THE VARIABLE INVERSION TEMPERATURE OF QUARTZ AS A POSSIBLE GEOLOGIC THERMOMETER

O. F. TUTTLE, Geophysical Laboratory, Washington, D.C.

Abstract

The high-low inversion temperature of quartz has been found to vary as much as 1.90° C. The inversion temperature varies inversely with the temperature of formation and therefore may become a useful geologic thermometer.

INTRODUCTION

The high-low inversion temperature of quartz has been investigated by many observers. For a comprehensive review of these studies the reader is referred to Sosman¹ (1927). The most accurate measurements of the inversion temperature are those by Bates and Phelps² (1921) who suggested using the inversion temperature as a fixed point on the thermometric scale. They found the rising-temperature inversion to be $573.3 \pm 0.1^{\circ}$ C.

The inversion temperature as a function of the geologic history of the quartz has not been investigated so far as the writer is aware, although Sosman suggested that such a study would be of considerable interest. The present report deals with a preliminary study of that relation.

Method

The quartz was crushed, sieved through a 35 mesh screen, and collected on a 200 mesh screen after which it was treated with boiling hydrochloric acid for 30 minutes, washed, and dried at 110° C. The high-low inversion temperature was measured by means of time-temperature heating curves using chromel-alumel thermocouples. The thermoelement junction was imbedded in 1.5 grams of powdered quartz.

Temperature measurements were made with a White potentiometer that gave readings on a standard quartz that were reproducible to \pm .04° C. This degree of reproducibility could be obtained only by taking special care to place the charge and thermoelement leads in exactly the same position in the furnace for each experiment and to have the cold junction portion of the leads immersed to the same depth each time. All determinations were made by heating the powder at a uniform rate of 1° C. per minute through the inversion region and recording the temperature at 15-second intervals. The inversion temperature was taken as the

¹ Sosman, Robert B., The properties of silica: Am. Chem. Soc., Monograph No. 37 (1927).

² Bates, F., and Phelps, F. P., The new fixed point on the thermometric scale: *Phys. Rev.* (2) 18, 115-116 (1921).

intersection of two straight lines drawn in the manner shown in Fig. 1. The present investigation is concerned with differences in the inversion

temperature and not the actual temperature of the transition, therefore



FIG. 1

no attempt has been made to fix the measurements on the thermometric scale.

All determinations reported are temperature differences between a "reference" quartz and the unknown. A large single crystal of quartz from Minas Gerais, Brazil, was selected as a reference. It is likely that the reference quartz used in this work has the same geologic origin as the material used by Bates and Phelps, therefore presumably has an inver-

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sion temperature of $573.3 \pm 0.1^{\circ}$ C. One half of the crystal was crushed and used in the determinations, the remainder being saved for other investigations.

Each determination was made as follows: Three time-temperature heating curves were run on the reference quartz, the last two being made without cooling more than a few degrees below the transition. The reference quartz was then removed and the unknown immediately placed inthe furnace and three time-temperature curves were made as before. To check any drift in the potentiometer the reference quartz was again placed in the furnace and rerun three additional times. In all determinations the value of the third run of the second set of runs on the reference quartz was within 0.08° C. of the first, and the mean of the two values was accepted. A typical series of experiments is shown in Table 1.

TABLE 1.	DETERMINATION	OF DIFFEREN	ACE IN	INVERSION
TE	MPERATURE OF ST	TANDARD AND	UNKN	OWN

Run	Standard	Unknown	Standard
1	23845.6	23829.9	23847.6
2	23842.0	23824.3	23842.0
3	23840.2	23823.0	23841.2
	Standard	23840.7	
	Unknown	23823.0	
		17.7 or 18 Microvolts	difference

It was necessary to make three time-temperature curves for each determination because the first and second runs on a sample that had been cooled to room temperature were always somewhat higher than subsequent runs (one exception to this was found). After the third run through the transition the temperature of the inversion was constant within the experimental error and this value was accepted.

Investigations of the inversion by means of cooling and differential curves have not been carried out. The interrelations between heating, cooling, and differential curves should provide much useful additional information.

