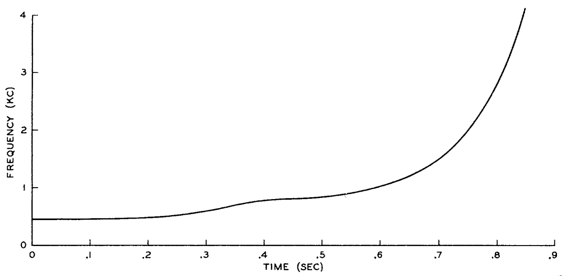

FIG. 1. Theoretical chorus dispersion curve.

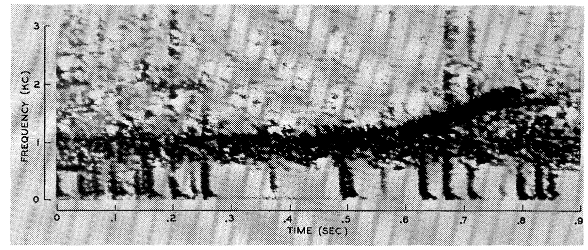

FIG. 2. Audio spectrogram of chorus.

of the final frequency-time curve; the curve shown in Fig. 1 has been corrected for travel times, and represents what would be received on the ground.

It is evident that one can get almost anything in the way of a frequency-time curve, by the proper choice of electron density distribution. However, the use of probable distributions appears to explain many of the chorus dispersion curves actually encountered. This mechanism would also account for the hiss often associated with chorus.

Chorus as observed at College usually is in the frequency range of 1 kc/sec to 4 kc/sec although it is occasionally observed below 1 kc/sec and above 10 kc/sec. The individual components generally are ascending tones beginning at about 1 kc/sec and ending at 3 to 4 kc/sec, 0.2 to 0.5 sec later.

The dispersion curve of chorus bears considerable resemblance to that shown in Fig. 1 (see Fig. 2). It sometimes shows a linear frequency-time curve but often begins in a concave upward curve as in Fig. 1. Its termination, however, is often a slightly concave downward curve not indicated in the figure which might be accounted for by a slowing down of the particles as they approach absorption or by their passing through a maximum of ion density. A study of the variations in the characteristics of chorus with the properties of the ionosphere might help to reject or confirm this hypothesis.

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[2] Francis S. Johnson, Lockheed Technical Report LMSD 49719, April, 1959 (unpublished).

QUESTION OF THE EXISTENCE OF A LUNAR MAGNETIC FIELD*

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Soon after their recent moon-impact, scientists of the U.S.S.R. announced[1] that the magnetometer on the vehicle had detected no evidence of a lunar magnetic field; their instrument was capable of detecting fields down to 6×10^{-4} gauss. The impact occurred on the sunlit side of the moon. The final magnetometer reading before impact presumably was obtained at a lunar altitude of the order of a kilometer, or more.

It is the purpose of this note to point out that this single piece of data is not sufficient evidence from which to conclude that the general lunar magnetic field is weaker than 6×10^{-4} gauss on the surface. It is suggested that, if a general lunar magnetic field existed, it would be confined by the solar corpuscular radiation, or solar wind, to a thin layer above the sunlit surface, but it could extend a considerable distance beyond the surface on the side away from the sun.

An upper limit to the strength of magnetic field which can be pushed around by the solar wind can be obtained by a calculation of the momentum of the solar corpuscular radiation. If it is assumed that the proton density, n, is 500 cm^{-3} and that the average particle velocity, v, is 1000 km/sec, the momentum flux per unit area, or pressure, in the solar wind is $nMv^2 = 8\times10^{-6}$

dynes/cm^2. A pressure of this magnitude is capable of compressing a magnetic field until the magnetic pressure, $B^2/8\pi$, builds up to this size; the magnetic-field strength corresponding to this pressure equals $(8\pi \times 8 \times 10^{-6})^{1/2} = 1.4 \times 10^{-2}$ gauss.

