are present in excess of 0.15 percent. The Fe and Ni concentration gradients were typical of those found in iron meteorites. The Ni content varied from 16 to 45 percent in taenite and from 6 to 6.5 percent in kamacite, except near the kamacite-taenite boundaries, where it was less than 6 percent. The Co content was, however, unusual. According to Krinov (*4*), the average Co content in fine octahedrites is 0.61 percent. The total variation in Co for all classes of iron meteorites, according to Lovering *et al.* (*5*), is from 0.38 to 0.75 percent. Butler contains 1.7 percent Co in kamacite, 0.6 percent Co in taenite, and 1.45 percent Co in plessite. The average Co content, 1.4 $\pm$ 0.1 percent, is almost twice as much as that found in any other iron meteorite to date.

The distribution of Ge in the meteoritic phases was measured with the electron microprobe, by use of a procedure described by Goldstein and Wood (*6*). Germanium concentrates only in kamacite and taenite. The kamacite bands which make up the typical Widmanstätten pattern of the meteorite contain 1700 $\pm$ 50 ppm Ge. The kamacite areas in plessite, less than 50 μ in width, contain 1550 $\pm$ 50 ppm. Typical Ge and Ni concentration gradients in kamacite and taenite are shown in Fig. 1. The Ge follows the Ni, and the maximum Ge content in taenite is over 4000 ppm (0.4 percent). The distribution of Ge with respect to Ni and kamacite band size is typical of that found for meteorites with overall Ge greater than 20 ppm (*7*). However, the absolute Ge contents of the metallic phases is much greater than in any other iron meteorite.

The cooling rate for the temperature range in which the Widmanstätten pattern developed (700° to 300°C) was also determined. This was accomplished by comparing the measured concentration gradients in several kamacite-taenite areas with gradients calculated by a theoretical growth analysis for the Widmanstätten pattern (*3, 8*). The calculated gradients vary with the cooling rate assumed. The cooling rate is determined when a fit is obtained between the measured and calculated gradients.

The relatively high levels of Co and Ge present in Butler have little or no influence on the Ni contents of the metallic phases. This can be seen by comparison with measured Ni values for other meteorites (*9*). The Co and Ge may also have an influence on the diffusion coefficients which control the Widmanstätten growth process. However, the diffusion coefficients in the temperature range (700° to 300°C) are not known to within $\pm$ 50 percent of their actual value. The influence of the Co and Ge is probably less than the uncertainty in the diffusion coefficients, and therefore was not considered further. The cooling rate determined for Butler is 0.5°C/10^6 years, with an estimated precision of $\pm$30 percent. This cooling rate is lower by a factor of 2 than any cooling rate determined for iron meteorites in the study of 27 iron and stony iron meteorites by Goldstein and Short (*8*). Thus the cooling history for Butler appears to be unique.

Butler is indeed an unusual meteorite. It not only contains more Ge and Co than any other iron meteorite, but also cooled more slowly than any other iron meteorite measured to date. It is probable that Butler formed in a different environment from that of the rest of the iron meteorites.

J. I. GOLDSTEIN
Geochemistry Laboratory,
Laboratory for Theoretical Studies,
Goddard Space Flight Center,
Greenbelt, Maryland

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Butler, Missouri: An Iron Meteorite with Extremely High Germanium Content

Abstract. *The Butler iron meteorite has been found to have a germanium concentration of 2000 parts per million, which is about five times higher than the highest concentration that has been measured previously in an iron meteorite. The gallium concentration is 87 parts per million, which is among the highest concentrations found in these objects. The nickel content is 16.0 percent, the second highest nickel concentration known in a meteorite displaying a Widmanstätten pattern. The high Ge/Ni ratio, as well as the association of a high nickel content with high gallium and germanium contents, make this object an exception to two geochemical generalizations regarding the iron meteorites.*

During the past 10 years a large body of evidence has been gathered on the Ge concentration of iron meteorites. Analyses of approximately 160 irons have revealed a very wide range of concentrations that extend from 400 parts per million (ppm) down to 0.03 ppm. There are arguments which show that the Ge/Ni ratio in the group of irons with about 400 ppm (Ga-Ge group I) is the maximum to be expected for an undifferentiated core of a meteorite parent body. This paper is a report of the discovery of an iron meteorite, Butler, which has a Ge content five times higher than the previous high measured in an iron meteorite, and a Ge/Ni ratio that is higher than the expected maximum mentioned above. The object also has a Ni content much higher than that found in the only previous analysis.

