Section 1: Crystalline Materials

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Section 1

CRYSTALLINE MATERIALS

1.1 Introduction*

Crystalline materials included in this section are insulators and semiconductors that have a transparent region within the range from the vacuum ultraviolet (from ~100 nm) to the infrared (up to 100 μm) portion of the electromagnetic spectrum. Crystals with wide band gaps are transparent from the ultraviolet through the visible region; crystals with a narrower band gap may appear opaque but are transparent in the infrared region. Using this broad transparency definition of optical crystals, virtually all known crystals can be included. Coverage, however, is limited to those crystals which either occur in nature or are produced in the laboratory for optical use or with potential for such use. For this reason hydrate or hydroxide crystals are generally excluded because they are thermally less stable and have limited tranmission range due to OH absorption. Highly hygroscopic materials are also excluded because of the obvious difficulty of handling, unless they have already been used, such as urea, KDP, CD*A, etc. Only pure compounds are considered. Compounds containing elements having intrinsic absorptions due to incompletely filled d or f shell electrons are also avoided.

Other critical issues for the use of optical crystals are solid-state phase transitions that occur as a function of both temperature and pressure and polymorphism. Compounds that have a very small stability field or serious phase transition problems have limited use as optical materials. Phase change and decomposition temperatures of crystals are noted in Section 1.5 on thermal properties. Generally only the thermodynamically stable structure at room temperature and pressure are listed in this section. Compounds that have naturally occurring polymorphic forms are included, however, e.g., $CaCO_3$, TiO_2, and aluminum silicate Al_2SiO_5. In other cases, only the stable phase is listed, e.g., quartz (α-SiO_2).

Many compounds were considered appropriate as entries of optical crystals in Sections 1.1–1.3 regardless of the amount of information available. As Chai* has noted, merely showing the existence of a compound with its chemical constituents can help to estimate the stability of its isomorphs and the structural tolerance of doping or other modifications. Most of the basic material properties such as optical transparency and refractive indices of an unstudied compound can be estimated with reasonable accuracy based on its better studied isomorphs that have measured properties listed in the tables.

Optical crystals in Sections 1.1–1.3 are classified into three categories:

Isotropic crystals include materials through which monochromatic light travels with the same speed, regardless of the direction of vibration, and the vibration direction of a light ray is always perpendicular to the ray path. Whereas amorphous materials such as glasses and plastics are isotropic, only those crystals with cubic symmetry are isotropic.

* This section was adapted from "Optical crystals" by B. H. T. Chai, *Handbook of Laser Science and Technology, Suppl. 2, Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 3 ff (with additions).

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Anisotropic crystals include materials through which a light ray may travel with different speeds for different directions of vibration and in which the angle between the vibration directions and ray path may not always be 90°. The index of refraction of such crystals varies according to the vibration direction of the light; the optical indicatrix is no longer a sphere but an ellipsoid. Depending on the geometry of the ellipsoid, it is necessary to divide the class of the anisotropic materials further into two subgroups. Crystals with tetragonal, hexagonal, and trigonal (or rhombohedral) symmetry exhibit a unique index of refraction (symbolized as e or ε) when light vibrates parallel to the *c*-axis (the extraordinary ray). For light vibrating at 90° to the *c*-axis (the ordinary ray), the refractive indices are the same (symbolized as o or ω) in all 360° directions. Crystals with these types of optical properties are called *uniaxial crystals*. Crystals with orthorhombic, monoclinic, and triclinic symmetry possess three significant indices of refraction, commonly symbolized as x, y, and z or α, β, and γ in the order from smallest to largest. The shape of the indicatrix is a three-dimensional ellipsoid with all central sections being ellipses, except for two. These two are circular sections with a radius of β. The normal of the two circular sections are called the optical axes. Crystals with these types of optical properties are called *biaxial crystals*. In Sections 1.2 and 1.3 crystals are grouped as isotropic, uniaxial, and biaxial.

Crystal symmetry plays a critical role in the selection of material for optical applications. Optically isotropic crystals are used most frequently for windows and lenses although a uniaxial single crystal (such as sapphire) precisely oriented along the optical axis can be used as a window material. Faraday rotator crystals for optical isolators based must be cubic or uniaxial, not biaxial. Anisotropic single crystals are widely used for other specific optical applications such as the polarizers, optical wave plates, and wedges. In nonlinear frequency conversion, all the optical materials used at present must not only be crystalline but also highly anisotropic and noncentrosymmetric.

For simplicity of crystal orientation and fabrication, materials with highest symmetry are preferred. It is easy to orient crystals with cubic (isometric), tetragonal, and hexagonal (uniaxial) symmetries. For the biaxial crystals, orthorhombic symmetry is still relatively easy to orient because all the crystallographic axes are still orthogonal and in alignment with the optical indicatrix axes. In monoclinic crystals, the crystallographic *a*- and *c*-axes are no longer orthogonal. With the exception of the *b*-axis, two of the optical indicatrix axes are no longer aligned with the crystallographic ones. With a few exceptions, crystals with triclinic symmetry are not listed because they are difficult to orient and have too many parameters to define (no degeneracy at all).

The preceding symmetry properties of a crystal structure refer to space group operations. For measured macroscopic properties the point group (the group of operations under which the property remains unchanged) is of interest. Eleven of the 32 point groups are centrosymmetric. Except for cubic 432, the remaining groups exhibit polarization when the crystal is subject to an applied stress (piezoelectric). Ten of these latter groups possess a unique polar axis and are pyroelectric, i.e., spontaneous polarize in the absence of stress. Crystallographic point groups and related properties are listed in the following table.

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Crystallographic Point Groups and Properties

Crystal system	International symbol	Schoenflies symbol	Centro-symmetric	Piezo-electric	Pyro-electric
Cubic	m3m	O_h	■		
	–43m	T_d		■	
	432	O			
	m3	T_h	■		
	23	T		■	
Hexagonal	6/mmm	D_{6h}	■		
	–6m2	D_{3h}		■	
	6mm	C_{6v}		■	■
	622	D_6		■	
	6/m	C_{6h}	■		
	–6	C_{3h}		■	
	6	C_6		■	■
Tetragonal	4/mmm	D_{4h}	■		
	–42m	D_{2d}		■	
	4mm	C_{4v}		■	■
	422	D_4		■	
	4/m	C_{4h}	■		
	–4	S_4		■	
	4	C_4		■	■
Trigonal	–3m	D_{3d}	■		
	3m	C_{3v}		■	■
	32	D_3		■	
	–3	S_6	■		
	3	C_3		■	■
Orthorhombic	mmm	D_{2h}	■		
	mm2	C_{2v}		■	■
	222	D_2		■	
Monoclinic	2/m	C_{2h}	■		
	m	C_s		■	■
	2	C_2		■	■
Triclinic	–1	C_i	■		
	1	C_1		■	■

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Crystals in the following table are listed alphabetically by chemical name (with mineral name* and acronym in parentheses) and include the chemical formula, crystal system, and space group. In the space group notation, a negative number indicates inversion symmetry.

* A mineralogy database containing names, physical properties, and an audio pronunciation guide for a very large number of materials is available at www.webmineral.com.

Name, Formula, Crystal System, and Space Group for Optical Crystals

Name	Formula	Crystal system (Space group)
Aluminum antimonide	AlSb	Cubic (F–43m)
Aluminum arsenate	$AlAsO_4$	Trigonal ($P3_12$)
Aluminum arsenide	AlAs	Cubic (F–43m)
Aluminum borate	$AlBO_3$	Trigonal (R–3c)
Aluminum borate	$Al_4B_2O_9$	Orthorhombic (Pbam)
Aluminum fluoride	AlF_3	Rhombohedral (R32)
Aluminum fluorosilicate (topaz)	$Al_2SiO_4F_2$	Orthorhombic (Pbnm)
Aluminum gallate	$AlGaO_3$	Hexagonal ($P6_3mmc$)
Aluminum germanate	$Al_2Ge_2O_7$	Monoclinic (C2/c)
Aluminum germanate	$Al_6Ge_2O_{13}$	Orthorhombic (Pbnm)
Aluminum germanate	$Al_6Ge_2O_{13}$	Orthorhombic (Pbnm)
Aluminum hafnium tantalate	$AlHfTaO_6$	Orthorhombic (Pbcn)
Aluminum molybdate	$Al_2(MoO_4)_3$	Monoclinic ($P2_1/a$)
Aluminum niobate	$AlNbO_4$	Monoclinic (C2/m)
Aluminum nitride	AlN	Hexagonal (6_3mc)
Aluminum oxide (corundum, sapphire, alumina)	Al_2O_3	Trigonal (R–3c)
Aluminum oxynitrate (ALON)	$Al_{23}O_{27}N_5$	Cubic (Fd3m)
Aluminum phosphate (berlinite)	$AlPO_4$	Trigonal ($P3_12$)
Aluminum phosphide	AlP	Hexagonal (6_3mc)
Aluminum silicate (andalusite)	Al_2SiO_5	Orthorhombic (Pmam)
Aluminum silicate (kyanite)	Al_2SiO_5	Triclinic (P–1)
Aluminum silicate (mullite)	$Al_6Si_2O_{13}$	Orthorhombic (Pbnm)
Aluminum silicate (sillimanite)	Al_2SiO_5	Orthorhombic (Pbnm)
Aluminum tantalate (alumotantite)	$AlTaO_4$	Orthorhombic ($Pc2_1n$)
Aluminum titanium tantalate	$AlTiTaO_6$	Tetragonal ($P4_2/mmm$)
Aluminum tungstate	$Al_2(WO_4)_3$	Orthorhombic (Pcna)
Amino carbonyl (urea)	$(NH_2)_2CO$	Tetragonal (I–42m)
Ammonium aluminum selenate	$NH_4Al(SeO_4)_2$	Trigonal (P321)
Ammonium aluminum sulfate	$NH_4Al(SO_4)_2$	Trigonal (P321)
Ammonium dihydrogen phosphate (ADP)	$NH_4H_2PO_4$	Tetragonal (I–42m)
Ammonium gallium selenate	$NH_4Ga(SeO_4)_2$	Trigonal (P321)
Ammonium gallium sulfate	$NH_4Ga(SO_4)_2$	Trigonal (P321)
Ammonium pentaborate	$NH_4B_5O_8 \cdot 4H_2O$	Orthorhombic (Aba2)
Antimony niobate (stibiocolumbite)	$SbNbO_4$	Orthorhombic ($Pna2_1$)
Antimony oxide (senarmontite)	Sb_2O_3	Cubic (Fd3m)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Antimony oxide (valentinite)	Sb_2O_3	Orthorhombic (Pccn)
Antimony tantalate (stibiotantalite)	$SbTaO_4$	Orthorhombic ($Pc2_1n$)
Arsenic antimony sulfide (getchellite)	$AsSbS_3$	Monoclinic (P21/a)
Arsenic oxide (arsenolite)	As_2O_3	Cubic (Fd3m)
Arsenic sulfide (orpiment)	As_2S_3	Monoclinic (P21n)
Arsenic sulfide (realgar)	AsS	Monoclinic (P21n)
Barium aluminate	$BaAl_2O_4$	Hexagonal ($P6_322$)
Barium aluminate	$Ba_3Al_2O_6$	Cubic (Pa3)
Barium aluminum borate	$BaAl_2B_2O_7$	Monoclinic (P2/c)
Barium aluminum fluoride	$Ba_3Al_2F_{12}$	Orthorhombic (Pnnm)
Barium aluminum germanate	$BaAl_2Ge_2O_8$	Monoclinic ($P2_1/a$)
Barium aluminum silicate (celsian)	$BaAl_2Si_2O_8$	Monoclinic (I2/a)
Barium antimonate	$BaSb_2O_6$	Triclinic (P−3 1m)
Barium beryllium fluorophosphate (babefphite)	$BaBe(PO_4)F$	Hexagonal(P–6c2)
Barium beryllium silicate (barylite)	$BaBe_2Si_2O_7$	Orthorhombic (Pnma)
Barium tetraborate	BaB_4O_7	Monoclinic (P21/c)
Barium borate	ß-BaB_2O_4	Trigonal (R3c)
Barium cadmium aluminum fluoride	$BaCdAlF_7$	Monoclinic (C2/c)
Barium cadmium gallium fluoride	$BaCdGaF_7$	Monoclinic (C2/c)
Barium cadmium magnesium aluminum fluoride	$Ba_2CdMgAl_2F_{14}$	Monoclinic (C2/c)
Barium calcium magnesium aluminum fluoride	$Ba_2CaMgAl_2F_{14}$	Monoclinic (C2/c)
Barium calcium magnesium silicate	$BaCa_2Mg(SiO_4)_2$	Orthorhombic
Barium calcium silicate (walstromite)	$BaCa_2Si_3O_9$	Triclinic(P−1)
Barium carbonate (witherite)	$BaCO_3$	Orthorhombic (Pnam)
Barium chloroarsenate (movelandite)	$Ba_5(AsO_4)_3Cl$	Hexagonal($P6_3/m$)
Barium chloroborate	$Ba_2B_5O_9Cl$	Tetragonal ($P4_22_1$–2)
Barium chlorophosphate (alforsite)	$Ba_5(PO_4)_3Cl$	Hexagonal($P6_3/m$)
Barium chlorovanadate	$Ba_5(VO_4)_3Cl$	Hexagonal($P6_3/m$)
Barium fluoride-calcium fluoride (T-12)	BaF_2-CaF_2	Cubic (Fm3m)
Barium fluoride (frankdicksonite)	BaF_2	Cubic (Fm3m)
Barium fluoroarsenate	$Ba_5(AsO_4)_3F$	Hexagonal($P6_3/m$)
Barium fluorophosphate	$Ba_5(PO_4)_3F$	Hexagonal($P6_3/m$)
Barium fluorovanadate	$Ba_5(VO_4)_3F$	Hexagonal($P6_3/m$)
Barium gallium fluoride	$BaGaF_5$	Orthorhombic ($P2_12_12_1$)
Barium germanate	$BaGeO_3$	Orthorhombic
Barium germanate	$BaGe_2O_5$	Monoclinic ($P2_1/a$)
Barium germanate	$BaGe_4O_9$	Hexagonal(P–6c2)
Barium germanium aluminate	$BaGeAl_6O_{12}$	Orthorhombic (Pnnm)
Barium germanium gallate	$BaGeGa_6O_{12}$	Othorhombic (Pnnm)
Barium hexa-aluminate	$BaAl_{12}O_{19}$	Hexagonal ($P6_3/mmc$)
Barium lithium niobate	$Ba_2LiNb_5O_{15}$	Orthorhombic (Im2a)
Barium lutetium borate	$Ba_3Lu(BO_3)_3$	Hexagonal($P6_3cm$)
Barium magnesium aluminum fluoride	Ba_2MgAlF_9	Tetragonal (P4)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Barium magnesium fluoride	$BaMgF_4$	Orthorhombic ($A2_1am$)
Barium magnesium fluoride	Ba_2MgF_6	Tetragonal (I422)
Barium magnesium germanate	$Ba_2MgGe_2O_7$	Tetragonal ($P42_1m$)
Barium magnesium silicate	$Ba_2MgSi_2O_7$	Tetragonal ($P42_1m$)
Barium magnesium tantalate	$Ba_3MgTa_2O_9$	Cubic (Fm3m)
Barium magnesium vanadate	$BaMg_2(VO_4)_2$	Tetragonal ($I4_1/acd$)
Barium molybdate	$BaMoO_4$	Tetragonal ($I4_1/a$)
Barium niobate	$BaNb_2O_6$	Orthorhombic (Pcan)
Barium nitrate (nitrobarite)	$Ba(NO_3)_2$	Cubic ($P2_13$)
Barium scandate	$Ba_2Sc_4O_9$	Trigonal(R–3)
Barium scandate	$BaSc_2O_4$	Monoclinic (C2/c)
Barium scandate	$Ba_6Sc_6O_{15}$	Tetragonal
Barium silicate (sabbornite)	β-$BaSi_2O_5$	Orthorhombic (Pmnb)
Barium sodium niobate	$Ba_2NaNb_5O_{15}$	Orthorhombic (Im2a)
Barium sodium phosphate	$Ba_2Na(PO_5)_5$	Orthorhombic (P212121))
Barium strontium niobate	$Ba_3SrNb_2O_9$	Hexagonal (P63/mmc)
Barium strontium tantalate	$Ba_3SrTa_2O_9$	Hexagonal (P63/mmc)
Barium sulfate (barite)	$BaSO_4$	Orthorhombic (Pbnm)
Barium tantalate	$BaTa_2O_6$	Orthorhombic (Pcan)
Barium tantalate	$BaTa_2O_6$	Orthorhombic (Pcan)
Barium tin borate	$BaSnB_2O_6$	Trigonal(R–3)
Barium tin silicate (pabstite)	$BaSnSi_3O_9$	Hexagonal (P–6c2)
Barium titanate	$BaTiO_3$	Cubic (Fm3m)
Barium titanate	$BaTiO_3$	Tetragonal (Pm3m)
Barium titanium aluminate	$BaTiAl_6O_{12}$	Orthorhombic (Pnnm)
Barium titanium aluminate	$Ba_3TiAl_{10}O_{20}$	Monoclinic (C2/m)
Barium titanium borate	$BaTiB_2O_6$	Trigonal(R–3)
Barium titanium gallate	$BaTiGa_6O_{12}$	Orthorhombic (Pnnm)
Barium titanium oxide	$BaTi_4O_9$	Orthorhombic (Pnmm)
Barium titanium silicate (benitoite)	$BaTiSi_3O_9$	Hexagonal (P–6c2)
Barium titanium silicate (fresnoite)	$Ba_2TiSi_2O_8$	Tetragonal (P4bm)
Barium tungstate	$BaWO_4$	Tetragonal ($I4_1/a$)
Barium vanadate	$Ba_3(VO_4)_2$	Rhombohedral (R–3m)
Barium yttrium borate	$Ba_3Lu(BO_3)_3$	Hexagonal($P6_3cm$)
Barium yttrium fluoride	BaY_2F_8	Monoclinic (C2/m)
Barium yttrium oxide	BaY_2O_4	Orthorhombic (Pnab)
Barium zinc aluminum fluoride	Ba_2ZnAlF_9	Orthorhombic (Pnma)
Barium zinc fluoride	$BaZnF_4$	Othorhombic (C222)
Barium zinc fluoride	$Ba_2Zn_3F_{10}$	Monoclinic (C2/m)
Barium zinc fluoride	Ba_2ZnF_6	Tetragonal (I422)
Barium zinc gallium fluoride	Ba_2ZnGaF_9	Monoclinic ($P2_{1/n}$)
Barium zinc germanate	$BaZnGeO_4$	Hexagonal ($P6_3$)
Barium zinc germanate	$Ba_2ZnGe_2O_7$	Tetragonal ($P42_1m$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Barium zinc silicate	$Ba_2ZnSi_2O_7$	Tetragonal ($P42_1m$)
Barium zinc silicate	$BaZnSiO_4$	Hexagonal ($P6_3$)
Barium zirconium silicate	$Ba_2ZrSi_2O_8$	Tetragonal (P4bm)
Barium zirconium silicate	$Ba_2Zr_2Si_3O_{12}$	Cubic ($P2_13$)
Barium zirconium silicate (bazirite)	$BaZrSi_3O_9$	Hexagonal ($P6_322$)
Beryllium aluminate	$BeAl_6O_{10}$	Orthorhombic (Pca2)
Beryllium aluminate (chrysoberyl)	$BeAl_2O_4$	Orthorhombic (Pnma)
Beryllium aluminum silicate (beryl)	$Be_3Al_2Si_6O_{18}$	Hexagonal (P6/mcc)
Beryllium fluoroborate (hambergite)	Be_2BO_3F	Monoclinic (C21)
Beryllium germanate	Be_2GeO_4	Trigonal(R–3)
Beryllium magnesium aluminate (taaffeite)	$BeMg_3Al_8O_{16}$	Hexagonal
Beryllium oxide (bormellite)	BeO	Hexagonal ($P6_3/mc$)
Beryllium scandium silicate (bazzite)	$Be_3Sc_2Si_6O_{18}$	Hexagonal (P6/mcc)
Beryllium silicate (phenakite)	Be_2SiO_4	Trigonal(R–3)
Bismuth aluminate	$Bi_2Al_4O_9$	Orthorhombic (Pbam)
Bismuth antimonate	$BiSbO_4$	Monoclinic ($P2_1/c$)
Bismuth borate	$Bi_4B_2O_9$	Monoclinic ($P2_1/c$)
Bismuth germanate	$Bi_2Ge_3O_9$	Hexagonal ($P6_3/m$)
Bismuth germanate	Bi_2GeO_5	Orthorhombic ($Cmc2_1$)
Bismuth germanate	$Bi_{12}GeO_{20}$	Cubic (I23)
Bismuth germanate (BGO)	$Bi_4Ge_3O_{12}$	Cubic (I43d)
Bismuth metaborate	BiB_3O_6	Monoclinic (2/m)
Bismuth molybdate	$Bi_2Mo_2O_9$	Monoclinic ($P2_1/m$)
Bismuth molybdate	$Bi_2Mo_3O_{12}$	Monoclinic ($P2_1/m$)
Bismuth niobate	$BiNbO_4$	Orthorhombic (Pann)
Bismuth oxide (bismite)	Bi_2O_3	Monoclinic ($P2_1/c$)
Bismuth oxymolybdate (koechlinite)	γ-Bi_2MoO_6	Orthorhombic (Pba2)
Bismuth oxytungstate (rusellite)	Bi_2WO_6	Orthorhombic (Pba2)
Bismuth silicate	Bi_2SiO_5	Orthorhombic ($Cmc2_1$)
Bismuth silicate (eulytite)	$Bi_4Si_3O_{12}$	Cubic (I43d)
Bismuth silicate (sillenite, BSO)	$Bi_{12}SiO_{20}$	Cubic (I23)
Bismuth tantalate	$BiTaO_4$	Orthorhombic (Pnna)
Bismuth tin oxide	$Bi_2Sn_2O_7$	Hexagonal ($P6_3/m$)
Bismuth titanate	$Bi_4Ti_3O_{12}$	Orthorhombic (B2cb)
Bismuth titanium niobate	Bi_3TiNbO_9	Orthorhombic ($A2_1am$)
Bismuth titanium oxide	$Bi_{12}TiO_{20}$	Cubic (I23)
Bismuth vanadate (clinobisvanite)	$BiVO_4$	Monoclinic (I2/a)
Bismuth vanadate (dreyerite)	$BiVO_4$	Tetragonal ($I4_1/amd$)
Bismuth vanadate (pucherite)	$BiVO_4$	Orthorhombic (Pnca)
Boron nitride	BN	Cubic (F–43m)
Boron phosphide	BP	Cubic (F–43m)
Cadmium antimonade	$Cd_2Sb_2O_7$	Cubic (Fd3m)
Cadmium borate	CdB_4O_7	Orthorhombic (Pbca)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Cadmium borate	$Cd_2B_2O_5$	Triclinic (P1)
Cadmium borate	$Cd_2B_6O_{11}$	Monoclinic ($P2_1/b$)
Cadmium borate	CdB_2O_4	Cubic (P–43m)
Cadmium carbonate (otavite)	$CdCO_3$	Rhombohedral (R−3c)
Cadmium chloride	$CdCl_2$	Rhombohedral (R–3m)
Cadmium chloroarsenate	$Cd_5(AsO_4)_3Cl$	Hexagonal ($P6_3/m$)
Cadmium chlorophosphate	$Cd_5(PO_4)_3Cl$	Hexagonal($P6_3/m$)
Cadmium chlorovanadate	$Cd_5(VO_4)_3Cl$	Hexagonal ($P6_3/m$)
Cadmium fluoride	CdF_2	Cubic (Fm3m)
Cadmium fluorophosphate	$Cd_5(PO_4)_3F$	Hexagonal ($P6_3/m$)
Cadmium gallate	$CdGa_2O_4$	Cubic (Fd3m)
Cadmium germanate	Cd_2GeO_4	Orthorhombic (Pbnm)
Cadmium germanium arsenide	$CdGeAs_2$	Tetragonal (I–42d)
Cadmium germanium phosphide	$CdGeP_2$	Tetragonal (I–42d)
Cadmium indium oxide spinel	$CdIn_2O_4$	Cubic (Fd3m)
Cadmium iodide	CdI_2	Hexagonal ($P6_3mc$)
Cadmium niobate	$Cd_2Nb_2O_7$	Cubic (Fd3m)
Cadmium oxide (monteponite)	CdO	Cubic (Fm3m)
Cadmium scandium germanate	$Cd_3Sc_2Ge_3O_{12}$	Cubic (Ia3d)
Cadmium selenide (cadmoselite)	CdSe	Hexagonal (P6mm)
Cadmium silicon arsenide	$CdSiAs_2$	Tetragonal (I–42d)
Cadmium silicon phosphide	$CdSiP_2$	Tetragonal (I–42d)
Cadmium sulfide (greenockite)	CdS	Hexagonal (6mm)
Cadmium tellurite (Irtran 6)	CdTe	Cubic (Fm3m)
Cadmium tin arsenide	$CdSnAs_2$	Tetragonal (I–42d)
Cadmium tin borate	$CdSnB_2O_6$	Rhombohedral (R–3c)
Cadmium tin phosphide	$CdSnP_2$	Tetragonal (I–42d)
Cadmium titanate	$CdTiO_3$	Rhombohedral(R–3)
Cadmium tungstate	$CdWO_4$	Monoclinic (P2/c)
Cadmium vanadate	CdV_2O_6	Monoclinic (C2/m)
Cadmium vanadate	$Cd_2V_2O_7$	Monoclinic (C2/m)
Calcium aluminate	$CaAl_2O_4$	Monoclinic ($P2_1/n$)
Calcium aluminate	$Ca_3Al_2O_6$	Cubic (Pa–3)
Calcium aluminate	$CaAl_4O_7$	Monoclinic (C2/c)
Calcium aluminate	$Ca_5Al_6O_{14}$	Orthorhombic (C222)
Calcium aluminate (brownmillerite)	$Ca_2Al_2O_5$	Orthorhombic
Calcium aluminate (mayenite)	$Ca_{12}Al_{14}O_{33}$	Cubic (I43d)
Calcium aluminum borate	$CaAlBO_4$	Otthorhombic (Pnam)
Calcium aluminum borate	$CaAl_2B_2O_7$	Hexagonal ($P6_322$)
Calcium aluminum borate (johachidolite)	$CaAlB_3O_7$	Orthorhombic (Cmma)
Calcium aluminum fluoride	$CaAlF_5$	Monoclinic (C2/c)
Calcium aluminum fluoride	Ca_2AlF_7	Orthorhombic (Pnma)
Calcium aluminum fluoride (prosopite)	$CaAl_2F_8$	Monoclinic