Recent observations by Kozyrev and by Dubois (see a recent publication by Kopal[2]) of both the energy content and the time variations of the luminescence of some parts of the lunar surface indicate that this luminescence is, in large part, caused by solar corpuscular radiation incident on the lunar surface rather than by solar electromagnetic radiation. As the luminescence is observed only in sunlit regions of the lunar surface, it can be argued that the solar corpuscular radiation must have travelled essentially straight into the moon's surface without being appreciably deflected by either a lunar or an interplanetary magnetic field. According to the argument in the preceding paragraph, the solar corpuscular radiation could not have reached the lunar surface if the moon's surface magnetic-field strength were greater than $\sim 10^{-2}$ gauss.

These observations and their interpretation are consistent with the estimates of the strength of a possible lunar magnetic field based on various theories of the formation and history of the moon; these estimates[3] range from zero to several hundred gamma (1 gamma $= 10^{-5}$ gauss).

Let it be supposed that, in the absence of the solar wind, the lunar magnetic field (B_0) would be a few hundred gamma or less on the surface. The protons and electrons in the solar corpuscular radiation are deflected by this field so as to set a current; the field resulting from this current tends to cancel the moon's field above the lunar surface and to add to it below the surface. The equilibrium properties of such a magnetic boundary layer can be calculated for the case of a cold plasma normally incident on a one-dimensional "moon" from the equations for such a plasma given by Davis, Lüst, and Schlüter.[4] If all the dependent variables but the magnetic-field strength are eliminated from these equations, there results the differential equation

$$\frac{d}{dx}\left[(1-\beta^2)\frac{d\beta}{dx}\right] = \frac{4\pi e^2 n}{m}\beta,$$

where

$$\beta^2 = \frac{1}{nMv^2}\frac{B^2}{8\pi}.$$

Also, M and m are the proton and electron masses, respectively, and x is the distance from the lunar surface (measured negatively out from the surface in order that the plasma flow is in the positive x direction). This equation can be solved subject to the boundary conditions that the magnetic-field strength is $2B_0$ at the surface of the "moon" and zero at $-\infty$, with the result that

$$(4\pi e^2 n/m)^{1/2}x = -\left[[1-\tfrac{1}{2}(\beta^*)^2]^{1/2} - (1-\tfrac{1}{2}\beta^2)^{1/2} + \ln(\beta^*/\beta) + \ln\frac{1+(1-\frac{1}{2}\beta^2)^{1/2}}{1+[1-\frac{1}{2}(\beta^*)^2]^{1/2}}\right],$$

where

$$(\beta^*)^2 = \frac{1}{nMv^2}\frac{(2B_0)^2}{8\pi}.$$

For small values of β, ($B_0 \ll 7\times 10^{-3}$ gauss), this expression can be approximated by

$$B = 2B_0\exp\left[-\left(\frac{4\pi e^2 n}{m}\right)^{1/2}x\right] = 2B_0 e^{-4.2x(\mathrm{km})}$$

Thus, if the moon had a surface field strength of less than ~ 700 gamma in the absence of the solar wind, the field would, according to this model, drop to $1/e$ of this value at ~ 500 meters above the surface on the sunlit side; this height is much less than the altitude of many of the lunar mountains. For an undistorted surface field as large as 700 gamma, the transverse displacement of the protons is only 8 meters.

This model is not completely realistic in many ways: For a three-dimensional moon, the current layer is curved; thus, the field strength at the surface is not exactly $2B_0$. Furthermore, the solar corpuscular radiation is not a cold plasma and, thus, a random velocity distribution will be superimposed on the flow previously described. Collisions between particles in the plasma were neglected; however, the mean free path for large-angle collisions is orders of magnitude greater than the calculated boundary-layer thickness. All reflection of charged particles from the lunar surface has been neglected, as has any contribution from the solar magnetic field which may be trapped in the solar corpuscular radiation. Furthermore, a steady-state solution was found and all plasma oscillations were ignored. It is believed that corrections for these effects would either be small or would lead to a smaller boundary-layer thickness than that calculated.

The author would like to thank Dr. L. Davis

for his interest in and assistance with this problem.