The Butler iron meteorite was plowed up by a farmer sometime before 1875 (*1*). At that time the object weighed about 40 kg, and pieces of it were soon distributed to many different meteorite collections throughout the world (*2*). The Prior-Hey catalog of meteorites (*3*) shows that most of the remaining material is in the Mineralogical Museum at Harvard where 14 kg is located. There has been only one study of the chemical composition of the object prior to my work. In 1877 J. Lawrence Smith (*4*) published an analysis that showed a nickel content of 10.02 percent, a value that this report shows to be 6 percent too low.

The structure of the meteorite is quite unusual. A distinct Widmanstätten pattern is observed, but the kamacite lamellae are extremely fine and discontinuous. The bulk of the object consists of plessite. Most researchers have assigned Butler to the structural class of "finest octahedrites," but Buchwald (*5*) had recently proposed a new catalog of "plessitic octahedrites" for Butler and several other similar meteorites. Perry and Brezina (6) include photographs that show the gross structure and microstructure of Butler. The cover photograph shows the structure at an intermediate magnification.

According to Brown and his co-workers, the iron meteorites tend to show "quantized" concentrations of Ga and Ge (7) and of certain noble metals (8). My associates and I are making similar studies with improved techniques (9, 10). We find that the quantization of Ga and Ge is even more pronounced than indicated by Brown and his co-workers; some of their Ga-Ge groups are complex and can be subdivided into new groups that are distinct and more compact (9, 11).

The Ga and Ge concentrations of about 160 meteorites have been published (7, 12) or have been determined by us. Before our measurements of Butler, the highest known concentrations of Ga and Ge were those determined in the members of Ga-Ge group I. This group is composed entirely of coarse octahedrites that contain about 6.5 percent Ni and have Ga and Ge concentrations of about 85 and 400 ppm, respectively.

There are certain geochemical arguments which indicate that the ratio of the concentration of a given metal to that of Ni is more important than the absolute concentration (9). These arguments are based on the fact that Ni is found almost entirely in the metal phase under any meteoritic conditions that have resulted in the formation of such a phase. Thus, although the iron concentrations in iron meteorites vary by only a factor of roughly 2 from 95 to 40 percent, the Fe/Ni ratios vary from about 19 to about 0.7, or an order of magnitude of more variation. There is evidence to indicate that the fractionation of a metal from Ni took place at the time of separation of the metal phase from the primordial material (13) and that any fractionation which took place within the separated metallic mass (for example, within the core of the meteorite parent body) was of minor importance. One of the principal arguments for this is the fact that the maximum metal/nickel ratio found in iron meteorites never exceeds a value equal to four times the ratio found in ordinary chondrites. In the case of Ga and Ge, the maximum metal/nickel ratios in iron are quite similar to the average concentrations found in carbonaceous I and enstatite I chondrites. These arguments are given in a considerably expanded form elsewhere (13). A survey of all the data for ten trace elements that are mainly concentrated in the metal phase of iron meteorites (14) reveals only two meteorites which are exceptions to this generalization—Negrillos, for the elements rhenium and osmium, and now Butler, for the element germanium.

Table 1. Concentrations of Ge, Ga, and Ni in samples of the Butler iron meteorite.

