



Designation: ~~D 934-80 (Reapproved 2003)~~ Designation: D 934 – 08

Standard Practices for Identification of Crystalline Compounds in Water-Formed Deposits By X-Ray Diffraction¹

This standard is issued under the fixed designation D 934; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These practices provide for X-ray diffraction analysis of powdered crystalline compounds in water-formed deposits. Two are given as follows:

Practice A—Camera	Sections 12 to 21
Practice B—Diffractometer	22 to 30

1.2 Both practices yield qualitative identification of crystalline components of water-formed deposits for which X-ray diffraction data are available or can be obtained. Greater difficulty is encountered in identification when the number of crystalline components increases.

1.3 Amorphous phases cannot be identified without special treatment. Oils, greases, and most organic decomposition products are not identifiable.

1.4 The sensitivity for a given component varies with a combination of such factors as density, degree of crystallization, particle size, coincidence of strong lines of components and the kind and arrangement of the atoms of the components. Minimum percentages for identification may therefore range from 1 to 40 %.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* Specific precautionary statements are given in Section 8 and Note 20.

2. Referenced Documents

2.1 *ASTM Standards:*²

D 887 Practices for Sampling Water-Formed Deposits

D 933 Practice for Reporting Results of Examination and Analysis of Water-Formed Deposits

D 1129 Terminology Relating to Water

D 1193 Specification for Reagent Water

D 2331 Practices for Preparation and Preliminary Testing of Water-Formed Deposits

E 11 Specification for Wire Cloth and Sieves for Testing Purposes

3. Terminology

3.1 ~~Definitions—~~*For definitions of terms used in these practices, refer to Terminology D 1129.*

4. Summary of Practices

4.1 Powdered samples are irradiated with a monochromatic X-ray beam of short wavelength (from about 0.05 to 0.25 nm). The X rays interact with the atoms in the crystal and are scattered in a unique diffraction pattern which produces a fingerprint of the crystal's atomic or molecular structure. The analytical instrumentation used in X-ray diffraction includes the powder camera and the diffractometer ~~(1), (2), (3), (4), (5)~~.³

5. Significance and Use

5.1 The identification of the crystalline structures in water-formed deposits assists in the determination of the deposit sources

¹ These practices are under the jurisdiction of ASTM Committee D19 on Water and are the direct responsibility of Subcommittee D19.03 on Sampling of Water and Water-Formed Deposits, Analysis of Water for Power Generation and Process Use, On-Line Water Analysis, and Surveillance of Water.

Current edition approved July 3, 1980; Oct. 1, 2008. Published November 1980; 2008. Originally approved in 1947. Last previous edition approved in 1980; 2003 as D 934 – 80 (2003).

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The boldface numbers in parentheses refer to the references listed at the end of these practices.

and mode of deposition. This information may lead to measures for the elimination or reduction of the water-formed deposits.

6. Purity of Reagents

6.1 Reagent grade chemicals shall be used in all tests. Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.⁴ Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

6.2 *Purity of Water*—~~Unless otherwise indicated, reference to water shall be understood to mean reagent water conforming to Specification D1193, Type H.~~—Unless otherwise indicated, reference to water shall be understood to mean water that meets or exceeds the quantitative specifications for Type I or Type II reagent water conforming to Specification D 1193, Section 1.1.

7. Sampling

7.1 Collect the sample in accordance with Practices D 887.

7.2 A suitable amount of sample should be obtained so that it is representative of the deposit under investigation.

7.3 Deposits shall be removed and protected in such a way that they remain as nearly as possible in their original states.

8. Safety Precautions

8.1 The potential danger of high-voltage and X-ray radiation makes it mandatory for anyone operating X-ray apparatus to be thoroughly familiar with basic safety precautions.

8.2 Place colorful signs displaying the international radiation symbol near X-ray equipment.

8.3 When X-ray equipment is producing radiation, illuminate a conspicuous light. There should be no X rays if the bulb burns out. Equipment without this feature can be modified.

8.4 Use a portable counter periodically to test for leakage of X rays from equipment. Lead or lead glass shielding is sometimes needed. X rays of shorter wavelength require more caution.

