

## Magnetic susceptibilities of some standard samples of silicate rocks and minerals

GERARDO ALZETTA, ARRIGO BATTAGLIA  
Dipartimento di Fisica dell'Università, 56100 Pisa

STEFANO BATTAGLIA  
Istituto per il Trattamento dei Minerali del C.N.R., Via Bolognola 7, 00138 Roma

**ABSTRACT.** — We report accurate measurements of specific magnetic susceptibilities of some « standard samples » of silicate rocks and minerals. These measurements, made with a simple and sensitive apparatus, can be useful in petrological studies.

*Key words:* magnetic susceptibility measurements, rocks, minerals.

**RIASSUNTO.** — Si riportano accurate misure di suscettività magnetica di alcuni standard internazionali costituiti da rocce silicee e minerali. Queste misure sono state effettuate con un semplice, ma molto sensibile apparato, che può essere di valido aiuto in molti studi petrologici.

*Parole chiave:* misure di suscettività magnetica, rocce, minerali.

### Introduction

Many geological agencies and laboratories operating in different countries have prepared samples of typical silicate rocks and minerals for use as « standard samples ».

These samples together with complete chemical (and sometimes mineralogical) analysis have been distributed to many geological laboratories asking for them.

For many purposes a good complement of these data can be the value of magnetic susceptibility  $\chi$ .

We report here accurate measurements of specific magnetic susceptibility of some standard samples of silicate rocks and minerals available in the « Istituto per il

Trattamento dei Minerali » of C.N.R. in Rome (Italy).

Some experimental data obtained in these measurements are related to chemical (or mineralogical) composition of the rocks and minerals and an attempt is made to compare theoretical to measured susceptibilities.

### Measurements of specific magnetic susceptibility

To measure the  $\chi$ , a simple but sensitive (sensitivity of the order of  $10^{-7}$  cgs units) instrument has been used (1).

The apparatus works on the detection of the magnetic flux variation produced in a permanent magnet by inserting in the gap the specimen under investigation. A schematic of the apparatus is reported in fig. 1.

A lucite plate, 30 cm diameter and 1 cm thick, supported by a vertical non magnetic stainless steel shaft, turns in an horizontal plane with a constant speed, driven by a d.c. motor. In symmetric position with respect to the center, two circular holes, 2 cm diameter, allow positioning of two polyethylene containers for the specimen under investigation and a reference sample.

For samples with a  $\chi$  different from that of the plate, a variation of flux takes place that gives rise to an induced voltage in two coils wound around the caps and connected in series.

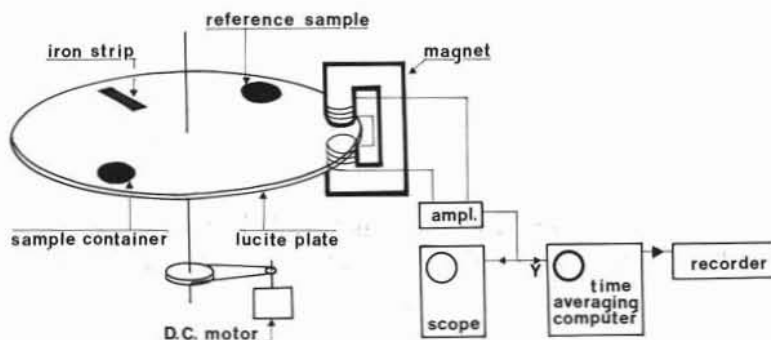


Fig. 1. — Schematic view of the experimental set-up.

TABLE 1  
Magnetic moments (Bohr magneton units)  
of some important ions

ION	MAGNETIC MOMENT $\mu_r$
Ti (3+)	1.7
Cr (3+)	3.86
Mn (2+)	5.68
Fe (3+)	5.68
Fe (2+)	5.25 - 5.53
Ni (2+)	3.23 - 3.43

The induced voltage, of the order of few millivolts or less, is amplified and monitored by an oscilloscope, and memorized in a summing device which after  $n$  periods of summation gets a signal-to-noise ratio  $n^{1/2}$  times better than the single one signal.

After that, the resulting signal is recorded on the paper to obtain a better measurement.

To trigger the scope of the averaging sweep circuits a strong signal is used produced by a radial strip of iron filings stuck on the lucite plate.

Our measurements are always referred to the same standard sample of  $\text{Nd}_2\text{O}_3$  neodymium oxide,  $\chi_m = 10200 \cdot E-06$  cgs units, as reported by the « Handbook of Chemistry and Physics », 48th ed., 1967-68, The Chemical Rubber Co., Cleveland-Ohio, U.S.A.

### Discussion and results

It is well known that paramagnetic ions are responsible of paramagnetic behaviour of compounds.

The main paramagnetic ions found in paramagnetic minerals and rocks are  $\text{Fe}^{(3+)}$ ,  $\text{Fe}^{(2+)}$ ,  $\text{Mn}^{(2+)}$ ,  $\text{Ni}^{(2+)}$ ,  $\text{Ti}^{(3+)}$  and  $\text{Cr}^{(3+)}$ .

From quantum theory of paramagnetism the specific magnetic susceptibility may be calculated from concentration and magnetic moments of paramagnetic ions by means of the expression (2):

$$\chi = 423.6 \cdot E-06 \sum c_r \mu_r^2$$

in cgs units and room temperature. Here  $c_r$  are the ionic concentrations (gr ions/gr) and  $\mu_r$  is the magnetic moment of ions in Bohr magneton units.