Date	Mass (g)	Ge (ppm)	Ga (ppm)	Ni (%)
29 Nov. 1965	0.996	2040	64.5*	15.94
13 Dec. 1965	1.073	2050	91.7	15.39*
1 Feb. 1966	1.168	1890	83.3	16.01
15 Feb. 1966	0.784	1960	84.4	15.60*
21 Feb. 1966†	1.193	2040	89.1	16.18
Means and 95% confidence limits		2000 ± 90	87.1 ± 6.3	16.04 ± 0.31

* Not used in the calculation of the mean. † The last sample was obtained from the Mineralogical Museum, Harvard University. The other four samples were taken from the specimen in the Leonard Meteorite Collection, UCLA.

The concentrations of Ge, Ga, and Ni that have been determined in five samples of Butler are listed in Table 1. Neutron activation (9, 10) was employed to determine Ge and Ga and atomic absorption spectrometry was used in the determination of Ni. One result for Ga was not included in the calculation of the mean because it was much lower than the remaining four values. The two lowest Ni results were also not included in the mean. Nickel is determined after a complicated procedure that involves the separation of a number of other elements. Although 97 percent of the Ni can be reproducibly recovered in test runs, it is clear that the stresses of neutron activation tend to result in a poor performance and we therefore feel that the higher results are more likely to reflect the true concentration.

All samples were etched after the neutron irradiation in order to avoid possible surface contamination. The possibility of terrestrial contamination by Ge that had somehow penetrated into the meteorite was checked by taking samples from different corners of the 7- by 5-cm slice in the Leonard Collection of Meteorites at the University of California, Los Angeles. The first four samples in Table 1 were removed from three different corners of the slice. As a final check, a piece of Butler was obtained from Harvard. The sample chosen was as far from the original surface of the object as possible. The fifth sample is from the Harvard specimen. It is clear that all results are in good agreement, especially for Ge. This seems very unlikely for a contaminated object. Goldstein (15) describes an electron microprobe study of Butler which shows the Ge to be distributed normally between kamacite and taenite, and confirms that the high Ge concentration is not due to contamination.

The data in Table 1 show that the Ge concentration in Butler is about 2000 ppm, which is about five times higher than the highest concentrations previously observed in iron meteorites. The Ga concentration is about the same as the highest values previously observed. The Ni concentration is about 6.0 percent higher than the literature value (4), and about 7.5 percent higher than that found in any iron meteorite with a Ge concentration greater than 150 ppm (7, 10). On the basis of this Ni determination, Butler has the second highest Ni concentration known in a meteorite showing a Widmanstätten pattern. The octahedrite with the highest Ni concentration is Tazewell. The Ge/Ni ratio is 125×10^{-4}, compared to a value of about 50×10^{-4} in Ga-Ge group I irons and a ratio of about 36×10^{-4} in type I carbonaceous chondrites. The difference between the Ge/Ni ratios in group I irons and in the single measurement of a type I carbonaceous chondrite may be mainly caused by analytical and sampling errors. The factor of 4 disagreement between the Butler Ge/Ni ratio and the carbonaceous chondrite value is definitely outside expected errors. The Ga/Ni ratio in Butler is 5.4×10^{-4}, which is not unusually high.

The chemical composition of Butler is therefore exceptional in two respects. The more important of these is the unusually high Ge/Ni ratio. Less important, but very interesting, is the association of a very high Ge and Ga content with a high Ni content. These facts do not agree with the generalization with regard to maximum metal/nickel ratios mentioned earlier, nor with another generalization that states that there is a tendency for high Ge and Ga contents in iron meteorites to be associated with low Ni concentration (10).

It will be interesting to see whether future studies reveal exceptional compositions in other meteorites. A suitable starting point in the search for such objects would be meteorites that are similar to Butler in Ni content and structure. The Prior-Hey catalog indicates that Tazewell, Cowra, Laurens County, and Victoria West might be suitable. We have studied the first two of these objects and find that they are anomalous in the sense that they are not members of the known Ga-Ge groups, but do not show exceptional metal/Ni ratios. We plan to study the latter two objects as soon as samples can be obtained.

