LETTERS TO THE EDITOR

RADIOPHYSICS

Very-Low-Frequency Discrete Emissions received at Conjugate Points

In a recent article[1] describing a geomagnetic conjugate point experiment an accurately synchronized pair of spectrograms was shown. As shown in Fig. 1 of that article a sequence of six noise bursts in the 5–6 kc./s. frequency region was observed at both Knob Lake, Canada (68° N., geomagnetic), and at Byrd Station, Antarctica (70° S., geomagnetic); but the sequence began at Knob Lake 0·8 ± 0·1 sec. before it began at Byrd.

However, close inspection of Fig. 1 indicates that in each case the sequence is not six separate bursts but a pair of bursts seen three times. In support of this it will be noticed that the shapes and separation of the two bursts in each pair are similar and in each case the first burst occurs at a slightly higher frequency than the second. Furthermore, the time separation between successive pairs (using the time-scale provided) is 1·6 ± 0·1 sec., which is just twice the delay between Knob Lake and Byrd. Thus at intervals of 0·8 sec. this pair of bursts appeared alternately at Knob Lake and Byrd.

This phenomenon cannot be due to successive reflexions in opposite hemispheres of electromagnetic energy because the observed time delays are too short. Whistler observations in these latitudes show 5 kc./s. propagation times between 1·5 and 2·5 sec. for a single hemisphere to hemisphere trip[1]. Even then these times refer to lower latitudes because geomagnetic field lines terminating at latitudes greater than about 62° do not allow 5 kc./s. propagation of this type[2]. Thus if this phenomenon were due to whistler type echoes the delays would be several times longer.

However, such a sequence of alternate reception at conjugate points was predicted in a theory proposed by me[3] for the production of very-low-frequency discrete emissions. In fact such a conjugate point experiment was suggested as a test for the theory.

According to this theory Doppler-shifted cyclotron radiation is emitted by a small cloud or bunch of electrons spiralling along a field line. Only the downward-shifted frequency can propagate so that radiation is only emitted backwards. If the bunch should survive several trips along the field line from hemisphere to hemisphere, being reflected at the ends by magnetic mirror effect, then an observer at each end of the field line would receive an emission each time the bunch was travelling away from him. Thus for each observer the time between successive emissions would be the complete (there and back) oscillation period of the cloud and the delay between the sequences observed in opposite hemispheres would be half this period[3].

The complete oscillation period of 1·6 sec. from Fig. 1 (ref. 1) would correspond to 60 keV. electrons (for minimum helical pitch angles of 20°) if the guiding field line was that connecting the two observing stations or 15 keV. electrons if the guiding field line was typical of those (around 60°) producing nose whistlers observed at Byrd[2]. These electron energies deduced from the oscillation period (15–60 keV.) are close to those (5–25 keV.) required by my theory to produce the detailed frequency-time shape of observed discrete emissions[3].

I thank Prof. G. R. A. Ellis, of the Physics Department, University of Tasmania, for advice.

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Dowden suggests that the six bursts of noise shown in Fig. 1 of our article consist of a pair of bursts seen three times at each end of the path, and that this interpretation provides support for a new theory of very-low-frequency emissions which he has published elsewhere.

We agree that this interpretation is entirely consistent with the data reported in our article. As a matter of fact, further study of the original tape recordings has shown additional noise bursts which can be fitted into a repetitive or echo pattern, in which the phase is opposite at the two ends of the path. The echoing of noise bursts between stations in opposite hemispheres is a common occurrence, and is the subject of a detailed study now in progress at the Radioscience Laboratory, Stanford University. Results of this work will be reported in the near future.

Although we can support the 'echo' interpretation of Fig. 1, we question Dowden's conclusion that the phenomenon cannot be due to successive reflexions in opposite hemispheres of electro-magnetic energy travelling in the whistler mode. His argument is based on the fact that whistler observations at these latitudes show 5 kc./s. propagation times between 1·5 and 2·5 sec. for a single hemisphere-to-hemisphere trip (one-hop), while the observed one-hop delay of the noise bursts is only 0·8 sec. (one-half of observed period of 1·6 sec.). It is implied that both the path of propagation and the electron density in the magnetosphere are about the same in the two cases. Neither of these assumptions is justified, as we shall see.

Whistler-mode path latitude bears little relation to the latitude of the receiving station. For example, data analysed by Smith[1] show a variation in the nose frequency (closely related to path latitude) at Byrd from 4·5 kc./s. to 12 kc./s. For the model of electron density derived by Smith, the corresponding minimum gyro-frequencies at the top of the path are about 11·2 kc./s. and 30 kc./s., respectively. The corresponding effective geomagnetic latitudes are 61° and 55°, respectively. Other data show that even lower latitude paths are often observed at Byrd Station[2].