8.5 Film badges, dosimeters, or other monitoring devices shall be worn by personnel who regularly work with X-ray equipment.

9. Preliminary Testing of Analytical Sample

9.1 It may be advantageous and even necessary to perform other analytical investigative methods to aid in the rapid identification of crystalline components in water-formed deposits. For other testing methods refer to Practices D 2331.

10. Preparation of Sample

10.1 *Apparatus*—The apparatus used for preparing the sample is as follows:

10.1.1 *Mullite or Agate Mortar.*

10.1.2 *Sieves*—A series of sieves from No. 100 mesh (150- μm) to No. 325 mesh (45- μm) as specified in Specification E 11.

10.1.3 *Soxhlet Extractor.*

10.2 *Procedure*—The following procedure is to be used in preparing the sample:

10.2.1 Air-dry moist samples before grinding. If there is special need to preserve the nature or composition of the original deposit, special handling must be observed. Handle deliquescent deposits in a dry-box atmosphere. Handle samples subject to oxidation in an inert atmosphere.

10.2.2 If samples contain oil or grease, prepare a chloroform-insoluble fraction by first drying the specimen for 1 h at 105°C and then extracting for 2 h using chloroform in a Soxhlet extracting apparatus. Air-dry to remove solvent from specimen.

10.2.3 Grind the sample in a mullite or agate (mechanical or hand) mortar until approximately 98 % passes a No. 325 mesh (45- μm) sieve (see Note 1). Remove fragments of fiber, wood, and metal. If the specimen is not sufficiently brittle at ordinary temperatures to be ground to a fine powder or if it is suspected that certain crystallites may be plastically deformed during the grinding, the deposit can be subjected to dry-ice temperatures and then ground immediately. Grind hydrated samples under alcohol, if indicated, to prevent structural damage.

NOTE 1—Most materials found in water-formed deposits are sufficiently brittle to be reduced to 45 μm and this crystallite dimension will generally give good identifiable diffraction patterns. However, it may not always be practical or possible to reduce certain materials to 45 μm . Often good diffraction results can be obtained from larger crystallite sizes (No. 200 mesh (75- μm) to No. 270 mesh (53- μm)). The only practical test for proper grain size is in reproducibility of diffraction line intensities. The ideal grain size may be in the subsieve range as small as 1 μm , but reduction to this size may be impractical.

11. Selective Segregation of Analytical Sample

11.1 *Chemical and Physical Treatment of Samples*—Depending on the contents of the sample, it may or may not be necessary to concentrate or segregate components by chemical or physical treatment (see Note 2). Many crystalline materials produce sharp

⁴ *Reagent Chemicals, American Chemical Society Specifications*, American Chemical Society, Washington, DC. For suggestions on the testing of reagents not listed by the American Chemical Society, see *Antarctic Annual Standards for Laboratory Chemicals*; BDH Ltd., Poole, Dorset, U.K., and the *United States Pharmacopeia and National Formulary*; U.S. Pharmaceutical Pharmacopeial Convention, Inc. (USPC), Rockville, MD.

diffraction patterns and they are identifiable when present to 1 or 2 % in a mixture. Other substances that can be readily identified alone are difficult to detect in mixtures even when they are present to the extent of 50%. Separation of phases by density, acid solubility, or magnetic properties followed by diffraction analysis of the separated phase(s) may help to identify various deposit components. Separation treatment is also helpful in resolving line coincidence in complex mixtures. If concentration or segregation is not deemed necessary, disregard any treatment and proceed in accordance with Section 10. When treatment is necessary, use one or more of the following chemical or physical treatments described in 11.2 to 11.7. It must be pointed out that the treatments provide no absolute separation, but serve only to concentrate or partially segregate specific components.

NOTE 2—It should be emphasized that water-formed deposits often occur in clearly defined layers and that physical separation at the time of sampling is more advantageous than later treatment.

11.2 *Water-Insoluble Fraction*—This treatment removes the water soluble from the water insoluble components. Soluble constituents would include most sodium, potassium, and lithium compounds (see Note 3).