RESULTS

The inversion temperature of 36 quartz samples has been determined with respect to the reference quartz (Table 2). Inversion temperatures 0.60° C. above, and 1.30° C. below the reference have been found.³

⁸ It should be pointed out that the value of quartz for calibration in routine thermal analysis as recently proposed by Dr. George T. Faust (*Am. Mineral.*, **33**, 337–345, 1948) is in no way affected by the variations in the inversion temperature reported here.

No.	Type of Occurrence	Locality	Remarks	±ref. quartz
1	Novaculite	Missouri		+18
2	Euhedral crystals in so-	Carrara, Italy		+17
	lution cavities in lime-			
2	stone			
3	Vein quartz	Brazil	Easily twinned by saw-	+15
1	Fubedral emistels from	Variation T	ing	
т	vilg in limestone	Keokuk(?), Iowa	Pronounced lineage	+15
5	Ouartz from Alpine-	Switzerland	Smoky twisted	<u> </u>
	type vein	ownedering	Shicky twisted	T14
6	Vein quartz	Brazil	Smoky, same crystal as	+12
			spec. 9	
7	Vein quartz	Brazil	Easily twinned	+12
8	Euhedral crystals from	Herkimer Co., New		+11
0	vug in limestone	York		
9	vein quartz	Brazil	Clear, same crystal as	+10
10	Fuhedral crystal from	Horkimor Co. No.	spec. 6	1.10
10	vug in limestone	Vork	Different source from 8	+10
11	Quartz vein in biotite	Washington, D. C.		+ 5
	gneiss	, <u> </u>		10
12	Quartz vein	Guanajuato, Mexico	Lineage present, ame- thyst	+ 5
13	Quartz-ankerite vein in	Medicine Bow Mts.,		+3
	marble	Montana		
14	Quartz vein in mica	2 miles North of Key-		+ 2
15	schist	stone, S. D. on Hwy. 16		
16	Glassy white cuarts	Hot Springs, Ark.		+1
10	core of pegmatite	Hille S D		0
17	Quartz vein containing	Black Hills S D		0
	andalusite	5.000 11110, 01 15.		0
18	Harney Peak Granite	North of Mt. Rush-		0
		more, Black Hills, S. D.		
19	Pegmatite in Harney	North side of Sylvan,		- 2
20	Peak granite	Lake, Black Hills, S. D.		
20	Pegmatite in Harney	South of Grizzly Bear		- 5
	r eak granite	Camp Grounds, Black		
21	Graphic granite	Bradbury Maine	•	12
22	Rhyolite tuff	New Mexico		-12
23	Biotite granite	Wallace Cove. Head		-17
	-	Harbor Island, Jones		
		Port, Maine		
24	Probably pegmatite	Brazil	Citrine quartz	-19

TABLE 2

No.	Type of Occurrence	Locality	Remarks	±ref. quartz
25	Gray quartz from	Helen Beryl Mine,		-21
	quartz-spodumene zone of pegmatite	Black Hills, S.D.		
26	Graphic granite	Minot, Maine		-23
27	Quartz core of pegma-	Etta Mine, Black Hills,		-24
	tite	S. D.		
28	Rhyolite	New Mexico	National Mus. 102458	-26
29	Pegmatite	West of New York	Small offshoot (?) of	-26
		Mine, Black Hills, S. D.	N. Y. pegmatite	
30	Pegmatite	Jones Port, Maine	Specimen taken near 23	-28
31	Rhyolite	Colorado	Nevadite	-29
32	Rhyolite	Locality unknown	Euhedral crystal	-38
33	Epithemal (?) vein	Cripple Creek, Colo-		-40
		rado		
34	Pegmatite	Probably Maine	Rose quartz	-52
35	Synthetic-grown in dil	ute NaOH solution at 3	00° C. and 1000 kg./cm	n. ²
	pressure			+24
36	Synthetic-grown in soc	lium tungstate melt at 80	0° C.	-12

TABLE 2—(continued)

Phenocrysts of quartz from five different rhyolites, presumably formed at high temperature, have transition temperatures below the reference quartz. Moreover one sample of quartz grown in the laboratory at 800° C. also inverted below the reference. On the other hand five samples believed to have grown at low temperature (from vugs in limestone) have inversion temperatures higher than the reference, as does one sample grown in the laboratory at 300° C. The relative temperature of formation of the remainder of the specimens is not known as they are from granites, pegmatites and quartz veins. Fig. 2 illustrates the relative temperatures of inversion of these samples.

