in the tip surface are those at kinks in the edges of such (110) layers, for example, Fig. 3 A and B. The surface re-arrangements observed are probably due to atoms from kink sites moving along the edge of the layer to other kink sites which act as traps. MacKenzie, Moore and Nicholas have pointed out that in a hemispherical surface the kink atoms are of two types determined by the spatial arrangement of the nearest neighbour bonds which are broken³. The resulting division of the surface into two regions is the same as that observed in the migration behaviour. Although the kink atoms are of two types, if it were valid to assume the pairwise addition of bond energies, they should be energetically very nearly equivalent. This is not the case, as the difference in the temperatures at

which atom movement begins in the two regions of the surface indicates a difference of about 0.2 eV in the height of the energy barrier to the migration of kink atoms. Either the assumption of pairwise addition of bond energies is incorrect, in which case the spatial arrangement of bonds between nearest neighbour atoms in a body-centred cubic metal should be considered, or possibly the positions of the kink atoms are displaced relative to the positions of atoms in the interior of the metal.

I thank Dr. J. S. Anderson for his advice.

¹ Müller, E. W., *Advances in Electronics and Electron Physics*, edit. by Marton, L., 13, 83 (Academic Press, Inc., New York, 1960).

² George, T. H., and Stier, P. M., *J. Chem. Phys.*, 37, 1935 (1962).

³ MacKenzie, J. K., Moore, A. J. W., and Nicholas, J. F., *J. Phys. Chem. Solids*, 23, 185 (1962).

TWILIGHT LITHIUM IN THE UPPER ATMOSPHERE

High Abundance of Twilight Lithium, November 1962

A LARGE enhancement of upper-atmospheric lithium abundance occurred during November 1962, closely resembling the event of August 1958¹. Both these can be correlated with thermonuclear explosions near 60 km, occurring a few days before the initial rise of abundance.

Observations were made at Saskatoon, Canada (52° N), in the zenith with the same birefringent photometer used for an earlier investigation². The intensities, measured in rayleighs, are shown in Fig. 1. According to Sullivan and Hunten², a brightness of 100 rayleighs corresponds to a lithium abundance of 6.2×10^6 atoms/cm²; the typical intensity of 4,000 rayleighs near the maximum in Fig. 1 therefore represents about 2.5×10^8 atoms/cm². Although the brightness is comparable with that of the sodium lines, the corresponding abundance is more than an order of magnitude lower, and it is unnecessary to make any corrections for resonance absorption³ in the lithium layer. Many of the observations, shown by open circles, were made under conditions of cloud or light overcast. Experience has shown that such results are still fairly reliable; the intensity may be either decreased or increased, but remains within ± 50 per cent of the original value. Much of the fine structure seen in Fig. 1 may be due to this difficulty; but the general form of the enhancement should be correct. There is also some uncertainty in the absolute intensity scale of the photometer; but this should be included in the error limits already given.

Previous experience^{1,2} has shown that a likely source of this lithium is a thermonuclear explosion at a height of about 60 km. Gadsden and Salmon¹ could find no effect

from an explosion at 30 km; Sullivan and Hunten² observed a possible effect, only one-tenth as strong as this one, from a much larger explosion in the lower atmosphere. The event recorded here can be correlated with an intermediate-yield explosion at a height of 30–40 miles (48–64 km) at 0900 U.T., October 26 (ref. 4); this time is shown by the arrow in Fig. 1. This is the only explosion, so far as we know, resembling the expected requirements since 1958. The similarity of Fig. 1 to the 1958 event¹ is striking. The first observed rise of intensity occurred 4 days after the explosion in both cases; the peaks are about 17 days after; and the half-life of the decay is a week or slightly more. Gadsden and Salmon¹ were unable to measure absolute intensities; but found the maximum values to be close to that of the sodium lines. Tinsley and Vallance Jones⁵ find this to be about 4,000 rayleighs in the southern hemisphere in August, in close agreement with Fig. 1.

It seems safe to conclude that the lithium enhancements of August 1958 and November 1962 were both caused by intermediate-yield thermonuclear explosions at a height near 60 km. The measurement of the isotopic ratio reported by Shepherd and Bens in the following communication was made at the time labelled SB in Fig. 1. Their somewhat surprising result was obtained when the intensity was well down from its maximum. However, there is little doubt that most of the lithium observed at that time was still of artificial origin.

The explosion of July 9, 1962, at a height of 400 km produced many violent geophysical effects; however, it might not be expected to deposit much lithium in the 80-km region. At Saskatoon, Sullivan⁶ observed an increase from 40 rayleighs early in July to a peak of 150 rayleighs on July 15. At Lauder, New Zealand, Gadsden reported a peak intensity estimated to be near 2,000 rayleighs. The present results strongly support his conclusion that thermonuclear explosions are indeed responsible for these enhancements.

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Fig. 1. Approximate zenith brightness of the lithium resonance lines during late 1962. The lines connecting the points are intended only to guide the eye. The arrow shows the date of the thermonuclear explosion believed to be responsible for the enhancement. The bar marked SB shows when the measurements of Shepherd and Bens (following communication) were made. Observing conditions: ●, good; ○, poor.

¹ Gadsden, M., and Salmon, K., *J. Atmos. Terr. Phys.*, 22, 75 (1961).

² Sullivan, H. M., and Hunten, D. M., *Nature*, 193, 1064 (1962).

³ Chamberlain, J. W., *Physics of the Aurora and Airglow* (Academic Press, New York, 1961).

⁴ *New York Times* (October 27, 1962).

⁵ Tinsley, B. A., and Vallance Jones, A., *J. Atmos. Terr. Phys.*, 24, 345 (1962).

⁶ Sullivan, H. M., thesis, Univ. Saskatchewan (1962). Sullivan, H. M., and Hunten, D. M. (to be published).