11.2.1 Weigh 0.5 g or more of sample that has been ground and passed through a No. 100 mesh (150- μ m) sieve. Add 100 mL of water to a beaker containing the powdered specimen. Heat to boiling and then cool. Allow 30 min of reaction time, filter through a 45- μ m membrane filter, wash, and air-dry the residue. Re grind to pass through a No. 325 mesh (45- μ m) sieve.

NOTE 3—The filtrate may be evaporated and the residue examined by diffraction. Although the crystalline structure may have changed from the original sample, it is often helpful in identifying simplified variations of the original crystals. Sodium phosphate compounds found dispersed in boiler deposits are often noncrystalline or are so complex that they are not easily identified. The water soluble residue from these deposits after evaporation is often more easily identified.

11.3 *Hydrochloric Acid-Insoluble Fraction*—This treatment removes carbonates, phosphates, and hydroxides. Partial decomposition occurs to some silicates such as serpentine, xonotlite, and analcite. Components such as anhydrite undergo only partial dissolution.

11.3.1 *Reagent*—The reagent used for this treatment is as follows:

11.3.1.1 *Hydrochloric Acid (1 + 6)*—Mix 1 volume of concentrated HCl (sp gr 1.19) with 6 volumes of water.

11.3.2 Weigh approximately 0.5 g of the sample that has been ground and passed through a No. 100 mesh (150- μ m) sieve. Add 100 ml of HCl (1 + 6) to a beaker containing the powdered specimen. Allow 30 min of reaction time, filter through a membrane filter, wash and air-dry the residue. Re grind to pass through a No. 325 mesh (45- μ m) sieve.

11.4 *Nitric Acid-Insoluble Fraction*—This treatment removes all the components indicated in 11.3 in addition to copper and most copper compounds.

11.4.1 *Reagent*—The reagent used for this treatment is as follows:

11.4.1.1 *Nitric Acid (1 + 13)*—Mix 1 volume of concentrated HNO₃ (sp gr 1.42) with 13 volumes of water.

11.4.2 Weigh 0.5 g or more of the sample which has been ground and passed through a No. 100 mesh (150- μ m) sieve. Add 100 ml of HNO₃(1 + 13) to a beaker containing the powdered specimen. Allow 30 min of reaction time, filter through a membrane filter, wash and air-dry the residue. Re grind to pass through a No. 325 mesh (45- μ m) sieve.

11.5 *Density Fraction*—This treatment separates compounds in water-formed deposits which differ appreciably in density such as copper oxide and calcite.

11.5.1 Weigh 0.5 g or more of sample that has been ground and passed through a 100 mesh (150- μ m) sieve. Add 100 mL of water to a beaker containing the powdered specimen. Stir the liquid with a mechanical stirrer, but do not use a magnetic stirrer (Note 4). The denser particles will settle to the bottom and the less dense particles will remain suspended. With continued stirring, withdraw sufficient liquid and filter through a membrane filter. Varying the speed of the stirrer will put more or less of the powdered sample into suspension. Air-dry the residue and re grind to pass through a No. 325 mesh (45- μ m) sieve.

NOTE 4—A magnetic stirrer would attract any particle that was magnetic and might prevent segregation of particles of different densities.

11.6 *Magnetic and Nonmagnetic Fraction*—This treatment separates the magnetic components from the nonmagnetic components such as magnetite from hydroxyapatite.

11.6.1 Weigh 0.5 g or more of sample that has been ground and passed through a No. 325 mesh (45- μ m) sieve. Add 100 mL of water to a beaker containing the powdered specimen. Stir with a mechanical stirrer for several minutes and then attach a magnet to the outside of the beaker (see Note 4). While stirring continues, magnetic components will be attracted to the area in front of the magnet, while the nonmagnetic components will remain in suspension. After 30 min, pour off the liquid while the magnet remains in place and filter. The residue should be essentially nonmagnetic. Remove the magnet from the side of the beaker, rinse the magnetic portion down the side of the beaker, swirl, and filter. Air-dry the residues and re grind to pass through a No. 325 mesh (45- μ m) sieve.

11.7 *Brittle Fraction*—This treatment concentrates the more brittle or friable components from those that are less brittle or less friable such as calcite from silica.

11.7.1 *Apparatus*—The apparatus necessary for this treatment is as follows:

11.7.1.1 *Electrical Mechanical Sieve Shaker*.

