GRAPHICAL DERIVATION OF REFRACTIVE INDEX ϵ FOR THE TRIGONAL CARBONATES

I. S. LOUPEKINE, *Geology Department, University of Bristol, Bristol, England.*

ABSTRACT

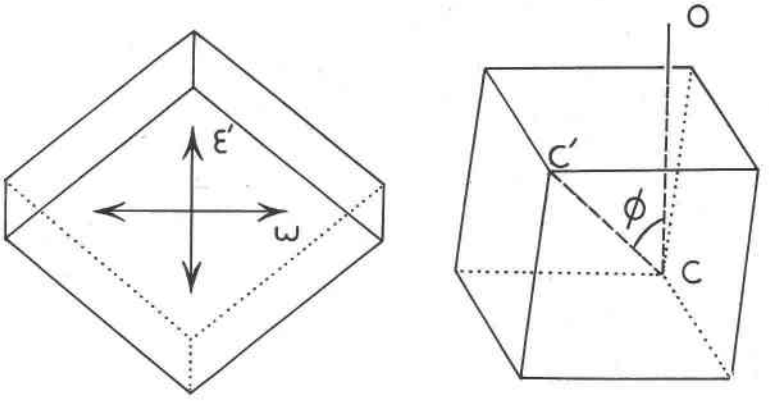
By means of a graphical method, rapid derivation of ϵ for trigonal carbonates may be obtained from the values of ω and ϵ' which are determined from cleavage fragments.

INTRODUCTION

In utilizing the immersion method to identify species of trigonal carbonates in certain industrial powders, the writer felt the need for a rapid method of determining the principal refractive indices. The presence of a perfect rhombohedral cleavage and the lack of any distinct optical indication as to when the *c* crystal axis is perpendicular to the optic axis of a microscope necessitates, in the determination of ϵ, a series of repeated observations of fixed or motile particles. A graph is presented to facilitate determinations carried out under routine conditions where absolute accuracy is not essential.

DERIVATION OF THE GRAPH

The principle of the method is based on the determination of the apparent refractive indices obtainable when a cleavage fragment of a trigonal carbonate rests on any one of its cleavage planes. The apparent



FIGS. 1–2. Optical and crystallographic relations in cleavage rhombohedra of trigonal carbonates. Fig. 1 (left). View of rhombohedron in direction of optic axis of microscope to show vibration-directions ω and ϵ^1. Fig. 2 (right). General view of rhombohedron to show ϕ (OC, direction of optic axis of microscope; CC′, crystal axis *c*).

refractive indices thus obtained are ω and ϵ' (Fig. 1) (Rogers, 1923), and ϵ' is related to ϵ by the equation,

$$\epsilon' = \frac{\omega\epsilon}{\sqrt{\omega^2 \sin^2\phi + \epsilon^2 \cos^2\phi}}$$

where ϕ is the angle between the c crystal axis and the direction representing the optic axis of the microscope which is normal to one of the rhombohedral cleavage sets (Fig. 2) (Salomon, 1896; Johannsen, 1918; Wahlstrom, 1943). The above equation has been applied by Hutchinson (1903), Gaubert (1919), Mountain (1926) in connection with refractive index determinations by the refractometer or prism methods, but no references have been found associating the equation with a practical use of the immersion method for the trigonal carbonates generally.

TABLE 1. CRYSTALLOGRAPHIC DATA FOR THE CLEAVAGE RHOMBOHEDRON OF TRIGONAL CARBONATES

Mineral Species	Chemical Composition	c/a (1)	α' (2)	ϕ (3)
calcite	$CaCO_3$	0.8543	101°55′	44°37′
dolomite	$CaMg(CO_3)_2$	0.8322	102°38′	43°52′
rhodochrosite	$MnCO_3$	0.8259	102°50′	43°39′
siderite	$FeCO_3$	0.8184	103° 4′	43°23′
magnesite	$MgCO_3$	0.8112	103°18′	43° 8′
sphaerocobaltite	$CoCO_3$	0.809	103°23′	43° 2′
smithsonite	$ZnCO_3$	0.8063	103°28′	42°57′

(1) Axial ratio values taken from Dana (1892) except for rhodochrosite (Winchell, 1933) and sphaerocobaltite (after Baccaredda, 1932).

(2) Values of the rhombohedral angles of cleavage fragments from Bragg (1937)Ford (1917); after Dana (1892), Baccaredda (1932).