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[1]"Preliminary Results of Data Processing from the Second Soviet Cosmic Rocket," Jet Propulsion Laboratory, Pasadena, California, October 23, 1959, JPLAI/Translation No. 12 (translated by J. L. Zygielbaum from Pravda and Izvestia, September 18-23, 1959).

[2]Z. Kopal, "Does the Moon Possess a Magnetic Field?," Space Journal, September, 1959 (p. 3).

[3]E. H. Vestine, "Utilization of a Moon-Rocket System for Measurement of the Lunar Magnetic Field," RAND Corporation Report RM-1933, July 9, 1957 (unpublished).

[4]Davis, Lüst, and Schlüter, Z. Naturforsch. 13a, 916 (1958).

DETERMINATION OF THE AGE OF THE ELEMENTS*

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We have found that xenon from the chondritic (stone) meteorite Richardton is heavily enriched in Xe^{129}. This isotope almost certainly was formed from the radioactive decay of I^{129}, now extinct as a natural radioactivity but not so at the time of formation of the meteorite. From the data we calculate that $(0.35 \pm 0.06) \times 10^9$ years elapsed between the time of formation of the elements and the meteorite. There is a large body of evidence that the chondrites were formed at a time close to 4.6×10^9 years ago. Thus the age of the elements is close to 4.95×10^9 years.

In 1947, Brown[1] suggested that the meteorites could be used to determine quite accurately the age of the elements if the daughter of an extinct natural radioactivity could be found there. The decay

$$I^{129} \xrightarrow{1.7 \times 10^7 \text{ yr}} Xe^{129}$$

has long been recognized as a particularly favorable case for stone meteorites, although previous searches for fossil Xe^{129} in the chondrite Beardsley[2] and the achondrite Nuevo Laredo[3] failed to give a positive result.

Figure 1 is a faithful tracing of the peak heights recorded with a sensitive mass spectrometer[4] during one of the sweeps of the spectrum of xenon which had been extracted from the vacuum melting of a 7-gram sample of Richardton. The horizontal lines drawn through the various peaks show where the peaks would fall for an analysis, under identical conditions, of a sample of atmospheric xenon[5] having the same Xe^{132} content. Differences between the two spectra, notably the large Xe^{129} excess in the meteoritic sample, are very obvious from the figure. A sequence of runs on four independently prepared xenon samples from this meteorite, interspersed with runs on atmospheric xenon, have established beyond any possible doubt

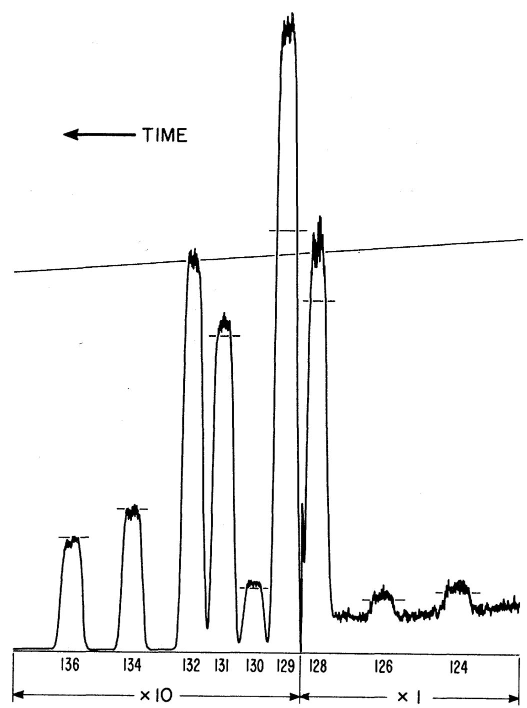

FIG. 1. Mass spectrum of Xe extracted from Richardton stone meteorite and sealed off in the mass spectrometer. Horizontal lines show the comparison spectrum of terrestrial Xe. The slant line through the 132 peak shows the extent of spectrometer pumping. Jagged peak tops are due to statistical fluctuations in the small ion currents.