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Calcium aluminum germanate	$Ca_2Al_2GeO_7$	Tetragonal ($P42_1m$)
Calcium aluminum germanate	$Ca_3Al_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium aluminum oxyfluoride	$Ca_2Al_3O_6F$	Hexagonal
Calcium aluminum silicate (anorthite)	$CaAl_2Si_2O_8$	Triclinic(P–1)
Calcium aluminum silicate (gehlenite, CAS)	$Ca_2Al_2SiO_7$	Tetragonal ($P42_1m$)
Calcium aluminum silicate (grossularite)	$Ca_3Al_2Si_3O_{12}$	Cubic (Ia3d)
Calcium antimonate	$Ca_2Sb_2O_7$	Orthorhombic (Imm2)
Calcium antimonate	$Ca_2Sb_2O_7$	Cubic (Fd3m)
Calcium barium carbonate (alstonite)	$CaBa(CO_3)_2$	Orthorhombic (Pnam)
Calcium beryllium fluorophosphate (herderite)	$CaBe(PO_4)F$	Monoclinic
Calcium beryllium phosphate (hurlbutite)	$CaBe_2(PO_4)_2$	Monoclinic ($P2_1/a$)
Calcium beryllium silicate (gugiaite)	$Ca_2BeSi_2O_7$	Tetragonal ($P42_1m$)
Calcium borate	$Ca_2B_2O_5$	Monoclinic ($P2_1/a$)
Calcium borate	$Ca_2B_6O_{11}$	Monoclinic ($P2_1/b$)
Calcium borate	CaB_4O_7	Monoclinic ($P2_1/c$)
Calcium borate	$Ca_3B_2O_6$	Rhombohedral (R–3c)
Calcium borate (calciborite)	CaB_2O_4	Orthorhombic (Pnca)
Calcium boron silicate (danburite)	$CaB_2Si_2O_8$	Orthorhombic (Pmam)
Calcium carbonate (aragonite)	$CaCO_3$	Orthorhombic (Pnam)
Calcium carbonate (calcite)	$CaCO_3$	Rhombohedral (R–3c))
Calcium carbonate (vaterite)	$CaCO_3$	Hexagonal ($P6_3/mmc$)
Calcium chloroarsenate	Ca_2AsO_4Cl	Orthorhombic (Pbcm)
Calcium chloroarsenate	$Ca_5(AsO_4)_3Cl$	Hexagonal($P6_3/m$)
Calcium chloroborate	Ca_2BO_3Cl	Monoclinic ($P2_1/c$)
Calcium chloroborate	$Ca_2B_5O_9Cl$	Tetragonal ($P4_22_12$)
Calcium chlorophosphate	Ca_2PO_4Cl	Orthorhombic (Pbcm)
Calcium chlorophosphate (chlorapatite)	$Ca_5(PO_4)_3Cl$	Hexagonal($P6_3/m$)
Calcium chlorovanadate	Ca_2VO_4Cl	Orthorhombic (Pbcm)
Calcium chlorovanadate	$Ca_5(VO_4)_3Cl$	Hexagonal($P6_3/m$)
Calcium fluoride (fluorite, fluorspar, Irtran 3)	CaF_2	Cubic (Fm3m)
Calcium fluoroarsenate (svabite, CAAP)	$Ca_5(AsO_4)_3F$	Hexagonal($P6_3/m$)
Calcium fluoroborate (fabianite)	CaB_3O_5F	Orthorhombic ($Pbn2_1$)
Calcium fluorophosphate (apatite, FAP)	$Ca_5(PO_4)_3F$	Hexagonal($P6_3/m$)
Calcium fluorophosphate (spodiosite)	$Ca_2(PO_4)F$	Orthorhombic (Pbcm)
Calcium fluorovanadate (VAP)	$Ca_5(VO_4)_3F$	Hexagonal($P6_3/m$)
Calcium gadolinium aluminate	$CaGaAlO_4$	Hexagonal ($P6_3/m$)
Calcium gadolinium double borate	$Ca_3Gd_2(BO_3)_4$	Orthorhombic ($Pc2_1n$)
Calcium gadolinium oxysilicate	$CaGd_4(SiO_4)_3O$	Tetragonal (I4/mmm)
Calcium gadolinium phosphate	$Ca_3Gd(PO_4)_3$	Cubic (I–43d)
Calcium gallate	$CaGa_2O_4$	Monoclinic ($P2_1/c$)
Calcium gallate	$Ca_3Ga_4O_9$	Orthorhombic (Cmm2)
Calcium gallate	$Ca_5Ga_6O_{14}$	Orthorhombic ($Cmc2_1$)
Calcium gallium germanate	$Ca_2Ga_2GeO_7$	Tetragonal ($P42_1m$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Calcium gallium germanate	$Ca_3Ga_2Ge_4O_{14}$	Trigonal ($P32_1$)
Calcium gallium germanium garnet	$Ca_3Ga_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium gallium silicate (CGS)	$Ca_2Ga_2SiO_7$	Tetragonal ($P42_1m$)
Calcium germanate	$CaGe_2O_5$	Monoclinic ($P2_1/a$)
Calcium germanate	$CaGe_4O_9$	Hexagonal (P–6c2)
Calcium hexa-aluminate	$CaAl_{12}O_{19}$	Hexagonal (P63/mmc)
Calcium indate	$CaIn_2O_4$	Orthorhombic (Pbcm)
Calcium indium germanate	$Ca_3In_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium indium oxide	$Ca_3In_2O_6$	Orthorhombic (Pbam)
Calcium iodate (lautarite)	$Ca(IO_3)_2$	Monoclinic
Calcium lanthanum aluminate	$CaLaAlO_4$	Tetragonal (I4/mmm)
Calcium lanthanum borate	$CaLaBO_4$	Hexagonal ($P6_322$)
Calcium lanthanum oxyphosphate	$Ca_4La(PO_4)_3O$	Hexagonal ($P6_3/m$)
Calcium lanthanum oxysilicate	$CaLa_4(SiO_4)_3O$	Hexagonal ($P6_3/m$)
Calcium lanthanum phosphate	$Ca_3La(PO_4)_3$	Cubic (I–43d)
Calcium lanthanum sulfide	$CaLa_2S_4$	Cubic (I–43d)
Calcium lithium magnesium vanadate	$Ca_2LiMg_2V_3O_{12}$	Cubic (Ia3d)
Calcium lithium magnesium vanadate	$Ca_3LiMgV_3O_{12}$	Cubic (Ia3d)
Calcium lithium zinc vanadate	$Ca_2LiZn_2V_3O_{12}$	Cubic (Ia3d)
Calcium lithium zinc vanadate	$Ca_3LiZnV_3O_{12}$	Cubic (Ia3d)
Calcium lutetium germanate	$Ca_3Lu_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium magnesium borate (kurchatovite)	$CaMgB_2O_5$	Orthorhombic
Calcium magnesium carbonate (dolomite)	$CaMg(CO_3)_2$	Rhombohedral (R–3c)
Calcium magnesium carbonate (huntite)	$CaMg_3(CO_3)_4$	Rhombohedral (R32)
Calcium magnesium fluoroarsenate (tilasite)	$CaMgAsO_4F$	Orthorhombic
Calcium magnesium fluorophosphate (isokite)	$CaMgPO_4F$	Monoclinic (C2/c)
Calcium magnesium germanate	$CaMgGe_2O_6$	Monoclinic (C2/c)
Calcium magnesium silicate (akermanite)	$Ca_2MgSi_2O_7$	Tetragonal ($P42_1m$)
Calcium magnesium silicate (diopside)	$CaMgSi_2O_6$	Monoclinic (C2/c)
Calcium magnesium silicate (merwinite)	$Ca_3MgSi_2O_8$	Monoclinic ($P2_1/a$)
Calcium magnesium silicate (monticellite)	$CaMgSiO_4$	Orthorhombic (Pmnb)
Calcium magnesium vanadate	$CaMg_2(VO_4)_2$	Tetragonal ($I4_1/acd$)
Calcium molybdate	$CaMoO_4$	Tetragonal ($I4_1/a$)
Calcium niobate	$Ca_2Nb_2O_7$	Orthorhombic ($Pn2_1a$)
Calcium niobate (rynersonite)	$CaNb_2O_6$	Orthorhombic (Pcan)
Calcium niobium gallium garnet	$Ca_3(Nb,Ga)_2Ga_3O_{12}$	Cubic (Ia3d)
Calcium oxide (lime)	CaO	Cubic (Fm3m)
Calcium phosphate	β-CaP_2O_7	Hexagonal (P–6c2)
Calcium phosphate	β-CaP_2O_7	Tetragonal ($P4_1$)
Calcium scandate	$CaSc_2O_4$	Orthorhombic (Pnam)
Calcium scandium germanate	$Ca_3Sc_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium scandium silicate	$Ca_3Sc_2Si_3O_{12}$	Cubic (Ia3d)
Calcium silicate (larnite)	b-Ca_2SiO_4	Monoclionic ($P2_1/n$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Calcium silicate (rankinite)	$Ca_3Si_2O_7$	Monoclinic
Calcium silicate (wollastonite)	$CaSiO_3$	Triclinic(P–1)
Calcium sodium magnesium vanadate	$Ca_2NaMg_2V_3O_{12}$	Cubic (Ia3d)
Calcium sodium zinc vanadate	$Ca_2NaZn_2V_3O_{12}$	Cubic (Ia3d)
Calcium sulfate (anhydrite)	$CaSO_4$	Orthorhombic (Bbmm)
Calcium tantalate	$CaTa_2O_6$	Orthorhombic (Pcan)
Calcium tellurate (denningite)	$Ca_2Te_2O_5$	Tetragonal
Calcium tin borate (nordenskiöldine)	$CaSnB_2O_6$	Trigonal (R–3m)
Calcium tin oxide	$CaSnO_3$	Orthorhombic ($P2_12_12_1$)
Calcium tin silicate (malayaite)	$CaSnSiO_5$	Monoclinic ($P2_1/a$)
Calcium titanate (perovskite)	$CaTiO_3$	Cubic (Pm3m)
Calcium titanium germanate	$CaTiGeO_4$	Monoclinic ($P2_1/a$)
Calcium titanium silicate (sphene)	$CaTiSiO_5$	Monoclinic ($P2_1/a$)
Calcium tungstate (scheelite)	$CaWO_4$	Tetragonal ($I4_1/a$)
Calcium vanadate	CaV_2O_6	Monoclinic (C2/m)
Calcium vanadate	$Ca_2V_2O_7$	Monoclinic (C2/m)
Calcium vanadate	$Ca_3(VO_4)_2$	Trigonal (R3c)
Calcium yttrium aluminate	$CaYAlO_4$	Tetragonal (I4/mmm)
Calcium yttrium borate	$CaYBO_4$	Orthorhombic (Pnam)
Calcium gadolinium double borate	$Ca_3Y_2(BO_3)_4$	Orthorhombic ($Pc2_1n$)
Calcium yttrium magnesium germanium garnet	$CaY_2Mg_2Ge_3O_{12}$	Cubic (Ia3d)
Calcium yttrium oxysilicate	$Ca_4Y_6(SiO_4)_6$	Hexagonal ($P6_3/m$)
Calcium yttrium oxysilicate (SOAP)	$CaY_4(SiO_4)_3O$	Hexagonal ($P6_3/m$)
Calcium zinc fluoride	$CaZnF_4$	Tetragonal ($I4_1/a$)
Calcium zinc germanate	$CaZnGe_2O_6$	Monoclinic (C2/c)
Calcium zinc silicate (esperite)	$CaZnSiO_4$	Tetragonal ($P–42_1m$)
Calcium zinc silicate (hardystonite)	$Ca_2ZnSi_2O_7$	Tetragonal ($P–42_1m$)
Calcium zirconium boron aluminate (painite)	$CaZrBAl_9O_{18}$	Hexagonal ($P6_3$)
Calcium zirconium silicate (gittinsite)	$CaZrSi_2O_7$	Monoclinic (C2/m)
Calcium zirconium titanate (zirkelite)	$CaZrTi_2O_7$	Monoclinic (C2/m)
Calcium zirconium titanium silicate	$Ca_3(Zr,Ti)Si_2O_9$	Monoclinic
Carbon (diamond)	C	Cubic (F–43m)
Cesium aluminum sulfate	$CsAl(SO_4)_2$	Trigonal (P321)
Cesium beryllium fluoride	Cs_2BeF_4	Orthorhombic ($Pna2_1$)
Cesium borate (CBO)	CsB_3O_5	Orthorhombic ($P2_12_12_1$)
Cesium bromide	CsBr	Cubic (Fm3m)
Cesium cadmium bromide	Cs_2CdBr_4	Orthorhombic (Pnma)
Cesium cadmium bromide	$CsCdBr_3$	Cubic (Pm3m)
Cesium cadmium chloride	Cs_2CdCl_4	Tetragonal (I4/mmm)
Cesium cadmium fluoride	$CsCdF_3$	Cubic (Pm3m)
Cesium cadmium zinc fluoride	Cs_2CdZnF_6	Rhombohedral (R–3m)
Cesium calcium fluoride	$CsCaF_3$	Cubic (Pm3m)
Cesium chloride	CsCl	Cubic (Fm3m)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Cesium dideuterium arsenate	CsD_2AsO_4	Tetragonal (I–42m)
Cesium dideuterium phosphate	CsD_2PO_4	Tetragonal (I–42m)
Cesium dihydrogen arsenate	CsH_2AsO_4	Tetragonal (I–42m)
Cesium dihydrogen phosphate	CsH_2PO_4	Tetragonal (I–42m)
Cesium fluoride	CsF	Cubic (Fm3m)
Cesium gadolinium molybdate	$CsGd(MoO_4)_2$	Orthorhombic (Pnma)
Cesium gallium sulfate	$CsGa(SO_4)_2$	Trigonal (P321)
Cesium germanate	Ga_2GeO_5	Orthorhombic (Pnnm)
Cesium iodide	CsI	Cubic (Fm3m)
Cesium lanthanum tungstate	$CsLa(WO_4)_2$	Tetragonal ($P4_2/nmc$)
Cesium lithium aluminum fluoride	$Cs_2LiAl_3F_{12}$	Rhombohedral (R–3m)
Cesium lithium aluminum fluoride	Cs_2LiAlF_6	Hexagonal ($P6_3/mmc$)
Cesium lithium beryllium fluoride	$CsLiBeF_4$	Monoclinic ($P2_1/n$)
Cesium lithium borate (CLBO)	$CsLiB_6O_{10}$	Tetragonal (I–42d)
Cesium lithium gallium fluoride	$Cs_2LiGa_3F_{12}$	Rhombohedral (R–3m)
Cesium lithium gallium fluoride	Cs_2LiGaF_6	Hexagonal ($P6_3/mmc$)
Cesium lithium sulfate	$CsLiSO_4$	Orthorhombic (Pc2)
Cesium magnesium chloride	Cs_2MgCl_4	Orthorhombic (Pnma)
Cesium mercury iodide	Cs_2HgI_4	Monoclinic ($P2_1$)
Cesium niobium borate (CNB)	$CsNbB_2O_6$	Orthorhombic ($Pn2_1m$)
Cesium niobium sulfate	$CsNbO(SO_4)_2$	Orthorhombic
Cesium potassium aluminum fluoride	$Cs_2KAl_3F_{12}$	Rhombohedral (R–3m)
Cesium potassium lanthanum fluoride	Cs_2KLaF_6	Cubic (Fm3m)
Cesium scandium molybdate	$CsSc(MoO_4)_2$	Trigonal (P–3m1)
Cesium scandium tungstate	$CsSc(WO_4)_2$	Trigonal (P–3m1)
Cesium silver fluoride	Cs_2AgF_4	Tetragonal (I4/mmm)
Cesium sodium aluminum fluoride	$Cs_2NaAl_3F_{12}$	Rhombohedral (R–3m)
Cesium sodium aluminum fluoride	Cs_2NaAlF_6	Rhombohedral (R–3m)
Cesium sodium gallium fluoride	Cs_2NaGaF_6	Rhombohedral ($R\bar{3}m$)
Cesium sodium yttrium fluoride	Cs_2NaYF_6	Cubic (Fm3m)
Cesium strontium fluoride	$CsSrF_3$	Cubic (Pm3m)
Cesium tin germanate	$Cs_2SnGe_3O_9$	Hexagonal ($P6_3/m$)
Cesium titanium germanate	$Cs_2TiGe_3O_9$	Hexagonal ($P6_3/m$)
Cesium titano arsenate (CTA)	$CsTiOAsO_4$	Orthorhombic ($P2_1nb$)
Cesium zinc aluminum fluoride	$CsZnAlF_6$	Orthorhombic
Cesium zinc bromide	Cs_2ZnBr_4	Orthorhombic (Pnma)
Cesium zinc chloride	Cs_2ZnCl_4	Orthorhombic (Pnma)
Copper bromide (cuprous)	CuBr	Cubic (Fm3m)
Copper chloride (cuprous, nantokite)	CuCl	Cubic (Fm3m)
Copper iodide (cuprous, marshite)	CuI	Cubic (Fm3m)
Cuprous oxide (cuprite)	Cu_2O	Cubic (Pm3m)
Gadolinium aluminate	$Gd_4Al_2O_9$	Monoclinic ($P2_1/a$)
Gadolinium aluminate	$GdAlO_3$	Orthorhombic (Pbnm)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Gadolinium aluminum borate	$GdAl_3(BO_3)_4$	Trigonal (R32)
Gadolinium aluminum germanate	$GdAlGe_2O_7$	Monoclinic ($P2_1/c$)
Gadolinium borate	$Gd(BO_2)_3$	Monoclinic (I2/a)
Gadolinium borate	$GdBO_3$	Hexagonal ($P6_3/mmc$)
Gadolinium calcium oxyborate	$GdCa_4O(BO_3)_3$	Monoclinic (Cm)
Gadolinium gallium borate	$GdGa_3(BO_3)_4$	Trigonal (R32)
Gadolinium gallium garnet (GGG)	$Gd_3Ga_5O_{12}$	Cubic (Ia3d)
Gadolinium gallium germanate	$GdGaGe_2O_7$	Monoclinic ($P2_1/c$)
Gadolinium germanate	Gd_2GeO_5	Monoclinic ($P2_1/c$)
Gadolinium germanium beryllate	$Gd_2GeBe_2O_7$	Tetragonal ($P42_1m$)
Gadolinium indate	$GdInO_3$	Hexagonal ($P6_3cm$)
Gadolinium magnesium borate	$GdMgB_5O_{10}$	Monoclinic ($P2_1/c$)
Gadolinium molybdate	$Gd_2(MoO_4)_3$	Orthorhombic (Pba2)
Gadolinium niobate	$GdNbO_4$	Monoclinic (I2/a)
Gadolinium niobate	Gd_3NbO_7	Orthorhombic ($C222_1$)
Gadolinium orthosilicate	Gd_2SiO_5	Monoclinic ($P2_1/c$)
Gadolinium oxide	Gd_2O_3	Monoclinic (C2/m)
Gadolinium oxymolybdate	Gd_2MoO_6	Monoclinic (I2/c)
Gadolinium oxysulfate	$Gd_2O_2SO_4$	Orthorhombic
Gadolinium oxytungstate	Gd_2WO_6	Monoclinic (I2/c)
Gadolinium pentaphosphate	GdP_5O_{14}	Monoclinic ($P2_{1/c}$)
Gadolinium phosphate	$GdPO_4$	Monoclinic ($P2_1/n$)
Gadolinium scandate	$GdScO_3$	Orthorhombic (Pbnm)
Gadolinium scandium aluminum garnet (GSAG)	$Gd_3Sc_2Al_3O_{12}$	Cubic (Ia3d)
Gadolinium scandium gallium garnet (GSGG)	$Gd_3Sc_2Ga_3O_{12}$	Cubic (Ia3d)
Gadolinium strontium borate	$Gd_2Sr_3(BO_3)_4$	Orthorhombic ($P2_1cn$)
Gadolinium tantalate	Gd_3TaO_7	Orthorhombic ($C222_1$)
Gadolinium titanate	$Gd_2Ti_2O_7$	Cubic (Fd3m)
Gadolinium tungstate	$Gd_2(WO_4)_3$	Monoclinic (C2/c)
Gadolinium vanadate	$GdVO_4$	Tetragonal ($I4_1/amd$)
Gallium antimonide	GaSb	Cubic (F–43m)
Gallium arsenide	GaAs	Cubic (F–43m)
Gallium germanate	α-Ga_4GeO_8	Monoclinic (C2/m)
Gallium molybdate	$Ga_2(MoO_4)_3$	Monoclinic ($P2_1/a$)
Gallium niobate	$GaNbO_4$	Monoclinic (C2)
Gallium nitride - wurtzite	α-GaN	Hexagonal($P6_3mc$)
Gallium nitride - zincblende	β-GaN	Cubic (F–43m)
Gallium oxide	β-Ga_2O_3	Monoclinic (A2/m)
Gallium phosphate	$GaPO_4$	Trigonal ($P3_12$)
Gallium phosphide	GaP	Cubic (F–43m)
Gallium selenide	GaSe	Hexagonal(P–62m)
Gallium sulfide	GaS	Hexagonal(P–62m)
Gallium tungstate	$Ga_2(WO_4)_3$	Orthorhombic (Pcna)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Germanium	Ge	Cubic (F–43m)
Germanium oxide (argutite)	GeO_2	Tetragonal ($P4_2/mnm$)
Hafnium oxide	HfO_2	Monoclinic ($P2_1/c$)
Hafnium silicate (hafnon)	$HfSiO_4$	Tetragonal ($I4_1/amd$)
Indium antimonide	InSb	Cubic (F–43m)
Indium arsenide	InAs	Cubic (F–43m)
Indium borate	$InBO_3$	Rhombohedral (R–3c)
Indium cadmium borate	$InCdBO_4$	Orthorhombic (Pnam)
Indium calcium borate	$InCaBO_4$	Orthorhombic (Pnam)
Indium gallate	$InGaO_3$	Monoclinic (C2/m)
Indium molybdate	$In_2(MoO_4)_3$	Monoclinic ($P2_1/a$)
Indium niobate	$InNbO_4$	Monoclinic (P2/c)
Indium nitride	InN	Hexagonal($P6_3mc$)
Indium oxide	In_2O_3	Rhombohedral (R3c)
Indium phosphate	$InPO_4$	Orthorhombic (Cmcm)
Indium phosphide	InP	Cubic (F–43m)
Indium tantalate	$InTaO_4$	Monoclinic (P2/c)
Indium tungstate	$In_2(WO_4)_3$	Orthorhombic (Pcna)
Indium vanadate	$InVO_4$	Monoclinic (C2/m)
Iodic acid	HIO_3	Orthorhombic ($P2_12_12_1$)
Lanthanum aluminate	$LaAlO_3$	Trigonal (R–3m)
Lanthanum aluminum germanate	$LaAlGe_2O_7$	Monoclinic ($P2_1/c$)
Lanthanum aluminum germanate	$LaAlGe_2O_7$	Monoclinic ($P2_1/c$)
Lanthanum antimonade	$LaSbO_4$	Monoclinic ($P2_1/c$)
Lanthanum antimonade	La_3SbO_7	Orthorhombic (Cmcm)
Lanthanum barium borate	$La_2Ba_3(BO_3)_4$	Orthorhombic ($P2_1cn$)
Lanthanum barium gallate	$BaLaGa_3O_7$	Tetragonal ($P42_1m$)
Lanthanum barium germanate	$LaBaGa_3O_7$	Tetragonal ($P42_1m$)
Lanthanum beryllate (BEL)	$La_2Be_2O_5$	Monoclinic (C2/c)
Lanthanum borate	$LaBO_3$	Orthorhombic (Pnam)
Lanthanum boron germanate	$LaBGeO_5$	Trigonal (C3m)
Lanthanum boron molybdate	$LaBMoO_6$	Monoclinic ($P2_1$)
Lanthanum boron silicate (stillwellite)	$LaBSiO_5$	Trigonal (C3m)
Lanthanum boron tungstate	$LaBWO_6$	Monoclinic ($P2_1$)
Lanthanum calcium aluminate	$LaCaAl_3O_7$	Tetragonal ($P42_1m$)
Lanthanum calcium borate	$La_2Ca_3(BO_3)_4$	Orthorhombic ($P2_1cn$)
Lanthanum calcium gallate	$LaCaGa_3O_7$	Tetragonal ($P42_1m$)
Lanthanum chloride	$LaCl_3$	Hexagonal ($P6_3/m$)
Lanthanum fluoride (tysonite)	LaF_3	Trigonal (P–3c1)
Lanthanum gallate	$LaGaO_3$	Orthorhombic (Pbnm)
Lanthanum gallium germanate	$LaGaGe_2O_7$	Monoclinic ($P2_1/c$)
Lanthanum gallium germanate	$La_3Ga_5GeO_{14}$	Trigonal ($P32_1$)
Lanthanum gallium silicate	$La_3Ga_5SiO_{14}$	Trigonal ($P32_1$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Lanthanum germanium beryllate	$La_2GeBe_2O_7$	Tetragonal ($P42_1m$)
Lanthanum indate	$LaInO_3$	Orthorhombic (Pbnm)
Lanthanum lutetium gallium garnet (LLGG)	$La_3Lu_2Ga_3O_{12}$	Cubic (Ia3d)
Lanthanum magnesium borate	$LaMgB_5O_{10}$	Monoclinic ($P2_1/c$)
Lanthanum magnesium hexa-aluminate (LMA)	$LaMgAl_{11}O_{19}$	Hexagonal ($P6_3/mmc$)
Lanthanum metaborate	LaB_3O_6	Monoclinic (I2/a)
Lanthanum molbydate	$La_2(MoO_4)_3$	Monoclinic (C2/c)
Lanthanum molybdate	$La_2(MoO_4)_3$	Tetragonal (I–42m)
Lanthanum niobate	$LaNbO_4$	Monoclinic (I2/a)
Lanthanum niobate	$LaNb_5O_{14}$	Orthorhombic (Pnam)
Lanthanum niobate	La_3NbO_7	Othorhombic (Cmcm)
Lanthanum niobogallate	$La_3Nb_{0.5}Ga_{5.5}O_{14}$	Trigonal ($P32_1$)
Lanthanum oxide	La_2O_3	Trigonal (P–3m1)
Lanthanum oxybromide	LaOBr	Tetragonal (P4/nmm)
Lanthanum oxymolybdate	La_2MoO_6	Tetragonal (I–42m)
Lanthanum oxysulfate	$La_2O_2SO_4$	Orthorhombic
Lanthanum oxysulfide	La_2O_2S	Trigonal (P–3m)
Lanthanum oxytungstate	La_2WO_6	Hexagonal ($P6_3/mmc$)
Lanthanum pentaphosphate	LaP_5O_{14}	Orthorhombic (Pcmn)
Lanthanum phosphate (monazite)	$LaPO_4$	Monoclinic ($P2_1/n$)
Lanthanum scandate	$LaScO_3$	Orthorhombic (Pbnm)
Lanthanum scandium borate	$LaSc_3(BO_3)_4$	Monoclinic
Lanthanum silicate	La_2SiO_5	Monoclinic
Lanthanum strontium borate	$La_2Sr_3(BO_3)_4$	Orthorhombic ($P2_1cn$)
Lanthanum strontium gallate	$LaSrGa_3O_7$	Tetragonal ($P42_1m$)
Lanthanum tantalate	La_3TaO_7	Orthorhombic (Cmcm)
Lanthanum tantalogallate	$La_3Ta_{0.5}Ga_{5.5}O_{14}$	Trigonal ($P32_1$)
Lanthanum titanate	La_2TiO_5	Orthorhombic (Pnam)
Lanthanum titanate	$La_2Ti_2O_7$	Monoclinic ($P2_1/c$)
Lanthanum tungstate	$La_2(WO_4)_3$	Monoclinic (C2/c)
Lanthanum yttrium tungstate	$LaY(WO_4)_3$	Monoclinic (C2/c)
Lathanium vanadate	$LaVO_4$	Monoclinic ($P2_1/c$)
Lead antimonade	$Pb_2Sb_2O_7$	Cubic (Fd3m)
Lead bismuth niobate	$PbBi_2Nb_2O_9$	Othorhombic (Fmm2)
Lead bromide	$PbBr_2$	Othorhombic (Pnma)
Lead cadmium niobate	$Pb_3CdNb_2O_9$	Orthorhombic
Lead calcium chloroarsenate (hedyphane)	$Pb_3Ca_2(AsO_4)_3Cl$	Hexagonal ($P6_3/m$)
Lead carbonate (cerussite)	$PbCO_3$	Orthorhombic (Pnam)
Lead chloride (cotunnite)	$PbCl_2$	Orthorhombic (Pnam)
Lead chloroarsenate (mimetite)	$Pb_5(AsO_4)_3Cl$	Hexagonal ($P6_3/m$)
Lead chlorophosphate (pyromorphite)	$Pb_5(PO_4)_3Cl$	Hexagonal ($P6_3/m$)
Lead chlorovanadate (vanadinite)	$Pb_5(VO_4)_3Cl$	Hexagonal ($P6_3/m$)
Lead fluoride	PbF_2	Cubic (Fm3m)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Lead fluoroarsenate	$Pb_5(AsO_4)_3F$	Hexagonal ($P6_3/m$)
Lead fluorophosphate	$Pb_5(PO_4)_3F$	Hexagonal ($P6_3/m$)
Lead fluorovanadate	$Pb_5(VO_4)_3F$	Hexagonal ($P6_3/m$)
Lead germanate	$PbGeO_3$	Monoclinic ($P2_1/a$)
Lead germanate	Pb_3GeO_5	Monoclinic (P12)
Lead germanate	$Pb_3Ge_3O_{11}$	Trigonal (P3)
Lead germanate	$Pb_5Ge_2O_7$	Hexagonal
Lead hafnate	$PbHfO_3$	Orthorhombic (Pbam)
Lead hexa-aluminate (magnetoplumbite)	$PbAl_{12}O_{19}$	Hexagonal ($P6_3/mmc$)
Lead indium niobate	Pb_2InNbO_6	Rhombohedral
Lead iodide	*2H*-PbI_2	Trigonal (P3m1)
Lead magnesium niobate	$Pb_3MgNb_2O_9$	Orthorhombic
Lead molybdate (wulfenite)	$PbMoO_4$	Tetragonal ($I4_1/a$)
Lead niobate (changbaiite)	$PbNb_2O_6$	Orthorhombic (Cm2m)
Lead nitrate	$Pb(NO_3)_2$	Cubic (Pa3)
Lead oxide (litharge)	PbO	Tetragonal (P4/nmm)
Lead oxide (massicot)	PbO	Orthorhombic (Pbcm)
Lead phosphate	$Pb_3(PO_4)_2$	Monoclinic (PC2/c)
Lead potassium niobate	$Pb_2KNb_5O_{15}$	Orthorhombic (Im2m)
Lead scandium niobate	Pb_2ScNbO_6	Rhombohedral
Lead selenate (kerstenite)	$PbSeO_4$	Orthorhombic (Pnma)
Lead selenide (clausthalite)	PbSe	Cubic (Fm3m)
Lead selenite (molybdomenite)	$PbSeO_3$	Monoclinic
Lead silicate (alamosite)	$PbSiO_3$	Monoclinic (Pn)
Lead sodium niobate	$PbNaNb_5O_{15}$	Orthorhombic (Im2a)
Lead sulfate (anglesite)	$PbSO_4$	Orthorhombic (Pnma)
Lead sulfide (galena)	PbS	Cubic (Fm3m)
Lead tantalate	$PbTa_2O_6$	Orthorhombic (Cm2m)
Lead telluride (altaite)	PbTe	Cubic (Fm3m)
Lead titanate (macedonite)	$PbTiO_3$	Tetragonal (P4mm)
Lead titanium phosphate	$PbTiP_2O_8$	Orthorhombic
Lead tungstate (stolzite)	$PbWO_4$	Tetragonal ($I4_1/a$)
Lead vanadate	$Pb_3(VO_4)_2$	Monoclinic (P2/c)
Lead vanadate (chervetite)	$Pb_2V_2O_7$	Monoclinic (P21/a)
Lead $_{zi}$nc niobate	Pb3ZnNb2O$_9$	Orthorhombic
Lead zinc silic$_a$te	Pb2ZnSi2O7	Tetragonal (P421m)
Lead zinc silicate (larsenite)	PbZnSiO4	Orthorhombic (Pnam)
Lithium aluminate	Li5AlO4	Orthorhombic (Pbca)
Lithium aluminate	γ-$LiAlO_2$	Tetragonal ($P4_12_12$)
Lithium aluminate spinel	$LiAl_5O_8$	Cubic ($P4_132$)
Lithium aluminum borate	$Li_6Al_2(BO_3)_4$	Triclinic(P−1)
Lithium aluminum fluorophosphate (amblygonite)	$LiAl(PO_4)F$	Triclinic(P−1)
Lithium aluminum germanate	$LiAlGe_2O_6$	Monoclinic (P21/n)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Lithium aluminum germanate	$LiAlGeO_4$	Trigonal(R–3)
Lithium aluminum molybdate	$LiAl(MoO_4)_2$	Triclinic(P–1)
Lithium aluminum silicate	$LiAlSi_2O_6$	Monoclinic (C2/c)
Lithium aluminum silicate	$LiAlSi_4O_{10}$	Monoclinic ($P2_1/n$)
Lithium aluminum silicate (eucryptite)	$LiAlSiO_4$	Rhombohedral(R–3)
Lithium aluminum silicate (petalite)	$LiAlSi_4O_{10}$	Monoclinic ($P2_1/n$)
Lithium aluminum silicate (spodumene)	$LiAlSi_2O_6$	Rhombohedral(R–3)
Lithium barium aluminum fluoride (LiBAF)	$LiBaAlF_6$	Monoclinic ($P2_1/a$)
Lithium barium fluoride	$LiBaF_3$	Cubic (Pm3m)
Lithium barium gallium fluoride	$LiBaGaF_6$	Monoclinic ($P2_1/a$)
Lithium beryllium fluoride	Li_2BeF_4	Cubic (Fd3m)
Lithium beryllium silicate (liberite)	Li_2BeSiO_4	Monoclinic (Pn)
Lithium borate	$LiBO_2$	Monoclinic ($P2_1/c$)
Lithium borate	LiB_3O_5	Orthorhombic ($Pna2_1$)
Lithium bromide	LiBr	Cubic (Fm3m)
Lithium cadmium borate	$LiCdBO_3$	Hexagonal (P–6)
Lithium cadmium chloride	Li_2CdCl_4	Cubic (Fd3m)
Lithium cadmium indium fluoride	$LiCdInF_6$	Trigonal (P321)
Lithium calcium aluminum fluoride (LiCAF)	$LiCaAlF_6$	Trigonal(P–31c)
Lithium calcium gallium fluoride (LiCGaF)	$LiCaGaF_6$	Trigonal(P–31c)
Lithium calcium germanate	Li_2CaGeO_4	Tetragonal (I–42m)
Lithium calcium indium fluoride	$LiCaInF_6$	Trigonal (P321)
Lithium calcium silicate	Li_2CaSiO_4	Tetragonal (I–42m)
Lithium carbonate (zabuyelite)	Li_2CO_3	Monoclinic (C2/c)
Lithium chloride	LiCl	Cubic (Fm3m)
Lithium fluoride (griceite)	LiF	Cubic (Fm3m)
Lithium gadolinium borate	$Li_3Gd_2(BO_3)_3$	Monoclinic ($P2_1/n$)
Lithium gadolinium borate	$Li_6Gd(BO_3)_3$	Monoclinic ($P2_1/b$)
Lithium gadolinium molybdate	$LiGd(MoO_4)_2$	Tetragonal ($I4_1/a$)
Lithium gadolinium molybdate	$LiGd(MoO_4)_2$	Tetragonal ($I4_1/a$)
Lithium gadolinium oxide	$LiGdO_2$	Orthorhombic (Pnma)
Lithium gadolinium tetrafluoride (GLF)	$LiGdF_4$	Tetragonal ($I4_1/a$)
Lithium gadolinium tetraphosphate	$LiGdP_4O_{12}$	Monoclinic (I2/c)
Lithium gadolinium tungstate	$LiGd(WO_4)_2$	Tetragonal ($I4_1/a$)
Lithium gallate	$LiGaO_2$	Orthorhombic ($Pna2_1$)
Lithium gallate	Li_5GaO_4	Orthorhombic (Pnam)
Lithium gallate spinel	$LiGa_5O_8$	Cubic ($P4_132$)
Lithium gallium germanate	$LiGaGe_2O_6$	Monoclinic ($P2_1/c$)
Lithium gallium germanate	$LiGaGe_2O_6$	Monoclinic ($P2_1/c$)
Lithium gallium germanate	$LiGaGeO_4$	Trigonal(R–3)
Lithium gallium silicate	$LiGaSi_2O_6$	Monoclinic (C2/c)
Lithium gallium silicate	$LiGaSiO_4$	Rhombohedral(R–3)
Lithium gallium tungstate	$LiGa(WO_4)_2$	Monoclinic (P2/c)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Lithium germanate	Li_2GeO_3	Orthorhombic ($Cmc2_1$)
Lithium indium germanate	$LiInGe_2O_6$	Orhtorhimbic (Pbca)
Lithium indium molybdate	$LiIn(MoO_4)_2$	Monoclinic ($P2_1/c$)
Lithium indium oxide	Li_3InO_3	Trigonal (P–3c1)
Lithium indium oxide	$LiInO_2$	Tetragonal($I4_1/amd$)
Lithium indium silicate	$LiInSiO_4$	Orthorhombic (Pnma)
Lithium indium silicate	$LiInSi_2O_6$	Monoclinic (C2/c)
Lithium indium tungstate	$LiIn(WO_4)_2$	Monoclinic (P2/c)
Lithium iodate	α-$LiIO_3$	Hexagonal ($P6_3$)
Lithium iodide	LiI	Cubic (Fm3m)
Lithium lanthanum borate	$Li_3La_2(BO_3)_3$	Monoclinic ($P2_1/n$)
Lithium lanthanum molybdate	$LiLa(MoO_4)_2$	Orthorhombic (Pbca)
Lithium lanthanum oxide	$LiLaO_2$	Orthorhombic (Pbmm)
Lithium lanthanum tetraphosphate	$LiLaP_4O_{12}$	Monoclinic (I2/c)
Lithium lanthanum tungstate	$LiLa(WO_4)_2$	Tetragonal ($I4_1/a$)
Lithium lutetium borate	$Li_6Lu(BO_3)_3$	Monoclinic ($P2_1/b$)
Lithium lutetium fluoride	$LiLuF_4$	Tetragonal ($I4_1/a$)
Lithium lutetium germanate	$LiLuGeO_4$	Orthorhombic (Pbcn)
Lithium lutetium oxide	$LiLuO_2$	Tetragonal ($I4_1/amd$)
Lithium lutetium silicate	$LiLuSiO_4$	Orthorhombic (Pbcn)
Lithium lutetium tetraphosphate	$LiLuP_4O_{12}$	Monoclinic (I2/c)
Lithium lutetium tungstate	$LiLu(WO_4)_2$	Monoclinic (P2/c)
Lithium magnesium aluminum fluoride	$LiMgAlF_6$	Trigonal (P321)
Lithium magnesium borate	$LiMgBO_3$	Monoclinic (C2/c)
Lithium magnesium borate	$Li_2MgB_2O_5$	Monoclinic
Lithium magnesium chloride	Li_2MgCl_4	Cubic (Fd3m)
Lithium magnesium gallium fluoride	$LiMgGaF_6$	Tetragonal ($P4_2/mmm$)
Lithium magnesium germanate	Li_2MgGeO_4	Orthorhombic ($Pmn2_1$)
Lithium magnesium indium fluoride	$LiMgInF_6$	Trigonal (P321)
Lithium niobate	$LiNbO_3$	Trigonal (R3c)
Lithium phosphate (lithiophosphate)	Li_3PO_4	Orthorhombic
Lithium scandate	$LiScO_2$	Tetragonal($I4_1/amd$)
Lithium scandium germanate	$LiScGeO_4$	Orthorhombic (Pbnm)
Lithium scandium germanate	$LiScGe_2O_6$	Orthorhombic (Pbca)
Lithium scandium silicate	$LiScSiO_4$	Orthorhombic (Pbnm)
Lithium scandium silicate	$LiScSi_2O_6$	Monoclinic (C2/c)
Lithium scandium tungstate	$LiSc(WO_4)_2$	Monoclinic (P2/c)
Lithium silicate	Li_2SiO_3	Orthorhombic ($Ccm2_1$)
Lithium strontium aluminum fluoride (LiSAF)	$LiSrAlF_6$	Trigonal(P–31c)
Lithium strontium gallium fluoride (LiSGF)	$LiSrGaF_6$	Trigonal(P–31c)
Lithium tantalate (LT)	$LiTaO_3$	Trigonal (R3c)
Lithium tetraborate (diomignite)	$Li_2B_4O_7$	Tetragonal ($I4_1cd$)
Lithium triborate (LBO)	LiB_3O_5	Orthorhombic ($Pn2_1a$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Lithium vanadate	$LiVO_3$	Monoclinic (C2/c)
Lithium vanadate	Li_3VO_4	Orthorhombic ($Pmn2_1$)
Lithium yttrium borate	$Li_3Y_2(BO_3)_3$	Monoclinic ($P2_1/n$)
Lithium yttrium borate	$Li_6Y(BO_3)_3$	Monoclinic ($P2_1/b$)
Lithium yttrium fluoride (YLF)	$LiYF_4$	Tetragonal ($I4_1/a$)
Lithium yttrium germanate	$LiYGeO_4$	Orthorhombic (Pbcn)
Lithium yttrium oxide	$LiYO_2$	Monoclinic ($P2_1/c$)
Lithium yttrium silicate	$LiYSiO_4$	Orthorhombic (Pbcn)
Lithium yttrium tungstate	$LiY(WO_4)_2$	Monoclinic (P2/c)
Lithium zinc borate	$LiZnBO_3$	Monoclinic (C2/c)
Lithium zinc indium fluoride	$LiZnInF_6$	Trigonal (P321)
Lithium zinc niobate	$LiZnNbO_4$	Tetragonal ($P4_122$)
Lutetium aluminum borate	$LuAl_3(BO_3)_3$	Trigonal (R32)
Lutetium aluminum garnet	$Lu_3Al_5O_{12}$	Cubic (Ia3d)
Lutetium borate	$LuBO_3$	Rhombohedral (R−3c)
Lutetium calcium borate	$LuCaBO_4$	Orthorhombic (Pnam)
Lutetium gallium garnet	$Lu_3Ga_5O_{12}$	Cubic (Ia3d)
Lutetium molybdate	$Lu_2(MoO_4)_3$	Orthorhombic (Pbcn)
Lutetium orthosilicate	Lu_2SiO_5	Monoclinic (C2/c)
Lutetium oxide	Lu_2O_3	Cubic (Ia3)
Lutetium oxymolybdate	Lu_2MO_6	Monoclinic (I2/c)
Lutetium oxysulfate	$Lu_2O_2SO_4$	Orthorhombic
Lutetium oxytungstate	Lu_2WO_6	Monoclinic (P2/c)
Lutetium pentaphosphate	LuP_5O_{14}	Monoclinic (C2/c)
Lutetium phosphate	$LuPO_4$	Tetragonal ($I4_1/amd$)
Lutetium scandate	$LuScO_3$	Cubic (Ia3)
Lutetium scandium aluminum garnet (LSAG)	$Lu_3Sc_2Al_3O_{12}$	Cubic (Ia3d)
Lutetium tantalate	$LuTaO_4$	Monoclinic (P2/a)
Lutetium titanate	$Lu_2Ti_2O_3$	Cubic (Fd3m)
Lutetium tungstate	$Lu_2(WO_4)_3$	Orthorhombic (Pcna)
Lutetium vanadate	$LuVO_4$	Tetragonal ($I4_1/amd$)
Magnesium aluminate (spinel)	$MgAl_2O_4$	Cubic (Fd3m)
Magnesium aluminum borate (sinhalite)	$MgAlBO_4$	Orthorhombic (Pnma)
Magnesium aluminum borosilicate (grandidierite)	$MgAl_3BSiO_9$	Orthorhombic
Magnesium aluminum silicate (cordierite)	$Mg_2Al_3(Si_5Al)O_{18}$	Hexagonal (P6/mcc)
Magnesium aluminum silicate (sapphirine)	$Mg_4Al_8Si_2O_{20}$	Monoclinic ($P2_1/a$)
Magnesium aluminum silicate garnet (pyrope)	$Mg_3Al_2Si_3O_{12}$	Cubic (Ia3d)
Magnesium borate (kotoite)	$Mg_3B_2O_6$	Orthorhombic (Pnma)
Magnesium borate (suanite)	$Mg_2B_2O_5$	Monoclinic
Magnesium carbonate (magnesite)	$MgCO_3$	Rhombohedral (R−3c)
Magnesium chloroborate (boracite)	$Mg_3B_7O_{13}Cl$	Orthorhombic
Magnesium fluoride (sellaite, Irtran 1)	MgF_2	Tetragonal ($P4_2/mnm$)
Magnesium fluoroborate	Mg_2BO_3F	Orthorhombic