11.7.2 Weigh 0.5 g or more of sample and hand grind in a mullite mortar until the largest particle size is approximately 1 mm in diameter. Set up the sieve-shaker apparatus with four different size sieves; No. 100 mesh (150- μ m), No. 140 mesh (105- μ m), No. 200 mesh (75- μ m) and No. 325 mesh (45- μ m). Shake the sample for several minutes and then collect the various fractions

from each sieve. The most friable portion of the deposit should have passed to the bottom-most sieve. Each fraction may be examined separately after regrinding to pass a No. 325 mesh (45- μ m) sieve.

PRACTICE A—CAMERA

12. Scope

12.1 This method covers the qualitative X-ray diffraction analysis of powdered crystalline substances using photographic film as the detector. The film-camera technique has the advantage of being less expensive initially and less costly to maintain. The camera practice permits the use of smaller samples. Film cameras do not require the well-stabilized power supply as electronic detection techniques do. Often faint diffraction lines are more readily detected with film.

13. Summary of Practice A

13.1 Practice A utilizes the Debye-Scherrer type camera. In this method a powdered sample is placed in the center of a camera cylinder and a narrow film is wrapped around the inner wall. A monochromatic X-ray beam is directed upon the sample and the randomly oriented crystallites diffract the incident beam into a set of concentric cones in accordance with Bragg's Law ($n\lambda = 2d \sin \theta$). The interceptions of the diffraction cones on the positioned film strip result in curved lines on that film. The spacings of these lines are used to identify the crystalline material.

14. Interferences

14.1 Large particles in the powder mount give spotty or discontinuous diffraction lines. A particle size that is too small will cause broadening of the diffraction lines.

14.2 For certain elements the absorption of the X rays is relatively high. This is especially true for the heavier elements when longer wavelength X rays are used (see Note 5). Therefore, larger samples of such elements can actually give rise to fainter diffraction lines than would be obtained from a smaller sample of the same element. Excessively large mounts should be avoided if the elemental composition of the sample has high absorption for a selected radiation.

NOTE 5—Values for absorption by different elements with various commonly-used X-ray sources can be found in the International Crystallographic Tables.

14.3 The proper filters should be used to remove beta radiation and to ensure essentially monochromatic radiation from the target.

14.4 Preferred orientation of crystallites will produce diffraction lines that are not of uniform intensity around the entire circumference.

14.5 Fluorescent radiation should be avoided if possible since it will obscure certain diffraction lines. This radiation may be minimized by selecting the incident-beam wavelength as far removed as possible from the K and L absorption edges of metallic elements expected in the deposit. If a prominent metallic element exists in the sample under investigation, a target of the same metal should be used if possible.

NOTE 6—Copper radiation is not as satisfactory as other recommended radiations for specimens containing considerable iron or iron bearing compounds because of excessive fluorescence, which will produce fogging on the film. However, copper targets are by far the most widely used and most generally applicable.

15. Apparatus

15.1 *Beta Filters*—Free metals or metal oxides filters of vanadium, manganese, iron, nickel, and zirconium. For the choice of filter refer to the following list (see Note 7):

X-ray Target Material	Filter
Chromium	Vanadium
Iron	Manganese
Cobalt	Iron
Copper	Nickel
Molybdenum	Zirconium

NOTE 7—The filter shall be of sufficient thickness to reduce the intensity of the K_{β} radiation to 1/100 of the K_{α} radiation. Monochromator crystal attachments are available for many cameras which will eliminate the use of beta filters and produce clean diffraction lines corresponding to a single X-ray wavelength with low background.

15.2 *Camera*, Debye-Scherrer type usually 57.3 or 114.6 mm in diameter so that 1 mm of film equals 2 or 1 degs, respectively. Features of the camera should include: (1) a device to hold film flush against the cylinder, (2) a sample holder with provision to center the mount, (3) a device for rotating or oscillating sample, (4) a collimating system to produce a narrow and nondivergent beam, and (5) a beam stop or exit tube that prohibits the direct beam from exposing the film or escaping into the room.⁴

15.3 X-ray Equipment⁵:

15.3.1 *X-ray Generator*, with stable high-voltage electrical supply.