In tab. 1 are shown the magnetic moments of some most important ions as they are quoted by STORNER E.C., in « Magnetism and Matter », Methuen & Co. Ltd., London.

These values have been used by many other authors.

For calculations of  $\chi$  with the above formula an arithmetic mean value between the two quoted values for  $\text{Fe}^{(2+)}$  and  $\text{Ni}^{(2+)}$  is largely sufficient.

The formula has been tested over some minerals (3, 4, 5, 6) and not always was found in good agreement with the measured values of  $\chi$ . The precision of measurements of  $\chi_m$  is about 3 %.

In tab. 2, on the right side of the sample number the measured ( $\chi_m$ ) and calculated ( $\chi_T$ ) values of the susceptibility have been written.

The value of  $\chi_T$  was calculated by means of the formula reported above and the calculations were made when the case was significant in account of the mineralogic composition of the sample.

Where two values are presented the lower one was calculated in the hypothesis of a ferrous oxide content and the highest in

TABLE 2  
Measured and calculated  
magnetic susceptibilities of samples

N.	SAMPLE	$\chi_M \cdot 10^6$	$\chi_T \cdot 10^6$	ferro- magnetic compound
1	AGU - 1	266.8		
2	BCR - 1	193.2		
3	BAH/0 - 1	250.5		
4	S - 2	231.4		
5	OSP - 1	202.8		
6	WAG - 1	18.13		
7	PCC - 1	24.29	14.00	
8	QLO - 1	168.5		
9	RGH - 1	63.4		
10	SGR - 1	19.28		
11	SDC - 1	96.2		
12	STM - 1	85.9		
13	CPB - 1	126.0		
14	CNZ - 1	85.0		
15	SY - 2	36.15		
16	SY - 3	33.00		
17	MR0 - 1	1648		yes
18	KC - 1	15.80		
19	UM - 1	258.0		yes
20	UM - 2	407.0		yes
21	UM - 4	1068		yes
22	HP - 1	17.18		
23	427/2 (501)	76.5		
24	428/1 (378)	19780		yes
25	429/1 (512)	58.06		
26	430/1 (568)	4172		yes
27	431/1 (278)	392.6		
28	432/1 (340)	116.9		
29	478/1 (370)	38610		yes
30	480/1 (395)	69.8	124.21 - 156.21	
31	S - 3	253.5	7.21	
32	S - 4	43.4		
33	S - 7	282.0	48.85	
34	174/2	58.0	145.17	
35	319	301.7		yes
36	368	3.04	0.54	
37	375	3.73	0.27	
38	376	3.31	0.18	
39	395	13.74		
40	88 a	0.89	0.571	
41	70 a	3.9	0.12	
42	99 a	3.44	0.12	
43	1 c	7.85	1.05	
44	DT - N	6.30		
45	64	186.4		
46	NIM - G	10.40		

1-12: International reference samples prepared by USGS (U.S.A.); 13-22: International reference samples prepared by CAN MET (Canada); 23-30: International reference samples prepared by Bundesanstalt f. Materialprüfung (BAH) Berlin-Dahlem; 31-33: International reference samples prepared by Institute for Metal Research. Drottning Kristinas Vag 48, 11428 Stockholm (Sweden); 34-39: International reference samples prepared by BCS (England); 40-43: International reference samples prepared by NBS (U.S.A.); 44: International reference sample prepared by ANRT (France); 45: International reference sample prepared by CRPG (France); 46: International reference sample prepared by NIM (South-Africa).

the hypothesis of ferric oxide content. These were the cases in which only the percent of Fe was specified in the chemical analysis certificate.

In the last column the cases are reported in which the presence of ferromagnetic components were evidenced also by an X-ray powder diffractometer.

The conclusion is that there is not a fair agreement between  $\chi_M$  and  $\chi_T$  in the cases we have considered.

*Acknowledgements.* — The Authors wish to express their appreciation to Mr. F. SBRANA of Physics Department of Pisa for his cooperation and help for measurements.

These researches have been carried out with the financial support of C.N.R. (Consiglio Nazionale delle Ricerche).

## REFERENCES

- (1) ALZETTA G., BATTAGLIA S., VILLA G. (1984) - *Measurement of magnetic susceptibilities of mineral and rocks by a simple induction device.* Rev. Phys. Appl., 19, 277-280.
- (2) SHUEY R.T. - *Semiconducting ore minerals.* Development in Economic Geology, 4, 96-99 - Elsevier Sc. Publ. Company, Oxford, England.
- (3) AKIMOTO S., HORAI K., BOKU T. (1958) - *Magnetic susceptibility of orthopyroxenes.* J. Geomagn. & Geoelect., 10, 7-11.
- (4) CHEVALLIER R., MATHIEU S. (1958) - *Susceptibilité magnétique spécifique des pyroxènes monocliniques.* Bull. Soc. Chim. Fr., 5, 726-729.
- (5) SYONO Y. (1960) - *Magnetic susceptibility of some rock forming silicate minerals such as amphiboles, biotites, cordierites and garnets.* J. Geomagn. & Geoelect., 11, 85-93.
- (6) VERNON R.H. (1961) - *Magnetic Susceptibility as a measure of total iron plus manganese in some ferro magnesian silicate minerals.* American Mineral, 46, 1141-1153.