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Magnesium fluoroborate	$Mg_5(BO_3)_3F$	Orthorhombic (P*nb)
Magnesium fluorophosphate (wagnerite)	Mg_2PO_4F	Monoclinic (P21/a)
Magnesium gallate spinel	$MgGa_2O_4$	Cubic (Fd3m)
Magnesium gallium borate	$MgGaBO_4$	Orthorhombic (Pnam)
Magnesium gallium germanate	$Mg_4Ga_8Ge_2O_{20}$	Monoclinic ($P2_1/a$)
Magnesium germanate	$MgGeO_3$	Orthorhombic (Pbca)
Magnesium germanate	Mg_2GeO_4	Orthorhombic (Pnma)
Magnesium molybdate	$MgMoO_4$	Monoclinic (C2/m)
Magnesium oxide (periclase, Irtran 5)	MgO	Cubic (Fm3m)
Magnesium phosphate (farringtonite)	$Mg_3(PO_4)_2$	Monoclinic
Magnesium pyroarsenate	$Mg_2As_2O_7$	Monoclinic (C2/m)
Magnesium silicate (enstatite)	$MgSiO_3$	Monoclinic ($P2_1/c$)
Magnesium silicate (forsterite)	Mg_2SiO_4	Orthorhombic (Pbcn)
Magnesium titanate	$MgTi_2O_5$	Orthorhombic (Bbmm)
Magnesium titanate	Mg_2TiO_4	Cubic (Fd3m)
Magnesium titanate (geikielite)	$MgTiO_3$	Trigonal(R–3)
Magnesium titanium sulfate	$MgTi(SO_4)_2$	Monoclinic ($P2_1/n$)
Magnesium titanum borate (warwickite)	$Mg_3TiB_2O_8$	Orthorhombic
Magnesium tungstate	$MgWO_4$	Monoclinic (P2/c)
Magnesium vanadate	MgV_2O_6	Orthorhombic (Pbcn)
Magnesium vanadate	$MgVO_3$	Monoclinic ($Cmc2_1$)
Magnesium vanadate	$Mg_2V_2O_7$	Monoclinic (C2/m)
Magnesium vanadate	$Mg_3(VO_4)_2$	Orthorhombic (Cmca)
Manganese fluoride	MnF_2	Tetragonal ($P4_2/mnm$)
Manganese oxide (manganosite)	MnO	Cubic (Fm3m)
Mercurous bromide (kuzminite)	Hg_2Br_2	Tetragonal (I4/mmm)
Mercurous chloride (calomel)	Hg_2Cl_2	Tetragonal (I4/mmm)
Mercurous iodide (moschelite)	Hg_2I_2	Tetragonal (I4/mmm)
Mercury antimonade	$Hg_2Sb_2O_7$	Cubic (Fd3m)
Mercury chloride	$HgCl_2$	Orthorhombic (Pmnb)
Mercury iodide	HgI_2	Tetragonal ($P4_2/mmc$)
Mercury oxide	HgO	Orthorhombic (Pmna)
Mercury peroxide	Hg_2O_2	Monoclinic (C2/m)
Mercury selenide (tiemannite)	HgSe	Cubic (F43m)
Mercury sulfide (cinnabar)	HgS	Trigonal (R32)
Mercury tellurite (coloradoite)	HgTe	Cubic (F43m)
Neodymium calcium aluminum oxide	$NdCaAlO_4$	Tetragonal (I4/mmm)
Neodymium gallate	$NbGaO_3$	Orthorhombic (Pbnm)
Neodymium yttrium aluminum borate	$Nd_xY_{1-x}Al_3(BO_3)_4$	Trigonal (R32)
Niobium phosphate	$NbOPO_4$	Tetragonal (P4/n)
Potassium aluminum borate	$K_2A_2lB_2O_7$	Trigonal (P321)
Potassium aluminum fluoride	K_3AlF_6	Cubic (Pm3m)
Potassium aluminum germanate	$KAlGeO_4$	Hexagonal ($P6_3$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Potassium aluminum molybdate	$KAl(MoO_4)_2$	Trigonal (P–3m1)
Potassium aluminum silicate (kaliophilite)	$KAlSiO_4$	Hexagonal ($P6_3$)
Potassium aluminum silicate (leucite)	$KAlSi_2O_6$	Tetragonal ($I4_1/a$)
Potassium aluminum silicate (orthoclase)	$KAlSi_3O_8$	Monoclinic (C2/m)
Potassium aluminum silicate hydroxide (mica)	$KAl_3Si_3O_{10}•(OH)_2$	Monoclinic
Potassium aluminum sulfate	$KAl(SO_4)_2$	Trigonal (P321)
Potassium aluminum tetrafluoride	$KAlF_4$	Tetragonal (P4/mbm)
Potassium beryllium fluoride	K_2BeF_4	Orthorhombic ($Pna2_1$)
Potassium beryllium fluoroborate (KBBF)	$KBe_2BO_3F_2$	Trigonal (R32)
Potassium bismuth niobate	$KBiNb_5O_{15}$	Tetragonal
Potassium boron fluoride (avogadvite)	KBF_4	Orthorhombic (Cmcm)
Potassium bromide	KBr	Cubic (Fm3m)
Potassium cadmium fluoride	$KCdF_3$	Cubic (Pm3m)
Potassium calcium fluoride	$KCaF_3$	Cubic (Pm3M)
Potassium calcium silicate	K_2CaSiO_4	Orthorhombic (Pnmm)
Potassium calcium zirconium silicate (wadeite)	$K_2CaZr(SiO_3)_4$	Hexagonal ($P6_3m$)
Potassium chloride (sylvite)	KCl	Cubic (Fm3m)
Potassium dideuterium phosphate (KDP)	KD_2PO_4	Hexagonal ($P6_3$)
Potassium dihydrogen phosphate (KDP)	KH_2PO_4	Tetragonal (I–42m)
Potassium fluoride (carobbiite)	KF	Cubic (Fm3m)
Potassium gadolinium niobate	$K_2GdNb_5O_{15}$	Tetragonal
Potassium gadolinium tungstate	$KGd(WO_4)_2$	Monoclinic (C2/c)
Potassium gadolinium vanadate	$K_3Gd(VO_4)_2$	Monoclinic ($P2_1/m$)
Potassium gallium germanate	$KGaGeO_4$	Hexagonal ($P6_3$)
Potassium gallium silicate	$KGaSi_3O_8$	Monoclinic (C2/m)
Potassium gallium silicate	$KGaSiO_4$	Hexagonal ($P6_3$)
Potassium indium molybdate	$KIn(MoO_4)_2$	Orthorhombic (Pnam)
Potassium indium tungstate	$KIn(WO_4)_2$	Trigonal (P–3m1)
Potassium iodide	KI	Cubic (Fm3m)
Potassium iodide	KIO_3	Monoclinic (P1)
Potassium lanthanum molybdate	$KLa(MoO_4)_4$	Tetragonal ($I4_1/a$)
Potassium lanthanum niobate	$K_2LaNb_5O_{15}$	Tetragonal
Potassium lanthanum phosphate	$K_3La(PO_4)_2$	Monoclinic ($P2_1/m$)
Potassium lanthanum tetraphosphate	$KLaP_4O_{12}$	Monoclinic ($P2_1$)
Potassium lanthanum tungstate	$KLa(WO_4)_2$	Monoclinic (C2/m)
Potassium lead chloride	KPb_2Cl_5	Monoclinic ($P2_1/c$)
Potassium lithium beryllium fluoride	$KLiBeF_4$	Hexagonal (P–3m1)
Potassium lithium gadolinium fluoride (KLGF)	$KLiGdF_5$	Monoclinic ($P2_1/c$)
Potassium lithium niobate (KLN)	$K_3Li_2Nb_5O_{15}$	Tetragonal (P4bm)
Potassium lithium yttrium fluoride (KLYF)	$KLiYF_5$	Monoclinic (P21/c)
Potassium lutetium tungstate	$KLu(WO_4)_4$	Monoclinic (C2/c)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Potassium lutetium vanadate	$K_3Lu(VO_4)_4$	Monoclinic (P21/m)
Potassium magnesium chloride	K_2MgCl_4	Tetragonal (I4/mmm)
Potassium magnesium fluoride	K_2MgF_4	Tetragonal (I4/mmm)
Potassium magnesium fluoride	$KMgF_3$	Cubic (Pm3m)
Potassium magnesium sulfate (langbeinite)	$K_2Mg_2(SO_4)_3$	Cubic ($P2_13$)
Potassium niobate (KN)	$KNbO_3$	Orthorhombic (Amm2)
Potassium niobium borate	$KNbB_2O_6$	Orthorhombic ($Pn2_1m$)
Potassium nitrate (nitre)	KNO_3	Orthorhombic (Pmcn)
Potassium pentaborate	$KB_5O_8{\bullet}4H_2O$	Orthorhombic (Aba2)
Potassium scandium molybdate	$KSc(MoO_4)_2$	Tetragonal (P–3m1)
Potassium scandium tungstate	$KSc(WO_4)_2$	Trigonal (P–3m1)
Potassium scandium vanadate	$KSc(VO_4)_2$	Trigonal
Potassium sodium aluminum fluoride (elpasolite)	K_2NaAlF_6	Cubic (Fm3m)
Potassium sodium gallium fluoride	K_2NaGaF_6	Cubic (Fm3m)
Potassium sodium lithium niobate	$KNaLi_2Nb_5O_{15}$	Trigonal
Potassium sodium lithum niobate	$K_2NaLi_2Nb_5O_{15}$	Tetragonal (P4bm)
Potassium strontium sulfate (kalistrontite)	$K_2Sr(SO_4)_2$	Trigonal
Potassium tantalate	$KTaO_3$	Cubic (Pm–3m)
Potassium tantalum borate	$KTaB_2O_6$	Orthorhombic (Pmm)
Potassium tin germanate	$K_2SnGe_3O_9$	Trigonal (P–3c1)
Potassium tin silicate	$K_2SnSi_3O_9$	Hexagonal ($P6_3/m$)
Potassium titanium germanate	$K_2TiGe_3O_9$	Trigonal (P–3c1)
Potassium titanium niobate	$KTiNbO_5$	Orthorhombic (Pnma)
Potassium titanium niobate	KTi_3NbO_9	Orthorhombic (Pnmm)
Potassium titanoarsenate (KTA)	$KTiOAsO_4$	Orthorhombic ($P2_1nb$)
Potassium titanophosphate (KTP)	$KTiOPO_4$	Orthorhombic ($P2_1nb$)
Potassium titanum silicate	$K_2TiSi_3O_9$	Hexagonal ($P6_3/m$)
Potassium vanadate	KVO_3	Orthorhombic (Pmab)
Potassium yttrium fluoride	KY_3F_{10}	Cubic (Fm3m)
Potassium yttrium molybdate	$KY(MoO_4)_2$	Orthorhombic (Pbna)
Potassium yttrium niobate	$K_2YNb_5O_{15}$	Tetragonal
Potassium yttrium tetrafluoride (KYF)	KYF_4	Trigonal ($P3_1$)
Potassium yttrium tungstate	$KY(WO_4)_2$	Monoclinic (C2/c)
Potassium yttrium vanadate	$K_3Y(VO_4)_2$	Monoclinic
Potassium zinc fluoride	K_2ZnF_4	Tetragonal (I4/mmm)
Potassium zinc fluoride	$KZnF_3$	Tetragonal
Rubidium aluminum selenate	$RbAl(SeO_4)_2$	Trigonal (P321)
Rubidium aluminum silicate	$RbAlSiO_4$	Orthorhombic (Pcmn)
Rubidium aluminum silicate	$RbAlSi_2O_6$	Tetragonal ($I4_1/a$)
Rubidium aluminum sulfate	$RbAl(SO_4)_2$	Trigonal (P321)
Rubidium aluminum tetrafluoride	$RbAlF_4$	Tetragonal (P4/mmm)
Rubidium beryllium fluoride	Rb_2BeF_4	Orthorhombic ($Pna2_1$)
Rubidium bismuth molybdate	$RbBi(MoO_4)_2$	Monoclinic ($P2_1/c$)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Rubidium bromide	RbBr	Cubic (Fm3m)
Rubidium cadmium fluoride	$RbCdF_3$	Cubic (Pm3m)
Rubidium calcium fluoride	$RbCaF_3$	Cubic (Pm3m)
Rubidium chloride	RbCl	Cubic (Fm3m)
Rubidium dihydrogen arsenate (RDA)	RbH_2AsO_4	Tetragonal ($I4_1/a$)
Rubidium dihydrogen phosphate (RDP)	RbH_2PO_4	Tetragonal ((I–42m)
Rubidium fluoride	RbF	Cubic (Fm3m)
Rubidium gadolinium bromide	$RbGd_2Br_7$	Orthorhombic (Pnma)
Rubidium gadolinium vanadate	$Rb_3Gd(VO_4)_2$	Trigonal
Rubidium gadolinium vanadate	$RbGd(VO_4)_2$	Tetragonal (P4/mmm)
Rubidium gallium selenate	$RbGa(SeO_4)_2$	Trigonal (P321)
Rubidium gallium sulfate	$RbGa(SO_4)_2$	Trigonal (P321)
Rubidium indium molybdate	$RbIn(MoO_4)_2$	Trigonal (P321)
Rubidium indium tungstate	$RbIn(WO_4)_2$	Trigonal (P321)
Rubidium iodide	RbI	Cubic (Fm3m)
Rubidium lanthanum niobate	$Rb_2LaNb_5O_{15}$	Tetragonal
Rubidium lanthanum tungstate	$RbLa(WO_4)_2$	Monoclinic (C2/c)
Rubidium lithium aluminum fluoride	Rb_2LiAlF_6	Rhombohedral (R–3m)
Rubidium lithium gallium fluoride	Rb_2LiGaF_6	Rhombohedral (R–3m)
Rubidium lutetium vanadate	$Rb_3Lu(VO_4)_2$	Trigonal
Rubidium lutetium vanadate	$RbLu(VO_4)_2$	Trigonal
Rubidium magnesium chloride	Rb_2MgCl_4	Tetragonal (I4/mmm)
Rubidium magnesium fluoride	Rb_2MgF_4	Tetragonal (I4/mmm)
Rubidium niobium borate	$RbNbB_2O_6$	Orthorhombic ($Pn2_1m$)
Rubidium pentaborate	$RbB_5O_8{\cdot}4H_2O$	Orthorhombic (Aba2)
Rubidium potassium gallium fluoride	Rb_2KGaF_6	Cubic (Fm3m)
Rubidium scandium molybdate	$RbSc(MoO_4)_2$	Trigonal (P–3m1)
Rubidium scandium tungstate	$RbSc(WO_4)_2$	Trigonal (P–3m1)
Rubidium scandium vanadate	$Rb_3Sc(VO_4)_2$	Trigonal
Rubidium scandium vanadate	$RbSc(VO_4)_2$	Trigonal
Rubidium sodium beryllium fluoride	Rb_3NaBeF_8	Hexagonal ($P6_3$)
Rubidium sodium indium fluoride	Rb_2NaInF_6	Cubic (Fm3m)
Rubidium tantalum borate	$RbTaB_2O_6$	Orthorhombic ($Pn2_1m$)
Rubidium tin germanate	$Rb_2SnGe_3O_9$	Trigonal (P–3c1)
Rubidium tin silicate	$Rb_2SnSi_3O_9$	Hexagonal ($P6_3/m$)
Rubidium titanium germanate	$Rb_2TiGe_3O_9$	Trigonal (P–3c1)
Rubidium titanium silicate	$Rb_2TiSi_3O_9$	Hexagonal ($P6_3/m$)
Rubidium titano arsenate (RTA)	$RbTiOAsO_4$	Orthorhombic ($P2_1nb$)
Rubidium titano phosphate (RTP)	$RbTiOPO_4$	Orthorhombic ($P2_1nb$)
Rubidium yttrium vanadate	$Rb_3Y(VO_4)_2$	Trigonal
Rubidium yttrium vanadate	$RbY(VO_4)_2$	Trigonal
Rubidium zinc bromide	Rb_2ZnBr_4	Orthorhombic (Pnma)
Rubidium zinc chloride	Rb_2ZnCl_4	Orthorhombic (Pnma)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Rubidium zinc fluoride	Rb_2ZnF_4	Tetragonal (I4/mmm)
Rubidium zinc fluoride	$RbZnF_3$	Cubic (Pm3m)
Scandium aluminum beryllate (SCAB)	$ScAlBeO_4$	Orthorhombic (Pmcn)
Scandium borate	$ScBO_3$	Rhombohedral (R–31)
Scandium calcium borate	$ScCaBO_4$	Orthorhombic (Pnam)
Scandium gallate	$ScGaO_3$	Monoclinic (A2/m)
Scandium germanate	Sc_2GeO_5	Monoclinic (B2/b)
Scandium magnesium borate	$ScMgBO_4$	Orthorhombic (Pnam)
Scandium metaphosphate	$Sc(PO_3)_3$	Monoclinic (Cc)
Scandium molybdate	$Sc_2(MoO_4)_3$	Orthorhombic (Pbcn)
Scandium niobate	$ScNbO_4$	Monoclinic (P2/c)
Scandium orthosilicate	Sc_2SiO_5	Monoclinic (I2/a)
Scandium oxide	Sc_2O_3	Cubic (I213)
Scandium phosphate	$ScPO_4$	Tetragonal ($I4_1$/amd)
Scandium silicate	$Sc_2Si_2O_7$	Monoclinic (C2/m)
Scandium tantalate	$ScTaO_4$	Monoclinic (P2/c)
Scandium titanate	Sc_2TiO_5	Orthorhombic (Bbmm)
Scandium tungstate	$Sc_2(WO_4)_3$	Orthorhombic (Pcna)
Scandium vanadate	$ScVO_4$	Tetragonal ($I4_1$/amd)
Scandium yttrium silicate (thortveitite)	$(Sc,Y)_2Si_2O_7$	Monoclinic (C2/m)
Selenium	Se	Trigonal (32)
Selenium dioxide (downeyite)	SeO_2	Tetragonal ($P4_2$/nbc)
Silicon	Si	Cubic (F–43m)
Silicon carbide (carborundum, moissanite)	α-SiC (2H)	Hexagonal ($P6_3$/m)
Silicon carbide	β-SiC (3C)	Cubic (Fd3m)
Silicon dioxide (α-quartz)	SiO_2	Trigonal ($P3_12$)
Silicon nitride	Si_3N_4	Hexagonal ($P6_3$/m)
Silver antimony sulfide (pyrargyrite)	Ag_3SbS_3	Trigonal (R3c)
Silver arsenic selenide	Ag_3AsSe_3	Trigonal (R3c)
Silver arsenic sulfide (proustite)	Ag_3AsS_3	Trigonal (R3c)
Silver arsenic sulfide (trechmannite)	$AgAsS_2$	Tetragonal (I–42d)
Silver bromide (bromyrite)	AgBr	Cubic (Fm3m)
Silver chloride (cerargyrite)	AgCl	Cubic (Fm3m)
Silver gallium selenide	$AgGaSe_2$	Tetragonal (I–42d)
Silver gallium sulfide	$AgGaS_2$	Tetragonal (I–42d)
Silver iodide (iodargyrite)	AgI	Hexagonal ($P6_3$mc)
Silver mercury iodide	Ag_2HgI_4	Tetragonal (I–4)
Sodium aluminum borate	$Na_2Al_2B_2O_7$	Tetragonal (I–42d)
Sodium aluminum chlorosilicate (sodalite)	$Na_8Al_6Si_6O_{24}Cl_2$	Cubic
Sodium aluminum fluoride (chiolite)	$Na_5Al_3F_{14}$	Tetragonal (P4/mnc)
Sodium aluminum fluoride (cryolite)	Na_3AlF_6	Monoclinic ($P2_1$/n)
Sodium aluminum fluoroarsenate (durangite)	$NaAl(AsO_4)F$	Monoclinic (C2/c)
Sodium aluminum fluorophosphate (lacroixite)	$NaAl(PO_4)F$	Monoclinic

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Sodium aluminum germanate	$NaAlGeO_4$	Monoclinic ($P2_1/n$)
Sodium aluminum silicate (albite)	$NaAlSi_3O_8$	Triclinic (P–1)
Sodium aluminum silicate (nepheline)	$NaAlSiO_4$	Hexagonal ($P6_3$)
Sodium antimony beryllate (swedenburgite)	$NaSbBe_4O_7$	Hexagonal ($P6_3mc$)
Sodium barium phosphate	$NaBaPO_4$	Hexagonal ($P\bar{3}m1$)
Sodium barium titanium silicate (batisite)	$Na_2BaTi_2Si_4O_{14}$	Orthorhombic
Sodium beryllium fluoride	Na_2BeF_4	Monoclinic ($P2_1/n$)
Sodium beryllium fluoroborate	$NaBe_2BO_3F_2$	Trigonal (R32)
Sodium beryllium phosphate (beryllonite)	$NaBePO_4$	Monoclinic ($P2_1/n$)
Sodium beryllium silicate (chkalovite)	$Na_2BeSi_2O_6$	Orthorhombic (Fddd)
Sodium beryllium silicate	Na_2BeSiO_4	Orthorhombic ($Pca2_1$)
Sodium bismuth magnesium vanadate	$Na_2BiMg_2V_3O_{12}$	Cubic (Ia3d)
Sodium bismuth zinc vanadate	$Na_2BiZn_2V_3O_{12}$	Cubic (Ia3d)
Sodium boron fluoride (ferruccite)	$NaBF_4$	Orthorhombic (Cmcm)
Sodium bromide	NaBr	Cubic (Fm3m)
Sodium cadmium magnesium fluoride	$NaCdMg_2F_7$	Cubic (Fd3m)
Sodium cadmium phosphate	$NaCdPO_4$	Orthorhombic (Pnma)
Sodium cadmium zinc fluoride	$NaCdZn_2F_7$	Cubic (Fd3m)
Sodium calcium fluorophosphate (arctite)	$Na_2Ca_4(PO_4)_3F$	Trigonal
Sodium calcium fluorophosphate (nacaphite)	Na_2CaPO_4F	Orthorhombic
Sodium calcium magnesium phosphate (brianite)	$Na_2CaMg(PO_4)_2$	Orthorhombic
Sodium calcium phosphate (bushwaldite)	$NaCaPO_4$	Orthorhombic (Pnam)
Sodium calcium silicate	Na_2CaSiO_4	Cubic (Fm3m)
Sodium calcium silicate (combeite)	$Na_2Ca_2Si_3O_9$	Trigonal ($P3_122_1$)
Sodium calcium yttrium fluoride (α-gagarinite)	α-$NaCaYF_6$	Hexagonal
Sodium carbonate (natrite	Na_2CO_3	Hexagonal ($P6_3mc$)
Sodium chloride (halite)	NaCl	Cubic (Fm3m)
Sodium fluoride (villiaumite)	NaF	Cubic (Fm3m)
Sodium gadolinium arsenate	$Na_3Gd(AsO_4)_2$	Monoclinic (Cc)
Sodium gadolinium germanate	$NaGdGeO_4$	Orthorhombic ($Pbn2_1$)
Sodium gadolinium germanate	$Na_5GdGe_4O_{12}$	Trigonal (R32)
Sodium gadolinium magnesium vanadate	$Na_2GdMg_2V_3O_{12}$	Cubic (Ia3d)
Sodium gadolinium molybdate	$NaGd(MoO_4)_2$	Tetragonal ($I4_1/a$)
Sodium gadolinium oxide	$NaGdO_2$	Tetragonal ($I4_1/amd$)
Sodium gadolinium phosphate	$Na_3Gd(PO_4)_2$	Monoclinic
Sodium gadolinium pyrophosphate	$NaGdP_2O_7$	Monoclinic
Sodium gadolinium silicate	$NaGdSiO_4$	Orthorhombic ($Pbn2_1$)
Sodium gadolinium silicate	$Na_3GdSi_3O_9$	Orthorhombic ($P2_12_12_1$)
Sodium gadolinium silicate	$Na_5GdSi_4O_{12}$	Trigonal (R32)
Sodium gadolinium tetraphosphate	$NaGdP_4O_{12}$	Monoclinic ($P2_1/n$)
Sodium gadolinium tungstate	$NaGd(WO_4)_2$	Tetragonal ($I4_1/a$)
Sodium gadolinium vanadate	$Na_3Gd(VO_4)_2$	Monoclinic (Cc)
Sodium gallium borate	$Na_2Ga_2B_2O_7$	Tetragonal

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Sodium gallium germanate	$NaGaGeO_4$	Monoclinic ($P2_1/n$)
Sodium gallium germanate	$NaGaGe_2O_6$	Monoclinic (C2/c)
Sodium gallium silicate	$NaGaSiO_4$	Monoclinic ($P2_1/n$)
Sodium germanate	Na_2GeO_3	Orthorhombic ($Cmc2_1$)
Sodium indate	$NaInO_2$	Rhombohedral (R3/m)
Sodium indium germanate	$Na_5InGe_4O_{12}$	Trigonal (R32)
Sodium indium molybdate	$NaIn(MoO_4)_2$	Triclinic (P–1)
Sodium indium silicate	$Na_5InSi_4O_{12}$	Trigonal (R32)
Sodium iodide	NaI	Cubic (Fm3m)
Sodium lanthanum arsenate	$Na_3La(AsO_4)_2$	Orthorhombic ($Pbc2_1$)
Sodium lanthanum borate	$Na_3La(BO_3)_2$	Monoclinic ($P2_1/c$)
Sodium lanthanum borate	$Na_3La_2(BO_3)_3$	Orthorhombic (Amm2)
Sodium lanthanum borate	$Na_{18}La(BO_3)_7$	Monoclinic
Sodium lanthanum molybdate	$NaLa(MoO_4)_2$	Tetragonal ($I4_1/a$)
Sodium lanthanum oxide	$NaLaO_2$	Tetragonal ($I4_1/amd$)
Sodium lanthanum phosphate	$Na_3La(PO_4)_2$	Orthorhombic ($Pbc2_1$)
Sodium lanthanum pyrophosphate	$NaLaP_2O_7$	Orthorhombic
Sodium lanthanum tetraphosphate	$NaLaP_4O_{12}$	Monoclinic ($P2_1/n$)
Sodium lanthanum tungstate	$NaLa(WO_4)_2$	Tetragonal ($I4_1/a$)
Sodium lanthanum vanadate	$Na_3La(VO_4)_2$	Orthorhombic ($Pbc2_1$)
Sodium lithium aluminum borosilicate (elbaite)	$Na(Li,Al)_3Al_6(BO_3)_3$-$Si_6O_{18}(OH)$	Trigonal (R3m)
Sodium lithium aluminum fluoride	Na_2LiAlF_6	Monoclinic ($P2_1/n$)
Sodium lithium aluminum fluorogarnet	$Na_3Li_3Al_2F_{12}$	Cubic (Ia3d)
Sodium lithium gallium fluorogarnet (GFG)	$Na_3Li_3Ga_2F_{12}$	Cubic (Ia3d)
Sodium lithium indium fluorogarnet	$Na_3Li_3In_2F_{12}$	Cubic (Ia3d)
Sodium lithium niobate	$Na_3Li_2Nb_5O_{15}$	Tetragonal (P4bm)
Sodium lithium scandium fluorogarnet	$Na_3Li_3Sc_2F_{12}$	Cubic (Ia3d)
Sodium lithium vanadate	$NaLiV_2O_6$	Monoclinic (C2/c)
Sodium lithium yttrium silicate	$Na_2LiYSi_6O_{15}$	Orthorhombic (Cmca)
Sodium lithium zirconium silicate (Zektzerite)	$Na_2LiZrSi_6O_{15}$	Orthorhombic (Cmca)
Sodium lutetium arsenate	$Na_3Lu(AsO_4)_2$	Monoclinic (Cc)
Sodium lutetium germanate	$NaLuGeO_4$	Orthorhombic ($Pbn2_1$)
Sodium lutetium germanate	$Na_5LuGe_4O_{12}$	Trigonal (R32)
Sodium lutetium magnesium vanadate	$Na_2LuMg_2V_3O_{12}$	Cubic (Ia3d)
Sodium lutetium oxide	$NaLuO_2$	Tetragonal($I4_1/amd$)
Sodium lutetium phosphate	$Na_3Lu(PO_4)_2$	Monoclinic
Sodium lutetium pyrophosphate	$NaLuP_2O_7$	Monoclinic
Sodium lutetium silicate	$NaLuSiO_4$	Orthorhombic (Pbcn)
Sodium lutetium silicate	$Na_5LuSi_4O_{12}$	Trigonal (R32)
Sodium lutetium vanadate	$Na_3Lu(VO_4)_2$	Monoclinic ($P2_1/n$)
Sodium magnesium aluminum fluoride (weberite)	$NaMgAlF_7$	Orthorhombic (Imm2)
Sodium magnesium carbonate (eitelite)	$Na_2Mg(CO_3)_2$	Trigonal (R–3)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Sodium magnesium fluoride (neighborite)	$NaMgF_3$	Orthorhombic (Pcmm)
Sodium magnesium gallium fluoride	$NaMgGaF_7$	Orthorhombic (Imm2)
Sodium magnesium indium fluoride	$NaMgInF_7$	Orthorhombic (Imm2)
Sodium magnesium scandium fluoride	$NaMgScF_7$	Orthorhombic (Imm2)
Sodium magnesium silicate	Na_2MgSiO_4	Monoclinic
Sodium niobate (natroniobite)	$NaNbO_3$	Orthorhombic (Pbma)
Sodium nitrate (soda-nitre)	$NaNO_3$	Trigonal (R–3c)
Sodium potassium titanoniobosilicate	$Na_2KTiNbSi_4O_{14}$	Orthorhombic
Sodium scandium germanate	$NaScGeO_4$	Orthorhombic (Pbnm)
Sodium scandium germanate	$NaScGe_2O_6$	Monoclinic (C2/m)
Sodium scandium germanate	$Na_5ScGe_4O_{12}$	Trigonal (R32)
Sodium scandium indium vanadate	$Na_3Sc_{1.5}In_{0.5}V_3O_{12}$	Cubic (Ia3d)
Sodium scandium oxide	$NaScO_2$	Rhombohedral (R3/m)
Sodium scandium silicate	$Na_3ScSi_2O_7$	Orthorhombic (Pbcn)
Sodium scandium silicate	$Na_5ScSi_4O_{12}$	Trigonal (R32)
Sodium scandium silicate (jervisite)	$NaScSi_2O_6$	Monoclinic (C2/c)
Sodium scandium vanadate	$Na_3Sc_2V_3O_{12}$	Cubic (Ia3d)
Sodium silicate	Na_2SiO_3	Orthorhombic ($Cmc2_1$)
Sodium silicate (natrosilite)	$Na_2Si_2O_5$	Monoclinic(P21/a)
Sodium strontium aluminum fluoride	$NaSrAlF_6$	Orthorhombic ($Pna2_1$)
Sodium strontium aluminum fluoride (jarlite)	$NaSr_3Al_3F_{16}$	Monoclinic
Sodium strontium phosphate	$Na_2Sr(PO_2)_4$	Tetragonal (P4/nbm)
Sodium tantalate	$NaTaO_3$	Orthorhombic (Pbma)
Sodium titanium silicate (lorenzenite)	$Na_2Ti_2Si_2O_9$	Orthorhombic (Pnca)
Sodium titanium silicate (natisite)	$Na_2TiOSiO_4$	Tetragonal (P4/nmm)
Sodium vanadate	$NaVO_3$	Monoclinic (C2/c)
Sodium yttrium fluoride	$5NaF–9YF_3$	Cubic (Ia3d)
Sodium yttrium fluorosilicate	$Na_5Y_4(SiO_4)_4F$	Rhombohedral (R–3)
Sodium yttrium germanate	$NaYGeO_4$	Orthorhombic ($Pbn2_1$)
Sodium yttrium germanate	$Na_5YGe_4O_{12}$	Trigonal (R32)
Sodium yttrium magnesium vanadate	$Na_2YMg_2V_3O_{12}$	Cubic (Ia3d)
Sodium yttrium molybdate	$NaY(MoO_4)_2$	Tetragonal ($I4_1/a$)
Sodium yttrium oxide	$NaYO_2$	Monoclinic ($P2_1/c$)
Sodium yttrium silicate	$NaYSiO_4$	Orthorhombic (Pbcn)
Sodium yttrium silicate	$Na_3YSi_3O_9$	Orthorhombic ($P2_12_12_1$)
Sodium yttrium silicate	$Na_3YSi_2O_7$	Hexagonal ($P6_3/m$)
Sodium yttrium silicate	$Na_5YSi_4O_{12}$	Trigonal (R32)
Sodium yttrium tetrafluoride	$NaYF_4$	Trigonal ($P3_1$)
Sodium zinc chloride	$NaZnF_3$	Orthorhombic (Pnmc)
Sodium zinc fluoride	Na_2ZnCl_4	Orthorhombic (Pnma)
Strontium aluminate	$SrAl_2O_4$	Monoclinic ($P2_1/n$)
Strontium aluminate	$SrAl_4O_7$	Monoclinic (C2/c)
Strontium aluminate	$Sr_3Al_2O_6$	Cubic (Pa3)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Strontium aluminum fluoride	$SrAlF_5$	Tetragonal (P4)
Strontium aluminum germanate	$SrAl_2Ge_2O_8$	Monoclinic ($P2_1/a$)
Strontium aluminum silicate	$SrAl_2Si_2O_8$	Monoclinic ($P2_1/a$)
Strontium aluminum silicate	$Sr_2Al_2SiO_7$	Tetragonal ($P42_1m$)
Strontium barium niobate (SBN)	$Sr_{0.6}Ba_{0.4}Nb_2O_6$	Tetragonal
Strontium borate	SrB_2O_4	Orthorhombic (Pnca)
Strontium borate	SrB_4O_7	Orthorhombic (Pbca)
Strontium borate	$Sr_3B_2O_6$	Rhombohedral (R–3c)
Strontium bromovanadate	Sr_2VO_4Br	Orthorhombic (Pbcm)
Strontium carbonate (strontianite)	$SrCO_3$	Orthorhombic (Pnam)
Strontium chloroarsenate	Sr_2AsO_4Cl	Orthorhombic (Pbcm)
Strontium chloroarsenate	$Sr_5(AsO_4)_3Cl$	Hexagonal($P6_3/m$)
Strontium chloroborate	$Sr_2B_5O_9Cl$	Tetragonal ($P4_22_12$)
Strontium chlorophosphate	$Sr_5(PO_4)_3Cl$	Hexagonal($P6_3/m$)
Strontium chlorovanadate	Sr_2VO_4Cl	Orthorhombic (Pbcm)
Strontium chlorovanadate	$Sr_5(VO_4)_3Cl$	Hexagonal($P6_3/m$)
Strontium fluoride	SrF_2	Cubic (Fm3m)
Strontium fluoroarsenate	$Sr_5(AsO_4)_3F$	Hexagonal($P6_3/m$)
Strontium fluorophosphate (SFAP)	$Sr_5(PO_4)_3F$	Hexagonal($P6_3/m$)
Strontium fluorovanadate (SVAP)	$Sr_5(VO_4)_3F$	Hexagonal($P6_3/m$)
Strontium gadolinium aluminate	$SrGdAlO_4$	Tetragonal (I4/mmm)
Strontium gadolinium gallate (SGGM)	$SrGdGa_3O_7$	Tetragonal ($P42_1m$)
Strontium gadolinium phosphate	$Sr_3Gd(PO_4)_3$	Cubic (I–43d)
Strontium gadolinum oxide	$SrGd_2O_4$	Orthorhombic (Pnma)
Strontium gallate	$SrGa_2O_4$	Monoclinic ($P2_1/n$)
Strontium gallium fluoride	$SrGaF_5$	Tetragonal (P4)
Strontium gallium germanate	$Sr_3Ga_2Ge_4O_{14}$	Trigonal ($P32_1$)
Strontium gallium silicate	$SrGa_2Si_2O_8$	Monoclinic ($P2_1/a$)
Strontium gallium silicate	$Sr_2Ga_2SiO_7$	Tetragonal ($P42_1m$)
Strontium hexa-aluminate	$SrAl_{12}O_{19}$	Hexagonal ($P6_3/mmc$)
Strontium indium germanium garnet	$Sr_3In_2Ge_3O_{12}$	Cubic (Ia3d)
Strontium indium oxide	$SrIn_2O_4$	Orthorhombic (Pnma)
Strontium lanthanum aluminate	$SrLaAlO_4$	Tetragonal (I4/mmm)
Strontium lanthanum borate	$SrLaBO_4$	Hexagonal ($P6_322$)
Strontium lanthanum gallate	$SrLaGaO_4$	Tetragonal (I4/mmm)
Strontium lanthanum oxysilicate	$SrLa_4(SiO_4)_3O$	Hexagonal ($P6_3/m$)
Strontium lanthanum phosphate	$Sr_3La(PO_4)_3$	Cubic (I–43d)
Strontium lutetium oxide	$SrLu_2O_4$	Orthorhombic (Pnma)
Strontium magnesium germanate	$Sr_2MgGe_2O_7$	Tetragonal ($P42_1m$)
Strontium magnesium silicate	$Sr_2MgSi_2O_7$	Tetragonal ($P42_1m$)
Strontium magnesium vanadate	$SrMg_2(VO_4)_2$	Tetragonal ($I4_1/acd$)
Strontium molybdate	$SrMoO_4$	Tetragonal ($I4_1/a$)
Strontium niobate	$SrNb_2O_6$	Orthorhombic (Pcan)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Strontium niobate	$Sr_2Nb_2O_7$	Orthorhombic ($Cmc2_1$)
Strontium niobate	$Sr_5Nb_4O_{15}$	Monoclinic ($P2_1/m$)
Strontium niobate	$SrNb_2O_6$	Monoclinic ($P2_1/c$)
Strontium potassium niobate	$Sr_2KNb_5O_{15}$	Orthorhombic (Im2a)
Strontium potassium tantalate	$Sr_2KTa_5O_{15}$	Orthorhombic (Im2a)
Strontium scandate	$SrSc_2O_4$	Orthorhombic (Pnam)
Strontium scandium germanium garnet	$Sr_3Sc_2Ge_3O_{12}$	Cubic (Ia3d)
Strontium silicate	$SrSiO_3$	Monoclinic (C2)
Strontium sodium niobate	$Sr_2NaNb_5O_{15}$	Orthorhombic (Im2a)
Strontium sulfate (celestite)	$SrSO_4$	Orthorhombic (Pmma)
Strontium tantalate	$Sr_2Ta_2O_7$	Orthorhombic (Pnma)
Strontium tin borate	$SrSnB_2O_6$	Trigonal (R–3)
Strontium tin oxide	$SrSnO_3$	Cubic ($P2_13$)
Strontium titanate	$Sr_3Ti_2O_7$	Tetragonal (I4/mmm)
Strontium titanate (tausonite)	$SrTiO_3$	Cubic (Pm3m)
Strontium titanium borate	$SrTiB_2O_6$	Trigonal (R–3)
Strontium tungstate	$SrWO_4$	Tetragonal ($I4_1/a$)
Strontium vanadate	SrV_2O_6	Monoclinic (C2/m)
Strontium vanadate	β-$Sr_2V_2O_7$	Tetragonal ($I4_1/amd$)
Strontium vanadate	$Sr_3(VO_4)_2$	Rhombohedral ($R\bar{3}m$)
Strontium vanadate	β-$Sr_2V_2O_7$	Tetragonal ($P4_1$)
Strontium vanadate	$SrVO_3$	Cubic (Pm3m)
Strontium yttrium borate	$Sr_3Y(BO_3)_3$	Trigonal (R–3)
Strontium yttrium oxide	SrY_2O_4	Orthorhombic (Pnma)
Strontium yttrium oxysilicate	$SrY_4(SiO_4)_3O$	Hexagonal ($P6_3/m$)
Strontium zinc fluoride	$SrZnF_4$	Tetragonal ($I4_1/a$)
Strontium zinc germanate	$SrZnGe_2O_6$	Monoclinic (C2/c)
Strontium zinc germanate	$Sr_2ZnGe_2O_7$	Tetragonal ($P42_1m$)
Strontium zinc silicate	$Sr_2ZnSi_2O_7$	Tetragonal ($P42_1m$)
Strontium zirconate	$SrZrO_3$	Orthorhombic (Pnma)
Strontium zirconium borate	$SrZrB_2O_6$	Trigonal (R–3)
Strontiun tantalate	$SrTa_2O_6$	Orthorhombic (Pcan)
Strontiun tantalate	$Sr_2Ta_2O_7$	Orthorhombic (Cmcm)
Strontiun tantalate	$Sr_5Ta_4O_{15}$	Hexagonal
Strontiun tantalate	$Sr_6Ta_2O_{11}$	Cubic
Tantalum borate (behierite)	$TaBO_4$	Tetragonal ($I4_1/amd$)
Tantalum oxide (tantite)	Ta_2O_5	Orthorhombic (P2mm)
Tantalum oxyphosphate	$TaOPO_4$	Tetragonal (P4/n)
Tellurium	Te	Trigonal (32)
Tellurium oxide (tellurite)	TeO_2	Orthorhombic (Pbca)
Thallium aluminum selenate	$TlAl(SeO_4)_2$	Trigonal (P321)
Thallium aluminum sulfate	$TlAl(SO_4)_2$	Trigonal (P321)
Thallium aluminum tetrafluoride	$TlAlF_4$	Tetragonal (P4/mmm)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Thallium arsenic selenide	Tl_3AsSe_3	Trigonal (R3c)
Thallium arsenic sulfide (ellisite)	Tl_3AsS_3	Trigonal (R3c)
Thallium bromide	TlBr	Cubic (Fm3m)
Thallium bromoiodide (KRS-5)	Tl(Br,I)	Cubic (Fm3m)
Thallium chloride	TlCl	Cubic (Fm3m)
Thallium chlorobromide (KRS-6)	Tl(Cl,Br)	Cubic (Fm3m)
Thallium gallium selenate	$TlGa(SeO_4)_2$	Trigonal (P321)
Thallium gallium sulfate	$TlGa(SO_4)_2$	Trigonal (P321)
Thallium niobium borate	$TlNbB_2O_6$	Orthorhombic ($Pn2_1m$)
Thallium oxide (avicennite)	Tl_2O_3	Cubic (Ia3d)
Thallium tantalium borate	$TlTaB_2O_6$	Orthorhombic ($Pn2_1m$)
Thallium tin germanate	$Tl_2SnGe_3O_9$	Trigonal (P–3c1)
Thallium titanium germanate	$Tl_2TiGe_3O_9$	Hexagonal ($P6_3/m$)
Thorium oxide (thorianite)	ThO_2	Cubic (Fm3m)
Thorium silicate (thorite)	$ThSiO_4$	Tetragonal ($I4_1/amd$)
Tin dioxide (cassiterite)	SnO_2	Tetragonal ($P4_2/mnm$)
Titanium dioxide (rutile)	TiO_2	Tetragonal ($P4_2/mnm$)
Tourmaline (elbaite)	$Na(Li,Al)_3Al_6(BO_3)_3$-$Si_6O_{18}(OH)$	Trigonal (R3m)
Urea	$(NH_2)_2CO$	Tetragonal (I–42m)
Vanadium oxide (shcherbinaite)	V_2O_5	Orthorhombic (Pmmm)
Yttrium aluminate	$Y_4Al_2O_9$	Monoclinic ($P2_1/a$)
Yttrium aluminate (YAP, YALO)	$YAlO_3$	Orthorhombic (Pnma)
Yttrium aluminum borate (YAB)	$YAl_3(BO_3)_4$	Trigonal (R32)
Yttrium aluminum garnet (YAG)	$Y_3Al_5O_{12}$	Cubic (Ia3d)
Yttrium antimonade	Y_3SbO_7	Orthorhombic ($C222_1$)
Yttrium arsenate (chernovite)	$YAsO_4$	Tetragonal ($I4_1/amd$)
Yttrium beryllate	$YBeBO_4$	Monoclinic (C2/c)
Yttrium beryllium aluminate	$Y_2BeAl_2O_7$	Tetragonal ($P42_1m$)
Yttrium borate	YBO_3	Hexagonal ($P6_3/mmc$)
Yttrium calcium aluminate	$YCaAl_3O_7$	Tetragonal ($P42_1m$)
Yttrium calcium gallium beryllium silicate	$YCaGaBe_2Si_2O_{10}$	Monoclinic ($P2_1/c$)
Yttrium calcium oxyborate	$YCa_4O(BO_3)_3$	Monoclinic (Cm)
Yttrium chlorosilicate	$Y_3(SiO_4)_2Cl$	Orthorhombic (Pnma)
Yttrium fluoride	YF_3	Orthorhombic (Pnma)
Yttrium gadolinium antimonade	Y_2GdSbO_7	Orthorhombic ($C222_1$)
Yttrium gadolinium niobate	YGd_2NbO_7	Orthorhombic ($C222_1$)
Yttrium gadolinium tantalate	Y_2GdTaO_7	Orthorhombic ($C222_1$)
Yttrium gallium borate	$YGa_3(BO_3)_4$	Trigonal (R32)
Yttrium gallium garnet (YGG)	$Y_3Ga_5O_{12}$	Cubic (Ia3d)
Yttrium germanate	Y_2GeO_5	Monoclinic ($P2_1/c$)
Yttrium germanium beryllate	$Y_2GeBe_2O_7$	Tetragonal ($P42_1m$)
Yttrium hafnium tantalate	$YHfTaO_6$	Orthorhombic