Another factor affecting propagation time is the electron density along the path of propagation. Carpenter has shown that electron densities are often markedly depressed during magnetic storms[2]. One-hop delays at 5 kc./s. can drop as low or lower than 0·8 sec. at Byrd following the onset of a magnetic storm. The record in question was obtained on the day following a magnetic disturbance in which the 3-hr. K_p index reached a maximum of 6. Thus it is quite possible that the delays observed are in fact consistent with the whistler-mode interpretation.

The fact that we cannot rule out the whistler-mode echo explanation does not, of course, disprove Dowden's hypothesis that the noise bursts were generated by bunches of electrons bouncing back and forth between magnetic mirror points. Our comments are intended only to suggest the inherent complexity of the problem and the need for more complete data on the relationship between whistler-mode propagation and very-low-frequency emissions.

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GEOPHYSICS

Age of the Earth's Crust and Lead Model Ages

OVER the past few years the observed time-dependence of the isotopic composition of lead in ore deposits has been used in attempts to estimate a 'model age' for each deposit. In the main, two general lines of attack appear to have been used. On one hand Canadian writers[1] have adopted a simple model, with a single growth curve, the parameters of which have been determined empirically; whereas the European workers[2] have set up models which allow for a greater variety of relative abundances of uranium–lead–thorium in the parent material, and where the parameters are physical constants which can be determined by independent methods. These two methods of attack have seemed to give different values of the age, and the further suggestion has recently been made[2] that the two models furnish very different values for the age of vein deposits.

In calculations which I have carried out in connexion with some results to be published elsewhere, I have shown that the major part of the discrepancy in model ages obtained by the two methods rests on the value of t_0, the 'age of the earth's crust'.

In the Holmes–Houtermans equation (2):

$$\frac{y - y_0}{x - x_0} = \frac{1}{137 \cdot 8} \times \frac{e^{\lambda_2 t_0} - e^{\lambda_2 t}}{e^{\lambda_1 t_0} - e^{\lambda_1 t}}$$

where x, y, are the ratios $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ for the sample, x_0, y_0, the corresponding values for 'primordial lead' (average of Patterson's[3] values for Canyon Diabolo and Henbury troilite leads), and λ_1, λ_2, the decay constants for ^{238}U, ^{235}U (ref. 4), three values now used of t_0 have yielded three very different values for the model age calculated for the one (x, y) (Table 1).

Table 1

t_0 × 10^9 yr.	4·50 (ref. 2)	4·510 (ref. 1)	4·550 (ref. 3)
age × 10^6 yr.	1669	1640	1524

These compare with a value 1,524 million yr. for t_{6-7} of Russell and Farquhar[1], whose empirical equation yields an independent value for $t_0 = 4 \cdot 56 \times 10^9$ yr. Over quite a variety of specimens from Precambrian localities, which range from 'conformable' leads through vein deposits to those distinctly anomalous, close agreement has been obtained between the t_{6-7} model age and that calculated according to the Holmes–Houtermans model, using $t_0 = 4 \cdot 55 \times 10^9$ yr., with the standard deviation of the ages of a set of comparable specimens slightly less in the first case than in the second.

Thus it would seem that both models yield very similar conclusions, and that any discordance which has appeared in the past has resided almost entirely in the value chosen for t_0. The large error magnification exhibited here would appear to be an inevitable consequence of the exponential function used in all lead calculations, of which the equation quoted is a typical example. Where t_0–t (or in the general case t_1–t_2) is small, this magnification should prove to be less than unity, which is perhaps one reason why this effect has not been remarked on previously.

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PHYSICS

Direct Conversion of Fission Heat to Electric Power

EXPERIMENTS have been performed in the reactor *Pluto* as a stage in the development of cæsium-neutralized diodes for the direct conversion of fission heat to electric power. This work is similar to that being carried out in the United States, and the first fission-operated diode was reported by Grover at Los Alamos in 1959[1]. Due to its greater cathode area, the present device has produced a larger value of output current than hitherto reported and incorporates a number of new features. Measurements were made with two rigs, the object being to test the fuel rod material and method of mounting, to determine temperature distributions and heat transfer data and to study the performance of the diodes as generators.

Each diode (Fig. 1) contained a cylindrical cathode of UC/ZrC solid solution brazed to a tantalum support, and a stainless-steel anode which was extended to form a catchpot and a cæsium reservoir. The radial spacing between cathode and anode was 0·5 cm. In this intermediate design the emission current circulated via the extended anode casing and cathode support, so that a ceramic/metal insulating seal was not required. The output was determined by monitoring the voltage across the extended anode casing above the ceramic spacer. The cathodes were 5·7 cm. long and 1·0 cm. in diameter, enriched to contain 8·3 gm. uranium-235 over the lower 3·0 cm., the remainder containing natural uranium. The composition of the UC/ZrC was 45/55 mol. per cent with a melting point more than 3,000° C. Cathode temperatures were monitored by means of a W/WRe, beryllium oxide insulated, tantalum sheathed thermocouple situated at the junction of the natural and enriched material. Other thermocouples of chromel/