

(crystals of order 100μ in diameter); so any orienting torque on the nucleus could have only negligible effect on the orientation of the encasing crystal.

Finally, as the most fundamental objection of all, even if all the foregoing points be overlooked, orientation of individual ice crystals within a cirrus cloud in no way implies orientation of the gross structure of the cloud itself the characteristic length of which is the order of kilometres to tens of kilometres in cirrus. Kellner offers no hint of the ultimate dynamics of any process by which cirrus strands might take up meridional alignment in the geomagnetic field; and none is obvious. In fact, all that is known of cloud dynamics suggests that one must look to the macroscopic field of air motions to account for cloud structure. If it is true that tropical cirrus often take up meridional alignment, one should seek for explanation in terms of characteristic air movements at cirrus-levels and not in terms of any microphysical characteristics of the nuclei inside individual cirrus ice crystals.

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¹Kellner, L., *Nature*, **199**, 900 (1963).

²Bowen, E. G., *Austral. J. Phys.*, **6**, 490 (1953).

³Mason, B. J., *Quart. J. Roy. Met. Soc.*, **86**, 552 (1960).

⁴Sobermann, R. K., *Sci. Amer.*, 51 (June 1953).

DR. McDONALD writes that meteoric dust is of spherical shape so that no preferred axis can occur; it must be pointed out, however, that the ferromagnetic materials occurring in meteorites such as pure iron and nickel, magnetite and haematite possess magnetic anisotropy which increases with decreasing temperature so that orientation along the axis of maximum magnetization takes place. Serpoley and Toye¹ have shown, moreover, that ice shows epitaxial growth on magnetite (Fe_3O_4); between -12° and -22° C, the ice crystals form whiskers. This epitaxial growth is probably facilitated by the formation of hydrogen bonds between the adsorbed water and the oxygen of the magnetite. Since the strength of the hydrogen bond is of the order of 7–10 kcal, the orientation of the magnetite nuclei in the geomagnetic field would enforce a corresponding orientation of the epitaxial growth of ice. It would be of interest to know whether a correlation could be established between the frequency of the appearance of meridionally-aligned cirrus clouds and the periodic meteoric showers. With regard to the dynamics of the problem, it was pointed out in the original communication that this alignment is unstable, that is, the forces of the motion of the air overcome the magnetic forces.

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¹Serpoley, R., and Toye, M. J., *C.R. Acad. Sci., Paris*, **254**, 4187 (1962).

RADIATION CHEMISTRY

Radiation-induced Formation of the Univalent Mg^+ , Zn^+ and Cd^+ from the Divalent Cations in γ -Irradiated Ice

It is now well established that the principal primary reducing species formed in the radiolysis of water and aqueous solutions are the negative polarons¹. Their occurrence in these media has been directly demonstrated by observation of their transient optical absorption spectrum in pulsed radiolysis experiments^{2,3}. Although their direct observation by electron spin resonance or optical absorption spectroscopy has not been possible in the case of pure ice, trapped at defect sites, they have been characterized in alkaline ice at 77° K by both these

techniques^{4,5}. Their reactions with Brønsted acid solutes present in ice to form hydrogen-atoms (identified through their characteristic electron spin resonance spectra) both in the presence and absence of various competing electron scavengers have been reported previously^{6,7}. In this communication we describe their reactions with metal cations such as Mg^{2+} , Zn^{2+} , and Cd^{2+} to form lower oxidation states which are normally unstable. Evidence for the occurrence of Zn^+ and Cd^+ , but not Mg^+ , in aqueous solutions had been previously obtained⁸ in pulsed radiolysis investigations.

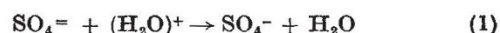
The electron spin resonance spectrum of γ -irradiated 0.2 M cadmium sulphate in ice at 77° K is shown in Fig. 1 and similar spectra were obtained when zinc sulphate (1.0 M) and magnesium sulphate (1.0 M) were the solutes. Comparison of this with the spectrum of γ -irradiated pure ice revealed the presence of two new lines designated here as *A* and *B*, in addition to the OH radical doublet. On warming the specimens to about 100° K, the OH radicals decay rapidly⁹, whereas the decay of the species responsible for these new lines is very slow and, therefore, the spectrum (Fig. 2) recorded at 77° K after the brief annealing at 100° K consists only of the lines *A* and *B*. That lines *A* and *B* are due to two different species was established by annealing as well as optical bleaching experiments. On annealing at 110° K, the line *B* disappeared first, whereas the line *A* is the more easily bleached on exposure to 'white' light from a projector lamp. Furthermore, the response of lines *A* and *B* are different towards different scavengers as discussed here.

Table 1. *g*-FACTORS OF SO_4^- AND THE UNIVALENT CATIONS Mg^+ , Zn^+ AND Cd^+ IN THE ICE MATRIX

| Species | Designation on Figs. 1 and 2 | <i>g</i> -factors | | | |
|-----------------|------------------------------|---------------------|--------|--------|----------|
| | | g_1 | g_2 | g_3 | g_{av} |
| SO_4^- | <i>A</i> | 2.0053 | 2.0135 | 2.0187 | 2.0125 |
| Mg^+ | <i>B</i> | $g_1 = g_2 = g_3 =$ | | 1.9953 | 1.9953 |
| Zn^+ | | $g_1 = g_2 =$ | | 1.9948 | 1.9948 |
| Cd^+ | | $g_1 = g_2 =$ | 1.9880 | 1.9989 | 1.9916 |

* Calculated according to the method indicated in ref. 11 for spectra from polycrystalline or glassy matrices. Relative errors on the *g*-factors given here are estimated to be ± 0.0003 and the absolute errors ± 0.0007 .

The line designated *A* was found to be identical in shape as well as *g*-factors (Table 1) in all the cases, namely, magnesium, zinc and cadmium sulphates as the solutes. An identical line has also been observed in the electron spin resonance spectrum of γ -irradiated ice containing sodium hydrogen sulphate⁷, in which case also it was noted that this line could be optically bleached and that it was more stable than the H-atom and OH-radical doublets to thermal annealing at 110° K. The sulphate group being common to all these systems, it is reasonable to attribute line *A* to a species containing this group or any unit derived from it. Since the *g*-factor (g_{av}) for line *A* is found to be slightly larger than the free electron *g*-factor of 2.0023, it should be an electron deficient centre¹⁰. Its assignment to SO_4^- radical ion formed by the reaction of the positive polaron $(\text{H}_2\text{O})^+$ with SO_4^- according to:



would then be consistent with the fact that it is an electron deficient centre. The occurrence of reaction (1) was further confirmed by studying the effect of Fe^{2+} . It was found that the presence of less than 0.02 M ferrous sulphate in any of these systems was sufficient to reduce the intensity of line *A* below the sensitivity of detection whereas it did not affect the intensities of the OH doublet or of lines *B*. Also, comparison of the intensities of the OH doublet in ice, both in the presence and absence of ferrous sulphate, revealed that the OH radical yield in ice at 77° K is not affected by Fe^{2+} , which is understandable since the OH radicals are not mobile in ice at this temperature.