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Yttrium indate	$YInO_3$	Hexagonal ($P6_3cm$)
Yttrium indium gallium garnet	$Y_3In_2Ga_3O_{12}$	Cubic (Ia3d)
Yttrium iron garnet (YAG)	$Y_3Fe_5O_{12}$	Cubic (Ia3d)
yttrium lithium fluoride (YLF)	$LiYF_4$	Tetragonal ($I4_1/a$)
Yttrium magnesium beryllium silicate (gadolinite)	$Y_2MgBe_2Si_2O_{10}$	Monoclinic ($P2_1/c$)
Yttrium molybdate	$Y_2(MoO_4)_3$	Orthorhombic (Pbcn)
Yttrium niobate (fergusonite)	$YNbO_4$	Monoclinic (C2/c)
Yttrium orthosilicate (YOS, YSO)	Y_2SiO_5	Monoclinic (C2/c)
Yttrium oxide (yttria)	Y_2O_3	Cubic (Ia3)
Yttrium oxychloride	YOCl	Rhombohedral (R–3m)
Yttrium molybdate	$Y_2Mo_2O_7$	Cubic (Fd3m)
Yttrium oxymolybdate	Y_2MoO_6	Monoclinic (I2/c)
Yttrium oxysulfate	Y_2OS_2	Monoclinic ($P2_1/c$)
Yttrium oxytungstate	Y_2WO_6	Monoclinic (P2/c)
Yttrium pentaphosphate	YP_5O_{14}	Orthorhombic (Pcmn)
Yttrium phosphate (xenotime)	YPO_4	Tetragonal ($I4_1/amd$)
Yttrium scandate	$YScO_3$	Orthorhombic (Pbnm)
Yttrium scandium aluminum garnet (YSAG)	$Y_3Sc_2Al_3O_{12}$	Cubic (Ia3d)
Yttrium scandium gallium garnet (YSGG)	$Y_3Sc_2Ga_3O_{12}$	Cubic (Ia3d)
Yttrium silicate (keiviite)	$Y_2Si_2O_7$	Monoclinic (C2/m)
Yttrium silicon beryllate	$Y_2SiBe_2O_7$	Tetragonal ($P42_1m$)
Yttrium tantalate	Y_3TaO_7	Orthorhombic ($C222_1$)
Yttrium tantalate (formanite)	$YTaO_4$	Monoclinic (P2/a)
Yttrium titanate	$Y_2Ti_2O_7$	Cubic (Fd3m)
Yttrium titanium silicate (trimounsite)	$Y_2Ti_2SiO_9$	Monoclinic
Yttrium titanium tantalate	$YTiTaO_6$	Orthorhombic (Pbcn)
Yttrium tungstate	$Y_2(WO_4)_3$	Orthorhombic (Pcna)
Yttrium vanadate (wakefieldite)	YVO_4	Tetragonal ($I4_1/amd$)
Yttrium zinc beryllium silicate	$Y_2ZnBe_2Si_2O_{10}$	Monoclinic ($P2_1/c$)
Zinc aluminate (gahnite)	$ZnAl_2O_4$	Cubic (Fd3m)
Zinc antimonate (ordonezite)	$ZnSb_2O_6$	Tetragonal ($P4_2/mnm$
Zinc arsenate	$ZnAsO_4$	Monoclinic ($P2_1/c$)
Zinc arsenide (reinerite)	$Zn_3(AsO_3)_2$	Orthorhombic (Pbam)
Zinc borate	$Zn_3(BO_3)_2$	Monoclinic (P2/c)
Zinc borate	ZnB_4O_7	Othorhombic (Pbca)
Zinc borate	$Zn_4B_6O_{13}$	Cubic (I–43m)
Zinc carbonate (smithsonite)	$ZnCO_3$	Rhombohedral ($R\bar{3}c$)
Zinc chloride	$ZnCl_2$	Tetragonal ($P4_2/mnm$)
Zinc fluoride	ZnF_2	Tetragonal ($P4_2/mnm$)
Zinc gallate	$ZnGa_2O_4$	Cubic (Fd3m)
Zinc germanate	Zn_2GeO_4	Tetragonal ($I4_122$)
Zinc germanium arsenide	$ZnGeAs_2$	Tetragonal (I–42d)
Zinc germanium phosphide	$ZnGeP_2$	Tetragonal (I–42d)

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Name, Formula, Crystal System, and Space Group for Optical Crystals—*continued*

Name	Formula	Crystal system (Space group)
Zinc oxide (zincite)	ZnO	Hexagonal (6mm)
Zinc pyroarsenade	$Zn_2As_2O_7$	Monoclinic (C2/m)
Zinc selenide (stilleite, Irtran 4)	ZnSe	Cubic (Fm3m)
Zinc silicate (willemite)	Zn_2SiO_4	Trigonal (R–3)
Zinc silicon arsenide	$ZnSiAs_2$	Tetragonal (I–42d)
Zinc silicon phosphide	$ZnSiP_2$	Tetragonal (I–42d)
Zinc sulfide (sphalerite, Irtran 2, zincblende)	β-ZnS	Cubic (Fm3m)
Zinc sulfide (wurtzite)	α-ZnS	Hexagonal (P6mm)
Zinc telluride	ZnTe	Cubic (Fm3m)
Zinc tin antimonide	$ZnSnSb_2$	Tetragonal (I–42d)
Zinc tin arsenide	$ZnSnAs_2$	Tetragonal (I–42d)
Zinc tin phosphide	$ZnSnP_2$	Tetragonal (I–42d)
Zinc tungstate	$ZnWO_4$	Monoclinic (P2/c)
Zinc vanadate	ZnV_2O_6	Monoclinic (C2)
Zirc silicon arsenate	$ZnSiAs_2$	Cubic (F–43m)
Zirconium oxide	ZrO_2	Tetragonal ($P4_2$/nmc)
Zirconium oxide (cubic zirconia, CZ)	ZrO_2:0.12Y_2O_3	Cubic (Fm3m)
Zirconium silicate (zircon)	$ZrSiO_4$	Tetragonal ($I4_1$/amd)

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1.2 Physical Properties*

Physical properties of optical crystals in this section are grouped into three tables: isotropic crystals, uniaxial crystals, and biaxial crystals. Materials are listed alphabetically in order of the chemical formulas. The following properties are included:

Density: Data are for room temperature.

Hardness: This is an empirical and relative measure of a material's resistance to wear. Average Knoop (indentation test) hardness numbers or range of values at room temperature are given when available. In many cases only Vicker (V) or Mohs hardness are known. This is indicated parentheses after the value. The hardness of a crystal varies with orientation even for cubic symmetry crystals.

Cleavage: The ease of cleavage varies greatly depending on the crystal quality and the nature and direction of stress applied. In many crystals there can be more than one set of cleavage planes. Miller indices are used to denote the cleavage planes. The actual number of cleavage planes depends on the plane orientation relative to the symmetry of the crystal. Only the easiest cleavage plane for each crystal is listed. They are ranked qualitatively as perfect (p) or imperfect (i). A crystal listed with a perfect cleavage plane can crack along that direction with a smooth surface if a stress is applied. The imperfect cleavage plane means that the crack does not easily move along the plane, although a small area of oriented flat surfaces may form along the cracking surface when the crystal is fractured.

Solubility: Solubility is defined as the weight loss in grams per 100 grams of water. The dissolution temperature in °C is included in parentheses, if given. If the solubility is less than 10^{-3} g/100 g, the material is generally considered to be insoluble. If a crystal is listed as insoluble, it means that, when submerged in water with a reasonable amount of time (a day or so), no noticeable loss of weight nor visible surface erosion of the crystal is observed.

* This section was adapted from "Optical Crystals" by B. H. T. Chai, *Handbook of Laser Science and Technology, Suppl. 2, Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 30 ff (with additions).

1.2.1 Isotropic Crystals

Physical Properties of Isotropic Crystalline Materials

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
AgBr	6.473	7	None	1.2×10^{-5} (20)
AgCl	5.56	9.5	None	1.5×10^{-4} (20)
AlAs	3.729	–	(111)-p	Insoluble
$Al_{23}O_{27}N_5$ (ALON)	3.713	1850	–	Insoluble
AlP	2.40	–	–	Slightly soluble
AlSb	4.26	–	–	
As_2O_3	3.87	1.5 (Mohs)	(111)	Soluble
$Ba(NO_3)_2$	3.24	–	None	Soluble
$Ba_2Zr_2Si_3O_{12}$	–	–	–	Insoluble
$Ba_3Al_2O_6$	5.008	–	–	–

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Physical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Ba_3MgTa_2O_9$	6.435	–	–	Insoluble
BaF_2	4.83	82(500)	(111)-p	0.12
BaF_2-CaF_2	4.89	–	(111)-p	0.16
$Bi_{12}GeO_{20}$	9.22	4.5(Mohs)	None	Insoluble
$Bi_{12}SiO_{20}$	9.20	–	None	Insoluble
$Bi_{12}TiO_{20}$	9.069	–	None	Insoluble
$Bi_4Ge_3O_{12}$	7.13	5.0 (Mohs)	None	Insoluble
$Bi_4Si_3O_{12}$	6.60	4.5 (Mohs)	(110)-i	Insoluble
BN	3.48	4600	(111)	Insoluble
BP	2.97	3600	–	Insoluble
C (diamond)	3.51	5700–10400	(111)	Insoluble
$Ca_{12}Al_{14}O_{33}$	2.68	–	None	Insoluble
$Ca_2LiMg_2V_3O_{12}$	3.447	–	–	–
$Ca_2LiZn_2V_3O_{12}$	3.726	–	–	–
$Ca_2NaMg_2V_3O_{12}$	3.414	–	–	–
$Ca_2NaZn_2V_3O_{12}$	3.976	–	–	–
$Ca_2Sb_2O_7$	–	–	None	Insoluble
$Ca_3Al_2Ge_3O_{12}$	4.357	–	None	Insoluble
$Ca_3Al_2Si_3O_{12}$	3.60	7 (Mohs)	None	Insoluble
$Ca_3Ga_2Ge_3O_{12}$	4.837	–	None	Insoluble
$Ca_3Gd(PO_4)_3$	3.900	–	–	Insoluble
$Ca_3In_2Ge_3O_{12}$	5.063	–	None	Insoluble
$Ca_3La(PO_4)_3$	3.678	–	–	Insoluble
$Ca_3Lu_2Ge_3O_{12}$	5.668	–	None	Insoluble
$Ca_3Sc_2Ge_3O_{12}$	4.203	–	None	Insoluble
$Ca_3Sc_2Si_3O_{12}$	3.514	–	None	Insoluble
CaF_2	3.180	158	(111)-p	1.6×10^{-3} (18)
$CaLa_2S_4$	4.524	570	–	–
CaO	3.3	3.5	(100)-p	0.13(10)
$CaTiO_3$	3.98	–	–	Insoluble
$CaY_2Mg_3Ge_3O_{12}$	–	–	None	Insoluble
$Cd_2Nb_2O_7$	6.216	–	None	Insoluble
$Cd_2Sb_2O_7$	–	–	None	Insoluble
$Cd_3Sc_2Ge_3O_{12}$	5.749	–	None	Insoluble
CdB_2O_4	4.58	–	–	–
CdF_2	6.64	–	(111)-p	4.4 (20)
$CdGa_2O_4$	–	–	None	Insoluble
$CdIn_2O_4$	7.00	–	None	–
CdO	8.24	3 (Mohs)	(111)	–
CdTe	6.20	56	(110)-p	Very slightly soluble
Cs_2KLaF_6	3.95	–	None	Slightly soluble
Cs_2NaYF_6	4.397	–	None	Slightly soluble
CsBr	4.44	19.5	None	124 (25)

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Physical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$CsCaF_3$	4.123	–	–	Slightly soluble
$CsCdF_3$	5.62	–	–	–
CsCl	3.9	–	None	186 (20)
CsF	4.638	–	(100)-p	367 (18)
CsI	4.510	1–2 (Mohs)	None	44 (0)
$CsSrF_3$	4.299	–	–	–
Cu_2O	6.11	3.5 (Mohs)	(111)-i	Insoluble
CuBr	4.77	21	–	Very slightly soluble
CuCl	4.14	2.5 (Mohs)	(110)-p	6.1×10^{-3}
CuI	5.68	2.5 (Mohs)	(110)-p	–
GaAs	5.316	721	(111)-p	$<5 \times 10^{-3}$ (25)
GaP	4.13	–	(111)-p	Insoluble
GaSb	5.619	–	(111)-p	Insoluble
$Gd_2Ti_2O_7$	6.52	1114	None	Insoluble
$Gd_3Ga_5O_{12}$	7.02	6.5–7(Mohs)	None	Insoluble
$Gd_3Sc_2Al_3O_{12}$	5.82	7.5 (Mohs)	None	Insoluble
$Gd_3Sc_2Ga_3O_{12}$	–	7.0 (Mohs)	None	Insoluble
Ge	5.35	800	(111)	Insoluble
$Hg_2Sb_2O_7$	–	–	None	Insoluble
HgSe	8.266	–	–	Insoluble
HgTe	–	–	–	–
InAs	5.66	330	(111)-p	Insoluble
InP	4.8	430	(111)-p	Insoluble
InSb	5.78	225	(111)-p	Insoluble
$K_2Mg_2(SO_4)_3$	2.83	3.5 (Mohs)	None	Slightly soluble
K_2NaAlF_6	2.99	2.5 (Mohs)	None	Slightly soluble
K_2NaGaF_6	3.34	–	None	Slightly soluble
K_3AlF_6	–	–	None	Soluble
KBr	2.75	7.0(200)	(100)-p	65.2 (20)
$KCaF_3$	2.709	–	–	–
$KCdF_3$	4.264	–	–	–
KCl	1.984	9.3(200)	(100)-p	34.7 (20)
KF	2.48	2 (Mohs)	(100)-p	92.3 (18)
KI	3.12	5	(100)-p	144 (20)
$KMgF_3$	3.15	2.5 (Mohs)	None	Insoluble
$KTaO_3$	7.015	–	–	Insoluble
KY_3F_{10}	4.312	4.5 (Mohs)	None	Insoluble
$La_3Lu_2Ga_3O_{12}$	–	7.0 (Mohs)	None	Insoluble
Li_2BeF_4	2.289	–	–	–
Li_2CdCl_4	2.956	–	–	–
Li_2MgCl_4	2.119	–	–	–
$LiAl_5O_8$	3.625	–	None	Insoluble
$LiBaF_3$	5.242	–	–	–

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Physical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
LiBr	3.464	–	(100)-p	145 (4)
LiCl	2.068	–	(100)-p	63.7 (0)
LiF	2.635	110 (600)	(100)-p	0.27 (18)
$LiGa_5O_8$	5.819	–	None	Insoluble
LiI	4.076	–	(100)-p	168 (20)
Lu_2O_3	9.426	–	–	–
$Lu_2Ti_2O_7$	7.31	1264	None	Insoluble
$Lu_3Al_5O_{12}$	6.695	7.5 (Mohs)	None	Insoluble
$Lu_3Ga_5O_{12}$	7.828	7.0 (Mohs)	None	Insoluble
$Lu_3Sc_2Ga_3O_{12}$	–	7.0 (Mohs)	None	Insoluble
$LuScO_3$	–	–	–	Insoluble
Mg_2TiO_4	3.546	–	–	Insoluble
$Mg_3Al_2Si_3O_{12}$	3.58	7.5 (Mohs)	None	Insoluble
$MgAl_2O_4$	3.58	1140 (1000)	None	Insoluble
$MgGa_2O_4$	5.37	7.0 (Mohs)	None	Insoluble
MgO	3.58	690 (600)	(100)-p	6.2×10^{-4}
MnO	5.44	5.5 (Mohs)	(100)-p	Insoluble
$Na_2BiMg_2V_3O_{12}$	4.388	–	–	–
$Na_2BiZn_2V_3O_{12}$	4.919	–	–	–
Na_2CaSiO_4	2.821	–	–	Insoluble
$Na_2GdMg_2V_3O_{12}$	4.115	–	–	–
$Na_2LuMg_2V_3O_{12}$	4.332	–	–	–
$Na_2YMg_2V_3O_{12}$	3.668	–	–	–
$Na_3Li_3Al_2F_{12}$	2.77	2 (Mohs)	(011)-i	–
$Na_3Li_3Ga_2F_{12}$	3.20	2 (Mohs)	None	–
$Na_3Li_3In_2F_{12}$	3.54	2 (Mohs)	None	–
$Na_3Li_3Sc_2F_{12}$	2.66	2 (Mohs)	None	–
$Na_3Sc_2V_3O_{12}$	3.342	–	–	–
$Na_8Al_6Si_6O_{24}Cl_2$	2.27	5.5 (Mohs)	(110)-i	Insoluble
NaBr	3.203	–	(100)-p	91 (20)
$NaCdMg_2F_7$	3.968	–	–	–
$NaCdZn_2F_7$	4.838	–	–	–
NaCl	2.165	18 (200)	(100)-p	39.8 (0)
NaF	2.588	60	(100)-p	4.2 (18)
$5NaF\text{-}9YF_3$	4.22	2 (Mohs)	None	Insoluble
NaI	3.667	–	(100)-p	179 (20)
$Pb(NO_3)_2$	4.530	–	–	–
$Pb_2Sb_2O_7$	–	–	None	Insoluble
PbF_2	8.24	200	(111)-p	0.064 (20)
PbS	7.5	2.5–2.75 (Mohs)	(100)-p	6.6×10^{-5}
PbSe	8.10	–	(100)-p	Insoluble
PbTe	8.164	–	(100)-p	Insoluble
Rb_2KGaF_6	3.751	–	None	–

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Physical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
Rb_2NaInF_6	4.302	–	None	–
RbBr	3.35	–	(100)-p	98 (5)
$RbCaF_3$	3.632	–	–	–
RbCl	2.80	–	(100)-p	77 (0)
RbF	–	–	(100)-p	367 (18)
RbI	3.55	1.0 (Mohs)	(100)-p	152 (17)
$RbZnF_3$	5.007	–	–	–
Sb_2O_3	5.50	2–2.5 (Mohs)	(111)-i	Insoluble
Sc_2O_3	3.840	–	–	Insoluble
Si	2.33	1150	(111)	Insoluble
β-SiC	3.214	2880	–	Insoluble
β-SiC (CVD)	3.21	2540	–	Insoluble
$Sr_3Al_2O_6$	4.136	–	–	–
$Sr_3Gd(PO_4)_3$	–	–	–	Insoluble
$Sr_3In_2Ge_3O_{12}$	5.632	–	None	Insoluble
$Sr_3La(PO_4)_3$	–	–	–	Insoluble
$Sr_3Sc_2Ge_3O_{12}$	4.838	–	None	Insoluble
$Sr_6Nb_2O_{11}$	5.0	–	–	Insoluble
$Sr_6Ta_2O_{11}$	6.088	–	–	Insoluble
SrF_2	4.24	130	(111)-p	0.012 (20)
$SrSnO_3$	6.432	–	–	Insoluble
$SrTiO_3$	5.122	595	None	Insoluble
$SrVO_3$	5.46	–	–	–
ThO_2	9.86	600	None	Insoluble
Tl(Br,I)	7.371	40 (500)	None	–
Tl(Cl,Br)	7.192	39 (500)	None	<0.32 (20)
Tl_2O_3	10.35	–	–	Insoluble
TlBr	7.557	12 (500)	None	0.05 (25)
TlCl	7.604	13 (500)	None	0.32 (20)
Y_2O_3	5.01	875	–	1.8×10^{-5} (20)
$Y_2Ti_2O_7$	4.987	1099	None	Insoluble
$Y_3Al_5O_{12}$	4.56	135 (200)	None	Insoluble
$Y_3Ga_5O_{12}$	5.79	7.0 (Moh)	None	Insoluble
$Y_3In_2Ga_3O_{12}$	6.03	–	None	Insoluble
$Y_3Sc_2Al_3O_{12}$	4.55	–	None	Insoluble
$Y_3Sc_2Ga_3O_{12}$	5.184	7.0 (Moh)	None	Insoluble
$Zn_4B_6O_{13}$	4.19	–	–	–
$ZnAl_2O_4$	4.62	7.5 (Moh)	None	Insoluble
$ZnGa_2O_4$	6.089	7.0 (Moh)	None	Insoluble
β-ZnS	4.09	178	(110)-p	6.9×10^{-4} (18)
β-ZnS (CVD)	4.04	178	–	–
ZnSe	5.42	137	(110)-p	0.001(25)
$ZnSiAs_2$	4.747	–	–	Insoluble

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Physical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
ZnTe	6.34	82	(110)-p	Insoluble
ZrO_2	5.64	990	None	Insoluble

1.2.2 Uniaxial Crystals

Physical Properties of Uniaxial Crystalline Materials

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
Ag_2HgI_4	6.091	–	–	–
Ag_3AsS_3	5.49	2–2.5 (Mohs)	(10$\underline{1}$1)	Insoluble
Ag_3AsSe_3	6.521	–	–	Insoluble
Ag_3SbS_3	5.82	2.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
$AgAsS_2$	–	–	–	Insoluble
$AgGaS_2$	4.702	–	(112)-p	Insoluble
$AgGaSe_2$	5.70	–	(112)-p	Insoluble
AgI	5.7	1.5 (Mohs)	(0001)-p	Insoluble
Al_2O_3	3.98	1370 (1000)	None	9.8×10^{-5}
$AlAsO_4$	3.359	–	–	Insoluble
AlF_3	3.192	–	–	–
$AlGaO_3$	4.78	–	(0001)-p	Insoluble
AlN	3.261	–	–	Insoluble
$AlPO_4$	2.566	5 (Mohs)	None	Insoluble
$AlTiTaO_6$	6.26	–	–	Insoluble
$Ba_2B_5O_9Cl$	3.762	–	–	Insoluble
Ba_2MgAlF_9	4.157	–	–	–
Ba_2MgF_6	5.08	–	–	Insoluble
$Ba_2MgGe_2O_7$	4.79	–	(001)	Insoluble
$Ba_2MgSi_2O_7$	4.265	–	(001)	Insoluble
$Ba_2Sc_4O_9$	5.372	–	–	Insoluble
$Ba_2TiSi_2O_8$	4.43	3.80	(001)-i	Insoluble
Ba_2ZnF_6	5.514	–	–	Insoluble
$Ba_2ZnGe2O_7$	–	–	(001)	Insoluble
$Ba_2ZnSi_2O_7$	–	–	(001)	Insoluble
$Ba_2ZrSi_2O_8$	–	–	–	Insoluble
$Ba_3(VO_4)_2$	5.176	–	–	–
$Ba_3Sc_4O_9$	5.318	–	–	Insoluble
$Ba_3SrNb_2O_9$	–	–	–	Insoluble
$Ba_3SrTa_2O_9$	–	–	–	Insoluble
$Ba_5(AsO_4)_3F$	5.073	–	(10$\underline{1}$1)-i	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Ba_5(AsO_4)_3Cl$	5.086	4.5 (Mohs)	(0001)-i	Insoluble
$Ba_5(PO_4)_3Cl$	4.802	–	–	Insoluble
$Ba_5(PO_4)_3F$	4.81	–	$(10\underline{1}1)$-i	Insoluble
$Ba_5(VO_4)_3Cl$	4.728	–	$(10\underline{1}1)$-i	Insoluble
$Ba_5(VO_4)_3F$	4.766	–	$(10\underline{1}1)$-i	Insoluble
$Ba_6Sc_6O_{15}$	5.115	–	–	Insoluble
$BaAl_{12}O_{19}$	4.075	–	–	Insoluble
$BaAl_2O_4$	4.080	–	–	Insoluble
β-BaB_2O_4	3.85	4 (Mohs)	(0001)-i	Slightly soluble
$BaBe(PO_4)F$	4.31	–	None	Insoluble
$BaGe_4O_9$	–	–	None	Insoluble
$BaMg_2(VO_4)_2$	4.226	–	–	–
$BaMoO_4$	4.946	–	–	–
$BaSb_2O_6$	–	–	–	–
$BaSnB_2O_6$	4.848	–	–	Insoluble
$BaSnSi_3O_9$	4.03	6 (Mohs)	None	Insoluble
$BaTiB_2O_6$	4.211	–	–	Insoluble
$BaTiO_3$	6.02	5 (Mohs)	–	Insoluble
$BaTiSi_3O_9$	3.64	6 (Mohs)	None	Insoluble
$BaWO_4$	6.383	–	–	Insoluble
$BaZnGeO_4$	5.12	–	–	Insoluble
$BaZnSiO_4$	4.706	–	–	Insoluble
$BaZrSi_3O_9$	3.85	–	None	Insoluble
Be_2GeO_4	3.893	–	None	Insoluble
Be_2SiO_4	2.96	1100	$(10\underline{1}0)$	Insoluble
$Be_3Al_2Si_6O_{18}$	2.66	7.5–8 (Mohs)	None	Insoluble
$Be_3Sc_2Si_6O_{18}$	2.77	6.5 (Mohs)	None	Insoluble
$BeMg_3Al_8O_{16}$	3.60	8.5 (Mohs)	–	Insoluble
BeO(dreyerite)	3.01	1250	$(10\underline{1}0)$-i	2×10^{-5} (20)
$Bi_2Ge_3O_9$	6.20	5.5 GPa	(0001)-p	Insoluble
$BiVO_4$ (dreyerite)	6.25	–	(110)-p	Insoluble
$Ca_2Al_2GeO_7$	3.421	–	(001)	Insoluble
$Ca_2Al_2SiO_7$	3.04	5.5 (Mohs)	(001)	Insoluble
$Ca_2Al_3O_6F$	2.95	–	$(10\underline{1}1)$-i	Insoluble
$Ca_2B_5O_9Cl$	2.639	–	–	Insoluble
$Ca_2BeSi_2O_7$	–	–	–	Insoluble
$Ca_2Ga_2GeO_7$	4.14	–	(001)	Insoluble
$Ca_2Ga_2SiO_7$	4.07	–	(001)	Insoluble
$Ca_2MgSi_2O_7$	2.94	5.5 (Mohs)	(001)-i	Insoluble
$Ca_2Te_2O_5$	5.05	4 (Mohs)	(001)-p	Insoluble
$Ca_2ZnSi_2O_7$	3.39	3.5 (Mohs)	(001)	Insoluble
$Ca_3B_2O_6$	3.09	–	–	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Ca_3Ga_2Ge_4O_{14}$	4.590	–	None	Insoluble
$Ca_4La(PO_4)_3O$	–	–	–	Insoluble
$Ca_4Y_6(SiO_4)_6O$	–	–	None	Insoluble
$Ca_5(AsO_4)_3Cl$	3.635	–	–	Insoluble
$Ca_5(AsO_4)_3F$	3.5	4.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
$Ca_5(PO_4)_3Cl$	2.90	5 (Mohs)	(0001)-i	Insoluble
$Ca_5(PO_4)_3F$	3.20	540	(0001)-i	Insoluble
$Ca_5(VO_4)_3F$	–	–	(10$\underline{1}$1)-i	Insoluble
$Ca_5(VO_4)_3Cl$	3.174	–	(10$\underline{1}$1)-i	Insoluble
$CaAl_{12}O_{19}$	3.78	–	–	Insoluble
$CaAl_2B_2O_7$	2.44	–	–	–
$CaCO_3$–calcite	2.715	75–135	(10$\underline{1}$1)-p	1.4×10^{-3} (25)
$CaCO_3$–vaterite	2.68	3 (Mohs)	–	Insoluble
$CaGd_4(SiO_4)_3O$	6.030	–	None	Insoluble
$CaGdAlO_4$	5.97	716	(001)	Insoluble
$CaGe_4O_9$	–	–	None	Insoluble
$CaLa_4(SiO_4)_3O$	5.112	–	None	Insoluble
$CaLaAlO_4$	–	–	(001)	Insoluble
$CaLaBO_4$	4.136	–	–	Insoluble
$CaMg(CO_3)_2$	2.86	3.5 (Mohs)	(10$\underline{1}$1)-p	Insoluble
$CaMg_3(CO_3)_4$	3.71	335	(10$\underline{1}$1)-p	Insoluble
$CaMoO_4$	4.25	4.0 (Mohs)	(112)(110)	–
$CaSnB_2O_6$	4.22	5.5 (Mohs)	(0001)-p	Insoluble
$CaWO_4$	6.062	4.5–5 (Mohs)	(101)-i	6.4×10^{-4} (15)
$CaY_4(SiO_4)_3O$	4.47	702	None	Insoluble
$CaYAlO_4$	–	–	–	Insoluble
$CaZrBAl_9O_{18}$	4.01	8 (Mohs)	None	Insoluble
$Cd_5(AsO_4)_3Cl$	5.917	–	(10$\underline{1}$1)-i	Insoluble
$Cd_5(PO_4)_3Cl$	5.600	–	(10$\underline{1}$1)-i	Insoluble
$Cd_5(PO_4)_3F$	5.784	–	(10$\underline{1}$1)-i	Insoluble
$Cd_5(VO_4)_3Cl$	5.375	–	(10$\underline{1}$1)-i	Insoluble
$CdCl_2$	4.047	–	–	140 (25)
$CdCO_3$	5.02	–	(10$\underline{1}$1)-p	Insoluble
CdI_2	5.670	–	–	86 (25)
CdS	4.82	122 (25)	(11$\underline{2}$2)-i	1.3×10^{-4} (18)
CdSe	5.81	44–90	–	Insoluble
$CdSnB_2O_6$	5.479	–	–	Insoluble
$CdTiO_3$	5.881	–	–	Insoluble
Cs_2AgF_4	5.02	–	–	–
Cs_2CdCl_4	3.697	–	–	–
Cs_2CdZnF_6	5.342	–	–	–
$Cs_2KAl_3F_{12}$	3.76	–	–	–
$Cs_2LiAl_3F_{12}$	3.949	–	–	–