(3) Values of the angle between the c crystal axis and the rhombohedral normal obtained from the equation,

$$\sin\phi = \frac{2}{3}\,\frac{c}{a}\tan\frac{\alpha'}{2}.$$

These values correspond with the $(0001)\wedge(10\bar{1}1)$ values as given by Dana (1892). The value for sphaerocobaltite is not given by Dana; that for rhodochrosite applies for an axial ratio of 0.8184.

The application of the equation necessitates a knowledge of the angle ϕ, which varies for different species of the trigonal carbonate minerals (Table 1). The largest value, for calcite, is 44°37′; the smallest, for smithsonite, is 42°57′. The average value for ϕ is therefore 43°47′, and it is suggested that for the purpose set out in this paper the value be as-

sumed for all the trigonal carbonates irrespective of species. The maximum error on this assumption is ± 0.003, which is not unreasonably high (Table 2).

TABLE 2. REFRACTIVE INDEX DATA FOR THE TRIGONAL CARBONATES

Mineral Species	ω	ϵ	ϵ'	ϵ' Calculated with True Value of ϕ	ϵ' Calculated with Assumed Value of ϕ	Difference
calcite	1.658	1.486	1.566	1.566	1.569	+0.003
dolomite	1.679	1.502	1.588	1.587	1.587	0.000
rhodochrosite	1.817	1.597	1.701	1.702	1.701	−0.001
siderite	1.875	1.633	1.747	1.748	1.746	−0.002
magnesite	1.700	1.509	1.599	1.602	1.600	−0.002
sphaerocobaltite	1.855	1.600	—	1.722	1.719	−0.003
smithsonite	1.849	1.621	—	1.732	1.729	−0.003

ω, ϵ, and ϵ' values from Winchell (1933).

A graphical representation of the relationship between ω, ϵ and ϵ' for $\phi = 43°47'$ is shown in Fig. 3. For given values of ω and ϵ', the corresponding value of ϵ can be directly obtained from the graph to an accuracy of ± 0.001.

By assuming the arbitrary value of $43°47'$ for ϕ, the total error incurred in the use of the graph in Fig. 3 is therefore ± 0.004. As will be shown in the next section, this error can be substantially reduced by the application of a correction factor.

CORRECTION FACTOR

A knowledge or partial knowledge of either the chemical composition or one of the angular values of the carbonate cleavage parallelopiped (from x-ray data, for example) can be utilized to reduce the error associated with the use of the graph in Fig. 3. It is to be noted that this correction factor can be applied as a result of preliminary data obtained from the refractive indices themselves. The magnitude of error plotted against α', ϕ, and the chemical composition (denoted by kations only) is shown in Fig. 4.* Theoretically, the error after correction is reduced to ± 0.001.

* The straight line in Fig. 4 was derived graphically, and is sufficiently approximate to the curve obtained from the equation,

$$\Delta\epsilon' = -\frac{1}{2}\left(\frac{1}{\epsilon^2} - \frac{1}{\omega^2}\right)\epsilon'^3\Delta\phi$$

owing to the small value of $\Delta\phi$ and the approximate constancy of $(1/\epsilon^2 - 1/\omega^2)\epsilon'^3$ for the range required.

