Magnetic susceptibility of garnet.

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Summary. The mass susceptibility of 23 analysed or partially analysed garnets has been measured by means of a calibrated Franz Isodynamic magnetic separator. Straight lines are fitted to the adjusted data for mass susceptibility and molecular composition. The mass susceptibilities of the theoretical end-members in electromagnetic units $\times 10^6$ are estimated as: almandine, 68 ± 2 e.m.u.; spessartine, 81 ± 3 e.m.u.; and andradite, 49 ± 3 e.m.u. Grossular and pyrope are assumed to have susceptibilities of nil.

ALTHOUGH with the increasing use of the isodynamic magnetic separator it has become more obvious that the magnetic susceptibility of ferromagnesian minerals varies considerably with their composition, only in the last few years have attempts been made to correlate these factors. The magnetic data in this paper were obtained with an unadapted laboratory separator during an entirely different research project,[2] nevertheless the results indicate that under suitable conditions magnetic susceptibility is comparable in accuracy with density for use either as a variable for the estimation of composition or as the basis of a method for the separation of garnets of fixed composition.

Method of investigation. Six of the samples were obtained in the form of analysed powders and the magnetic susceptibility of these was measured without further treatment. The other samples were prepared by crushing to pass 120 mesh, washing to remove dust, and then removing impurities by means of heavy liquids and the magnetic separator. Purity was checked by microscopic examination.

After the determination of the magnetic susceptibility portions of the samples were analysed for total iron, manganese, magnesium, and calcium by an adaptation of the rapid method of Shapiro and Brannock.[3] The results for iron and manganese are considered to have a coefficient

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[2] M. J. Frost, unpublished Ph.D. thesis, 1957, University of Western Australia.

[3] L. Shapiro and W. W. Brannock, U.S. Geol. Surv. Bull., 1952, No. 165, and 1956, No. 1036-C.

of variation of about 1 % and those for lime and magnesia a standard deviation of about 0·1 %. All analyses were checked by partial summation and by the comparison of the measured and calculated densities and refractive indices.

Magnetic susceptibility was obtained by measuring, on a standard Franz Isodynamic magnetic separator at constant slope and tilt, the amperage at which the sample was divided into two equal fractions (the critical amperage) and applying the formula $\chi = c/I^2$ where χ is the mass susceptibility in electro-magnetic units, I is the critical amperage, and c is a constant characteristic of the instrument in use. This formula has been independently derived both by Tillé and Kirkpatrick[1] and by McAndrew.[2]

The value of the constant was obtained by measuring the critical amperage for manganese sulphate and ferrous ammonium sulphate, for both of which the susceptibility is known, and substituting in the formula. Slightly greater accuracy was obtained for the critical amperage by measuring it at several different tilts, plotting the values against the sines of the angles of tilt, and reading the required value from the freehand fitted curve. For the instrument used the constant had a value of $6{\cdot}2 \times 10^{-6}$.

All measurements were made with a slope of 20°, a tilt of 15°, and a feeding speed of 0·5 c.c./min. Although an unadapted instrument was used considerable care was used in reading the amperage and it is believed that readings were reproducible to 0·01 amp. For a mineral of mass susceptibility of 50×10^{-6} e.m.u. this gives a value correct to ±5 %, the error decreasing with increasing susceptibility.

Results. The regression lines for magnetic susceptibility on molecular composition were separately determined for each of the three series: pyrope–almandine, almandine–spessartine, and grossular–andradite. The data are given in table I.

In the pyrope–almandine series only the data for those garnets with less than 5 % (molecular) spessartine plus andradite were used. For the purpose of calculation both spessartine and andradite were added to the almandine percentage and both pyrope and grossular were considered to have $\chi = 0$. The regression coefficient of mass susceptibility in e.m.u. on molecular percentage almandine was found to be $(0{\cdot}69 \pm 0{\cdot}02) \times 10^{-6}$ (standard error based on 14 observations). The distribution of the

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[1] R. Tillé and W. Kirkpatrick, Zeits. Erzbergbau Metallhüttenwesen, 1955, vol. 8, Suppl. p. B. 117.

[2] J. McAndrew, Proc. Australian Inst. Mining Eng., 1957, No. 181, p. 59.

TABLE I. Magnetic susceptibility, χ, of garnets (e.m.u.).