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
Cs_2LiAlF_6	4.38	–	–	–
$Cs_2LiGa_3F_{12}$	4.43	–	–	–
Cs_2LiGaF_6	4.406	–	–	–
$Cs_2NaAl_3F_{12}$	3.817	–	–	–
Cs_2NaAlF_6	4.346	–	–	–
Cs_2NaGaF_6	4.654	–	–	–
$Cs_2SnGe_3O_9$	5.145	–	–	Insoluble
$Cs_2TiGe_3O_9$	4.835	–	–	Insoluble
$CsAl(SO_4)_2$	3.382	–	–	–
CsH_2AsO_4	3.747	1.5 (Mohs)	(101)-p	Very soluble
CsH_2PO_4	3.253	1.5 (Mohs)	(101)-p	Very soluble
$CsSc(MoO_4)_2$	3.54	–	$(10\underline{1}1)$-p	–
$CsSc(WO_4)_2$	4.74	–	$(10\underline{1}1)$-p	–
α-GaN	6.109	750	—	Insoluble
$GaPO_4$	2.995	4 (Mohs)	None	Insoluble
GaS	3.86	–	–	–
GaSe	5.03	–	–	–
$GdAl_3(BO_3)_4$	4.335	7 (Mohs)	$(10\underline{1}1)$	Insoluble
$GdBO_3$	6.357	–	–	Insoluble
$GdGa_3(BO_3)_4$	5.257	–	$(10\underline{1}1)$	Insoluble
$GdInO_3$	7.41	–	–	–
$GdVO_4$	5.474	–	(110)-p	Insoluble
GeO_2	6.239	–	None	Insoluble
$HfSiO_4$	6.97	–	(110)-i	Insoluble
Hg_2Br_2	7.68	1.5 (Mohs)	(110)	Insoluble
Hg_2Cl_2	7.15	1.5 (Mohs)	(110)-i	3×10^{-4}
Hg_2I_2	7.68	–	–	Insoluble
HgI_2	6.28	–	–	0.0055 (35)
HgS	8.10	2–2.5 (Mohs)	(1010)-p	1×10^{-6} (18)
In_2O_3	7.31	–	–	–
$InBO_3$	5.555	–	$(10\underline{1}1)$-p	Insoluble
$K_2BiNb_5O_{15}$	5.29	–	–	–
$K_2CaZr(SiO_3)_4$	3.10	5.5 (Mohs)	None	Insoluble
$K_2GdNb_5O_{15}$	5.147	–	–	Insoluble
$K_2LaNb_5O_{15}$	4.921	–	–	Insoluble
K_2MgCl_4	2.13	–	–	–
K_2MgF_4	2.839	–	(001)-p	–
$K_2NaLi_2Nb_5O_{15}$	–	–	(001)-p	Insoluble
$K_2SnGe_3O_9$	4.324	–	–	Insoluble
$K_2SnSi_3O_9$	3.46	–	–	Insoluble
$K_2Sr(SO_4)_2$	3.20	2 (Mohs)	(0001)-p	Slightly soluble
$K_2TiGe_3O_9$	3.945	–	–	Insoluble
$K_2TiSi_3O_9$	3.239	–	–	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$K_2YNb_5O_{15}$	4.807	–	–	Insoluble
K_2ZnF_4	3.378	–	(001)-p	–
$K_3LiNb_5O_{15}$	4.376	–	(001)-p	Insoluble
$K_3Sc(VO_4)_2$	3.02	–	–	Slightly soluble
$KAl(MoO_4)_2$	3.42	–	(10$\underline{1}$1)-p	–
$KAl(SO_4)_2$	2.481	–	–	–
$KAlF_4$	3.009	–	–	–
$KAlGeO_4$	3.617	–	–	Insoluble
KAlSi2O$_6$	2.47	5.5 (Mohs)	None	Insoluble
$KAlSiO_4$	2.59	6 (Mohs)	None	Insoluble
KD_2PO_4	–	1.5 (Mohs)	(101)-p	Very soluble
$KGaGeO_4$	4.261	–	–	Insoluble
$KGaSiO_4$	3.691	–	–	Insoluble
KH_2PO_4	2.338	1.5 (Mohs)	(101)-p	33 (25)
$KIn(WO_4)_2$	5.13	–	(10$\underline{1}$1)-p	–
$KLa(MoO_4)_2$	4.61	–	–	–
$KLiBeF_4$	2.284	–	–	–
$KSc(MoO_4)_2$	3.23	–	(10$\underline{1}$1)-p	–
$KSc(WO_4)_2$	4.64	–	(10$\underline{1}$1)-p	–
KYF_4	3.49	3 (Mohs)	None	Insoluble
$KZnF_3$	4.018	2.5 (Mohs)	None	Insoluble
$La_2GeBe_2O_7$	5.424	–	(001)	Insoluble
La_2MoO_6	5.834	–	(100)-p	–
La_2O_2S	5.75	350–450	–	–
La_2O_3	6.574	–	–	–
La_2WO_6	7.44	–	–	–
$La_3Ga_5GeO_{14}$	–	–	None	Insoluble
$La_3Ga_5SiO_{14}$	5.754	–	None	Insoluble
$La_3Nb_{0.5}Ga_{5.5}O_{14}$	5.934	–	None	Insoluble
$La_3Ta_{0.5}Ga_{5.5}O_{14}$	6.164	–	None	Insoluble
$LaAlO_3$	–	–	–	Insoluble
$LaBaGa_3O_7$	5.60	–	(001)	Insoluble
$LaBGeO_5$	5.04	–	–	Insoluble
$LaBSiO_5$	4.58	–	–	Insoluble
$LaCaAl_3O_7$	–	–	(001)	Insoluble
$LaCaGa_3O_7$	–	–	(001)	Insoluble
$LaCl_3$	3.85	–	–	–
LaF_3	5.94	450	(0001)	Insoluble
$LaMgAl_{11}O_{19}$	4.285	–	–	Insoluble
$LaSrGa_3O_7$	5.64	–	(001)-i	Insoluble
$Li_2B_4O_7$	2.44	–	None	Slightly soluble
Li_2CaGeO_4	3.63	–	–	Insoluble
Li_2CaSiO_4	2.935	–	–	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
Li_3InO_3	4.394	–	–	–
$LiAlGeO_4$	3.338	–	None	Insoluble
γ-$LiAlO_2$	2.615	–	–	Insoluble
$LiAlSiO_4$	2.66	6.5 (Mohs)	(10$\underline{1}$1)	Insoluble
$LiCaAlF_6$	2.983	3.5 (Mohs)	None	0.005
$LiCaGaF_6$	3.517	–	None	Very slightly soluble
$LiCaInF_6$	–	–	None	Very slightly soluble
$LiCdBO_3$	4.53	–	–	–
$LiCdInF_6$	–	–	None	Very slightly soluble
$LiGaGeO_4$	4.077	–	None	Insoluble
$LiGaSiO_4$	3.445	–	–	Insoluble
$LiGd(MoO_4)_2$	5.273	–	–	–
$LiGd(WO_4)_2$	7.19	–	–	–
$LiGdF_4$	5.343	3.5 (Mohs)	None	Insoluble
$LiIO_3$	4.487	3.5 (Mohs)	–	80 (18)
$LiLa(WO_4)_2$	6.57	–	–	–
$LiLuF_4$	6.186	3.5 (Mohs)	None	Insoluble
$LiMgAlF_6$	3.14	–	–	Insoluble
$LiMgGaF_6$	3.772	–	–	Insoluble
$LiMgInF_6$	4.267	–	–	–
$LiNbO_3$	4.644	5 (Mohs)	(10$\underline{1}$1)-p	Insoluble
$LiSrAlF_6$	3.45	3.0 (Mohs)	None	0.05
$LiSrGaF_6$	3.600	2.5 (Mohs)	None	0.10
$LiTaO_3$	7.43	6 (Mohs)	(10$\underline{1}$1)	Insoluble
$LiYF_4$	3.99	260–325	None	Insoluble
$LiZnInF_6$	–	–	None	Very slightly soluble
$LiZnNbO_4$	4.504	–	–	–
$LuAl_3(BO_3)_4$	4.569	7 (Mohs)	(10$\underline{1}$1)	Insoluble
$LuBO_3$	6.871	–	–	Insoluble
$LuPO_4$	–	–	–	Insoluble
$LuVO_4$	6.263	–	(110)-p	Insoluble
$Mg_2Al_3(Si_5Al)O_{18}$	2.53	7 (Mohs)	(10$\underline{1}$0)-i	Insoluble
$MgCO_3$	3.00	4 (Mohs)	(10$\underline{1}$1)-p	Insoluble
MgF_2	3.18	415	(010),(110)	$< 2 \times 10^{-4}$
$MgTiO_3$	4.03	5.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
MnF_2	4.478	–	–	0.66 (40)
$Na_2Al_2B_2O_7$	2.62	–	–	–
$Na_2Ca_2Si_3O_9$	2.840	–	–	Insoluble
Na_2CO_3	2.27	–	–	Very soluble
$Na_2Mg(CO_3)_2$	2.74	3.5 (Mohs)	(0001)-i	–
$Na_2TiOSiO_4$	–	3.5 (Mohs)	(001)-p	Insoluble
$Na_3Li_2Nb_5O_{15}$	–	–	(001)-p	Insoluble
$Na_3YSi_2O_7$	3.063	–	–	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Na_5Al_3F1_4$	3.00	3.5 (Mohs)	(001)-p	–
$Na_5GdGe_4O_{12}$	3.861	–	–	Insoluble
$Na_5GdSi_4O_{12}$	3.213	–	–	Insoluble
$Na_5InGe_4O_{12}$	3.831	–	–	Insoluble
$Na_5InSi_4O_{12}$	3.134	–	–	Insoluble
$Na_5LuGe_4O_{12}$	4.051	–	–	Insoluble
$Na_5LuSi_4O_{12}$	3.348	–	–	Insoluble
$Na_5ScGe_4O_{12}$	3.476	–	–	Insoluble
$Na_5ScSi_4O_{12}$	2.743	–	–	Insoluble
$Na_5Y_4(SiO_4)_4F$	3.938	–	–	–
$Na_5YGe_4O_{12}$	3.548	–	–	Insoluble
$Na_5YSi_4O_{12}$	2.863	–	–	Insoluble
$NaAlSiO_4$	2.63	–	–	Insoluble
$NaBaPO_4$	4.270	1.5 (Mohs)	–	–
$NaGd(WO_4)_2$	7.184	–	–	–
$NaGdO_2$	6.162	–	–	Slightly soluble
$NaInO_2$	5.711	–	–	Slightly soluble
$NaLa(MoO_4)_2$	4.773	–	–	–
$NaLaO_2$	4.949	–	–	Soluble
$NaNO_3$	2.261	19.2(200)	(1010)-p	92 (25)
$NaSbBe_4O_7$	4.28	8 (Mohs)	(0001)-i	Insoluble
$NaScO_2$	3.515	–	–	Slightly soluble
$NaYF_4$	3.85	–	–	Insoluble
$NbCaAlO_4$	5.56	–	–	Insoluble
$Nd_xY_{1-x}Al_3\ (BO_3)_4$	–	8 (Mohs)		–
$NH_4Al(SeO_4)_2$	3.13	–	–	–
$NH_4Al(SO_4)_2$	2.472	–	–	–
$NH_4Ga(SeO_4)_2$	3.476	–	–	–
$NH_4Ga(SO_4)_2$	2.854	–	–	–
$NH_4H_2PO_4$	1.803	1 (Mohs)	(101)-p	36.8 (20)
Pb_2InNbO_6	8.567	.	.	Insoluble
$Pb_2ZnSi_2O_7$	–	–	(001)	Insoluble
$Pb_3Ca_2(AsO_4)_3Cl$	5.82	4.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
$Pb_3Ge_2O_7$	–	–	–	Insoluble
$Pb_5(AsO_4)\ _3F$	–	–	(10$\underline{1}$1)-i	Insoluble
$Pb_5(AsO_4)_3Cl$	7.28	3.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
$Pb_5(PO_4)_3Cl$	7.04	3.5 (Mohs)	(10$\underline{1}$1)-i	Insoluble
$Pb_5(PO_4)_3F$	6.868		(10$\underline{1}$1)-i	Insoluble
$Pb_5(VO_4)_3Cl$	6.88	3 (Mohs)	None	Insoluble
$Pb_5(VO_4)_3F$	7.155	–	(10$\underline{1}$1)-i	Insoluble
$PbAl_{12}O_{19}$	4.731	–	–	Insoluble
PbI_2	6.16	–	–	0.076 (25)
$PbMoO_4$	6.92	2.5–3 (Mohs)	(011)	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
PbO (litharge)	9.36	–	(110)-p	1.7×10^{-3} (20)
$PbTiO_3$	–	–	–	Insoluble
$PbWO_4$	8.23	2.5–3 (Mohs)	(001)-i	Insoluble
$Rb_2LaNb_5O_{15}$	5.35	–	–	Insoluble
Rb_2LiAlF_6	3.878	–	–	–
Rb_2LiGaF_6	4.258	–	–	–
Rb_2MgCl_4	2.791	–	–	–
Rb_2MgF_4	3.972	–	(001)-p	–
$Rb_2SnGe_3O_9$	4.850	–	–	Insoluble
$Rb_2SnSi_3O_9$	4.103	–	–	Insoluble
$Rb_2TiGe_3O_9$	4.425	–	–	Insoluble
$Rb_2TiSi_3O_9$	3.626	–	–	Insoluble
Rb_2ZnF_4	4.637	–	(001)-p	–
$Rb_3Gd(VO_4)_2$	4.50	–	–	Slightly soluble
$Rb_3Lu(VO_4)_2$	4.56	–	–	Slightly soluble
Rb_3NaBeF_8	3.376	–	–	–
$Rb_3Sc(VO_4)_2$	3.83	–	–	Slightly soluble
$Rb_3Y(VO_4)_2$	3.76	–	–	Slightly soluble
$RbAl(SeO_4)_2$	3.725	–	–	–
$RbAl(SO_4)_2$	3.126	–	–	–
$RbAlF_4$	3.792	–	–	–
$RbAlSi_2O_6$	2.893	–	–	Insoluble
$RbCdF_3$	4.836	–	–	–
$RbGa(SeO_4)_2$	4.088	–	–	–
$RbGa(SO_4)_2$	3.504	–	–	–
RbH_2AsO_4	–	1.5 (Mohs)	(101)-p	Very soluble
RbH_2PO_4	–	1.5 (Mohs)	(101)-p	Very soluble
$RbIn(MoO_4)_2$	3.88	–	$(10\underline{1}1)$-p	–
$RbIn(WO_4)_2$	5.19	–	$(10\underline{1}1)$-p	–
$RbSc(MoO_4)_2$	3.41	–	$(10\underline{1}1)$-p	–
$RbSc(WO_4)_2$	4.68	–	$(10\underline{1}1)$-p	–
$ScBO_3$	3.45	5 (Moh)	$(10\underline{1}1)$-p	Insoluble
$ScPO_4$	–	–	–	Insoluble
$ScVO_4$	–	–	–	–
Se	4.81	2.6 (Moh)	$(01\underline{1}2)$-i	Insoluble
SeO_2	4.16	–	–	–
α-SiC	3.219	3720	None	Insoluble
Si_3N_4	3.24	3400	None	Insoluble
SiO_2	2.65	741(500)	None	Insoluble
SnO_2	6.95	6.5 (Mohs)	(100)-i	Insoluble
$Sr_2Al_2SiO_7$	–	–	(001)	Insoluble
$Sr_2B_5O_9Cl$	3.250	–	–	Insoluble
$Sr_2Ga_2SiO_7$	–	–	(001)	Insoluble

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Sr_2MgGe_2O_7$	4.266	–	(001)	Insoluble
$Sr_2MgSi_2O_7$	–	–	(001)	Insoluble
$Sr_2ZnGe_2O_7$	–	–	(001)	Insoluble
$Sr_2ZnSi_2O_7$	4.027	–	(001)	Insoluble
$Sr_3(VO_4)_2$	4.464	–	–	–
$Sr_3B_2O_6$	4.257	–	–	Insoluble
$Sr_3Ga_2Ge_4O_{14}$	5.087	–	None	Insoluble
$Sr_3Ti_2O_7$	5.04	–	–	Insoluble
$Sr_5(AsO_4)_3F$	4.538	–	(10$\underline{1}$1)-i	Insoluble
$Sr_5(AsO_4)_3Cl$	4.525	–	–	Insoluble
$Sr_5(PO_4)_3Cl$	4.095	–	–	Insoluble
$Sr_5(PO_4)_3F$	4.14	380	(0001)-i	Insoluble
$Sr_5(VO_4)_3F$	4.13	–	(10$\underline{1}$1)-i	Insoluble
$Sr_5(VO_4)_3Cl$	4.122	–	(10$\underline{1}$1)-i	Insoluble
$Sr_5Nb_4O_{15}$	5.46	–	–	–
$Sr_5Ta_4O_{15}$	7.321	–	–	Insoluble
$SrAl_{12}O_{19}$	3.985	–	–	Insoluble
$SrAlF_5$	3.86	–	–	Insoluble
$(Sr_{0.6}Ba_{0.4})Nb_2O_6$	5.4	5.5 (Mohs)	–	Insoluble
$SrGaF_5$	4.40	–	–	Insoluble
$SrGdAlO_4$	6.602	–	(001)-p	Insoluble
$SrGdGa_3O_7$	5.64	–	–	Insoluble
$SrLa_4(SiO_4)_3O$	–	–	None	Insoluble
$SrLaAlO_4$	5.826	–	(001)-p	Insoluble
$SrLaBO_4$	4.802	–	–	Insoluble
$SrLaGaO_4$	5.372	–	(001)-p	Insoluble
$SrMg_2(VO_4)_2$	3.827	–	–	–
$SrMoO_4$	4.701	–	–	–
$SrSnB_2O_6$	–	–	–	Insoluble
$SrTiB_2O_6$	–	–	–	Insoluble
$SrWO_4$	6.354	–	–	Insoluble
$SrY_4(SiO_4)_3O$	–	–	None	Insoluble
$SrZrB_2O_6$	–	–	–	Insoluble
Ta_2O_5	8.2	–	–	Insoluble
$TaBO_4$	8.02	7.5 (Mohs)	(110)(010)	Insoluble
Te	6.25	18	None	Insoluble
$ThSiO_4$	6.7	4.5 (Mohs)	None	Insoluble
TiO_2	4.26	879 (500)	(110)-i	0.001
$Tl_2SnGe_3O_9$	6.617	–	–	Insoluble
$Tl_2TiGe_3O_9$	6.256	–	–	Insoluble
Tl_3AsS_3	7.18	–	–	Insoluble
Tl_3AsSe_3	7.834	–	–	Insoluble
$TlAl(SeO_4)_2$	4.894	–	–	–

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Physical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$TlAl(SO_4)_2$	4.337	–	–	–
$TlAlF_4$	6.131	–	–	–
$TlGa(SeO_4)_2$	5.163	–	–	–
$TlGa(SO_4)_2$	4.719	–	–	–
$Y_2BeAl_2O_7$	–	–	(001)	Insoluble
$Y_2GeBe_2O_7$	4.810	–	(001)	Insoluble
$Y_2SiBe_2O_7$	4.423	–	(001)	Insoluble
$YAl_3(BO_3)_4$	3.724	1890	$(10\underline{1}1)$	Insoluble
$YAsO_4$	4.85	4.5 (Mohs)	–	Insoluble
YBO_3	–	–	–	Insoluble
$YCaAl_3O_7$	–	–	(001)	Insoluble
$YGa_3(BO_3)_4$	4.684	–	$(10\underline{1}1)$	Insoluble
$YInO_3$	6.032	–	–	–
YPO_4	4.31	4.5 (Mohs)	(110)-p	Insoluble
YVO_4	4.23	480	(110)-p	Insoluble
Zn_2GeO_4	4.781	–	–	Insoluble
Zn_2SiO_4	4.25	5.5 (Mohs)	(0001)-i	Insoluble
$ZnCO_3$	4.43	4 (Mohs)	$(10\underline{1}1)$-p	Insoluble
$ZnCl_2$	2.907	–	–	408 (25)
ZnF_2	4.95	–	–	1.62 (20)
$ZnGeP_2$	–	–	–	Insoluble
ZnO	5.606	4 (Mohs)	$(10\underline{1}0)$-p	1.6×10^{-4} (20)
$ZnSb_2O_6$	6.64	6.5 (Mohs)	–	–
$ZnSiP_2$	–	–	–	Insoluble
ZnS (wurtzite)	3.98	3.5 (Mohs)	$(11\underline{2}0)$-i	Insoluble
ZrO_2	5.861	–	–	Insoluble
$ZrSiO_4$	4.56	1000	(110)-i	Insoluble

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1.2.3 Biaxial Crystals

Physical Properties of Biaxial Crystalline Materials

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Al_2(MoO_4)_3$	3.495	–	–	Insoluble
$Al_2(WO_4)_3$	5.079	–	(010)-p	Insoluble
$Al_2Ge_2O_7$	4.06	–	–	Insoluble
$Al_2SiO_4F_2$	3.57	8 (Mohs)	(001)-p	Insoluble
Al_2SiO_5-andalusite	3.13	6.5 (Mohs)	(110)	Insoluble
Al_2SiO_5-kyanite	3.6	4–7.5 (Mohs)	(100)-p	Insoluble
Al_2SiO_5-sillimanite	3.25	6.5 (Mohs)	(010)-p	Insoluble
$Al_4B_2O_9$	2.904	–	–	–
$Al_6Ge_2O_{13}$	3.662	–	–	Insoluble
$Al_6Si_2O_{13}$	3.19	1750	(010)-i	Insoluble
$AlHfTaO_6$	8.33	–	–	Insoluble
$AlNb_{11}O_{29}$	4.46	–	–	Insoluble
$AlNbO_4$	4.673	–	–	Insoluble
$AlTaO_4$	6.86	–	–	Insoluble
As_2S_3	3.49	1.5 (Mohs)	(010)-p	Insoluble
AsS	3.56	1.5 (Mohs)	(010)-i	Insoluble
$AsSbS_3$	3.92	1.5 (Mohs)	(001)-p	Insoluble
$Ba_2CaMgAl_2F_{14}$	4.204	3.5 (Mohs)	(001)-p	
$Ba_2CdMgAl_2F_{14}$	4.735	–	–	–
$Ba_2LiNb_5O_{15}$	–	–	–	Insoluble
$Ba_2NaNb_5O_{15}$	5.41	–	–	Insoluble
$Ba_2Zn_3F_{10}$	5.26	–	–	–
Ba_2ZnAlF_9	4.909	–	–	–
Ba_2ZnGaF_9	5.169	–	–	–
$Ba_3Al_2F_{12}$	4.37	–	–	–
$Ba_3TiAl_{10}O_{20}$	4.13	–	–	–
$BaAl_2B_2O_7$	3.559	–	–	–
$BaAl_2Ge_2O_8$	–	–	–	Insoluble
$BaAl_2Si_2O_8$	3.96	6–6.5 (Mohs)	(001)-p	Insoluble
$BaBe_2Si_2O_7$	4.00	7 (Mohs)	(001)(100)-p	Insoluble
$BaCa_2Mg(SiO_4)_2$	3.974	–	–	Insoluble
$BaCa_2Si_3O_9$	3.73	3.5 (Mohs)	(011)(010)-p	Insoluble
$BaCdAlF_7$	5.04	–	–	–
$BaCdGaF_7$	5.406	–	–	–
$BaCO_3$	4.31	3.5 (Mohs)	(010)-i	Very slightly soluble
$BaGaF_5$	5.104	–	–	–
$BaGe_2O_5$	5.85	–	–	Insoluble
$BaGeAl_6O_{12}$	4.031	–	–	–
$BaGeGa_6O_{12}$	5.201	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$BaGeO_3$	5.072	–	–	Insoluble
$BaMgF_4$	4.538	–	–	–
$BaNb_2O_6$	–	–	–	Insoluble
$BaSO_4$	4.50	3 (Mohs)	(001)-p	Insoluble
$BaTa_2O_6$	7.824	–	–	Insoluble
$BaTi_4O_9$	4.52	–	–	Insoluble
$BaTiAl_6O_{12}$	3.791	–	–	–
$BaTiGa_6O_{12}$	4.981	–	–	–
BaY_2F_8	5.047	250–350	–	–
BaY_2O_4	5.806	–	–	–
$BaZnF_4$	5.178	–	–	–
β-$BaSi_2O_5$	3.77	5 (Mohs)	(001)	Insoluble
β-Ca_2SiO_4	3.31	6 (Mohs)	(100)-i	Insoluble
Be_2BO_3F	2.37	7.5 (Mohs)	(010)-p	Insoluble
$BeAl_2O_4$	3.75	1600–2300 (V)	None	Insoluble
$BeAl_6O_{10}$	3.75	–	–	–
β-Ga_2O_3	5.95	–	(010)-p	Insoluble
$Bi_2Al_4O_9$	6.229	–	–	–
Bi_2GeO_5	–	–	–	Insoluble
$Bi_2Mo_2O_9$	6.518	–	–	Insoluble
$Bi_2Mo_3O_{12}$	6.196	–	(100)-p	Insoluble
Bi_2O_3	9.37	–	–	Very slightly soluble
Bi_2SiO_5	–	–	–	Insoluble
Bi_2WO_6	7.35	3.5 (Mohs)	–	–
Bi_3TiNbO_9	–	–	–	Insoluble
$Bi_4B_2O_9$	8.185	–	–	–
$Bi_4Ti_3O_{12}$	8.045	313	–	Insoluble
γ-Bi_2MoO_6	7.068	–	–	–
BiB_3O_6	5.03	5–5.5 (Mohs)	–	Insoluble
$BiNbO_4$	–	–	–	Insoluble
$BiSbO_4$	8.48	–	–	Insoluble
$BiTaO_4$	8.958	–	–	Insoluble
$BiVO_4$-clinobisvanite	6.95	–	–	–
$BiVO_4$-pucherite	6.63	4 (Mohs)	(001)-p	–
$Ca(IO_3)_2$	4.48	3.5 (Mohs)	(011)-i	–
$Ca_2(AsO_4)Cl$	–	–	(010)-p	–
$Ca_2(PO_4)Cl$	–	–	(010)-p	–
$Ca_2(PO_4)F$	–	–	(010)-p	Insoluble
$Ca_2(VO_4)Cl$	3.075	–	(010)-p	–
$Ca_2Al_2O_5$	3.73	–	–	–
$Ca_2B_6O_{11}$	2.85	–	–	–
Ca_2BO_3Cl	2.766	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Ca_2Nb_2O_7$	–	–	–	Insoluble
$Ca_2Sb_2O_7$	5.204	–	–	Insoluble
$Ca_2V_2O_7$	3.36	5.5 (Mohs)	(110)-p	–
$Ca_3(VO_4)_2$	3.16	–	(110)(001)-p	–
$Ca_3Al_2O_6$	3.017	–	–	–
$Ca_3Ga_4O_9$	4.208	–	–	–
$Ca_3MgSi_2O_8$	3.31	6 (Mohs)	None	Insoluble
$Ca_3Si_2O_7$	2.96	5.5 (Mohs)	–	Insoluble
$Ca_5Al_6O_{14}$	3.03	–	(001)-p	–
$Ca_5Ga_6O_{14}$	4.18	5 (Mohs)	–	–
$CaAl_2F_8$	2.89	4.5 (Mohs)	(111)-p	Insoluble
$CaAl_2O_4$	2.942	–	–	–
$CaAl_2Si_2O_8$	2.76	6–6.5 (Mohs)	(001)-p	Insoluble
$CaAl_4O_7$	2.894	8.5 (Mohs)	–	–
$CaAlB_3O_7$	3.44	7.5 (Mohs)	None	Insoluble
$CaAlBO_4$	2.60	–	–	–
CaB_2O_4	2.702	–	–	–
$CaB_2Si_2O_8$	3.00	7 (Mohs)	None	Insoluble
CaB_3O_5F	2.729	–	–	Insoluble
CaB_4O_7	2.69	–	–	–
$CaBa(CO_3)_2$	3.67	4 (Mohs)	(110)-i	Very slightly soluble
$CaBe(PO_4)F$	2.95	5 (Mohs)	(110)-i	Insoluble
$CaBe_2(PO_4)_2$	2.89	6 (Mohs)	None	Insoluble
$CaCO_3$-aragonite	2.93	3.5–4 (Mohs)	(010)-i	Very slightly soluble
$CaGa_2O_4$	4.333	–	–	–
$CaGe_2O_5$	4.868	–	–	Insoluble
$CaIn_2O_4$	6.15	–	–	–
$CaMg(PO_4)F$	–	–	–	Insoluble
$CaMgAsO_4F$	3.77	5 (Mohs)	(101)-i	Very slightly soluble
$CaMgB_2O_5$	3.02	4.5 (Mohs)	(010)-p	Very slightly soluble
$CaMgGe_2O_6$	4.265	–	–	Insoluble
$CaMgSi_2O_6$	3.26	6.5 (Mohs)	(110)-i	Insoluble
$CaMgSiO_4$	3.06	5.5 (Mohs)	(010)-i	Insoluble
$CaNb_2O_6$	4.78	5.5 (Mohs)	None	Insoluble
$CaSc_2O_4$	3.897	–	–	Insoluble
$CaSiO_3$	2.9	5 (Mohs)	(100)-p	Insoluble
$CaSnO_3$	5.759	–	–	Insoluble
$CaSnSiO_5$	4.56	4 (Mohs)	–	Insoluble
$CaSO_4$	2.96	3.5 (Mohs)	(010)(100)	Very slightly soluble
$CaTa_2O_6$	–	–	–	Insoluble
$CaTiO_3$	4.04	–	–	Insoluble
$CaTiSiO_5$	3.53	5.5 (Mohs)	(110)-i	Insoluble
CaV_2O_6	3.59	–	(100)(001)-p	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$CaYBO_4$	3.783	–	–	–
$CaZnGe_2O_6$	4.807	–	–	Insoluble
$CaZnSiO_4$	4.25	5 (Mohs)	(010)(100)	Insoluble
$CaZrSi_2O_7$	3.63	–	–	Insoluble
$CaZrTi_2O_7$	4.407	–	–	Insoluble
$Cd_2B_2O_5$	5.24	–	–	–
Cd_2GeO_4	6.313	–	–	Insoluble
CdB_4O_7	3.51	–	–	–
$CdWO_4$	8.005	–	–	–
Cs_2BeF_4	4.128	–	–	–
Cs_2CdBr_4	4.069	–	–	–
Cs_2HgI_4	4.357	–	–	–
Cs_2MgCl_4	2.952	–	–	–
Cs_2ZnBr_4	4.034	–	–	–
Cs_2ZnCl_4	3.357	–	–	–
CsB_3O_5	3.39	–	–	Soluble
$CsGd(MoO_4)_2$	–	–	(100)-p	–
CsLiBeF4	3.411	–	–	–
CsLiSO4	3.455	–	–	Very soluble
CsNbB2O6	–	–	(001)-p	Insoluble
$CsLiSO_4$	3.455	–	–	Very soluble
$CsNbB_2O_6$	–	–	(001)-p	Insoluble
$CsTiOAsO_4$	4.511	–	None	Insoluble
$CsZnAlF_6$	4.04	–	–	–
$Ga_2(WO_4)_3$	–	–	(010)-p	–
Ga_2GeO_5	4.97	–	–	Insoluble
$GaNbO_4$	5.01	–	–	Insoluble
$Gd(BO_2)_3$	4.84	–	–	–
$Gd_2(MoO_4)_3$	4.65	–	–	–
$Gd_2(WO_4)_3$	7.475	–	–	–
Gd_2GeO_5	–	–	–	Insoluble
Gd_2MoO_6	7.068	–	–	–
$Gd_2O_2SO_4$	6.483	–	–	–
Gd_2O_3	8.33	–	–	–
Gd_2SiO_5	6.77	6 (Mohs)	(100)-p	Insoluble
$Gd_2Sr_3(BO_3)_4$	5.266	–	–	–
Gd_2WO_6	8.339	–	–	–
Gd_3NbO_7	7.459	–	–	Insoluble
Gd_3TaO_7	8.414	–	–	Insoluble
$Gd_4Al_2O_9$	6.467	–	–	–
α-Ga_4GeO_8	5.65	–	–	Insoluble
$GdAlGe_2O_7$	–	–	–	Insoluble
$GdAlO_3$	7.437	–	–	Insoluble

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$GdGaGe_2O_7$	6.08	–	–	Insoluble
$GdMgB_5O_{10}$	4.309	–	–	–
$GdNbO_4$	–	–	–	Insoluble
GdP_5O_{14}	3.55	–	–	Insoluble
$GdPO_4$	5.986	470	–	Insoluble
$GdScO_3$	6.642	–	–	Insoluble
HfO_2	10.11	–	–	Insoluble
$HgCl_2$	5.490	–	–	–
HgO	11.14	1.5–2.0 (Mohs)	(010)-p	–
HIO_3	4.637	–	–	–
$In_2(MoO_4)_3$	3.92	–	–	–
$In_2(WO_4)_3$	5.619	–	(010)-p	–
$InCaBO_4$	4.536	–	–	–
$InGaO_3$	6.447	–	–	–
$InNbO_4$	6.27	–	(010)-p	Insoluble
$InPO_4$	4.830	–	–	Insoluble
$InTaO_4$	8.296	–	(010)-p	Insoluble
$InVO_4$	4.50	–	–	Insoluble
K_2CaSiO_4	2.865	–	–	Insoluble
$K_3Gd(VO_4)_2$	3.15	–	–	Slightly soluble
$K_3La(PO_4)_2$	5.293	–	–	Insoluble
$K_3Lu(VO_4)_2$	3.15	–	–	Slightly soluble
$K_3Y(VO_4)_2$	3.15	–	–	Slightly soluble
$KAlSi_3O_8$	2.57	6 (Mohs)	(001)-p	Insoluble
$KAl_3Si_3O_{10}(OH)_2$	2.78	–	–	Insoluble
KBF_4	2.51	–	–	Slightly soluble
$KB_5O_8 \cdot 4H_2O$	1.740	2.5 (Mohs)	(010)-p	–
$KGaSi_3O_8$	2.887	–	–	Insoluble
$KIn(MoO_4)_2$	4.17	–	–	–
$KLaP_4O_{12}$	–	–	–	Insoluble
$KLu(WO_4)_2$	7.759	–	–	–
$KNbB_2O_6$	3.151	–	(001)-p	Insoluble
$KNbO_3$	4.617	–	–	Insoluble
KNO_3	2.11	2 (Mohs)	(011)-p	Soluble
KPb_2Cl_5	4.78	2.5 (Mohs)	–	Insoluble
$KTaB_2O_6$	4.262	–	(001)-p	Insoluble
$KTaO_3$	5.996 ?	–	–	Insoluble
KTi_3NbO_9	3.88	–	–	Insoluble
$KTiNbO_5$	3.82	–	–	Insoluble
$KTiOAsO_4$	3.454	–	None	Insoluble
$KTiOPO_4$	3.024	702	None	Insoluble
KVO_3	2.879	–	(010)-p	–
$KY(MoO_4)_2$	5.40	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$KY(WO_4)_2$	6.56	–	–	–
LaB_3O_6	4.216	–	(010)-p	–
$La_2(WO_4)_3$	6.626	–	–	–
$La_2Ba_3(BO_3)_4$	5.353	–	–	–
$La_2Be_2O_5$	6.061	900(100)	(010)-i	Insoluble
$La_2Ca_3(BO_3)_4$	4.157	–	–	–
$La_2O_2SO_4$	5.467	–	–	–
La_2SiO_5	–	–	–	Insoluble
$La_2Sr_3(BO_3)_4$	4.783	–	–	–
$La_2Ti_2O_7$	5.782	648	(010)-p	Insoluble
La_2TiO_5	5.5	–	–	Insoluble
La_3NbO_7	6.25	–	–	Insoluble
La_3SbO_7	6.558	–	–	Insoluble
La_3TaO_7	7.139	–	–	Insoluble
$LaAlGe_2O_7$	5.18	–	–	Insoluble
$LaBMoO_6$	5.293	–	–	–
$LaBO_3$	5.304	–	–	–
$LaBWO_6$	6.185	–	–	–
$LaGaGe_2O_7$	–	–	–	Insoluble
$LaGaO_3$	7.21	–	–	Insoluble
$LaInO_3$	–	–	–	–
$LaMgB_5O_{10}$	3.923	–	–	–
$LaNb_5O_{15}$	6.264	–	–	Insoluble
$LaNbO_4$	5.914	–	–	Insoluble
LaP_5O_{14}	3.290	–	–	Insoluble
$LaPO_4$	5.067	5.5 (Mohs)	(100)-i	Insoluble
$LaSbO_4$	6.30	–	–	Insoluble
$LaScO_3$	5.79	–	–	Insoluble
$LaVO_4$	–	–	–	Insoluble
$LaY(WO_4)_3$	6.53	–	–	–
Li_2BeSiO_4	2.69	7 (Mohs)	(010)-i	Insoluble
Li_2CO_3	2.097	–	–	Slightly soluble
Li_2GeO_3	3.489	–	–	Insoluble
Li_2MgGeO_4	3.31	–	–	Insoluble
Li_2SiO_3	2.527	–	–	Insoluble
$Li_3La_2(BO_3)_3$	4.50	–	–	–
Li_3PO_4	2.48	4 (Mohs)	(010)-p	Insoluble
Li_3VO_4	2.645	–	–	Insoluble
$Li_3Y_2(BO_3)_3$	3.50	–	–	–
Li_5AlO_4	2.251	–	–	–
$Li_6Al_2(BO_3)_4$	2.58	–	–	–
$Li_6Lu(BO_3)_3$	3.538	–	–	–
$Li_6Y(BO_3)_3$	2.76	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$LiAl(MoO_4)_2$	3.95	–	–	–
$LiAl(PO_4)F$	3.10	5.5 (Mohs)	(100)(110)-p	Insoluble
$LiAlGe_2O_6$	4.354	–	–	Insoluble
$LiAlSi_2O_6$	3.1	7 (Mohs)	(010)-p	Insoluble
$LiAlSi_4O_{10}$	2.40	6.5 (Mohs)	(001)-p	Insoluble
$LiBaAlF_6$	4.114	–	–	–
$LiBaGaF_6$	4.526	–	–	–
$LiBO_2$	2.883	–	–	–
LiB_3O_5	2.474	7 (Mohs)	None	Insoluble
$LiGa(WO_4)_2$	7.44	–	–	–
$LiGaGe_2O_6$	4.783	–	–	Insoluble
$LiGaO_2$	4.175	–	–	Insoluble
$LiGaSi_2O_6$	–	–	–	Insoluble
$LiGdO_2$	6.246	–	–	–
$LiGdP_4O_{12}$	–	–	–	Insoluble
$LiIn(MoO_4)_2$	4.149	–	–	–
$LiIn(WO_4)_2$	7.47	–	–	–
$LiInGe_2O_6$	5.041	–	–	Insoluble
$LiInSi_2O_6$	4.071	–	–	Insoluble
$LiInSiO_4$	4.160	–	–	Insoluble
$LiLa(MoO_4)_2$	4.551	–	–	–
$LiLaO_2$	6.18	–	–	Soluble
$LiLaP_4O_{12}$	–	–	–	Insoluble
$LiLu(WO_4)_2$	8.02	–	–	–
$LiLuGeO_4$	5.98	–	–	Insoluble
$LiLuP_4O_{12}$	–	–	–	Insoluble
$LiLuSiO_4$	5.46	–	–	Insoluble
$LiSc(WO_4)_2$	6.716	–	–	–
$LiScGe_2O_6$	4.157	–	–	Insoluble
$LiScGeO_4$	3.928	–	–	Insoluble
$LiScSi_2O_6$	3.090	–	–	Insoluble
$LiScSiO_4$	3.183	–	–	Insoluble
$LiVO_3$	2.971	–	(100)-p	Insoluble
$LiY(WO_4)_2$	6.83	–	–	–
$LiYGeO_4$	4.365	–	–	Insoluble
$LiYO_2$	6.258	–	–	–
$LiYSiO_4$	3.746	–	–	Insoluble
$LiZnBO_3$	3.64	–	–	–
Lu_2MoO_6	8.167	–	–	–
$Lu_2O_2SO_4$	7.854	–	–	–
Lu_2SiO_5	5.892	6.5 (Mohs)	None	Insoluble
Lu_2WO_6	9.718	–	–	–
$LuCaBO_4$	6.036	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
LuP_5O_{14}	3.72	–	–	Insoluble
$LuTaO_4$	9.761	–	–	Insoluble
$Mg_2(PO_4)F$	3.15	5 (Mohs)	(100)-i	Insoluble
$Mg_2B_2O_5$	2.910	5.5 (Mohs)	(hk0)-p	Insoluble
Mg_2BO_3F	2.784	–	–	Insoluble
Mg_2GeO_4	4.028	–	–	Insoluble
Mg_2SiO_4	3.22	7 (Mohs)	(010)-i	Insoluble
$Mg_3(PO_4)_2$	2.76	–	(100)(010)	Insoluble
$Mg_3B_2O_6$	3.04	6.5 (Mohs)	(110)-p	Insoluble
$Mg_3B_7O_{13}Cl$	2.95	7 (Mohs)	None	Slightly soluble
$Mg_3TiB_2O_8$	3.35	3.5 (Mohs)	(100)-p	Insoluble
$Mg_4Al_8Si_2O_20$	3.489	7.5 (Mohs)	(010)(001)-i	Insoluble
$Mg_4Ga_8Ge_2O_{20}$	–	–	–	Insoluble
$Mg_5(BO_3)_3F$	3.112	–	–	Insoluble
$MgAl_3BSiO_9$	2.98	7.5 (Mohs)	(100)-p	Insoluble
$MgAlBO_4$	3.45	7 (Mohs)	None	Insoluble
$MgGaBO_4$	4.285	–	–	Insoluble
$MgGeO_3$	4.282	–	–	Insoluble
$MgMoO_4$	3.809	–	–	–
$MgSiO_3$	3.21	5–6 (Mohs)	(110)-i	Insoluble
$MgTi(SO_4)_3$	2.82	–	–	–
$MgTi_2O_5$	3.649	–	–	Insoluble
$MgWO_4$	6.893	–	–	–
$Na(Sr,Ba)PO_4$	2.919	–	–	Insoluble
$Na_2BaTi_2Si_4O_{14}$	3.43	6 (Mohs)	(100)-i	Insoluble
Na_2BeF_4	2.482	–	–	–
$Na_2BeSi_2O_6$	2.70	6 (Mohs)	(100)-i	Insoluble
$Na_2Ca(PO_4)F$	2.88	–	–	Insoluble
$Na_2CaMg(PO_4)_2$	3.10	4.5 (Mohs)	–	Insoluble
Na_2GeO_3	3.319	–	–	Insoluble
$Na_2KTiNbSi_4O_{14}$	2.968	6.5 (Mohs)	–	Insoluble
Na_2LiAlF_6	2.98	–	(001)-p	Slightly soluble
$Na_2LiYSi_6O_{15}$	2.76	–	–	Insoluble
Na_2MgAlF_7	2.97	3.5 (Mohs)	(110)-i	Slightly soluble
Na_2MgGaF_7	3.359	–	–	–
Na_2MgInF_7	3.627	–	–	–
Na_2MgScF_7	2.853	–	–	–
Na_2MgSiO_4	2.75	–	–	Insoluble
$Na_2Si_2O_5$	–	–	(100)-p	Slightly soluble
Na_2SiO_3	2.64	–	–	Insoluble
$Na_2Ti_2Si_2O_9$	3.44	6 (Mohs)	(010)-i	Insoluble
Na_2ZnCl_4	2.382	–	–	–
Na_3AlF_6	2.90	2.5 (Mohs)	(001)-p	Slightly soluble