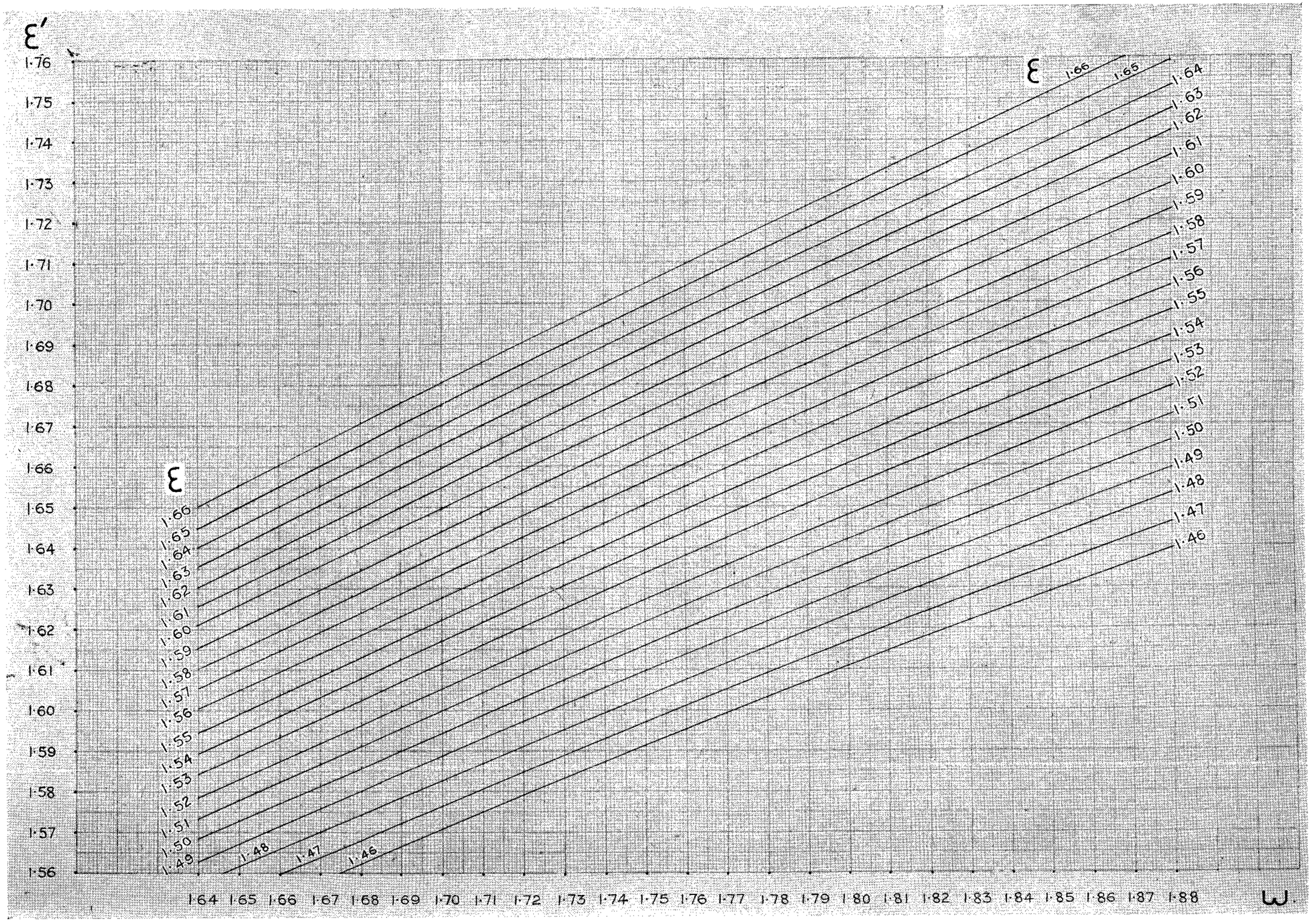


FIG. 3. Relationship between ω, ϵ, and ϵ' in trigonal carbonates.

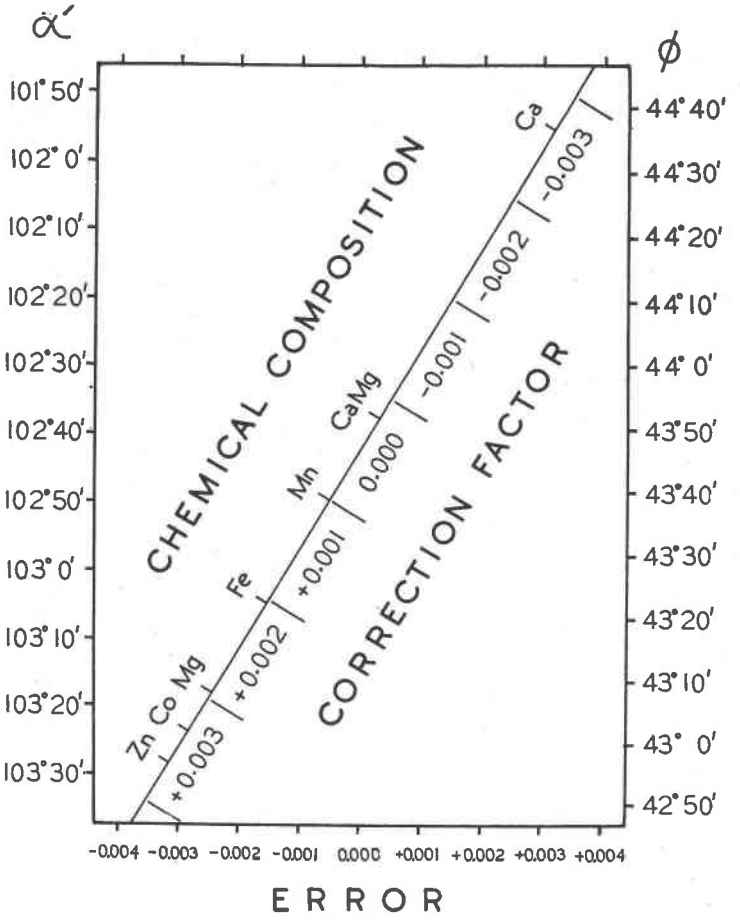


FIG. 4. Correction factor (α^1, ϕ, and composition are plotted against error due to use of the assumed, instead of the true, value of ϕ).