15.3.2 *X-ray Generator Control Unit*, containing the following: (1) a milliammeter connected across the secondary circuit to indicate current flow through the X-ray tube, (2) a warning light in full view that indicates that X rays are being produced, (3) an overload relay to trip the circuits when the tube current exceeds normal operating values, (4) a pressure switch in the water line to trip the circuits if the tube receives an insufficient flow of cooling water, (5) an electric timer that will shut off the unit at the end of a preset time, (6) a time totalizer that indicates the total time the generator has been on, and (7) interlocking safety switches that turn off the high voltage circuit if the panels of the unit are opened.

15.4 *Filtered Cooling Water System*—Installed prior to X-ray equipment.

15.5 *X-ray Source*—A number of X-ray targets are available that produce K_{α} radiation of various desired wavelengths. They include: Targets of chromium, iron, cobalt, copper, and molybdenum.

16. Reagents and Material

16.1 *Capillary Tubes*—Diameter 0.1 to 1.0 mm thin-walled, nonabsorbing glass or quartz. Also, fine glass fibers 0.1 to 0.5-mm diameter.

16.2 *Collodion*, gum tragacanth, or other suitable amorphous binders.

16.3 *Film*—X-ray film with the following characteristics: (1) fine-grained texture and homogenous emulsion, (2) high sensitivity for the wavelength of the selected radiation, (3) low fogging and low expansion due to changes in temperature and humidity. The film should be of the screenless type (see Note 8). All film should be handled and processed in accordance with manufacturer's recommendations.

NOTE 8—If molybdenum radiation is used, a screen-type film with the fluorazure type intensifying screen may be used.

17. Preparation of Test Specimen

17.1 Prepare the powdered specimens in such a shape or form as required by the camera used.

17.2 *Common Mounts*:

17.2.1 *Rod Mount*—A few milligrams of the powdered sample are mixed with an amorphous binder such as collodion or gum tragacanth and rolled into a rod 0.1 to 1.0-mm diameter.

17.2.2 *Coated Glass Fiber Mount*—A fine glass fiber is dipped in collodion or some amorphous glue and rolled in the powdered sample to coat the outer cylindrical surface. Photographs made with glass fibers usually show one or two diffused halos at about 0.42 nm (see Note 9).

17.2.3 *Capillary Mount*—Small diametered nonabsorbing glass tubes can be filled with the powdered sample and then compacted by dropping through a 1 to 2-ft (0.3 to 0.6-m) length of small diameter glass tubing. The capillary can be sealed with wax if desired to prevent hydration, oxidation, or carbonation (see Note 9).

17.2.4 *Ball Mount*—A small amount of powdered sample is mixed with collodion and rolled into a ball and then glued onto a small glass fiber.

17.2.5 *Wedge Mount*—The powdered sample is pressed into a wedge-shaped cavity which can be supported without a binder.

NOTE 9—Glass fibers, and thin-walled tubes contribute scattering to the diffraction pattern. Wall thicknesses of the capillary tubes and diameters of fibers should be kept to minimum. Amorphous substances contribute blackening of the film at low Bragg angles.

18. Calibration and Standardization

18.1 Prepare standard X-ray diffraction film patterns from pure compounds and mixtures which are likely to occur in water-formed deposits. These patterns can be compared with standard films which are available from various companies. An alternative and more precise identification method is one in which the d-spacings are obtained from carefully measured diffraction angles and compared with published authenticated data of interplaner spacings and relative intensities (see Note 10 and Note 11). Table 1 lists some of the more common crystalline compounds found in water-formed deposits, and the relative intensities of the three strongest lines.

TABLE 1 List of Common Crystalline Compounds Reported to be Found in Water-Formed Deposits

Three Strongest Lines			Relative Intensity			ASTM Index Number	Mineral Name	Formula
1.931	3.153	1.647	100	94	35	4-864	Fluorite	CaF ₂
12.3	2.58	4.40	100	60	35	14-1	Sepiolite	2MgO·3SiO ₂ ·2H ₂ O
9.04	4.57	2.86	100	100	100	9-497	Hopeite	Zn ₃ (PO ₄) ₂ ·4H ₂ O
7.56	3.06	4.27	100	55	50	6-0046	Gypsum	CaSO ₄ ·2H ₂ O

⁵ The equipment listed is generally sold as a package by most manufacturers of X-ray diffractometers. The International Union of Crystallography (I.C.Cr.) publishes an Index of Crystallographic Supplies and lists various suppliers.