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Na_3GdSi_3O_9$	3.439	–	–	Insoluble
$Na_3La(BO_3)_2$	3.49	–	–	–
$Na_3La_2(BO_3)_3$	4.19	–	–	–
$Na_3ScSi_2O_7$	2.861	–	–	Insoluble
$Na_3YSi_3O_9$	2.962	–	–	Insoluble
$NaAl(AsO_4)F$	3.64	5 (Mohs)	(110)-i	Slightly soluble
$NaAl(PO_4)F$	3.126	4.5 (Mohs)	(111)-i	Insoluble
$NaAlGeO_4$	3.337	–	(010)-p	Insoluble
$NaAlSi_3O_8$	2.63	6–6.5 (Mohs)	(001)-p	Insoluble
$NaBePO_4$	2.81	5.5 (Mohs)	(010)-p	Insoluble
$NaBF_4$	2.53	3 (Mohs)	(100)(010)	Soluble
$NaCaPO_4$	3.117	3 (Mohs)	–	–
$NaCdPO_4$	4.10	–	–	–
$NaGaGe_2O_6$	4.864	–	–	Insoluble
$NaGaGeO_4$	4.028	–	(010)-p	Insoluble
$NaGaSiO_4$	3.336	–	(010)-p	Insoluble
$NaGdGeO_4$	5.366	–	–	Insoluble
$NaGdP_2O_7$	4.287	–	–	Insoluble
$NaGdP_4O_{12}$	3.45	–	–	Insoluble
$NaGdSiO_4$	–	–	–	Insoluble
$NaIn(MoO_4)_2$	4.02	–	–	–
$NaLaP_2O_7$	3.803	–	–	Insoluble
$NaLaP_4O_{12}$	3.4	–	–	Insoluble
$NaLiV_2O_6$	2.962	–	–	–
$NaLuGeO_4$	6.025	–	–	Insoluble
$NaLuP_2O_7$	4.114	–	–	Insoluble
$NaLuSiO_4$	5.435	–	–	Insoluble
$NaMgF_3$	3.06	–	–	–
$NaNbO_3$	4.57	5.5 (Mohs)	–	Insoluble
$NaScGeO_4$	3.39	–	–	Insoluble
$NaScSi_2O_6$	3.22	–	–	Insoluble
$NaSr_3Al_3F_{16}$	3.51	4 (Mohs)	None	Slightly soluble
$NaTaO_3$	7.123	–	–	Insoluble
$NaVO_3$	2.91	–	(110)-p	0.8
$NaYGeO_4$	4.302	–	–	Insoluble
$NaYO_2$	4.382	–	–	Slightly soluble
$NaYSiO_4$	4.083	–	–	Insoluble
$NaZnF_3$	4.105	–	–	–
$NH_4B_5O_8 \cdot 4H_2O$	1.57	2.5 (Mohs)	(100)-p	–
$Pb_2KNb_5O_{15}$	6.143	–	(001)	Insoluble
$Pb_2NaNb_5O_{15}$	–	–	–	Insoluble
$Pb_2V_2O_7$	6.46	3 (Mohs)	–	-
$Pb_3(PO_4)_2$	7.456	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Pb_3(VO_4)_2$	7.44	–	–	–
Pb_3GeO_5	–	–	–	Insoluble
$Pb_3MgNb_2O_9$	–	–	–	Insoluble
$Pb_3ZnNb_2O_9$	–	–	–	Insoluble
$PbBi_2Nb_2O_9$	6.684	–	–	Insoluble
$PbBr_2$	6.693	–	(001)-p	–
$PbCl_2$	5.85	31	(001)-p	0.99 (20)
$PbCO_3$	6.55	3 (Mohs)	(110)(021)-i	Very slightly soluble
$PbGeO_3$	6.968	–	–	Insoluble
PbO (massicot)	9.642		(100)-p	–
$PbNb_2O_6$	–	–	–	Insoluble
$PbSeO_3$	7.12	3.5 (Mohs)	(001)-p	–
$PbSeO_4$	7.08	3.5 (Mohs)	None	–
$PbSiO_3$	6.32	4.5 (Mohs)	(010)-p	Insoluble
$PbSO_4$	6.32	3.5 (Mohs)	(001)(210)	Insoluble
$PbTa_2O_6$	7.65	–	–	Insoluble
$PbTiP_2O_8$	–	–	–	Insoluble
$PbZnSiO_4$	6.13	3 (Mohs)	(120)-i	Insoluble
$RbAlSiO_4$	–	–	–	Insoluble
$RbB_5O_8 \cdot 4H_2O$	1.946	2.5 (Mohs)	–	–
Rb_2BeF_4	3.749	–	–	–
$RbBi(MoO_4)_2$	5.52	–	–	–
$RbGd_2Br_7$	4.79	–	–	Slightly soluble
$RbLa(WO_4)_2$	6.88	–	–	–
$RbNbB_2O_6$	3.584	–	(001)-p	Insoluble
$RbTaB_2O_6$	4.65	–	(001)-p	Insoluble
$RbTiOAsO_4$	4.018	–	None	Insoluble
$RbTiOPO_4$	3.647	–	None	Insoluble
$Sb2O_3$	5.83	2.5–3 (Mohs)	(110)-p	Insoluble
$SbNbO_4$	5.68	5.5 (Mohs)	(010)-i	Insoluble
$SbTaO_4$	7.53	5–5.5 (Mohs)	(010)-i	Insoluble
$Sc(PO_3)_3$	2.736	–	–	Insoluble
$Sc_2(MoO_4)_3$	3.102	–	–	–
$Sc_2(WO_4)_3$	4.566	–	(010)-p	Slightly soluble
$Sc_2Si_2O_7$	–	–	–	Insoluble
$(Sc,Y)_2Si_2O_7$	3.39	6.5 (Mohs)	(110)-i	Insoluble
Sc_2SiO_5	3.49	–	–	Insoluble
Sc_2TiO_5	3.611	–	–	Insoluble
$ScAlBeO_4$	–	–	None	Insoluble
$ScCaBO_4$	3.319	–	–	–
$ScGaO_3$	5.10	–	(010)-p	Insoluble
$ScGe_2O_5$	5.286	–	–	Insoluble
$ScMgBO_4$	3.287	–	–	–

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$ScNbO_4$	4.843	–	(010)-p	Insoluble
$ScTaO_4$	6.90	–	(010)-p	Insoluble
$Sr_2(AsO_4)Cl$	–	–	(010)-p	–
$Sr_2(VO_4)Br$	4.342	–	–	–
$Sr_2(VO_4)Cl$	3.883	–	(010)-p	–
$Sr_2KNb_5O_{15}$	–	–	–	Insoluble
$Sr_2KTa_5O_{15}$	–	–	–	Insoluble
$Sr_2NaNb_5O_{15}$	5.19	–	–	Insoluble
$Sr_2Nb_2O_7$	5.204	–	–	Insoluble
$Sr_2Ta_2O_7$	7.074	–	–	Insoluble
$SrAl_2Ge_2O_8$	3.714	–	–	Insoluble
$SrAl_2O_4$	3.554	–	–	–
$SrAl_2Si_2O_8$	3.13	–	–	Insoluble
$SrAl_4O_7$	3.266	–	–	–
SrB_2O_4	3.350	–	–	–
$SrCO_3$	3.79	3.5 (Mohs)	(010)-i	Very slightly soluble
$SrGa_2O_4$	4.85	–	–	–
$SrGa_2Si_2O_8$	3.797	–	–	Insoluble
$SrGd_2O_4$	7.287	–	–	Insoluble
$SrIn_2O_4$	6.854	–	–	–
$SrLu_2O_4$	8.496	–	–	Insoluble
$SrNb_2O_6$	–	–	–	Insoluble
$SrSc_2O_4$	–	–	–	Insoluble
$SrSiO_3$	3.66	–	–	Insoluble
$SrSO_4$	3.97	3 (Mohs)	(001)-p	Insoluble
$SrTa_2O_6$	–	–	–	Insoluble
SrY_2O_4	5.344	–	–	–
$SrZnGe_2O_6$	–	–	–	Insoluble
TeO_2	6.00	2 (Mohs)	(010)-p	Very slightly soluble
$TlNbB_2O_6$	–	–	(001)-p	Insoluble
$TlTaB_2O_6$	–	–	(001)-p	Insoluble
V_2O_5	3.37	–	–	–
$Y_2(MoO_4)_3$	3.3	–	–	Very soluble
$Y_2(WO_4)_3$	–	–	(010)-p	Very soluble
Y_2BeO_4	4.582	–	–	Insoluble
Y_2GdSbO_7	6.443	–	–	Insoluble
Y_2GdTaO_7	7.102	–	–	Insoluble
Y_2GeO_5	–	–	–	Insoluble
$Y_2MgBe_2Si_2O_{10}$	4.152	6.5 (Mohs)	None	Insoluble
Y_2MoO_6	5.366	–	–	–
$Y_2O_2SO_4$	4.813	–	–	–
$Y_2Si_2O_7$	4.3	6 (Mohs)	None	Insoluble
Y_2SiO_5	4.543	6.5 (Mohs)	None	Insoluble

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Physical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Density (g/cm^3)	Hardness (kg/mm^2)	Cleavage plane	Solubility (°C) ($g/100\ g\ H_2O$)
$Y_2Ti_2SiO_9$	–	–	–	Insoluble
Y_2WO_6	6.818	–	–	–
Y_3SbO_7	5.699	–	–	Insoluble
Y_3TaO_7	6.413	–	–	Insoluble
$Y_4Al_2O_9$	4.518	–	–	Insoluble
$YAlO_3$	5.35	1030–1450	(110)-p	Insoluble
$YCa_4O(BO_3)_3$	–	6–6.5 (Mohs)	None	Insoluble
$YCaGaBe_2Si_2O_{10}$	4.107	6.5 (Mohs)	None	Insoluble
YF_3	5.056	–	–	–
$YGd_2Nb_2O_9$	6.802	–	–	Insoluble
$YHfTaO_6$	8.13	–	–	Insoluble
$YNbO_4$	5.58	–	–	Insoluble
YP_5O_{14}	–	–	–	Insoluble
$YScO_3$	4.94	–	–	Insoluble
$YTaO_4$	7.579	–	–	Insoluble
$YTiTaO_6$	6.51	–	–	Insoluble
$Zn_3(AsO_3)_2$	4.27	5 (Mohs)	(110)-i	Insoluble
$Zn_3(BO_3)_2$	4.12	–	–	–
ZnB_4O_7	3.07	–	–	–
$ZnWO_4$	7.87	–	–	–
ZrO_2	5.82	6.5 (Mohs)	(001)-p	Insoluble

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1.3 Optical Properties*

The optical properties of crystals in this section are grouped into three tables: isotropic crystals, uniaxial crystals, and biaxial crystals. Materials are listed alphabetically in order of the chemical formulas. The following properties are included:

Transmission Range: Electronic and lattice absorption edges are given in terms of the wavelengths between which the transmission of a 1-mm-thick sample at 300 K is ≥ 10%. The values cited are approximate and are intended to as a general guide because many factors such as impurities, imperfections, temperature, crystallographic orientations, and compositional variations can affect the values.

Band Gap: Band gap data for transitions at room temperature unless noted otherwise. The energy gap depends on the structure of the material and varies with direction in anisotropic crystals. Optical transition: (D) – direct, (I) – indirect.

Refraction Index (n)**:** For isotropic crystals, there is only one refractive index. Uniaxial crystals with tetragonal, hexagonal, and trigonal (or rhombohedral) symmetry exhibit a unique index of refraction (symbolized as e or ε) when light vibrates parallel to the *c*-axis (the extraordinary ray). For light vibrating at 90° to the *c*-axis (the ordinary ray), the refractive indices are the same (symbolized as o or ω) in all 360° directions. Biaxial crystals with orthorhombic, monoclinic, and triclinic symmetry possess three significant indices of refraction, commonly symbolized as x, y, z or α, β, γ in the order from smallest to largest.

Unless specified, the refraction indices are the average values for standard daylight or are the values measured at 632.8 nm at room temperature (the differences in the daylight and He-Ne values are within 0.1%). In a few instances, e.g., tellurides, these materials are opaque to visible light so that the refractive indices are measured with an infrared light source. In these cases, the wavelength used is listed with parentheses.

Birefringence (Δn)**:** Birefringence of anisotropic materials is a measure of the maximum difference of the refractive indices within a crystal for a given wavelength.

Dispersion formulas: Refractive indices at specific wavelengths within specified ranges can be derived from dispersion formulas given in Section 1.3.4. Note that several different functional forms have been used to represent the dispersion of the refractive index.

Thermooptic coefficients (dn/dt): Thermooptic coefficients of optical crystals at various wavelengths are given in Section 1.3.5.

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* This section was adapted from "Optical crystals" by B. H. T. Chai, *Handbook of Laser Science and Technology, Suppl. 2, Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 3 ff (with additions).

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1.3.1 Isotropic Crystals

Optical Properties of Isotropic Crystalline Materials

Cubic material	Transmission (μm)	Band gap (eV)	Refractive index n
AgBr	0.49–35	2.7 (I), 4.3 (D)	2.242
AgCl	0.42–28	3.2 (I), 5.1 (D)	2.0568
AlAs	0.6 –15	2.153 (I)	2.87
$Al_{23}O_{27}N_5$ (ALON)	0.23–4.8	–	1.79
β-AlN	4.9	–	–
AlSb	–	1.63 (I), 2.22 (D)	–
As_2O_3	–	4–5	1.755
$Ba(NO_3)_2$	–	–	1.5714
BaF_2	0.14–13	9.1	1.4733
BaF_2-CaF_2	0.15–12	–	–
$Bi_{12}GeO_{20}$	0.47–7	–	2.5476
$Bi_{12}SiO_{20}$	0.52–	–	–
$Bi_{12}TiO_{20}$	–	–	2.5619
$Bi_4Ge_3O_{12}$	0.31–6	4.2	1.835
$Bi_4Si_3O_{12}$	–	–	2.051
BN	0.2–6	7.5 (I)	≈2.117
BP	0.5–6	2 (I)	2.8
$Ca_{12}Al_{14}O_{33}$	0.35–6	–	1.643
$Ca_3Al_2Si_3O_{12}$	–	–	1.734
$Ca_3Ga_2Ge_3O_{12}$	–	–	1.814
C (diamond)	0.24–2.7	5.47	2.4175
CaF_2	0.12–10	10	1.433
$CaLa_2S_4$	0.65–14.3	–	2.7
CaO	0.2–10	7.7	1.838
CdF_2	0.13–12	6	1.562
CdO	–	2.3	2.49
CdTe	0.9–30	1.56 (D)	2.817
CsBr	0.23–440	6.9	1.6929
CsCl	0.19–30	7.4	1.64
CsF	0.27–>15	10 (80 K)	1.48
CsI	0.25–62	6.2	1.7806
Cu_2O	–	2.1 (I), 2.6 (D)	–
CuBr	0.45–26	3.0 (80 K)	2.117
CuCl	0.4–19	3.3 (80 K)	1.97
CuI	–	3.1	2.346
GaAs	0.9–17.3	1.42 (D)	4.02
β-GaN	–	3.3	–
GaP	0.54–10.5	2.26 (I), 2.78 (D)	3.350
GaSb	1.7–20	0.726 (D)	3.82 (1.8 μm)
$Gd_2Ti_2O_7$	–	–	2.36
$Gd_3Ga_5O_{12}$	0.32–6	–	1.9637
$Gd_3Sc_2Al_3O_{12}$	–	–	1.901

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Optical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Transmission (μm)	Band gap (eV)	Refractive index n
$Gd_3Sc_2Ga_3O_{12}$	–	–	1.9628
Ge	1.8–15	0.664 (I)	4.052 (2.8 μm)
HgS	–	–	2.5
HgSe	2.1–20	0.6	–
HgTe	6–30	0.17 (D)	–
InAs	3.8–15	0.354 (D)	4.10
β-InN	4.98	–	–
InP	0.93–14	1.344 (D)	3.43
InSb	6–25	0.17	5.13
$K_2Mg_2(SO_4)_3$	–	–	1.53
K_2NaAlF_6	–	–	1.376
KBr	0.20–306	7.6 (D)	1.5566
KCl	0.18–25	8.5 (D)	1.4879
KF	0.146–16	10.9 (D)	1.362
KI	0.25–39	6.2 (D)	1.6581
$KMgF_3$	–	–	1.404
$KTaO_3$		3.5	2.2
$LiBaF_3$	–	–	1.544
LiBr	–	7.9 (D)	1.78
LiCl	–	9.3 (D)	1.66
LiF	0.12–6.6	13.6 (D)	1.3912
LiI	–	6 (D)	1.95
Lu_2O_3		3.9 (733 K)	–
$Lu_2Ti_2O_7$	–	–	2.57
$Lu_3Al_5O_{12}$	–	–	1.842
$Mg_3Al_2Si_3O_{12}$	–	–	1.713
$MgAl_2O_4$	0.21–5.3	–	1.715
$MgGa_2O_4$	–	–	1.879
MgO	0.16–9	7.8 (D)	1.735
MnO	–	3.7	2.18
$Na_3Li_3Al_2F_{12}$	0.15–13	–	1.3395
$Na_3Li_3Ga_2F_{12}$	0.15–13	–	–
$Na_3Li_3In_2F_{12}$	0.15–13	–	–
$Na_3Li_3Sc_2F_{12}$	0.15–13	–	–
$Na_8Al_6Si_6O_{24}Cl_2$	–	–	1.483
NaBr	0.2–24	7.5 (D)	1.64
NaCl	0.17–18	9.0 (D)	1.531
NaF	0.13–12	10.5	1.326
$5NaF\text{-}9YF_3$	–	–	1.470
NaI	0.26–24	5.9 (D)	1.77
$Pb(NO_3)_2$	–	–	1.780
PbF_2	0.29–12.5	5.0	1.7611
PbI_2	–	2.4	–
PbS	3–7	0.42 (D)	4.1 (3 μm)

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Optical Properties of Isotropic Crystalline Materials—*continued*

Cubic material	Transmission (μm)	Band gap (eV)	Refractive index n
PbSe	4.5–20	0.278 (D)	4.59 (3 μm)
PbTe	4–30	0.311 (D)	5.35 (3 μm)
RbBr	0.23–40	7.25 (D)	1.55
$RbCaF_3$	–	–	–
RbCl	0.2–30	8.3 (D)	1.49
RbF	–	10.4 (80 K)	–
RbI	0.26–50	5.83 (D)	1.64
Sb_2O_3	–	–	2.087
Sc_2O_3	–	–	1.964
Si	1.1–6.5	1.124 (I)	3.4777 (1.55 μm)
β-SiC	0.5–4	2.6 (I)	~2.6
SrF_2	0.13–12	9.4	1.4371
$SrSnO_3$	–	–	1.90
$SrTiO_3$	0.4–5.1	4.1	2.3878
ThO_2	0.22–9	5.7	2.07
Tl(Br,I)	0.58–42	–	2.573
Tl(Cl,Br)	0.42–27	–	2.329
Tl_2O_3	–	–	–
TlBr	0.44–38	3.1 (D)	2.384
TlCl	0.4–30	3.6	2.223
Y_2O_3	0.29–7.1	5.6	1.92
$Y_2Ti_2O_7$	–	–	2.34
$Y_3Al_5O_{12}$	0.21–5.2	–	1.8289
$Y_3Fe_5O_{12}$	–	–	2.25 (μm)
$Y_3Ga_5O_{12}$	–	–	1.913
$Y_3Sc_2Al_3O_{12}$	–	–	1.96
$ZnAl_2O_4$	–	–	1.7902
β-ZnS	0.4–12.5	3.68 (D)	2.3505
β-ZnS(CVD)	–	–	2.36
ZnSe	0.5–20	2.71 (D)	2.5907
ZnSe (CVD)	–	–	2.59
$ZnSiAs_2$	–	2.1	–
ZnTe	0.55–25	2.30 (D)	2.962
ZrO_2	0.35–7	5.0	2.1226
ZrO_2:Y_2O_3	0.38–6.0	~4.1	2.12

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1.3.2 Uniaxial Crystals

Optical Properties of Uniaxial Crystalline Materials

Uniaxial material	Transmission (μm)	Band gap (eV)	Refractive index n_e	Refractive index n_o	Birefringence Δn
Ag_3AsS_3	0.61–13.5	2.1	2.738	3.019	–0.281
Ag_3SbS_3	0.7–14	–	2.67	2.86	–0.19
$AgGaS_2$	0.5–13	2.6	2.507	2.554	–0.047
$AgGaSe_2$	0.78–18	1.7	2.676	2.700	–0.024 (1 μm)
β-AgI	–	2.9	2.21	2.22	–0.01
Al_2O_3	0.19–5.2	9.9	1.7579	1.7659	–0.008
AlF_3	–	–	1.3765	1.3770	–0.0005
α-AlN	–	6.23 (D)	2.13	2.20	–0.07
$AlPO_4$	0.2–3.6	–	1.5334	1.5243	0.0091
$Ba_2TiSi_2O_8$	0.3–5	–	1.765	1.775	–0.001
$Ba_2ZnSi_2O_7$	–	–	1.710	1.724	–0.014
$Ba_3(VO_4)_2$	0.3–5.6	–	–	–	–
$Ba_5(AsO_4)_3Cl$	–	–	1.880	1.884	0.004
$Ba_5(VO_4)_3Cl$	–	–	1.870	1.900	0.030
$BaAl_2O_4$	–	–	1.657	?	–
β-BaB_2O_4	0.19–3.5	6.2	1.54254	1.65510	0.11256
$BaBe(PO_4)F$	–	–	1.632	1.629	0.003
$BaGe_4O_9$	–	–	–	–	5.147
$BaSnSi_3O_9$	–	–	1.674	1.685	–0.011
$BaZrSi_3O_9$	–	–	1.6751	1.6850	–0.0099
Be_2GeO_4	–	–	1.720	1.734	–0.014
Be_2SiO_4	–	–	1.670	1.654	0.016
$Be_3Al_2Si_6O_{18}$	–	–	1.5682	1.5746	–0.0064
$Be_3Sc_2Si_6O_{18}$	–	–	1.607	1.627	0.02
$BeMg_3Al_8O_{16}$	–	–	1.717	1.722	0.005
BeO	0.11–4.5	10.6 (D)	1.7322	1.7166	0.0156
$Bi_2Ge_3O_9$	0.25–6.5	–	2.08	2.01	0.07
$Ca_2Al_2SiO_7$	–	–	1.658	1.669	–0.011
$Ca_2MgSi_2O_7$	–	–	1.64	1.632	0.008
$Ca_2Te_2O_5$	–	–	2.00	1.89	0.11
$Ca_2ZnSi_2O_7$	–	–	1.657	1.669	–0.012
$Ca_3Ga_2Ge_4O_{14}$	0.26–6.5	–	1.822	1.795	0.027
$Ca_5(AsO_4)_3F$	–	–	1.698	1.706	–0.008
$Ca_5(PO_4)_3Cl$	–	–	1.647	1.650	–0.003
$Ca_5(PO_4)_3F$	–	–	1.624	1.629	–0.005
$Ca_5(VO_4)_3Cl$	–	–	1.865	1.893	0.028
$CaAl_{12}O_{19}$	–	–	1.79	1.807	–0.017
$CaAl_2B_2O_7$	–	–	–	1.563	–
$CaCO_3$–calcite	0.2–5.5	5.9	1.486	1.658	–0.172

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Optical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Transmission (μm)	Band gap (eV)	Refractive index n_e	Refractive index n_o	Birefringence Δn
$CaCO_3$–vaterite	–	–	1.65	1.55	0.10
$CaGdAlO_4$	0.35–7	–	1.9564	1.9331	0.0233
$CaGe_4O_9$	–	–	1.78	–	–
$CaLa_4(SiO_4)_3O$	–	–	1.7637	1.7915	–0.028
$CaLaAlO_4$	0.35–7	–	–	≈2.6	–
$CaMg(CO_3)_2$	–	–	1.503	1.680	–0.177
$CaMg_3(CO_3)_4$	–	–	1.609	1.708	0.099
$CaMoO_4$	–	–	1.9796	1.9703	0.0093
$CaSnB_2O_6$	–	–	1.660	1.778	–0.118
$CaWO_4$	0.13–5.6	–	1.9375	1.9208	0.017
$CaYAlO_4$	0.35–7	–	–	–	–
$CaZrBAl_9O_{18}$	–	–	1.7875	1.8159	–0.0284
$CdCl_2$	–	5.7	1.681	1.719	–0.038
$CdCO_3$	–	–	–	1.842	–
CdI_2	–	3.9	–	1.574	–
CdS	0.51–14.8	2.42 (D)	2.529	2.506	0.023
CdSe	0.75–20	1.70 (D)	2.557	2.537	0.02
CsD_2AsO_4	0.27–1.66	–	1.53	1.55	–0.02
CsD_2PO_4	0.27–1.66	–	–	–	–
$CsGa(SO_4)_2$	–	–	–	–	–
CsH_2AsO_4	0.26–1.43	–	1.53	1.55	–0.02
$CsLiB_6O_{10}$	0.18–2.7				
α-GaN	–	3.37 (D)	~2.25	~2.29	~0.04
GaS		2.3 (I), 3.8 (D)	–	–	–
GaSe	0.65–18	–	2.57	2.91	0.34 (1 μm)
$Gd_2GeBe2O_7$	–	–	–	–	–
$GdAl_3(BO_3)_4$	–	–	1.720	1.780	–0.060
$GdBO_3$	–	–	1.840	1.824	0.016
GeO_2	0.25–5	5.6	–	1.6045	–
Hg_2Br_2	0.4–30	2.6	–	–	–
Hg_2Cl_2	0.36–20	3.9	2.656	1.973	0.683
Hg_2I_2	0.45–40	2.4	–	–	–
HgI_2	–	2.1	–	–	–
HgS	0.6–28	2	3.232	2.885	0.347
InN	–	1.99	~2.09	–	–
In_2O_3	–	2.7 (I)	–	–	–
$InBO_3$	–	–	1.773	1.873	–0.100
$K_2Al_2B_2O_7$	0.18–3.6	–	–	–	–
$K_2BiNb_5O_{15}$	–	–	2.253	2.237	0.016
$K_2CaZr(SiO_3)_4$	–	–	1.655	1.625	0.03
$K_2Sr(SO_4)_2$	–	–	1.549	1.569	–0.020
$K_3LiNb_5O_{15}$	–	–	2.156	2.294	0.148
$KAlSi_2O_6$	–	–	1.509	1.508	0.001

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Optical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Transmission (μm)	Band gap (eV)	Refractive index n_e	Refractive index n_o	Birefringence Δn
$KAlSiO_4$	–	–	1.5372	1.541	–0.0038
$KBe_2BO_3F_2$	0.155	–	1.406	1.472	–0.066
KD_2PO_4	0.20–1.5	–	1.46	1.49	0.03
KH_2PO_4	0.18–1.5	7.0	1.4669	1.5074	–0.0405
$KZnF_3$	–	–	–	–	–
$La_2GeBe_2O_7$	–	–	1.905	1.890	0.015
La_2O_3	–	2.9 (530 K)	–	–	–
La_2WO_6	–	–	2.18	2.16	0.02
$La_3Ga_5GeO_{14}$	0.24–7.5	–	1.940	1.925	0.015
$La_3Ga_5SiO_{14}$	0.35 –	–	1.9106	1.89965	0.01141
$La_3Nb_{0.5}Ga_{5.5}O_{14}$	0.29–6.7	–	1.896	1.955	0.059
$La_3Ta_{0.5}Ga_{5.5}O_{14}$	0.29–6.7	–	1.970	1.945	0.025
$LaAlO_3$	–	–	–	–	–
$LaBaGa_3O_7$	–	–	1.850	1.845	0.005
$LaBSiO_5$	–	–	1.7753	1.7843	–0.009
$LaCaGa_3O_7$	–	–	1.831	1.826	0.005
$LaCl_3$	–	–	1.8929	1.8265	0.0664
LaF_3	0.2–10	6.6	1.602	1.606	0.004
$LaSrGa_3O_7$	–	–	1.820	1.806	0.014
$Li_2B_4O_7$	–	–	1.560	1.605	–0.045
$LiAlSiO_4$	–	–	1.572	1.56	0.012
$LiCaAlF_6$	–	–	1.3852	1.3882	–0.003
$LiGdF_4$	–	–	1.474	1.502	–0.028
$LiIO_3$	0.38–5.5	4.0	1.7351	1.8815	–0.1464
$LiLuF_4$	–	–	1.468	1.494	–0.026
$LiNbO_3$	0.35–5.0	4.0	2.156	2.232	–0.076
$LiSrAlF_6$	–	–	1.384	1.380	0.004
$LiTaO_3$	–	–	2.188	2.183	–0.005
$LiYF_4$	0.12–8	~11	1.4762	1.4535	0.0227
$LuAl_3(BO_3)_4$	–	–	1.712	1.771	–0.059
$Mg_2Al_3(Si_5Al)O_{18}$	–	–	1.527	1.524	0.003
$MgCO_3$	–	–	1.510	1.700	–0.190
MgF_2	0.13–7.7	10.8	1.3886	1.3768	0.0118
$MgTiO_3$	–	–	1.95	2.31	–0.36
MnF_2	–	10.2	–	–	–
$Na_2Al_2B_2O_7$	–	–	1.504	1.540	–0.036
$Na(Li,Al)_3Al_6(BO_3)_3$ -$Si_6O_{18}(OH)$	variable	–	1.615–1.632	1.635–1.65	0.0180–0.0200
$NaNO_3$	0.35–3	–	1.3361	1.5874	–0.251
$NaSbBe_4O_7$	–	–	1.770	1.772	0.002
$NaScO_2$	–	–	–	–	–
$NH_4H_2PO_4$	0.19–1.5	6.8	1.48	1.53	–0.0458
$Pb_3Ca_2(AsO_4)_3Cl$	–	–	1.948	1.958	–0.010

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Optical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Transmission (μm)	Band gap (eV)	Refractive index n_e	Refractive index n_o	Birefringence Δn
$Pb_5(AsO_4)_3Cl$	–	–	2.106	2.124	–0.018
$Pb_5(PO_4)_3Cl$	–	–	2.408	2.058	–0.010
$Pb_5(PO_4)_3F$	–	–	–	–	–
$Pb_5(VO_4)_3Cl$	–	–	2.350	2.416	–0.066
$PbAl_{12}O_{19}$	–	–	1.88	1.80	0.08
$PbMoO_4$	0.4–5.9	3.6	2.2584	2.3812	–0.123
PbO-litharge	–	2.8	2.535	2.655	0.130
$PbWO_4$	–	5.6	2.19	2.27	–0.08
RbH_2AsO_4	0.26–1.46	–	1.50	1.55	–0.05
RbH_2PO_4	0.22–1.4	–	1.47	1.50	–0.03
$ScBO_3$	–	–	1.780	1.872	–0.092
Se	1–30	1.7	3.61	2.79	0.82 (1μm)
α-SiC	0.5–4	2.8 (I)	~2.6	–	–
Si_3N_4	0.3–4.6	5	–	2.04	–
α-SiO_2	0.16–4.0	8.4	1.56	1.55	0.0095
SnO_2	– (4.3)	2.5 (I), 3.4 (D)	2.091	1.990	0.010
$Sr_2MgGe_2O_7$	–	–	1.800	1.816	–0.016
$Sr_3Ga_2Ge_4O_{14}$	0.26–6.8	–	1.85	1.8336	0.0164
$Sr_5(PO_4)_3F$	–	–	1.6252	1.6314	–0.062
$Sr_5(VO_4)_3F$	–	–	1.809	1.824	–0.015
$Sr_5(VO_4)_3Cl$	–	–	1.868	1.895	0.027
$SrAlF_5$	0.16–7	–	–	–	–
$(Sr_{0.6}Ba_{0.4})Nb_2O_6$	0.5–5.5	–	2.270	2.310	0.04
$SrGdGa_3O_7$	–	–	1.830	1.838	0.008
$SrLa_4(SiO_4)_3O$	–	–	1.8227	1.8567	–0.034
$SrMoO_4$	–	–	1.9110	1.9064	0.0046
Ta_2O_5	– (4.6)	–	2.21	2.20	0.01
$TaBO_4$	–	–	> 2.12	> 2.12	–
Te	3.5–32	0.33	4.929	6.372	–1.45 (4 μm)
$ThSiO_4$	–		1.79	1.78	0.01
TiO_2 (rutile)	0.42–4.0	3.5 (D)	2.872	2.584	0.288
Tl_3AsS_3	1.26–17	–	–	–	–
Tl_3AsSe_3	1.3–16	–	3.227	3.419	–0.192
$Y_2SiBe_2O_7$	–	–	1.80	1.83	–0.03
$YAl_3(BO_3)_4$	–	–	1.704	1.778	0.074
$YAsO_4$	–	–	1.879	1.783	0.096
YBO_3	–	–	1.802	1.788	0.014
YPO_4	–	–	1.816	1.827	–0.011
YVO_4	0.35–4.8	–	2.2148	1.9915	0.2233
Zn_2SiO_4	–	–	1.719	1.691	0.028
$ZnCO_3$	–	–	1.625	1.850	–0.275
$ZnCl_2$	~0.4–~15	–	–	–	–
ZnF_2	–	–	1.502	1.529	–0.027

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Optical Properties of Uniaxial Crystalline Materials—*continued*

Uniaxial material	Transmission (μm)	Band gap (eV)	Refractive index n_e	Refractive index n_o	Birefringence Δn
$ZnGeP_2$	0.74–15	–	3.28	3.23	0.05 (1 μm)
ZnO	0.37–	3.35 (D)	2.015	1.998	0.017
$ZnSb_2O_6$	–	–	>1.95	>1.95	–
α-ZnS	–	–	2.378	2.356	0.022
ZrO_2	–	4.99–	–	–	–
$ZrSiO_4$	0.4–	–	1.967	1.920	0.042

1.3.3 Biaxial Crystals

Optical Properties of Biaxial Crystalline Materials

Biaxial material	Transmission (μm) [Band gap (eV)]	Refractive index n_x	Refractive index n_y	Refractive index n_z	Birefringence Δn
$Al_2(WO_4)_3$	0.3–5.0	–	–	–	–
$Al_2SiO_4F_2$	–	1.630	1.631	1.638	0.008
Al_2SiO_5 (andalusite)	–	1.629	1.633	1.638	0.009
Al_2SiO_5 (kyanite)	–	1.712	1.720	1.727	0.015
Al_2SiO_5	–	1.653	1.654	1.669	0.023
$Al_4B_2O_9$	–	1.605	1.610	1.645	0.040
$Al_6Ge_2O_{13}$	–	1.72	–	1.758	0.046
$Al_6Si_2O_{13}$	0.21	1.642	1.644	1.654	0.012
$AlNb_{11}O_{29}$	–	2.20	–	2.22	0.02
$AlNbO_4$	–	1.985	–	2.005	0.02
As_2S_3	[2.5]	2.4	2.81	3.02	~0.6
AsS	–	2.538	2.684	2.704	0.116
$AsSbS_3$			>2.11	>2.73	>0.62
$Ba_2CaMgAl_2F_{14}$	–	1.441	1.442	1.444	0.003
$Ba_2NaNb_5O_{15}$	0.38–6.0	2.2177	2.3205	2.3222	0.1045
$BaAl_2Si_2O_8$	–	1.587	1.593	1.600	0.013
$BaBe_2Si_2O_7$	–	1.694	1.70	1.706	0.012
$BaCa_2Mg(SiO_4)_2$	–	1.731	–	1.752	0.021
$BaCa_2Si_3O_9$	–	1.668	1.684	1.685	0.017
$BaCO_3$	–	1.530	1.679	1.680	0.150
$BaMgF_4$	0.185–10	1.4496	1.4661	1.4738	0.0242
β-$BaSi_2O_5$	–	1.598	1.617	1.625	0.027
$BaSO_4$	–	1.6362	1.6373	1.6482	0.012
BaY_2F_8	0.2–9.5	1.5142	1.5232	1.5353	0.0211
Be_2BO_3F	–	1.554	1.587	1.628	0.074
$BeAl_2O_4$	–	1.746	1.748	1.756	0.010
BiB_3O_6	0.3–2.5	–	–	–	–