JOHN T. WASSON

Department of Chemistry and
Institute of Geophysics and Planetary Physics, University of California, Los Angeles 90024

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Stokes Parameters for 1665-Megacycles-per-second Emission from OH near Source W3

Abstract. *The Stokes parameters were measured as a function of frequency for the anomalous 1665-megacycles-per-second OH emission originating near the thermal radio source W3. The emission is highly polarized, and the polarization parameters vary rapidly with frequency. The observed polarization can be described in terms of narrow, roughly Gaussian, emission features, all with uniform polarization but with several features overlapping without coherence near the center of the spectrum. Most of the individual features may be 100-percent polarized. Detailed examination of the brightest features suggest that they are not exactly Gaussian in shape.*

The anomalous 1665-Mc/sec spectral line emission from OH near source W3 has been observed to be partially linearly polarized (*1*). Subsequent observations of right and left circular polarization from this source (*2*) revealed that all four of the OH transitions at 1612, 1665, 1667, and 1720 Mc/sec produce features in the emission spectrum with predominantly circular polarization. Linear and circular polarization in the 1665 Mc/sec emission from the W3 source have also been observed (*3*).

We now report measurement of the Stokes parameters as a function of frequency for the 1665-Mc/sec OH emission near W3. The polarization parameters—ellipticity, ellipse position angle, and degree of polarization—are computed, and their rapid variation with frequency is described in terms of a simple model.

The polarization properties of an electromagnetic wave are completely specified by the four Stokes parameters (*4*), which may be determined from measurements of the intensities of the wave with four independent polarizations. If $I(\phi)$ is the intensity for linear polarization at a position angle ϕ, and if $I(\mathrm{R})$ and $I(\mathrm{L})$ are the intensities for right and left circular polarization (*5*), then the Stokes parameters are defined:

$$\begin{aligned} S_0 &= I(0°) + I(90°) = I(\mathrm{R}) + I(\mathrm{L}) \\ S_1 &= I(0°) - I(90°) \\ S_2 &= I(45°) - I(135°) \\ S_3 &= I(\mathrm{R}) - I(\mathrm{L}). \end{aligned} \tag{1}$$

These parameters have such a property that the polarization of an incoherent superposition of waves is described by Stokes parameters which are just the sums of respective parameters for the separate waves. Other parameters describing the polarization can be obtained from the Stokes parameters thus: The position angle ϕ of the major axis of the polarization ellipse is given by

$$\tan(2\phi) = S_2/S_1 \tag{2}$$

The amplitude ratio of minor to major axes, b/a, for the polarization ellipse is expressed as

$$\tan x = \pm\, b/a \tag{3}$$

where

$$\sin 2x = S_3/\sqrt{S_1^2 + S_2^2 + S_3^2} \tag{4}$$

and the plus sign in Eq. 3 applies to right elliptical, and the minus sign to left elliptical, polarization. Finally the degree of polarization P is obtained from

$$P = \sqrt{S_1^2 + S_2^2 + S_3^2}\ \ /S_0 \tag{5}$$

It is convenient to work with the Stokes parameters because of their additive property, but the ellipse position angle ϕ, the ellipticity $\pm b/a$, and the degree of polarization P, as we have defined them, yield somewhat better physical insight.

Polarization parameters for the 1665-Mc/sec OH emission were measured with a 120-foot (37-m) parabolic antenna (*6*) between 28 November and 9 December 1965. Observation of various linear and circular polarizations with a single system enabled complete determination of the polarization parameters of the spectral features as functions of frequency, or, equivalently, as functions of radial velocity relative to the local standard of rest. At this OH-transition frequency a radial velocity of +1 km/sec gives a Doppler shift of −5.555 kc/sec.

The spectral-line radiometer used for these measurements included a 100-channel digital autocorrelator and a room-temperature parametric amplifier. The autocorrelator was tied directly to a real-time computer which produced plots of the observed spectra immediately after each integration period. Most of the observations were made with a 1-kc/sec frequency resolution, but the brightest features were also examined with 200-cy/sec resolution. The overall system temperature was 320°K for linear-polarization measurements and 360°K for circular polarization. The increased system temperature resulted from a network that combined horizontal and vertical linear polariza-