REFRACTIVE INDEX DETERMINATIONS OF SELECTED SPECIMENS

In order to test the applicability of the graphs embodied in Figs. 3 and 4, twelve specimens of trigonal carbonate species were selected from the collections of the Geology Department, University of Bristol, for determination. Samples were crushed to small fragments, and the values of ω, ϵ, and ϵ' were determined by the immersion method. The media employed consisted of various oils and iodide mixtures; a micro-refractometer was used to determine the refractive indices of the liquids. The source of light was sodium discharge tube or suitably filtered white light, and the

temperature at which the determinations were made was maintained at $20° \pm \frac{1}{2}°$ C.

The results are set out in Table 3, which also includes the values of ϵ derived from the graph in Fig. 3, and the corrected values derived from Fig. 4 as a result of preliminary information of composition gained by reference to the data published by Winchell (1933). The accuracy of determination is believed to be $\pm$ 0.001 for all values except for readings above 1.8 where the accuracy is probably ± 0.002.

Inspection of results reveals a maximum error of ± 0.004 before correction, and ± 0.002 after correction.

TABLE 3. DETERMINATIONS OF REFRACTIVE INDICES OF SELECTED SPECIMENS OF TRIGONAL CARBONATES

Specimen Number	Determinations			ϵ Read from Graph	Error in Reading of ϵ	Correction	Corrected Value of ϵ	Error after Correction
	ω	ϵ'	ϵ					
1	1.662	1.575	1.492	1.495	+0.003	−0.003	1.492	0.000
2	1.663	1.577	1.493	1.497	+0.004	−0.003	1.494	+0.001
3	1.679	1.587	1.502	1.503	+0.001	0.000	1.503	+0.001
4	1.688	1.591	1.500	1.502	+0.002	0.000	1.502	+0.002
5	1.691	1.595	1.511	1.509	−0.002	+0.002	1.511	0.000
6	1.692	1.607	1.527	1.529	+0.002	0.000	1.529	+0.002
7	1.705	1.608	1.523	1.521	−0.002	+0.002	1.523	0.000
8	1.713	1.611	1.520	1.520	0.000	+0.002	1.522	+0.002
9	1.763	1.630	1.518	1.515	−0.003	+0.001	1.516	−0.002
10	1.807	1.702	1.605	1.606	+0.001	0.000	1.606	+0.001
11	1.847	1.727	1.621	1.620	−0.001	+0.003	1.623	+0.002
12	1.872	1.745	1.634	1.632	−0.002	+0.002	1.634	0.000

1. Calcite; Styria, Austria.
2. Calcite; Mulatto, Predazzo, Italy.
3. Dolomite; West Chester, Penn., U.S.A.
4. Dolomite; Schemnitz, Hungary.
5. Dolomite; Hrubschütz, Moravia, Czechoslovakia.
6. Dolomite; Cumberland, England.
7. Magnesite, var. breunnerite; Carlsbad, Czechoslovakia.
8. Magnesite, var. mesitite; Flachau, Salzburg, Austria.
9. Ankerite; Schemnitz, Hungary.
10. Rhodochrosite; Alma, Colorado, U.S.A.
11. Smithsonite; Laurium, Greece.
12. Siderite; Siegen, Prussia, Germany.

Conclusions

1. The graphical method of deriving the value of ϵ from determined values of ω and ϵ' can probably be maintained to within ± 0.004 without correction, and to within ± 0.001 after correction. These values do not include the experimental error.

2. Use of a graphical method in deriving the value of ϵ reduces the expenditure of time and effort since careful orientative measures and repeated determinations of the refractive indices are not required. The method should be suitable for routine determinations.

3. A graphical method of deriving the value of ϵ enables a ready determination of the principal refractive indices of more than one species of trigonal carbonate in the same powder.

4. The graphs presented in this paper will be found to have other applications, as for instance in checking determinations of ω and ϵ.

Acknowledgment

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