TABLE 1 *Continued*

Three Strongest Lines			Relative Intensity			ASTM Index Number	Mineral Name	Formula
7.17	1.49	3.58	100	90	80	14-164	Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄
6.80	2.97	2.71	100	67	67	3-0070	Vivianite	Fe ₃ (PO ₄) ₂ ·8H ₂ O
6.30	3.12	2.63	100	70	70	7-43	Ferrous hydrogen carbonate	Fe(HCO ₃) ₂
6.26	3.29	2.47	100	90	80	8-98	Iron oxide hydrate	FeO(OH)
6.11	3.16	2.35	100	65	53	5-0190	Boehmite	α Al ₂ (OOH) ₂
5.03	2.97	2.31	100	80	80	15-37	Mackinawite	FeS
4.82	4.34	4.30	100	40	20	12-460	Gibbsite	α Al(OH) ₃
4.47	5.46	3.97	100	90	70	16-699	Iron (II) sulfate hydrate	FeSO ₄ ·4H ₂ O
4.30	3.05	1.93	100	100	100	17-528	Monohydrocalcite	CaCO ₃ ·H ₂ O
4.18	2.69	2.45	100	30	25	17-536	Goethite	FeO(OH)
4.05	2.49	2.84	100	20	13	11-695	Cristobalite (low)	SiO ₂
3.72	3.68	2.15	100	53	28	5-0378	Witherite	BaCO ₃
3.71	2.63	6.45	100	75	70	17-538	Nosean	Na ₈ Al ₆ SO ₄ (SiO ₄) ₆
3.69	2.61	2.13	100	60	60	2-0339	Noselite	Na ₈ Al ₆ (SiO ₄) ₆ SO ₄
3.58	3.30	3.73	100	100	100	13-192	Vaterite	CaCO ₃
3.50	2.85	2.33	100	30	20	6-0226	Anhydrite	CaSO ₄
3.44	4.84	3.11	100	90	90	12-226	Iron (II) sulfate hydrate	FeSO ₄ ·H ₂ O
3.44	3.10	2.12	100	97	80	5-0448	Barite	BaSO ₄
3.43	5.61	2.93	100	80	70	7-363	Analcime (analcite)	NaAl(SiO ₃) ₂ ·H ₂ O
3.40	1.98	3.27	100	65	52	5-0453	Aragonite	CaCO ₃
3.34	4.26	1.82	100	35	17	5-0490	Quartz (alpha)	SiO ₂
3.19	4.61	3.61	100	67	40	3-0503	Cancrinite	3NaAlSiO ₄ ·CaCO ₃
3.07	2.04	1.95	100	85	85	10-488	Xonotlite	Ca ₆ Si ₆ O ₁₇ (OH) ₂
3.16	22.0	3.10	100	90	90	12-217	Gyrolite	Ca ₄ (Si ₆ O ₁₅)(OH) ₂ ·3H ₂ O
3.12	1.91	1.63	100	51	30	5-0566	Sphalerite	ZnS
3.10	6.60	3.29	100	86	75	5-0555	Hemimorphite	Zn ₄ (OH) ₂ Si ₂ O ₇ ·H ₂ O
3.04	2.41	2.57	100	50	45	16-818	Sodium silicate	Na ₂ SiO ₃
3.04	2.29	2.10	100	18	18	5-0586	Calcite	CaCO ₃
3.00	6.01	2.80	100	95	50	14-453	Calcium sulfate hydrate	2CaSO ₄ ·H ₂ O
3.00	3.20	3.07	100	50	50	2-0647	Calcium pyrophosphate	Ca ₂ P ₂ O ₇
2.97	3.83	3.52	100	80	80	10-487	Wollastonite	CaSiO ₃
2.97	3.30	2.73	100	98	63	5-0593	Celestite	SrSO ₄
2.96	3.35	3.37	100	75	70	9-80	Calcium hydrogen orthophosphate	CaHPO ₄