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Optical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Transmission (μm) [Band gap (eV)]	Refractive index n_x	Refractive index n_y	Refractive index n_z	Birefringence Δn
$Bi_2Mo_3O_{12}$	0.42–5.2 [2.9]	2.254	2.306	2.497	0.243
Bi_2O_3	[2.8]	?	2.42	?	–
Bi_2WO_6	–	–	2.2	–	–
$BiSbO_4$	–	2.04	–	2.14	0.10
$BiTaO_4$	–	–	2.35	–	–
$BiVO_4$ (puucherite)	–	2.41	2.50	2.51	0.10
$Ca(IO_3)_2$	–	1.792	1.840	1.888	0.096
β-Ca_2SiO_4	–	1.707	1.715	1.730	0.023
$Ca_2(VO_4)Cl$	–	1.835	–	1.865	0.03
$Ca_2Al_2O_5$	–	1.96	2.01	2.04	0.08
$Ca_2V_2O_7$	–	1.942	2.00	2.132	0.19
$Ca_3(VO_4)_2$	–	1.864	1.885	1.890	0.026
$Ca_3(Zr,Ti)Si_2O_9$	–	1.735	1.737	1.758	0.023
$Ca_3MgSi_2O_8$	–	1.706	1.712	1.724	0.018
$Ca_3Si_2O_7$	–	1.641	1.644	1.650	0.009
$Ca_5Al_6O_{14}$	–	1.68	1.682	1.685	0.005
$Ca_5Ga_6O_{14}$	0.255–6.5	–	–	–	–
$CaAl_2F_8$	–	1.501	1.503	1.510	0.009
$CaAl_2Si_2O_8$	–	1.577	1.585	1.590	0.013
$CaAl_4O_7$	0.23–5.1	1.6178	1.6184	1.6516	0.0338
$CaAlB_3O_7$	–	1.712	1.717	1.726	0.014
$CaAlBO_4$	–	1.558	1.585	1.614	0.056
$CaB_2Si_2O_8$	–	1.630	1.633	1.635	0.005
CaB_3O_5F	–	1.612	1.636	1.653	0.041
$CaBa(CO_3)_2$	–	1.5261	1.6710	1.6717	0.146
$CaBe(PO_4)F$	–	1.580	1.600	1.610	0.030
$CaBe_2(PO_4)_2$	–	1.595	1.601	1.604	0.009
$CaCO_3$-α	–	1.530	1.6810	1.6854	0.1554
$CaGe_2O_5$	–	1.84	–	1.88	0.04
$CaMgAsO_4F$	–	1.640	1.660	1.675	0.035
$CaMgB_2O_5$	–	1.635	1.681	1.698	0.063
$CaMgSi_2O_6$	–	1.664	1.671	1.694	0.030
$CaMgSiO_4$	–	1.641	1.649	1.655	0.014
$CaNb_2O_6$	0.3–5.5	2.07	2.10	2.19	0.12
$CaSc_2O_4$	0.3–6.5	–	–	–	–
$CaSiO_3$	–	1.615	1.627	1.629	0.014
$CaSnSiO_5$	–	1.765	1.784	1.799	0.034
$CaSO_4$	–	1.570	1.575	1.614	0.044
$CaTiSiO_5$	–	1.84	1.870	1.943	0.103
CaV_2O_6	–	1.916	1.995	2.13	0.214
$CaZnSiO_4$	–	1.767	1.770	1.774	0.007
$CaZrSi_2O_7$	–	1.720	1.736	1.738	0.018
$Cd_2B_6O_{11}$	–	1.617	1.630	–	–

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Optical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Transmission (μm) [Band gap (eV)]	Refractive index n_x	Refractive index n_y	Refractive index n_z	Birefringence Δn
CsB_3O_6	0.17–3.0	1.5294	1.5588	1.5864	0.0570
$CsNbO(SO_4)_2$	–	1.597	1.604	1.703	0.106
$CsTiOAsO_4$	0.35–5.3	1.8796	1.8961	1.9608	0.0812
β-Ga_2O_3	0.3–4.5	–	1.962	–	–
Gd_2O_3	[2.9, 933 K]	–	–	–	–
$Gd_2(MoO_4)_3$	0.32–5.2	1.8385	1.8390	1.8915	0.053
Gd_2SiO_5	0.2–5	1.871	1.884	1.910	0.039
GdP_5O_{14}	–	1.6094	1.6158	1.6298	0.0204
HfO_2	[5.5]	–	–	–	–
$HgCl_2$	–	1.725	1.859	1.965	0.240
HIO_3	0.3–1.8	2.37	2.5	2.65	0.280
$InPO_4$	–	1.608	1.618	1.623	0.015
$KAl_3Si_3O_{10}(OH)_2$	–	1.552	1.582	1.587	0.036
$KAlSi_3O_8$	–	1.518	1.520	1.523	0.005
KBF_4	–	1.324	1.325	1.325	0.001
$KB_5O_8 \cdot 4H_2O$	0.16–1.5	1.422	1.435	1.488	0.066
$KLaP_4O_{12}$	–	1.592	1.600	1.608	0.016
$KNbB_2O_6$	0.27–3.1	1.773	1.773	1.801	0.028
$KNbO_3$	0.4–4.5	2.168	2.279	2.329	0.161
KNO_3	–	1.332	1.505	1.509	0.172
KPbCl	0.3–20		n≈2		
$KTiOAsO_4$	0.35–3.0	1.8079	1.8138	1.9044	0.0965
$KTiOPO_4$	0.35–4.5 [3.5]	1.7614	1.7704	1.8636	0.1022
KVO_3	0.4–5.5	–	–	–	–
$La(BO_2)_3$	–	1.694	1.769	1.791	0.097
$La_2Be_2O_5$	0.3–4	1.9641	1.9974	2.0348	0.071
$La_2Ti_2O_7$	–	2.17	2.24	2.265	0.095
$LaBO_3$	–	1.800	1.877	1.882	0.082
LaP_5O_{14}	–	1.5956	1.6015	1.6145	0.0189
$LaPO_4$	–	1.774	1.77	1.828	0.054
Li_2BeSiO_4	–	1.622	1.633	1.638	0.016
Li_2CO_3	–	1.430	1.567	1.570	0.140
Li_2GeO_3	–	?	1.686	?	–
Li_3PO_4	–	1.550	1.557	1.566	0.016
Li_3VO_4	0.32 –	–	–	–	–
$LiAl(PO_4)F$	–	1.575	1.587	1.590	0.015
$LiAlSi_2O_6$	–	1.648	1.655	1.662	0.014
$LiAlSi_4O_{10}$	–	1.504	1.510	1.516	0.012
LiB_3O_5	0.16–2.6	1.5742	1.6014	1.6163	0.0421
$LiBO_2$	–	1.540	1.612	1.616	0.076
$LiGaO_2$	0.25–6	1.730	1.758	1.761	0.031
$LiVO_3$	0.5–5.5	1.850	1.970	2.13	0.28
Lu_2SiO_5	0.2–5	1.797	1.803	1.825	0.028

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Optical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Transmission (μm) [Band gap (eV)]	Refractive index n_x	Refractive index n_y	Refractive index n_z	Birefringence Δn
LuP_5O_{14}	–	1.5950	1.6072	1.6125	0.0175
$Mg_2(PO_4)F$	–	1.569	1.570	1.580	0.011
$Mg_2B_2O_5$	–	1.596	1.639	1.670	0.074
Mg_2GeO_4	–	1.698	1.717	1.765	0.067
Mg_2SiO_4	–	1.635	1.651	1.670	0.035
$Mg_3(PO_4)_2$	–	1.540	1.544	1.559	0.015
$Mg_3B_2O_6$	–	1.652	1.653	1.673	0.021
$Mg_3B_7O_{13}Cl$	–	1.658	1.662	1.668	0.010
$Mg_3TiB_2O_8$	–	1.806	1.809	1.830	0.024
$Mg_4Al_8Si_2O_{20}$	–	1.701	1.703	1.705	0.004
$Mg_5(BO_3)_3F$	–	1.614	1.623	1.648	0.034
Mg_2SiO_4	–	1.635	1.651	1.670	0.035
$MgAl_3BSiO_9$	–	1.590	1.618	1.623	0.033
$MgAlBO_4$	–	1.667	1.697	1.705	0.038
$MgMoO_4$	–	1.82	1.83	1.84	0.02
$MgSiO_3$	–	1.654	1.655	1.665	0.011
$Na_2BaTi_2Si_4O_{14}$	–	1.727	1.732	1.789	0.062
$Na_2BeSi_2O_6$	–	1.544	1.549	1.549	0.005
$Na_2Ca(PO_4)F$	–	1.508	1.515	1.520	0.012
$Na_2CaMg(PO_4)_2$	–	1.598	1.605	1.608	0.010
Na_2MgAlF_7	–	1.346	1.348	1.350	0.004
Na_2MgSiO_4	–	1.534	1.536	1.543	0.009
$Na_2Si_2O_5$	–	1.507	1.517	1.521	0.014
$Na_2Ti_2Si_2O_9$	–	1.91	2.01	2.03	0.12
Na_3AlF_6	–	1.338	1.338	1.339	0.001
$NaAl(AsO_4)F$	–	1.634	1.672	1.685	0.051
$NaAl(PO_4)F$	–	1.545	1.554	1.565	0.020
$NaAlSi_3O_8$	–	1.527	1.531	1.538	0.011
$NaBe_2BO_3F_2$	~0.15–	1.370	1.474	1.474	0.104
$NaBePO_4$	–	1.552	1.558	1.561	0.009
$NaBF_4$	–	1.301	1.3012	1.3068	0.0058
$NaCaPO_4$	–	1.607	1.610	1.616	0.009
$NaMgF_3$	–	–	1.364	–	–
$NaNbO_3$	–	2.10	2.19	2.21	0.11
$NaScSi_2O_6$	–	1.683	1.715	1.724	0.041
$NaSr_3Al_3F_{16}$	–	1.429	1.433	1.436	0.007
$NaVO_3$	0.4–5.5	–	–	–	–
$NaZnF_3$	–	–	1.440	–	–
$NH_4B_5O_8{\bullet}4H_2O$	–	1.42	1.43	1.48	0.06
$Pb_2KNb_5O_{15}$	—	2.39	2.445	2.46	0.07
$Pb_2V_2O_7$	–		2.2–2.6		0.279
$PbBr_2$	0.36–30 [3.3]	–	–	–	–
$PbCl_2$	0.35–20	2.1992	2.2172	2.2596	0.0604

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Optical Properties of Biaxial Crystalline Materials—*continued*

Biaxial material	Transmission (μm) [Band gap (eV)]	Refractive index n_x	Refractive index n_y	Refractive index n_z	Birefringence Δn
$PbCO_3$	–	1.803	2.074	2.076	0.273
PbO (massicot)	[1.7]	2.51	2.61	2.71	0.200
$PbSeO_3$	–	2.12	2.14	2.14	0.02
$PbSeO_4$	–	1.96	1.97	1.98	0.02
$PbSiO_3$	–	1.947	1.961	1.968	0.021
$PbSO_4$	–	1.878	1.883	1.895	0.017
$PbZnSiO_4$	–	1.91	1.95	1.96	0.05
$RbNbB_2O_6$	0.27–3.0	1.751	1.771	1.795	0.044
$RbTiOAsO_4$	0.35–5.3	1.8294	1.838	1.9186	0.0892
$RbTiOPO_4$	0.35–4.3	1.7884	1.7992	1.8859	0.0975
Sb_2O_3	–	2.18	2.35	2.35	0.17
$SbNbO_4$	–	2.3977	2.4190	2.4588	0.061
$SbTaO_4$	–	2.3742	2.4039	2.4568	0.083
$Sc_2(WO_4)_3$	0.3–5.0	1.728	1.754	1.755	0.027
$Sc_2Si_2O_7$	–	1.754	1.785	1.803	0.049
Sc_2SiO_5	–	1.835	?	1.850	–
$(Sc,Y)_2Si_2O_7$	–	1.756	1.793	1.809	0.053
$Sr_2(VO_4)Cl$	–	1.785	–	1.816	0.03
$Sr_2Nb_2O_7$	–	1.85	2.044	2.05	0.20
$SrAl_2O_4$	–	1.638	–	1.656	0.018
$SrAl_4O_7$	0.2–5.5	1.620	1.636	1.644	0.024
SrB_2O_4	–	1.632	1.650	1.660	0.028
$SrCO_3$	–	1.517	1.663	1.667	0.150
$SrGa_2O_4$	–	1.737	–	1.767	0.03
$SrSO_4$	–	1.6215	1.6237	1.6308	0.0057
$SrZrO_3$	0.28–7.7	–	–	–	–
Ta_2O_5	[4.6]	–	–	–	–
TeO_2	0.33–5.0 [3]	2.00	2.18	2.35	0.35
V_2O_5	[~2.3]	2.42	?	–	–
Y_2BeO_4	–	1.840	–	1.855	0.015
$Y_2MgBe_2Si_2O_{10}$	–	1.78	1.80	1.82	0.04
$Y_2Si_2O_7$	–	1.731	1.738	1.744	0.013
Y_2SiO_5	0.2–5	1.780	1.784	1.811	0.031
$Y_4Al_2O_9$	–	1.826	1.830	1.832	0.006
$YAlO_3$	0.2–7	1.9243	1.9387	1.9478	0.0235
$Zn_3(AsO_3)_2$	–	1.74	1.79	1.82	0.08
ZrO_2	–	2.13	2.19	2.20	0.07

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1.3.4 Dispersion Formulas for Refractive Indices

Dispersion formulas for the refractive indices of crystals at room temperature are given in the following pages. Tabulated values of refractive indices at many wavelengths are given in Refs. 1–4 for most of the crystals below. Dispersion formulas for several organic materials are given in Refs. 1 and 3.

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Dispersion Formulas for Refractive Indices

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
Ag_3AsS_3	$n_o^2 = 7.483 + 0.474/(\lambda^2 - 0.09) - 0.0019\lambda^2$ $n_e^2 = 6.346 + 0.342/(\lambda^2 - 0.09) - 0.0011\lambda^2$	0.63–4.6 0.59–4.6	5
	$n_o^2 = 9.220 + 0.4454\lambda^2/(\lambda^2 - 0.1264) + 1733\lambda^2/(\lambda^2 - 1000)$ $n_e^2 = 7.007 + 0.3230\lambda^2/(\lambda^2 - 0.1192) + 660\lambda^2/(\lambda^2 - 1000)^2$	0.6–20	5
AgBr	$(n^2 - 1)/(n^2 - 2) = 0.452505 + 0.09939/(\lambda^2 - 0.070537) - 0.001509\lambda^2$	0.49–0.67	6
AgCl	$(n^2 - 1) = 2.062508\lambda^2/[\lambda^2 - (0.1039054)^2] + 0.9461465\lambda^2/[\lambda^2 - (0.2438691)^2] + 4.300785\lambda^2/[\lambda^2 - (70.85723)^2]$	0.54–21.0	7
$AgGaS_2$	$n_o^2 = 3.6280 + 2.1686\lambda^2/(\lambda^2 - 0.1003) + 2.1753\lambda^2/(\lambda^2 - 950)$ $n_e^2 = 4.0172 + 1.5274\lambda^2/(\lambda^2 - 0.1310) + 2.1699\lambda^2/(\lambda^2 - 950)$	0.49–12	8
$AgGaSe_2$	$n_o^2 = 4.6453 + 2.2057\lambda^2/(\lambda^2 - 0.1897) + 1.8377\lambda^2/(\lambda^2 - 1600)$ $n_e^2 = 5.2912 + 1.3970\lambda^2/(\lambda^2 - 0.2845) + 1.9282\lambda^2/(\lambda^2 - 1600)$	0.73–13.5	8
β-AgI	no = 2.184; n_e = 2.200 @ 0.659 μm n_o = 2.104; n_e = 2.115 @ 1.318 μm	—	9
Ag_3SbS_3	$n_o^2 = 1 + 6.585\lambda^2/[\lambda^2 - (0.4)^2] + 0.1133\lambda^2/[\lambda^2 - (15)^2]$ $n_e^2 = 1 + 5.845\lambda^2/[\lambda^2 - (0.4)^2] + 0.0202\lambda^2/[\lambda^2 - (15)^2]$	1.5–10.6	10
Al_2O_3	$n_o^2 = 1 + 1.43134936\lambda^2/[\lambda^2 - (0.0726631)^2] + 0.65054713\lambda^2/[\lambda^2 - (0.1193242)^2] + 5.3414021\lambda^2/[\lambda^2 - (18.028251)^2]$ $n_e^2 = 1 + 1.5039759\lambda^2/[\lambda^2 - (0.0740288)^2] + 0.55069141\lambda^2/[\lambda^2 - (0.1216529)^2] + 6.59273791\lambda^2/[\lambda^2 - (20.072248)^2]$	0.22–5.0	13
AlAs	$n^2 = 2.0729 + 6.0840\lambda^2/[\lambda^2 - 0.2822)^2] + 1.900\lambda^2/[\lambda^2 - 27.62)^2]$	0.56–2.2	11
AlN	$n_o^2 = 3.1399 + 1.3786\lambda^2/[\lambda^2 - (0.1715)^2] + 3.861\lambda^2/[\lambda^2 - (15.03)^2]$ $n_e^2 = 3.0729 + 1.6173\lambda^2/[\lambda^2 - (0.1746)^2] + 4.139\lambda^2/[\lambda^2 - (15.03)^2]$	0.22–5.0	12
ALON	$n^2 - 1 = 2.1375\lambda^2/[\lambda^2 - (0.10256)^2] + 4.582\lambda^2/[\lambda^2 - (18.868)^2]$	0.4–2.3	14

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BaB_2O_4	$n_o^2 = 2.7405 + 0.0184/(\lambda^2 - 0.0179) - 0.0155\lambda^2$ $n_e^2 = 2.3730 + 0.0128/(\lambda^2 - 0.0156) - 0.0044\lambda^2$	0.22–1.06	15
BaF_2	$n_o^2 = 1 + 0.643356\lambda^2/[\lambda^2 - (0.057789)^2] + 0.506762\lambda^2/[\lambda^2 - (0.10968)^2] + 3.8261^2/[\lambda^2 - (14.3864)^2]$	0.27–10.3	16
$BaTiO_3$	$n_o^2 = 1 + 4.187\lambda^2/[\lambda^2 - (0.223)^2]$ $n_e^2 = 1 + 4.064\lambda^2/[\lambda^2 - 0.211)^2]$	0.4–0.7	17
$BaMgF_4$	$n_x^2 = 2.1462 + 0.00736\lambda^2/(\lambda^2 - 0.0090)$ $n_y^2 = 2.007 + 0.0076\lambda^2/(\lambda^2 - 0.00799)$ $n_z^2 = 2.1238 + 0.0086\lambda^2/(\lambda^2 - 0)$	0.53–1.06	18
$Ba_2NaNb_5O_{12}$	$n_x^2 = 1 + 3.6008\lambda^2/(\lambda^2 - 0.032199)$ $n_y^2 = 1 + 3.9495\lambda^2/(\lambda^2 - 0.040140)$ $n_z^2 = 1 + 3.9495\lambda^2/(\lambda^2 - 0.040389)$	0.46–1.06	19, 20
BeO	$n_o^2 = 1 + 1.92274\lambda^2/[\lambda^2 - (0.07908)^2] + 1.24209\lambda^2/[\lambda^2 - (9.7131)^2]$ $n_e^2 = 1 + 1.96939\lambda^2/[\lambda^2 - (08590)^2] + 1.67389\lambda^2/[\lambda^2 - (10.4797)^2]$	0.44–7.0	38, 50
BiB_3O_6	$n_x^2 = 3.6545 + 0.0511\lambda^2/(\lambda^2 - 0.0371) - 0.0226\lambda^2$ $n_y^2 = 3.0740 + 0.03233\lambda^2/(\lambda^2 - 0.0316) - 0.01337\lambda^2$ $n_z^2 = 3.1685 + 00373\lambda^2/(\lambda^2 - 0.0346) - 0.01750\lambda^2$		117
$Bi_4Ge_3O_{12}$	$n^2 = 1 + 3.08959\lambda^2/(\lambda^2 - 0.01337)$	0.48–1.06	21
$Bi_{12}GeO_{20}$	$n^2 = 1 + 4.601\lambda^2/[\lambda^2 - (0.242)^2]$	0.48–0.7	22, 32
$Bi_{12}SiO_{20}$	$n^2 = 2.72777 + 3.01705\lambda^2/[\lambda^2 - (0.266)^2]$	0.4–0.7	23
BP	$n^2 = 1 + 6.841\lambda^2/[\lambda^2 - (0.267)^2]$	0.48–0.7	24
C (diamond)	$n^2 = 1 + 4.3356\lambda^2/[\lambda^2 - (0.1.60)^2] + 0.3306\lambda^2/[\lambda^2 - (0.1750)^2]$	0.225–∞	29

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
$Ca_2Al_2SiO_7$	$n_o^2 = 1 + 1.712/(\lambda^2 - 0.0196)$ $n_e^2 = 1 + 1.687/(\lambda^2 - 0.01133)$	0.31–1.06	26
$Ca_5(PO_4)_3F$	$n_o^2 = 2.626769 + 0.014626/(\lambda^2 - 0.012833) - 0.007653\lambda^2$ $n_e^2 = 2.620175 + 0.014703/(\lambda^2 - 0.011037) - 0.007544\lambda^2$	0.4–1.0	27
$CaCO_3$	$n_o = 1 + 0.8559\lambda^2/[\lambda^2 - (0.0588)^2] + 0.83913\lambda^2/[\lambda^2 - (0.141)^2] + 0.0009\lambda^2/[\lambda^2 - (0.197)^2] + 0.6845\lambda^2/[\lambda^2 - (7.005)^2]$ $n_e = 1 + 1.0856\lambda^2/[\lambda^2 - (0.07897)^2] + 0.0988\lambda^2/[\lambda^2 - (0.142)^2] + 0.317\lambda^2/[\lambda^2 - (1.468)^2]$	0.2–2.2	28
CaF_2	$n^2 = 1 + 0.5675888\lambda^2/[\lambda^2 - (0.050263605)^2] + 0.4710914\lambda^2/[\lambda^2 - (0.1003909)^2] + 3.8484723\lambda^2/[\lambda^2 - (34.649040)^2]$	0.23–9.7	45
$CaMoO_4$	$n_o^2 = 1 + 2.7840\lambda^2/[\lambda^2 - (0.1483)^2] + 1.2425\lambda^2/[\lambda^2 - (11.576)^2]$ $n_e^2 = 1 + 2.8045\lambda^2/[\lambda^2 - (0.1542)^2] + 1.0055\lambda^2/[\lambda^2 - (10.522)^2]$	0.45–3.8	30, 50
$CaWO_4$	$n_o^2 = 1 + 2.5493\lambda^2/[\lambda^2 - (0.1347)^2] + 0.9200\lambda^2/[\lambda^2 - (10.815)^2]$ $n_e^2 = 1 + 2.6041\lambda^2/[\lambda^2 - (0.11379)^2] + 4.1237\lambda^2/[\lambda^2 - (21.371)^2]$	0.45– 4.0	30, 50
$CdGeAs_2$	$n_o^2 = 10.1064 + 2.2988\lambda^2/(\lambda^2 - 1.0872) + 1.6247\lambda^2/(\lambda^2 - 1370)$ $n_e^2 = 11.8018 + 1.2152\lambda^2/(\lambda^2 - 2.6971) + 1.6922\lambda^2/(\lambda^2 - 1370)$	2.4–11.5	8
$CdGeP_2$	$n_o^2 = 5.9677 + 4.2286\lambda^2/(\lambda^2 - 0.2021) + 1.6351\lambda^2/(\lambda^2 - 671.33)$ $n_e^2 = 61573 + 4.0970\lambda^2/(\lambda^2 - 0.2330) + 1.4925\lambda^2/(\lambda^2 - 671.33)$	5.5–12.5	31
CdS	$n_o^2 = 1 + 3.96582820\lambda^2/[\lambda^2 - (0.23622804)^2] + 0.18113874\lambda^2/[\lambda^2 - (0.48285199)^2]$ $n_e^2 = 1 + 3.97478769\lambda^2/[\lambda^2 - (0.22426984)^2] + 0.26680809\lambda^2/[\lambda^2 - (0.46693785)^2]$ $+0.00074077\lambda^2/[\lambda^2 - (0.50915139)^2]$	0.51–1.4	93
CdSe	$n_o^2 = 4.2243 + 1.7680\lambda^2/(\lambda^2 - 0.2270) + 3.1200\lambda^2/(\lambda^2 - 3380)$ $n_e^2 = 4.2009 + 1.8875\lambda^2/(\lambda^2 - 0.2171) + 3.6461\lambda^2/(\lambda^2 - 3629)$	1–12	8

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CdTe	$n^2 = 1 + 6.1977889\lambda^2/[\lambda^2 - (0.317069)^2] + 3.22438216\lambda^2/[\lambda^2 - (72.0663)^2]$	6–22	33
CsB_3O_5	$n_x^2 = 2.2916 + 0.02105\lambda^2/(\lambda^2 - 0.06525) - 0.000031848\lambda^2$ $n_y^2 = 3.34498 + 1.04863\lambda^2/(\lambda^2 - 0.22044) - 0.01483\lambda^2$ $n_z^2 = 3.53666 + 1.10600\lambda^2/(\lambda^2 - 0.24988]) - 0.01711\lambda^2$	0.35–1.06	117
CsBr	$n^2 = 1 + 0.9533786\lambda^2/[\lambda^2 - (0.0905643)^2] + 0.8303809\lambda^2/[\lambda^2 - (0.1671517)^2] + 2.847172\lambda^2/[\lambda^2 - (119.0155)^2]$	0.36–39	34
CsCl	$n^2 = 1.33013 + 0.98369\lambda^2/[\lambda^2 - (0.119)^2] + 0.00009\lambda^2/[\lambda^2 - (0.137)^2] + 0.00018\lambda^2/[\lambda^2 - (145)^2]$ $+ 0.30914\lambda^2/[\lambda^2 - (0.162)^2] + 4.320\lambda^2/[\lambda^2 - (100.50)^2]$	0.18–40	35
CsD_2AsO_4	$n_o^2 = 1 + 1.40840\lambda^2/(\lambda^2 - 0.01299)$ $n_e^2 = 1 + 1.34731\lambda^2/(\lambda^2 - 0.01185)$	0.35–1.06	36
CsH_2AsO_4	$n_o^2 = 1 + 1.39961\lambda^2/(\lambda^2 - 0.01156)$ $n_e^2 = 1 + 1.34417\lambda^2/(\lambda^2 - 0.01155)$	0.35–1.06	36
CsI	$n^2 = 1 + 0.34617251\lambda^2/[\lambda^2 - (0.0229567)^2] + 1.0080886\lambda^2/[\lambda^2 - (0.1466)^2] + 0.28551800\lambda^2/[\lambda^2 - (0.1830)^2]$ $+ 0.39743178\lambda^2/[\lambda^2 - (0.2120)^2] + 3.3605359\lambda^2/[\lambda^2 - (161.0)^2]$	0.29–50	37
$CsLiB_6O_{10}$	$n_o^2 = 2.2049 + 0.0110259/(\lambda^2 - 0.0118119) - 0.0000695625\lambda^2$ $n_e^2 = 2.05936 + 0.00864948/(\lambda^2 - 0.0128929) - 0.0000267532\lambda^2$	0.24–0.63	118
	$n_o^2 = 2.14318 + 0.0158749/(\lambda^2 + 1.37559) - 0.00062375\lambda^2$ $n_e^2 = 2.04195 + 0.0273245/(\lambda^2 + 0.286672) - 0.000342718\lambda^2$	0.63–1.06	
$CsTiOAsO_4$	$n_x^2 = 3.74440 + 0.70733\lambda^2/(\lambda^2 - 0.26033) - 0.01526\lambda^2$ $n_y^2 = 3.34498 + 1.04863\lambda^2/(\lambda^2 - 0.22044) - 0.01483\lambda^2$ $n_z^2 = 3.53666 + 1.10600\lambda^2/(\lambda^2 - 0.24988) - 0.01711\lambda^2$	0.45–1.55	91
CuCl	$n^2 = 3.580 + 0.03162\lambda^2/(\lambda^2 - 0.1642) + 0.09288/\lambda^2$	0.43–2.5	25
$CuGaS_2$	$n_o^2 = 3.9064 + 2.3065\lambda^2/(\lambda^2 - 0.1149) + 1.5479\lambda^2/(\lambda^2 - 738.43)$ $n_e^2 = 4.3165 + 1.8692\lambda^2/(\lambda^2 - 0.1364) + 1.7575\lambda^2/(\lambda^2 - 738.43)$	0.55–11.5	39, 116

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
$CuGaS_2$	$n_o^2 = 3.9064 + 2.3065\lambda^2/(\lambda^2 - 0.1149) + 1.5479\lambda^2/(\lambda^2 - 738.43)$ $n_e^2 = 4.3165 + 1.8692\lambda^2/(\lambda^2 - 0.1364) + 1.7575\lambda^2/(\lambda^2 - 738.43)$	0.55–11.5	39, 116
GaAs	$n^2 = 3.5 + 7.4969\lambda^2/(\lambda^2 - 0.4082) + 1.9347\lambda^2/[(\lambda^2 - 37.17)^2]$	0.43–2.5	41
α-GaN	$n_o^2 = 3.6 + 1.75\lambda^2/[\lambda^2 - (0.256)^2] + 4.1\lambda^2/[\lambda^2 - (17.86)^2]$ $n_e^2 = 5.35 + 5.08\lambda^2/[\lambda^2 - (18.76)^2] + 1.0055\lambda^2/[\lambda^2 - (10.522)^2]$	<10	42
GaP	$n^2 = 1 + 1.390\lambda^2/[\lambda^2 - (0.172)^2] + 4.131\lambda^2/[\lambda^2 - (0.234)^2] + 2.570\lambda^2/[\lambda^2 - (345)^2] + 2.056\lambda^2/[\lambda^2 - (27.52)^2]$	0.8–10	43
GaSe	$n_o^2 = -0.05466\lambda^{-4} + 0.48605\lambda^{-2} + 7.8902 - 0.00824\lambda^2 - 0.00000276\lambda^4$ $n_e^2 = 6.0476 + 0.3423\lambda^2/(\lambda^2 - 0.16491) - 0.001042\lambda^2$	—	44
$Gd_2(MoO_4)_3$	$n_x^2 = 1 + 2.2450\lambda^2/(\lambda^2 - 0.022693)$ $n_y^2 = 1 + 2.24654\lambda^2/(\lambda^2 - 0.0226803)$ $n_z^2 = 1 + 2.41957\lambda^2/(\lambda^2 - 0.0245458)$	0.46–1.06	102
$Gd_3Ga_5O_{12}$	$n^2 = 3.749719 + 1.7083005/(39.509089\lambda^2 - 1) + 0.01048372\lambda^2/(0.001855744\lambda^2 - 1)$	0.40–1.06	46
$Gd_3Sc_2Al_3O_{12}$	$n^2 = 1 + 2.510\lambda^2/(\lambda^2 - 0.01537)$	0.54–0.64	47
$Gd_3Sc_2Ga_3O_{12}$	$n^2 = 3.743782 + 1.9139566/(43.240392\lambda^2 - 1) + 0.01067490\lambda^2/(0.01558170\lambda^2 - 1)$	0.40–1.06	48
Ge	$n^2 = 9.28156 + 6.72880\lambda^2/(\lambda^2 - 0.44105) + 0.21307\lambda^2/(\lambda^2 - 3870.1)$	2–12	49, 120
α–HgS	$n_o^2 = 6.9443 + 0.3665/(\lambda^2 - 0.1351) - 0.0019\lambda^2$ $n_e^2 = 8.3917 + 0.5405/(\lambda^2 - 0.1380) - 0.0027\lambda^2$	0.62–11	51
InAs	$n^2 = 11.1 + 0.71\lambda^2/[\lambda^2 - (2.551)^2] + 2.75\lambda^2/[\lambda^2 - (44.66)^2]$	3.7–31.3	
InP	$n^2 = 7.255 + 2.316\lambda^2/[\lambda^2 - (0.6263)^2] + 2.765\lambda^2/[\lambda^2 - (32.935)^2]$	0.95–10	53, 122

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$KB_5O_8 \cdot 4H_2O$	$n_x^2 = 1 + 1/(0.852497 - 0.0087588\lambda^2)$ $n_y^2 = 1 + 1/(0.972682 - 0.0087757\lambda^2)$ $n_z^2 = 1 + 1/(1.008157 - 0.0094050\lambda^2)$	0.23–0.76	54, 121
KBr	$n^2 = 1.39408 + 0.79221\lambda^2/[\lambda^2 - (0.146)^2] + 0.01981\lambda^2/[\lambda^2 - (0.173)^2] + 0.15587\lambda^2/[\lambda^2 - (0.187)^2]$ $+ 0.17673\lambda^2/[\lambda^2 - (60.61)^2] + 2.06217\lambda^2/[\lambda^2 - (87.72)^2]$	0.2–40	35
KCl	$n^2 = 1.26486 + 0.30523\lambda^2/[\lambda^2 - (0.100)^2] + 0.41620\lambda^2/[\lambda^2 - (0.131)^2] + 0.18870\lambda^2/[\lambda^2 - (0.162)^2]$ $+ 2.6200\lambda^2/[\lambda^2 - (70.42)^2]$	0.18–35	35
KF	$n^2 = 1.55083 + 0.29162\lambda^2/[\lambda^2 - (0.126)^2] + 3.60001\lambda^2/[\lambda^2 - (51.55)^2]$	0.15–22	35
KD_2PO_4	$n_o^2 = 1 + 1.2392348\lambda^2/(\lambda^2 - 0.83531147) + 14.78889\lambda^2/(\lambda^2 - 0.8851187)$ $n_e^2 = 1 + 1.125324\lambda^2/(\lambda^2 - 0.78980364) + 7.124567\lambda^2/(\lambda^2 - 1.190864)$	0.4–1.06	55, 56
KH_2AsO_4	$n_o^2 = 1 + 1.411981\lambda^2/(\lambda^2 - 1.1955269) + 28.100751\lambda^2/(\lambda^2 - 1.00681)$ $n_e^2 = 1 + 1.260916\lambda^2/(\lambda^2 - 1.1188613) + 5.258787\lambda^2/(\lambda^2 - 1.055210)$	0.4–1.06	55, 56
KH_2PO_4	$n_o^2 = 1 + 1.256618\lambda^2/(\lambda^2 - 0.84478168) + 33.89909\lambda^2/(\lambda^2 - 1.113904)$ $n_e^2 = 1 + 1.131091\lambda^2/(\lambda^2 - 0.8145980) + 5.75675\lambda^2/(\lambda^2 - 0.8117537)$	0.4–1.06	56
KI	$n^2 = 1.47285 + 0.16512\lambda^2/[\lambda^2 - (0.129)^2] + 0.41222\lambda^2/[\lambda^2 - (0.175)^2] + 0.44163\lambda^2/[\lambda^2 - (0.187)^2]$ $+ 0.16076\lambda^2/[\lambda^2 - (0.219)^2] + 0.33571\lambda^2/[\lambda^2 - (69.44)^2] + 1.92474\lambda^2/[\lambda^2 - (98.04)^2]$	0.25–50	35
$K_3Li_2Nb_5O_{15}$	$n_o^2 = 1 + 3.708\lambda^2/(\lambda^2 - 0.04601)$ $n_e^2 = 1 + 3.349\lambda^2/(\lambda^2 - 0.03564)$	0.45–0.68	57
$KNbO_3$	$n_x^2 = 1 + 2.49710\lambda^2/([\lambda^2 - (0.12909)^2] + 1.33660\lambda^2/[\lambda^2 - (0.25816)^2] - 0.025174\lambda^2$ $n_y^2 = 1 + 2.54337\lambda^2/([\lambda^2 - (0.13701)^2] + 1.44122\lambda^2/[\lambda^2 - (0.27275)^2] - 0.028450\lambda^2$ $n_z^2 = 1 + 2.37108\lambda^2/([\lambda^2 - (0.11972)^2] + 1.04825\lambda^2/[\lambda^2 - (0.25523)^2] - 0.019433\lambda^2$	0.40–3.4	59
$KTaO_3$	$n^2 = 1 + 3.591\lambda^2/([\lambda^2 - (0.193)^2]$	0.4–1.06	60

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
$KTiAsO_4$	$n_x^2 = 2.388887 + 0.77900\lambda^2/(\lambda^2 - (0.23784)^2 - 0.01501\lambda^2$ $n_y^2 = 2.11055 + 1.03177\lambda^2/[\lambda^2 - (0.21088)^2 - 0.01064\lambda^2$ $n_z^2 = 2.34723 + 1.10111\lambda^2/(\lambda^2 - (0.24016)^2 - 0.01739\lambda^2$	0.45–1.55	58, 91
$KTiOPO_4$	$n_x^2 = 2.16747 + 0.83733\lambda^2/([\lambda^2 - (0.04611)^2] - 0.01713\lambda^2$ $n_y^2 = 2.19229 + 0.83547\lambda^2/([\lambda^2 - (0.04970)^2] - 0.01621\lambda^2$ $n_z^2 = 2.25411 + 1.06543\lambda^2/([\lambda^2 - (0.05486)^2] - 0.02140\lambda^2$	0.4–1.06	61–64
$LaCl_3$	$n_o^2 = 1 + 2.235\lambda^2/(\lambda^2 - (0.01734)$ $n_e^2 = 1 + 2.469\lambda^2/(\lambda^2 - (0.017674)$	0.49–0.63	65
LaF_3	$n_o^2 = 1 + 1.53763\lambda^2/([\lambda^2 - (0.0881)^2]$ $n_e^2 = 1 + 1.5148\lambda^2/([\lambda^2 - (0.08781)^2]$	0.35–0.70	66
$La_2Be_2O_5$	$n_x^2 = 1 + 2.7990\lambda^2/(\lambda^2 + 0.01875)$ $n_y^2 = 1 + 2.9268\lambda^2/(\lambda^2 - 0.01918)$ $n_z^2 = 1 + 3.0725\lambda^2/(\lambda^2 - 0.01950)$	0.6–2	67
LiB_3O_5	$n_x^2 = 2.45768 + 0.0098877\lambda^2/([\lambda^2 - (0.026095)^2] - 0.013847\lambda^2$ $n_y^2 = 2.52500 + 0.017123\lambda^2/([\lambda^2 - (0.0060517)^2] - 0.0087838\lambda^2$ $n_z^2 = 2.58488 + 0.012737\lambda^2/([\lambda^2 - (0.016293)^2] - 0.016293\lambda^2$	0.29–1.06	68
$LiCaAlF_6$	$n_o^2 = 1.92552 + 0.00492/(\lambda^2 - 0.00569) - 0.00421\lambda^2$ $n_e^2 = 1.92155 + 0.00494/(\lambda^2 - 0.00617) - 0.00373\lambda^2$	0.4–1.0	69
LiF	$n^2 = 1 + 0.92549\lambda^2/[\lambda^2 - (0.7376)^2] + 6.96747\lambda^2/[\lambda^2 - (32.79)^2]$	0.1–10	35
$LiIO_3$	$n_o^2 = 2.03132 + 1.37623\lambda^2/(\lambda^2 - 0.0350823) + 1.06745\lambda^2/(\lambda^2 - 169.0)$ $n_e^2 = 1.83086 + 1.08807\lambda^2/(\lambda^2 - 0.0313810) + 0.554582\lambda^2/(\lambda^2 - 158.76)$	0.5–5	71

