea ice (3, 5) permits extrapolation into the UV,

Fig. 1. A plot of the temporal development of the UV radiance at 305 nm under sea ice normalized to the surface radiance on 21 December (1). The lower curve ( $\triangle$ ) is for an unperturbed ozone layer assuming 315 Dobson units (DU). The upper curve (O) demonstrates the 20-fold increase in UV transmission during the presence of the ozone hole, assuming a changing ozone atmo-sphere, that is, 110 DU (5 October), 250 DU (5 November), and 315 DU (21 December) (1). The error bars on the point for 21 December cover the two turbidity limits discussed in the text. The error bars on the other points result from variations we have encountered in sea ice transmission.

relying only on the UV absorption coefficient of pure ice. This coefficient is not accurately known, but estimates based on measurements on water (6) suggest a value of about 0.2 m<sup>-1</sup> at 300 nm. For an absorption coefficient in this range, we have found that the radiance transmitted through the ice falls from  $\sim 0.75\%$  in early November to  $\sim 0.25\%$  3 weeks later. As a guide to evaluating the transmission beyond this period, we note that the measured (8) under-ice solar radiance in early October implies a 5% transmission at a wavelength (620 nm) for which the absorption coefficient is  $0.2 \text{ m}^{-1}$ . To estimate transmission of the ice after 20 November, we consider two limits: (i) there



SCIENCE, VOL. 245

is no further turbidity development and (ii) the observed order of magnitude change in turbidity of early spring is reproduced. It is found that the springtime-enhanced UV dose under the ice is independent of these limits.

Using the data developed above, we have calculated the temporal development of UV radiation at 305 nm transmitted through sea ice without a snow cover. Two cases are illustrated in Fig. 1. The lower curve shows the decrease in transmitted UV light that accompanies the increase in ice turbidity associated with the springtime warming. The upper curve was generated assuming the changing atmospheric ozone content calculated in (1). Thus, Fig. 1 demonstrates a 20-fold increase in under-ice UV radiance in early October resulting from the coincidence of the presence of the ozone hole and the period of relatively high transparency for sea ice. This clearly has implications for organisms living within and under the ice.

H. J. TRODAHL Department of Physics, Victoria University, Wellington, New Zealand, and Max-Planck-Institut für Festkörperforschung, D-7000 Stuttgart 80, Federal Republic of Germany R. G. BUCKLEY Physics and Engineering Laboratory, Department of Scientific and Industrial Research, Post Office Box 31313, Lower Hutt, New Zealand

#### REFERENCES

- 1. J. E. Frederick and H. E. Snell, Science 241, 438 (1988).
- R. G. Buckley and H. J. Trodahl, *Nature* **326**, 867 (1987).
  H. J. Trodahl, R. G. Buckley, S. Brown, *Appl. Optics*
- 26, 3005 (1987).
- R. G. Buckley and H. J. Trodahl, *Cold Reg. Sci. Technol.* 14, 201 (1987).
   H. J. Trodahl, R. G. Buckley, M. Vignaux, *ibid.*, in
- 6. S. G. Warren, Appl. Optics 23, 1206 (1984).
- C. W. Sullivan et al., Antarct. J. U.S. 18, 117 (1983).
  8 November 1988; accepted 1 March 1989

Response: The response of organisms to enhanced levels of ultraviolet radiation depends on numerous factors, only one of which involves atmospheric radiative transfer. Trodahl and Buckley make the very important point that the transmission of Antarctic ice decreases as spring progresses. Since the "ozone hole" is primarily a phenomenon of early spring, this suggests that potential biological effects of the ozone depletion may be larger than otherwise anticipated. Trodahl and Buckley show that the "hole" of October 1987 was accompanied by an increase in radiation dose beneath the ice by a factor of 20 as compared with that in years before the appearance of the ozone depletion. Despite the percentage increase in irradiance beneath the ice, the absolute radiation level is still small, since the albedo of ice remains large. The change in ice transmission over time is cause for concern, although a central issue involves a comparison between the radiation doses and radia-