		Composition (mol. %)					χ
Number.	Occurrence.	Pyr.	Alm.	Spess.	Gross.	And.	$\times 10^6$
UWA 37815	Biotite gneiss	29·4	70·0	0·6	0·0	—	46·6
UWA 35719	Cordierite gneiss	24·9	72·0	1·6	1·5	—	54·7
UWA 36159	Cordierite gneiss	20·1	75·1	2·4	2·4	—	48·8
UWA 36337	Garnet granulite	18·5	60·6	1·5	19·4	—	46·6
UWA 25447	Cordierite gneiss	18·0	74·6	4·0	3·4	—	51·6
UWA 37813	Hornblende gneiss	17·2	76·7	1·0	4·1	—	51·6
UWA 36175	Anthophyllite schist	16·6	60·5	1·9	21·0	—	51·6
UWA 37937	Hornblende granulite	11·5	64·7	3·3	20·5	—	62·9
UWA 36336	Secretion pegmatite	9·9	80·3	3·2	6·6	—	54·7
UWA 35274	Garnet gneiss	9·9	83·0	2·5	4·6	—	58·3
UWA 37933	Eclogite	9·8	57·1*	1·3	31·8*	—	39·6
UWA 25370	Hypersthene gneiss	7·7	73·9	2·8	15·6	—	54·7
UWA 36335	Garnet granulite	5·7	85·8	4·1	4·4	—	58·3
UWA 32217	Hornblende gneiss	5·1	70·8	4·3	19·8	—	46·6
UWA 37812	Biotite schist	5·6	85·0	8·6	0·8	—	70·6
UWA 32231	Biotite gneiss	6·6	75·7	14·1	3·6	—	66·1
UWA 36338	Intrusive pegmatite	0·0	64·9	34·8	0·3	—	75·6
GCL 359/28	?	0·2	49·1	50·5	0·2	—	75·6
GCL 2382/32	?	0·3	16·0	78·7	0·0	3·3†	75·6
GCL 1160/26	?	0·8	9·5	87·3	2·4	0·0	75·6
GCL 428/28	?	1·9	3·2	0·2	81·0	13·7	11·5
GCL 3554/32	?	0·2	4·1	0·9	58·0	36·8	24·2
GCL 809/28	?	0·0	0·7	0·5	0·0	98·8	48·8

* Probably includes significant andradite.

† Also 1·7 % quartz.

UWA Catalogue number in the collection of the Geology Department of the University of Western Australia. All analyses by the author.

GCL Catalogue number in the collection of the Government Chemical Laboratory, Perth, Western Australia. Analysts: 359/28, 2382/32, and 809/28, C. R. LeMesurier; 1160/26 and 428/28, E. S. Simpson; 3554/32, D. G. Murray.

values of χ/(mol. % almandine) is skew with a mean, median, and mode of 0·70, 0·66, and 0·65, all $\times 10^{-6}$, respectively. The regression coefficient calculated only on those 10 samples in which χ/(mol. % almandine) does not differ from the mean by more than three times the standard deviation is $0{\cdot}68 \times 10^{-6}$. Since it is believed that most of the anomalies are due to the presence of sub-microscopic inclusions of magnetite with an effective susceptibility possibly greater than that of the garnet by a factor of 10^4, the lower value is more likely to be accurate. This gives a mass susceptibility for pure almandine of $(68 \pm 2) \times 10^{-6}$ e.m.u.

In the almandine–spessartine series only the data for those garnets with less than 15 % of pyrope plus grossular, less than 5 % andradite, and more than 10 % spessartine were used. The measured magnetic susceptibilities were corrected on the assumption that pyrope, grossular, and quartz as an impurity have $\chi = 0$. Andradite was added to the almandine percentage and almandine was taken as having $\chi = 68 \times 10^{-6}$ e.m.u. The regression coefficient of corrected mass susceptibility on molecular % spessartine is found to be $(0{\cdot}13 \pm 0{\cdot}02) \times 10^{-6}$ (5 samples). The low standard error, despite the corrections, may be partly due to the high purity of the mainly pegmatitic garnets, but the low number of spessartine-rich garnets in the sample precludes high accuracy. If this value is accepted the mass susceptibility of pure spessartine is 81×10^{-6} e.m.u. The high susceptibility of spessartine compared with almandine is fully in accord with the ionic susceptibility of manganese and with the results[1] on wolframite.

In the grossular-andradite series only the data for specimens with less than 5 % almandine plus spessartine were used. The measured magnetic susceptibilities were corrected on the assumption that almandine and spessartine have the susceptibilities already obtained. The mass susceptibility of grossular was experimentally determined to be less than $10\ ^{6}$ e.m.u. and it is assumed for the purpose of calculation to be nil. The regression coefficient of corrected mass susceptibility on molecular percentage andradite is $0{\cdot}49 \times 10^{-6}$ (3 samples). Although the number of samples is small the value of 49×10^{-6} e.m.u. for the mass susceptibility of pure andradite is probably at least as accurate as that for spessartine.

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[1] E. M. Spokes and D. R. Mitchell, Mining Engineering (New York), 1958, vol. 10, p. 373.