2.92	3.10	3.90	100	80	60	12-238	Pectolite	NaCa ₂ Si ₃ O ₈ OH
2.92	1.74	6.80	100	90	70	11-94	Foshagite	Ca ₄ Si ₃ O ₉ (OH) ₂
2.90	6.37	2.98	100	90	90	15-787	Acmite	NaFeSi ₂ O ₆
2.89	2.19	1.79	100	30	30	11-78	Dolomite	CaMg(CO ₃) ₂
2.88	2.61	3.21	100	65	55	9-169	Whitlockite	β Ca ₃ (PO ₄) ₂
2.86	5.90	4.38	100	64	64	3-0705	Natrolite	Na ₂ Al ₂ Si ₃ O ₁₀ ·2H ₂ O
2.86	3.69	5.06	100	85	75	10-399	Malachite	CuCO ₃ ·Cu(OH) ₂
2.85	1.75	3.07	100	35	25	9-216	Gehlenite	Ca ₂ Al ₂ SiO ₇
2.83	2.50	2.57	100	70	50	7-164	Olivine	2(Fe _{0.94} Mg _{0.06})O·SiO ₂
2.82	2.66	3.87	100	100	63	1-0990	Meta Thenardite	Na ₂ SO ₄
2.82	1.99	1.63	100	55	15	5-0628	Halite	NaCl
2.81	2.78	2.72	100	60	60	9-432	Hydroxyapatite	Ca ₅ (PO ₄) ₃ (OH)
2.81	1.90	3.08	100	75	67	6-464	Covellite	CuS
2.79	1.73	1.96	100	45	30	12-531	Siderite	FeCO ₃
2.78	4.66	3.18	100	73	51	5-0631	Thenardite	Na ₂ SO ₄
2.78	3.78	2.58	100	80	80	2-0840	Burkeite	Na ₆ CO ₃ (SO ₄) ₂
2.78	2.62	1.91	100	100	80	3-0751	α Sodium calcium orthophosphate	CaNaPO ₄
2.77	2.37	2.75	100	62	61	8-448	Thermonatrite	Na ₂ CO ₃ ·H ₂ O
2.69	1.69	2.51	100	60	50	13-534	Hematite	Fe ₂ O ₃
2.63	4.90	1.93	100	74	42	4-0733	Portlandite	Ca(H) ₂
2.53	1.61	1.48	100	85	85	11-614	Magnetite	Fe ₃ O ₄
2.52	2.95	1.61	100 +	100 +	100 +	15-615	Maghemite	Fe ₂ O ₃ (gamma)
2.52	2.32	2.53	100	96	49	5-0661	Tenorite	CuO
2.50	7.25	3.62	100	60	60	11-386	Serpentine	(Mg ₆ Al)Si ₄ AlO ₁₀ (OH) ₃
2.48	2.82	2.60	100	71	56	5-0664	Zincite	ZnO
2.47	2.14	1.51	100	37	27	50667	Cuprite	Cu ₂ O
2.46	2.51	1.51	100	73	69	4-0768	Forsterite	Mg ₂ SiO ₄
2.63	2.83	3.49	100	97	81	8-492	Willemite	Zn ₂ SiO ₄
2.40	1.97	1.88	100	100	100	12-227	Chalcocite	Cu ₂ S
2.37	4.77	1.79	100	90	55	7-239	Brucite	Mg(OH) ₂
2.15	2.49	1.52	100	80	60	6-0615	Wustite	FeO
2.11	1.49	1.22	100	52	12	4-0829	Periclase	MgO
2.09	2.41	1.48	100	91	57	4-0835	Bunsenite	NiO
2.09	2.66	1.72	100	60	50	11-151	Troilite	FeS
2.09	2.55	1.60	100	90	80	10-173	Corundum	α Al ₂ O ₃
2.09	1.81	1.28	100	46	20	4-0836	Copper	Cu

Note—In some cases the same compound or mineral name may appear under several ASTM card numbers.

Ex: Troilite FeS 11-151