Observations of geological significance may be summarized as follows: (a) All quartz specimens whose geologic environment indicates low temperature of growth and one synthetic at 300° C. invert at higher temperatures than the reference quartz.

(b) All quartz from rhyolites and one synthetic at 800° C. invert at temperatures below the reference sample.

(c) All specimens whose morphology indicates low quartz invert at the same temperature as or at a higher temperature than the reference quartz.

(d) All specimens having recognizable lineage invert at higher temperatures than the reference. This inverse relation between lineage and tem-

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INVERSION TEMPERATURE OF QUARTZ SPECIMENS VS REFERENCE QUARTZ

FIG. 2

perature of formation has been reported for other crystals.⁴ It is unfortunate that a quantitative method of evaluating the magnitude of lineage has not been devised.

(e) Two specimens of chert showed no break in the heating curve although x-ray analysis indicates that both samples are quartz.

(f) All specimens except number 24 inverted at a higher temperature on heating through the inversion from room temperature than on heating from a few degrees below the inversion temperature. In other words there appears to be some type of readjustment on cooling to room temperature that does not take place on cooling only a few degrees below the transition temperature. Much additional experimental work will have to be carried out to exclude experimental uncertainties before the significance of this observation can be evaluated.

THEORETICAL CONSIDERATIONS

Variability of the inversion temperature of quartz is probably the result of solid solution. Knowledge of the amount and kind of "impurities" must await careful spectrographic analysis.

Solid solution can raise the inversion temperature, lower it, or leave it unaffected, depending on the solubility relations between the two modifications of the crystal and the material entering into solid solution. If the solubility is greater in the high temperature modification, the inversion temperature will be lowered; whereas greater solubility in the low temperature form will raise the transition temperature.

The greater specific volume of the high temperature modification suggests that solid solution, especially of the interstitial type, would be greater in the high temperature form, with consequent lowering of the transition temperature. This is the relation actually found.

Quartz is a unique mineral in that it reputedly does not vary in composition despite its wide geologic distribution and the variability of the chemical environment in which it has grown. However, the possibility that small amounts of other elements may enter into solid solution cannot be excluded. A certain amount of interstitial solid solution seems probable, and substitutional solid solution does not appear to be improbable. Germanium, which is a likely candidate for substitutional solid solution, has been reported in small amounts in quartz.⁵ Also, Ba, Al, and

⁴ Smith, F. G., Lineage structure and conditions of deposition of pyrite: *Econ. Geol.*, **37**, 519 (1942).

Tuttle, O. F., and Twenhofel, W. S., Effect of temperature on lineage structure in some synthetic crystals: Am. Mineral., 31, 569-573 (1946).

⁵ Goldschmidt, V. M., and Peters, C., Zur Geochemie des Germaniums: Nachr. Ges. Wiss. Göttingen, Math.-Phys. Kl., 141 (1933).

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Ti have been reported in quartz from granitic rocks in amounts up to 0.90%.⁶ These impurities, if present in solid solution, might be sufficient to change the inversion temperature appreciably. Theoretically strain, such as may be present in the quartz from mylonitic rocks, could affect the inversion characteristics. An investigation of this possibility is being carried out.

CONCLUSIONS

The inversion temperature of quartz believed to have grown at low temperature is higher than specimens believed to have grown at high temperatures. The same contrast is shown by quartz grown in the laboratory at measured temperatures. If this inverse relation between inversion temperature and temperature of formation is found to be universally valid the quartz inversion will become a valuable geologic thermometer especially when calibrated by quartz grown at known temperatures and pressures in the laboratory. Solid solution is believed to be the most likely cause of the variable transformation temperature.

ACKNOWLEDGMENTS

The writer is indebted to Drs. N. L. Bowen and M. L. Keith for many helpful suggestions concerning this investigation. Thanks are due also Drs. Clifford Frondel of Harvard University, W. F. Foshag of the National Museum, and Felix Chayes of this Laboratory for providing many of the quartz specimens used in this work.

⁶ Bray, J. M., Spectroscopic distribution of minor elements in igneous rocks from Jamestown, Colorado: *Bull. Geol. Soc. Am.*, **53**, 765–814 (1942).