## Ice Volcanism on Ariel

The report "Solid-state ice volcanism on the satellites of Uranus" by David G. Jankowski and Steven W. Squyres (1) proposes a novel emplacement mechanism for surface "lava" flows on Ariel and Miranda (on Ariel the "lava" is almost certainly a mixture of water and ammonia with perhaps additional components). Whereas terrestrial lava flows are a mixture of liquid and solids (crystals), Jankowski and Squyres propose that the flows on the Uranian satellites were entirely crystalline during emplacement. Existing models of lava flows are capable of accounting for the parabolic cross sections measured by Jankowski and Squyres. It is thus incumbent on the authors to demonstrate that their novel mechanism is really required.

For the past 20 years it has been clear to volcanologists working on terrestrial lava flows (2) that flowing lava behaves, not as a viscous fluid, but as a "Bingham" fluid with a well-defined yield stress. A Bingham fluid is one that responds elastically to applied shear stresses until the stresses exceed its yield strength, after which it flows as a viscous fluid. Bingham rheology characterizes a wide class of mixtures of liquids with solid particles, such as suspensions of clay in water, pigments in oil (paint), rock debris in mud, and crystals in melted rock (lava). Studies of lava flows on Mount Etna, Hawaii, and the moon (2) support the idea that erupted lava is a Bingham fluid with a yield stress ranging from about  $10^3$  to  $10^5$  Pa, depending on silica content. The most characteristic aspect of such flows is the approximately parabolic profile of their margins (with suitable corrections when slopes exceed the angle of repose), which can be directly related to the Bingham yield strength,  $Y_{\rm B}$ . A formula valid for the profiles of lava flows, ice sheets, and debris flow lobes (all of which can be treated approximately as Bingham substances) relates the thickness of the flow's center  $h_0$  to its horizontal width w:

$$Y_{\rm B} = \frac{\rho g h_0^2}{w}$$

where  $\rho$  is the density of the flow and g is the

tion tolerances of organisms beneath the ice. This topic clearly merits additional research.

JOHN E. FREDERICK Department of the Geophysical Sciences, University of Chicago, 5734 South Ellis Avenue, Chicago, IL 60637 21 November 1988; accepted 1 March 1989

planet's surface acceleration of gravity (0.27  $m/s^2$  for Ariel).

Jankowski and Squyres use photoclinometry to measure the profiles of five probable "lava" flows on Ariel. As they show, these profiles can be adequately fit by parabolas (except, of course, where the slope of the parabola becomes too steep-mass movement and regolith processes act to gently taper the flow's edges). They then propose a model that treats the extruded material as a Newtonian viscous fluid spreading from a central vent until cooling raises the viscosity past the point where flow is possible. They show that this model predicts parabolic flow profiles as long as the "lava" is moving. They then assume that the profile of the flow does not change as it cools and stiffens and derive a viscosity from the distance the flow has traveled within the cooling time (estimated from flow thickness and the thermal diffusivity of water ice).

A much more natural explanation of the morphology of Ariel's "lava" flows is that the extruded material is a mixture of liquid and crystals and that the parabolic profiles are an expression of the Bingham yield strength of the mixture at the time of solidification. All information about the rheology during extrusion and flow is lost during solidification and cannot be recovered without additional information. In Table 1 we have used the parabolic fits of Jankowski and Squyres and the equation above to deduce the yield strength of the flow material. These yield strengths vary from 6.7  $\times$  $10^3$  Pa to  $3.7 \times 10^4$  Pa, right in the midrange of terrestrial lavas. We do not

**Table 1.** Viscosities from (1) and Bingham yield stresses inferred from profiles in (1, figure 5).

Profile	Viscosity (Pa·s)	Bingham yield stress (Pa)
A	$4.5 \times 10^{15}$	$3.7 \times 10^{4}$
В	$3.5 \times 10^{15}$	$3.1  imes 10^4$
С	$9.0 \times 10^{14}$	$1.4  imes 10^4$
D top	$1.1 \times 10^{15}$	$1.4  imes 10^4$
D bottom	$9.0 \times 10^{14}$	$6.7 \times 10^{3}$