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$LiNbO_3$	$n_o^2 = 2.39198 + 2.51118\lambda^2/[\lambda^2 - (0.217)^2] + 7.1333\lambda^2/[\lambda^2 - (16.502)^2]$ $n_e^2 = 2.32468 + 2.25650\lambda^2/[\lambda^2 - (0.210)^2] + 14.503\lambda^2/[\lambda^2 - (25.915)^2]$	0.4–3.1	72
$LiSrAlF_6$	$n_o^2 = 1.97673 + 0.00309/(\lambda^2 - 0.00935) - 0.00828\lambda^2$ $n_e^2 = 1.98448 + 0.00235/(\lambda^2 - 0.10936) - 0.01057\lambda^2$	0.4–1.2	73
$LiYF_4$	$n_o^2 = 1.38757 + 0.70757\lambda^2/(\lambda^2 - 0.00931) + 0.18849\lambda^2/(\lambda^2 - 50.99741)$ $n_e^2 = 1.31021 + 0.84903\lambda^2/(\lambda^2 - (0.00876)^2 + 0.53607\lambda^2/(\lambda^2 - 134.9566)^2$	0.23–2.6	74
$Lu_3Al_5O_{12}$	$n^2 = 3.3275151 - 0.0149248\lambda^2 + 0.0178355\lambda^{-2} + 0.0046614\lambda^{-4} - 0.0009334\lambda^{-6} + 0.0000737\lambda^{-8}$	0.44–1.2	75
$MgAl_2O_4$	$n^2 = 1 + 1.8938\lambda^2/[\lambda^2 - (0.09942)^2] + 3.0755\lambda^2/[\lambda^2 - (15.826)^2]$	0.35–5.5	50, 76
MgF_2	$n_o^2 = 1 + 0.48755108\lambda^2/[\lambda^2 - (0.04338408)^2] + 0.39875031\lambda^2/[\lambda^2 - (0.09461442)^2] + 2.3120353\lambda^2/[\lambda^2 - (23.793604)^2]$ $n_e^2 = 1 + 0.41344023^2/[\lambda^2 - (0.03684262)^2] + 0.50497499\lambda^2/[\lambda^2 - (0.09076162)^2] + 2.4904862\lambda^2/[\lambda^2 - (12.771995)^2]$	0.4–3.1	77
MgO	$n^2 = 1 + 1.111033\lambda^2/[\lambda^2 - (0.0712465)^2] + 0.8460085\lambda^2/[\lambda^2 - (0.1375204)^2] + 7.808527\lambda^2/[\lambda^2 - (26.89302)^2]$	0.36–5.4	78
$NaBr$	$n^2 = 1.06728 + 1.10463\lambda^2/[\lambda^2 - (0.125)^2] + 0.18816\lambda^2/[\lambda^2 - (0.145)^2] + 0.00243\lambda^2/[\lambda^2 - (0.176)^2] + 0.24454\lambda^2/[\lambda^2 - (0.188)^2] + 3.7960\lambda^2/[\lambda^2 - (74.63)^2]$	0.21–34	35
$(Na,Ca)(Mg,Fe)_3B_3Al_6Si_6(O,OH,F)_{31}$ (tourmaline)	$n_o^2 = 1 + 1.6346\lambda^2/(\lambda^2 - 0.010734)$ $n_e^2 = 1 + 1.57256\lambda^2/(\lambda^2 - 0.011346)$	0.48–1.06	79
$NaBrO_3$	$n^2 = 1 + 1.3194\lambda^2/[\lambda^2 - (0.09)^2] + 0.2357\lambda^2/[\lambda^2 - (0.2)^2] - 0.0174\lambda^2$	—	80
$NaCl$	$n^2 = 1.00055 + 0.19800\lambda^2/[\lambda^2 - (0.050)^2] + 0.48398\lambda^2/[\lambda^2 - (0.100)^2] + 0.38696\lambda^2/[\lambda^2 - (0.128)^2] + 0.25998\lambda^2/[\lambda^2 - (0.158)^2] + 0.08796\lambda^2/[\lambda^2 - (40.50)^2] + 3.17064\lambda^2/[\lambda^2 - (60.98)^2] + 0.30038\lambda^2/[\lambda^2 - (120.34)^2]$	0.2–30	35
$NaClO_3$	$n^2 = 1 + 1.1825\lambda^2/[\lambda^2 - (0.09)^2] + 0.07992\lambda^2/[\lambda^2 - (0.185)^2] - 0.00864\lambda^2$	0.23–0.72	81
NaF	$n^2 = 1.41572 + 0.32785\lambda^2/[\lambda^2 - (0.117)^2] + 3.18248\lambda^2/[\lambda^2 - (40.57)^2]$	0.15–17	35

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
$[NH_4]_2CO$	$n_o^2 = 2.1823 + 0.0125\lambda^2/(\lambda^2 - 0.0300)$ $n_e^2 = 2.51527 + 0.0240\lambda^2/(\lambda^2 - 0.0300) + 0.020(\lambda - 1.52)/[(\lambda - 1.52)^2 + 0.8771$	0.3–1.06	82
$NH_4D_2AsO_4$	$n_o^2 = 1 + 1.418168\lambda^2/(\lambda^2 - 1.2246852) + 24.39162\lambda^2/(\lambda^2 - 1.175687)$ $n_e^2 = 1 + 1.262661\lambda^2/(\lambda^2 - 1.1728953) + 6.250606\lambda^2/(\lambda^2 - 0.9188848)$	0.4–1.06	55, 56
$NH_4H_2AsO_4$	$n_o^2 = 1 + 1.441185\lambda^2/(\lambda^2 - 1.2290244) + 30.08674\lambda^2/(\lambda^2 - 0.8843874)$ $n_e^2 = 1 + 1.274199\lambda^2/(\lambda^2 - 1.1750136) + 11.96164\lambda^2/(\lambda^2 - 1.041567)$	0.4–1.06	55, 56
$NH_4H_2PO_4$	$n_o^2 = 1 + 1.298990\lambda^2/(\lambda^2 - 0.0089232927) + 43.17364\lambda^2/(\lambda^2 - 1188.531)$ $n_e^2 = 1 + 1.162166\lambda^2/(\lambda^2 - 0.085932421) + 12.01997\lambda^2/(\lambda^2 - 831.8239)$	0.4–1.06	55, 56
NaI	$n^2 = 1.478 + 1.532\lambda^2/[\lambda^2 - (0.170)^2] + 4.27\lambda^2/[\lambda^2 - (86.21)^2]$	0.25–17	35
PbF_2	$n^2 = 1 + 0.66959342\lambda^2/[\lambda^2 - (0.00034911)^2] + 1.3086319\lambda^2/[\lambda^2 - (0.17144455)^2]$ $+ 0.01670641\lambda^2/[\lambda^2 - (0.28125513)^2] + 2007.8865\lambda^2/[\lambda^2 - (796.67469)^2]$	0.3–11.9	83
$PbMoO_4$	$n_o^2 = 1 + 3.54642\lambda^2/[\lambda^2 - (0.18518)^2] + 0.582703\lambda^2/[\lambda^2 - (0.33764)^2]$ $n_e^2 = 1 + 3.52555\lambda^2/[\lambda^2 - (0.17950)^2] + 0.20660\lambda^2/[\lambda^2 - (0.32537)^2]$	0.44–1.08	50, 84
$PbNb_4O_{11}$	$n_x^2 = 1 + 4.124\lambda^2/[(\lambda^2 - (0.202)^{2]}$ $n_y^2 = 1 + 4.139\lambda^2/[\lambda^2 - (0.2011)^{2]}$ $n_z^2 = 1 + 4.246\lambda^2/([\lambda^2 - (0.2014)^{2]}$	0.45–1.55	85
PbS	$n^2 = 1 + 15.9\lambda^2/([\lambda^2 - (0.77)^2] + 133.2\lambda^2/([\lambda^2 - (141)^2]$	3.5–10	86
PbSe	$n^2 = 1 + 21.1\lambda^2/([\lambda^2 - (1.37)^2]$	5–10	86
PbTe	$n^2 = 1 + 30.046\lambda^2/([\lambda^2 - (1.563)^2]$	4.0–12.5	87
$PbTiO_3$	$n_o^2 = 1 + 5.363\lambda^2/([\lambda^2 - (0.224)^2]$	0.45–1.15	

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	$n_e^2 = 1 + 5.366\lambda^2/([\lambda^2 - (0.0217)^2]$		
RbD_2AsO_4	$n_o^2 = 1 + 1.371661\lambda^2/(\lambda^2 - 1.1700309) + 16.30710\lambda^2/(\lambda^2 - 1.0114844)$ $n_e^2 = 1 + 1.269201\lambda^2/(\lambda^2 - 1.1202311) + 4.300136\lambda^2/(\lambda^2 - 1.149464)$	0.4–1.06	55, 56
RbD_2PO_4	$n_o^2 = 1 + 1.237455\lambda^2/(\lambda^2 - 0.8274984) + 17.69334\lambda^2/(\lambda^2 - 0.8839832)$ $n_e^2 = 1 + 1.154309\lambda^2/(\lambda^2 - 0.81539261) + 585751\lambda^2/(\lambda^2 - 0.8927180)$	0.4–1.06	55, 56
RbH_2AsO_4	$n_o^2 = 1 + 1.37723\lambda^2/(\lambda^2 - 0.01301)$ $n_e^2 = 1 + 1.272831\lambda^2/(\lambda^2 - 0.01157)$	—	89
RbH_2PO_4	$n_o^2 = 1 + 1.2068\lambda^2/(\lambda^2 - 0.01539)$ $n_e^2 = 1 + 1.15123\lambda^2/(\lambda^2 - 0.010048)$	0.48–1.06	90
$RbTiOAsO_4$	$n_x^2 = 1.97756 + 1.25726\lambda^2/[(\lambda^2 - (0.20448)^2] - 0.00865\lambda^2$ $n_y^2 = 2.22681 + 0.99616\lambda^2/[\lambda^2 - (0.21423)^2] - 0.01369\lambda^2$ $n_z^2 = 2.28779 + 1.20629\lambda^2/([\lambda^2 - (0.23484)^2] - 0.01583\lambda^2$	0.45–1.55	91
$RbTiOPO_4$	$n_x^2 = 2.38494 + 0.73603\lambda^2/([\lambda^2 - (0.23891)^2] - 0.01583\lambda^2$ $n_y^2 = 2.15559 + 0.93307\lambda^2/[\lambda^2 - (0.20994)^2] - 0.01452\lambda^2$ $n_z^2 = 2.27723 + 1.11030\lambda^2/([\lambda^2 - (0.23454)^2] - 0.01995\lambda^2$	0.45–1.55	91
Se	$n_o = 2.790$; $n_e = 3.608$ @ 1.06 μm $n_o = 2.64$; $n_e = 3.41$ @ 10.6 μm	—	92
Si	$n^2 = 1 + 10.66842933\lambda^2/[\lambda^2 - (0.3015116485)^2] + 0.003043475\lambda^2/[\lambda^2 - (1.13475115)^2]$ $+ 1.54133408\lambda^2/[\lambda^2 - (1104.0)^2]$	1.36–11	93, 94
α-SiC	$n_o^2 = 1 + 5.5515\lambda^2/([\lambda^2 - (0.16250)^2]$ $n_e^2 = 1 + 5.7382\lambda^2/([\lambda^2 - (0.16897)^2]$	0.49–1.06	95
β-SiC	$n^2 = 1 + 5.5705\lambda^2/([\lambda^2 - (0.1635)^2]$	0.47–0.69	96

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
SiO_2 (α-quartz)	$n_o^2 = 1 + 0.663044\lambda^2/[\lambda^2 - (0.060)^2] + 0.517852\lambda^2/[\lambda^2 - (0.106)^2] + 0.175912\lambda^2/[\lambda^2 - (0.119)^2] + 0.565380\lambda^2/[\lambda^2 - (8.844)^2] + 1.675299\lambda^2/[\lambda^2 - (20.742)^2]$ $n_e^2 = 1 + 0.665721\lambda^2/[\lambda^2 - (0.060)^2] + 0.503511\lambda^2/[\lambda^2 - (0.106)^2] + 0.214792\lambda^2/[\lambda^2 - (0.119)^2] + 0.539173\lambda^2/[\lambda^2 - (8.792)^2] + 1.807613\lambda^2/[\lambda^2 - (197.709)^2]$	0.18–0.71	97
SrF_2	$n^2 = 1 + 0.67805894\lambda^2/[\lambda^2 - (0.05628989)^2] + 0.37140533\lambda^2/[\lambda^2 - (0.10801027)^2] + 3.8484723\lambda^2/[\lambda^2 - (34.649040)^2]$	0.21–11.5	98
$SrMoO_4$	$n_o^2 = 1 + 2.4839\lambda^2/[\lambda^2 - (0.1451)^2] + 0.1015\lambda^2/[\lambda^2 - (4.603)^2]$ $n_e^2 = 1 + 2.4923\lambda^2/[\lambda^2 - (0.1488)^2] + 0.1050\lambda^2/[\lambda^2 - (4.544)^2]$	0.45–2.4	30
$SrTiO_3$	$n = 2.28355 + 0.035906/(\lambda^2 - 0.028) + 0.001666/(\lambda^2 - 0.028)^2 - 0.0061335\lambda^2 - 00001502\lambda^4$	0.4–5.4	99
$Sr_5(VO_4)_3F$	$n_o^2 = 3.29417 + 0.047212/(\lambda^2 - 0.048260) - 0.008518\lambda^2$ $n_e^2 = 3.24213 + 0.043872/(\lambda^2 - 0.053139) - 0.008773\lambda^2$	0.5–1.0	100
$Tb_2(MoO_4)_3$	$n_x^2 = 1 + 2.273955\lambda^2/(\lambda^2 - 0.02333)$ $n_y^2 = 1 + 2.2724\lambda^2/(\lambda^2 - 0.023359)$ $n_z^2 = 1 + 2.4430166\lambda^2/[\lambda^2 - 0.05133)$	0.46–1.06	101
Te	$n_o^2 = 18.5346 + 4.3289\lambda^2/(\lambda^2 - 3.9810) + 3.7800\lambda^2/(\lambda^2 - 11813)$ $n_e^2 = 29.5222 + 9.3068\lambda^2/(\lambda^2 - 2.5766) + 9.2350\lambda^2/(\lambda^2 - 13521)$	4–14	8
	$n_o^2 = 4.0164 + 18.8133\lambda^2/(\lambda^2 - 1.1572) + 7.3729\lambda^2/(\lambda^2 - 10000)$ $n_e^2 = 1.9041 + 36.8133\lambda^2/(\lambda^2 - 1.0803) + 6.2456\lambda^2/(\lambda^2 - 10000)$	8.5–30	8
TeO_2	$n_o^2 = 1 + 2.584\lambda^2/[\lambda^2 - (0.1342)^2] + 1.157\lambda^2/[\lambda^2 - (0.2638)^2]$ $n_e^2 = 1 + 2.823\lambda^2/[\lambda^2 - (0.1342)^2] + 1.542\lambda^2/[\lambda^2 - (0.2631)^2]$	0.4–1	103
TiO_2	$n_o^2 = 5.913 + 0.2441\lambda^2/(\lambda^2 - 0.0803)$	0.43–1.5	104

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rutile	$n_e^2 = 7.097 + 0.3322\lambda^2/(\lambda^2 - 0.0843)$		
TlBr	$(n^2 - 1)/(n^2 - 2) = 0.48484 + 0.10279/(\lambda^2 - 0.090000) - 0.0047896\lambda^2$	0.54–0.65	6
Tl[Br,Cl]	$n^2 = 1 + 3.821\lambda^2/[\lambda^2 - (0.02234)^2] - 0.000877\lambda^2$	0.6–24	106
Tl[Br,I]	$n^2 = 1 + 1.8293958\lambda^2/[\lambda^2 - (0.150)^2] + 1.6675593\lambda^2/[\lambda^2 - (0.250)^2] + 1.1210424\lambda^2/[\lambda^2 - (0.350)^2] + 0.04513366\lambda^2/[\lambda^2 - (0.450)^2] + 12.380234\lambda^2/[\lambda^2 - (164.59)^2]$	0.58–39.4	107
TlCl	$(n^2 - 1)/(n^2 - 2) = 0.47856 + 0.078588/(\lambda^2 - 0.08277) - 0.00881\lambda^2$	0.43–0.66	105
Tl_3AsSe_3	$n_o^2 = 1 + 10.210\lambda^2/[\lambda^2 - (0.444)^2] + 0.522\lambda^2/[\lambda^2 - (25.0)^2]$ $n_e^2 = 1 + 8.933\lambda^2/[\lambda^2 - (0.444)^2] + 0.308\lambda^2/[\lambda^2 - (25.0)^2]$	2–12	108
Y_2O_3	$n^2 = 1 + 2.578\lambda^2/[\lambda^2 - (0.1387)^2] + 3.935\lambda^2/[\lambda^2 - (22.936)^2]$	0.2–12	109
$YAlO_3$	$n_x^2 = 1 + 2.61960\lambda^2/(\lambda^2 + 0.012338)$ $n_y^2 = 1 + 2.67171\lambda^2/(\lambda^2 - 0.012605)$ $n_z^2 = 1 + 2.70381\lambda^2/(\lambda^2 - 0.012903)$	0.4–1.06	110
Y_2SiO_5	$n_x^2 = 3.0895 + 0.0334/(\lambda^2 + 0.0043) + 0.0199\lambda^2$ $n_y^2 = 3.1173 + 0.0283/(\lambda^2 - 0.0313)$ $n_z^2 = 3.1871 + 0.03022/(\lambda^2 - 0.138)$	0.44–0.64	111
YVO_4	$n_o^2 = 1 + 2.7665\lambda^2/(\lambda^2 - 0.026884)$ $n_e^2 = 1 + 3.5930\lambda^2/(\lambda^2 - 0.032103)$	0.5–1.06	112, 113
$Y_3Al_5O_{12}$	$n^2 = 1 + 2.293\lambda^2/[\lambda^2 - (0.1095)^2] + 3.705\lambda^2/[\lambda^2 - (17.825)^2]$	0.4– 4.0	30
$Y_3Ga_5O_{12}$	$n^2 = 1 + 2.5297\lambda^2/(\lambda^2 - 0.019694)$	0.46–0.63	48
$Y_3Sc_2Al_3O_{12}$	$n^2 = 1 + 2.4118\lambda^2/(\lambda^2 - 0.01477)$	0.53–0.65	115

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Dispersion Formulas for Refractive Indices—*continued*

Material	Dispersion formula (wavelength λ in μm)	Range (μm)	Ref.
$ZnGeP_2$	$n_o^2 = 4.4733 + 5.2658\lambda^2/(\lambda^2 - 0.1338) + 1.49090\lambda^2/(\lambda^2 - 662.55)$ $n_e^2 = 4.6332 + 5.3422\lambda^2/(\lambda^2 - 0.1426) + 1.4580\lambda^2/(\lambda^2 - 662.55)$	0.4–12	40
ZnO	$n_o^2 = 2.81419 + 0.87968\lambda^2/([\lambda^2 - (0.00569)^2] - 0.00711\lambda^2$ $n_e^2 = 2.80333 + 0.94470\lambda^2/([\lambda^2 - (0.3004)^2] - 0.00714\lambda^2$	0.45–4.0	30
α–ZnS	$n_o^2 = 4.4175 + 1.73968\lambda^2/([\lambda^2 - (0.2677)^2]$ $n_e^2 = 4.42643 + 1.7491\lambda^2/([\lambda^2 - (0.2674)^2]$	0.36–1.4	50, 105
β–ZnS	$n^2 = 1 + 0.3390426\lambda^2/([\lambda^2 - (0.31423026)^2] + 3.7606868\lambda^2/([\lambda^2 - (0.1759417)^2]$ $+ 2.7312353\lambda^2/([\lambda^2 - (33.886560)^2]$	0.55–10.5	98
ZnSe	$n^2 = 1 + 4.2980149\lambda^2/([\lambda^2 - (0.1920630)^2] + 0.62776557\lambda^2/([\lambda^2 - (0.37878260)^2]$ $+ 2.8955633\lambda^2/([\lambda^2 - (46.994595)^2]$	0.55–18	98
ZnTe	$n^2 = 9.921 + 0.42530\lambda^2/([\lambda^2 - (0.37766)^2] + 2.63580/([\lambda^2/(56.5)^2 - 1]$	0.55–30	114
ZrO_2: 12%Y_2O_3	$n^2 = 1 + 1.347091\lambda^2/([\lambda^2 - (0.062543)^2] + 2.117788\lambda^2/([\lambda^2 - (0.166739)^2] + 9.452943\lambda^2/([\lambda^2 - (24.320570)^2]$	0.36–5.1	116

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1.3.5 Thermooptic Coefficients

Thermooptic Coefficients

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
AgBr	3390	–61	RT	1
	10600	–50	RT	1
AgCl	610	–61	298	4
	633	–61	RT	1
	3390	–58	RT	1
	10600	–35	RT	1
$AgGaS_2$	600	258 (o)	RT	1
		255 (e)	RT	1
	1000	176 (o)	RT	1
		179 (e)	RT	1
	3390	154 (o)	RT	5
		155 (e)	RT	5
	10000	153 (o)	RT	1
		155 (e)	RT	1
$AgGaSe_2$	1064	98 (o)	RT	5
		66 (e)	RT	5
	3390	74 (o)	RT	5
		43 (e)	RT	5
	10600	58 (o)	RT	5
		46 (e)	RT	5
Al_2O_3	457.9	1.8 (o)	93	4
		1.9 (e)	93	4
		11.7 (o)	293	4
		12.8 (e)	293	4
		15.4 (o)	473	4
		16.9 (e)	473	4
	589	13.6 (o)	RT	1
		14.7 (e)	RT	1
	633	12.6	RT	1
$Al_{23}O_{27}N_5$	633	11.7	RT	1
BaB_2O_4	404.7	–16.4 (o)	RT	1
		–9.4 (e)	RT	1
	579	–16.6 (o)	RT	1
		–9.8 (e)	RT	1
	1014	–16.8 (o)	RT	1
		–8.8 (e)	RT	1
BaF_2	457.9	–7.8	90	4
		–15.6	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
BaF_2		–15.6	293	4
		–18.8	473	4
	632.8	–16.3	313	2
	1150	–8.1	90	4
		–16.2	293	4
		–19.3	473	4
	3390	–15.9	RT	1
	10600	–7.3	90	4
		–14.5	293	4
		–17.5	473	4
$Ba_2NaNb_5O_{15}$	1064	–25 (y)	RT	5
		80 (z)		5
$BeAl_2O_4$	1064	8	300	
BeO	458	8.2 (o)	RT	1
		13.4 (e)	RT	1
	633	8.2 (o)	RT	1
		13.4 (e)	RT	1
	1064	8.18 (o)	RT	5
		13.40 (e)	RT	5
$Bi_{12}GeO_{20}$	510	–34.5	RT	1
	650	–34.9	RT	1
C (diamond)	546	10.1	RT	1
	587	10	300	4
	30000	9.6	RT	1
$CaCO_3$	211	21.5 (o	334	4
		22.0 (e)	334	4
	365	3.6 (o)	RT	1
		14.4 (e)	RT	1
	441	3.2 (o	334	4
		13.2 (e)	334	4
	458	3.2 (o)	RT	1
		13.1 (e)	RT	1
	633	2.1 (o)	RT	1
		11.9 (e)	RT	1
CaF_2	254	–7.5	RT	1
	457.9	–3.9		
		–11.0	93	4
		13.4	293	4
	632.8	–11.5		
	663	–10.4	473	4
	1150	–4.1	313	2

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
CaF_2		–11.5	RT	1
		–14.1		
	3390	–8.1	93	4
			293	4
			473	4
			RT	1
$CaMoO_4$	587.6	–9.6 (o)	273–373	4
		–10.0 (e)	273–373	4
$Ca_5(PO_4)_3F$	500–1000	–10 (o)	293–338	3
		–8 (e)	293–338	3
$CaWO_4$	546.1	–7.1 (o)	293	4
	546.1	–10.2 (e)	293	2
CdF_2	457.9	–4.3	93	4
		–9.2	293	4
		–12.4	473	4
	1150	–5.7	93	4
		–11.5	293	4
		–15.1	473	4
	3390	–5.3	93	4
		–11.1	293	4
		–14.8	473	4
CdS	10600	58.6 (o)	RT	1
		62.4 (e)	RT	1
CdTe	1150	147	RT	1
	3390	98.2	RT	1
	10600	98.0	RT	1
CsBr	254	–82	RT	1
	288	–86	293	4
	400	–86	293	4
	633	–84.7	RT	1
	640	–85	293	4
	1150	–84	293	4
	3400	–84	293	4
	10600	–83	293	4
	17000	–82	293	4
	30000	–75.8	RT	1
CsCl	288	–79	293	4
	365	–78.7	293	1
	400	–78	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
CsCl	633	–77.4	293	1
	640	–77	293	4
	1150	–77	293	4
	3400	–76	293	4
	10600	–75	293	4
	17000	–72	293	4
	20000	–70.0	RT	1
CsF	288	–41	293	4
	400	–42	293	4
	640	–42	293	4
	1150	–42	293	4
	3400	–42	293	4
	10600	–39	293	4
	17000	–32	293	4
CsI	300	–79	288–307	4
	365	–87.5	RT	1
	633	–99.3	RT	1
	1000	–98.6	288–307	4
	10000	–91.7	288–307	4
	20000	–89.3	288–307	4
	30000	–88.0	288–307	4
	40000	–86.2	288–307	4
	50000	–78.5	288–307	4
GaAs	1150	250	RT	1
	3390	200	RT	1
	10600	200	RT	1
GaN	1150	61	RT	1
GaP	546	200	RT	1
	633	160	RT	1
GaSb	1550	380	80	4
	3700	312	100–400	4
$Gd_3Sc_2Al_3O_{12}$	543	8.9	298–308	3
	1152	5.05	308–313	3
$Gd_3Sc_2Ga_3O_{12}$	441.6	13.46	308–313	3
	543	13.3	298–308	3
	632.8	10.76	308–313	3
	1064	10.7	283–303	3
	1152	9.04	308–313	3
Ge	2500	462	RT	1
	5000	416	RT	1

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
Ge	20000	401	RT	1
InAs	3250	315	300–600	4
	4000	500	RT	1
	6000	400	RT	1
	10000	300	RT	1
InP	5000	83	RT	1
	10600	82	RT	1
	20000	77	RT	1
InSb	2000–40000	560	120–360	4
	5000–200000	460	100–400	4
KBr	457.9	–28.5	93	4
		–39.3	293	4
		–43.8	473	4
	1150	–30.5	93	4
		–41.9	293	4
		–46.3	473	4
	10600	30.6	93	4
		41.1	293	4
		45.6	473	4
KCl	457.9	–22.6	93	4
		–34.9	293	4
		–39.6	473	4
	1150	–23.5	93	4
		–36.2	293	4
		–41.1	473	4
	10600	–23.3	93	4
		–34.8	293	4
		–39.1	473	4
KF	254	–19.9	RT	1
	288	–21	293	4
	400	–22	293	4
	640	–23	293	4
	1150	–23	293	4
	3400	–23	293	4
	10600	–17	293	4
	17000	3	293	4
KH_2PO_4	624	–39.6 (o)	RT	1
		–38.2 (e)	RT	1
KI	288	268	293	4
	400	5	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
KI	458	–41.5	RT	1
	640	–49	293	4
	1150	–66	293	4
	3400	–72	293	4
	10600	–66	293	4
	17000	–52	293	4
	30000	–30.8	RT	1
$KNbO_3$	436	–67 (x)	RT	1
		–26 (y)	RT	1
		125 (z)	RT	1
	1064	23 (x)	RT	1
		–34 (y)	RT	1
		63 (z)	RT	1
	3000	21 (x)	RT	1
		–23 (y)	RT	1
		55 (z)	RT	1
$KTiOPO_4$	365	–6.5 (x)	RT	5
	532	–7.4 (x)	RT	5
		–0.9 (y)	RT	5
		–13.5 (z)	RT	5
LiB_3O_5	532	–1.9 (x)	RT	1
		–13.0 (y)	RT	1
		–7.4 (z)	RT	1
	1064	–1.9 (x)	RT	5
		–13.0 (y)	RT	5
		–8.3 (z)	RT	5
LiBr	288	56	293	4
	355	2	293	4
	640	–39	293	4
	1150	–48	293	4
	3400	–50	293	4
	10600	–37	293	4
	17000	–1	293	4
$LiCaAlF_6$	546, 764	–4.6 (o)	293–353	3
		–4.2 (e)	293–353	3
LiCl	288	9.9	293	4
	640	–32	293	4
	1150	–37	293	4
	3400	–38	293	4
	10600	–21	293	4
		–16	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
LiF	457.9	–3.3	93	4
		–21.6	473	4
	632.8	–17.0	313	2
	1150	–3.8	93	4
		–16.7	293	4
		–19.9	473	4
	3390	–4.0	93	4
		–14.5	293	4
		–18.0	473	4
LiI	288	268	293	4
	410	5	293	4
	640	–49	293	4
	1150	–66	293	4
	3400	–72	293	4
	10600	–66	293	4
	17000	–52	293	4
$LiIO_3$	400	–74.5 (o)	RT	1
		–63.5 (e)	RT	1
	1000	–84.9 (o)	RT	1
		–69.2 (e)	RT	1
$LiNbO_3$	660	4.4 (o)	RT	1
		37.9 (e)	RT	1
	3390	0.3 (o)	RT	1
		28.9 (e)	RT	1
$LiSrAlF_6$	900	–4.0 (o)	293–353	3
		–2.5 (e)	293–353	3
$LiTaO_3$	468	62 (o)	298	3
		12 (e)	298	3
	546	58 (o)	298	3
		7 (e)	298	3
	644	52 (o)	298	3
		5 (e)	298	3
$LiYF_4$	436	–0.54 (o)	RT	1
		–2.44	RT	1
	546	–0.67 (o)	RT	1
		–2.30 (e)	RT	1
	578	–0.91 (o)	RT	1
		–2.86 (e)	RT	1
$MgAl_2O_4$	589	9.0	RT	1
		1.8	93	4
		1.5	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
MgF_2	457.9	2.4	93	4
		0.9	293	4
		0.6	473	4
		0.1	473	4
	632.8	1.12 (o)	293	2
		0.58 (e)	293	2
	1150	2.0	93	4
		1.4	93	4
		0.9	293	4
		0.3	293	4
		–0.1	473	4
		–0.7	473	4
	3390	2.0	93	4
		1.5	93	4
		1.1	293	4
		0.6	293	4
		0.3	473	4
		–0.3	473	4
MgO	365	19.5	RT	1
	404.7	18.9	293	4
		19.1	303	4
		19.3	313	4
	546	16.5	RT	1
	589.3	15.3	293	4
		15.5	303	4
		15.7	313	4
	767.9	13.6	293	4
		13.8	303	4
		14.0	313	4
Mg_2SiO_4	488	2.8	298–313	3
NaBr	288	12.9	293	4
	350	–29	293	4
	365	–30.4	RT	1
	640	–39	293	4
	1150	–40	293	4
	3400	–40	293	4
	10600	–38	293	4
	17000	–32	293	4
NaCl	457.9	–20.6	93	4
		–34.2	293	4
		–39.2	473	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
NaCl	633	–35.4	RT	1
	1150	–22.2	93	4
		–36.4	293	4
		–41.4	473	4
	3390	22.4	93	4
		–36.6	293	4
		–41.8	473	4
NaF	457.9	–4.1	93	4
		–11.9	293	4
		–14.7	473	4
	632.8	–13.0	313	2
	1150	–4.5	93	4
		–13.2	293	4
		–15.9	473	4
	3390	–4.5	93	4
		–12.5	293	4
		–14.9	473	4
NaI	288	72	293	4
	325	3	293	4
	640	–46	293	4
	1150	–50	293	4
	3400	–50	293	4
	10600	–49	293	4
	17000	–44	293	4
$NH_4H_2PO_4$	624	–47.1 (o)	RT	1
		–4.3 (e)	RT	1
$PbMoO_4$	588	–75 (o)	273–373	4
		–41 (e)	273–373	4
PbS	3390	–2100	RT	1
	5000	–1900	RT	1
	10600	–1700	RT	1
PbSe	3390	–2300	RT	1
	5000	–1400	RT	1
	10600	–860	RT	1
PbTe	3390	–2100	RT	1
	5000	–1500	RT	1
	10600	–1200	RT	1
RbBr	288	–40	293	4
	400	–44	293	4
	640	–45	293	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
RbBr	1150	–45	293	4
	3400	–45	293	4
	10600	–44	293	4
	17000	–43	293	4
RbCl	288	–38	293	4
	400	–39	293	4
	640	–39	293	4
	1150	–39	293	4
	3400	–39	293	4
	10600	–38	293	4
	17000	–35	293	4
RbI	288	–37	293	4
	400	–55	293	4
	640	–56	293	4
	1150	–56	293	4
	3400	–56	293	4
	10600	–56	293	4
	17000	–55	293	4
Si	1407	206	291	4
	2500	166	RT	1
	3826	174	312	4
	5000	159	RT	1
	10600	157	RT	1
SiO_2 (α-quartz)	254	–2.9 (o)	RT	1
		–4.0 (e)	RT	1
	365	–5.4 (o)	RT	1
		–6.2 (e)	RT	1
	546	–6.2 (o)	RT	1
		–7.0 (e)	RT	1
$Sr_5(VO_4)_3F$	750–1000	–11 (o)	293–338	3
		–8 (e)	293–338	3
SrF_2	457.9	–54	93	4
		–12.0	293	4
		–13.4	473	4
	632.8	–12.5	313	2
	1150	–5.5	93	4
		–12.6	293	4
		–14.0	473	4
	10600	–3.5	93	4
		–9.8	293	4
		–12.0	473	4

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
TeO_2	436	30 (o)	RT	1
		25 (e)	RT	1
	644	9 (o)	RT	1
		8 (e)	RT	1
TiO_2 (rutile)	405	4 (o)	RT	1
		–9 (e)	RT	1
Tl[Br,I] KRS-5	576.9	–254	292–304	4
	1014	–240	292–304	4
	11035	–233	292–304	4
	25970	–202	292–304	4
	39380	–154	292–304	4
Tl_5AsSe_3	2–10	–45 (o)	RT	1
		36 (e)	RT	1
YVO_4	—	3.9 (o)	—	3
		8.5 (e)	—	3
YVO_4	—	3 (o)	—	3
		8.5 (e)	—	3
Y_2O_3	633	8.3	RT	1
Y_2SiO_5	546.1	9.05 (x)	298–343	3
		5.70 (y)	298–343	3
		6.73 (z)	298–343	3
$Y_3Al_5O_{12}$	457.9	11.89	303–318	2
	476.5	12.00	303–318	2
	488.8	11.60	303–318	2
	496.5	11.38	303–318	2
	501.7	11.37	303–318	2
	514.5	10.57	303–318	2
	543	9.7	298–308	3
	632.8	10.35	303–318	2
	1064.2	9.05	303–318	2
$YAlO_3$	1064	9.8 (a)	—	4
b–axis rod		14.5 (c)	—	4
$ZnGeP_2$	640	359 (o)	—	1
		376 (e)	—	1
	1000	212 (o)	—	1
		230 (e)	—	1
	10000	165 (o)	—	1
		170 (e)	—	1

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Thermooptic Coefficients—*continued*

Material	Wavelength (nm)	dn/dt (10^{-6}/K)	Temperature (K)	Ref.
β-ZnS	633	63.5	RT	1
	1150	35	93	4
		46	293	4
		49.8	RT	1
		50	473	4
	3390	28	93	4
		42	293	4
		46	473	4
	10600	27	93	4
		41	293	4
		47	473	4
β-ZnS (CVD)	633	63.5	RT	6
	1150	49.8	RT	6
	3390	45.9	RT	6
	10600	46.3	RT	6
ZnSe	633	76	93	4
		106	293	4
		121	473	4
	1150	59.7	RT	1
	3390	50	93	4
		62	293	4
		67	473	4
	10600	49	93	4
		61	293	4
		69	473	4
ZnSe (CVD)	633	1.6	RT	6
	1150	70	RT	6
	3390	62	RT	6
	10600	61	RT	6
ZrO_2:12%Y_2O_3			RT	1
	360	16	293–403	4
	458	10.0	RT	1
	633	7.9	RT	1
	800	7.2	293–403	4
	1690	6.2	293–403	4

(o) ordinary ray
(e) extraordinary ray
RT room temperature

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1.4 Mechanical Properties

1.4.1 Elastic Constants

The following tables are from the *CRC Handbook of Chemistry and Physics*, 82nd edition, Lide, D. R., Ed. (CRC Press, Boca Raton, FL, 2001), p. 12–37, with additions from the *Handbook of Optics*, Vol. 2 (McGraw–Hill, New York, 1999) and the *Handbook of Laser Science and Technology*, Vol. IV and Suppl. (CRC Press, Boca Raton, FL, 1995).

The elastic constants C_{ij} for single crystals are given in units of 10^{11} N/m^2 (equivalent to 100 GPa or 10^{12} dyn/cm^2). The values are for room temperature.

A useful compilation of published values from various sources may be found in Simmons, G., and Wang, H., *Single Crystal Elastic Constants and Calculated Aggregate Properties: A Handbook,* 2nd edition*,* (The MIT Press, Cambridge, MA, 1971). Temperature and pressure coefficients of the elastic constants for many materials are included in *Landolt–Börnstein, New Series*, III/11, Hellwege, K.–H. and Hellwege, A. M., Eds. (Springer–Verlag, New York, 1979).

Cubic Crystals

Material	Temperature (K)	Elastic constants (10^{11} N/m^2) C_{11}	C_{12}	C_{44}	Ref.
AgBr	300	0.5920	0.3640	0.0616	48
AlAs	RT	1.163	0.576	0.541	117
$Al_{23}O_{27}N_5$	RT	3.93	1.08	1.19	117
AlSb	300	0.8939	0.4427	0.4155	2
$Ba(NO_3)_2$	293	0.2925	0.2065	0.1277	7
BaF_2	298	0.9199	0.4157	0.2568	6
$Bi_4Ge_3O_{12}$	RT	1.250	0.324	0.249	117
$Bi_4Si_3O_{12}$	RT	1.298	0.297	0.247	117
BN	RT	7.83	1.46	4.18	117
BP	RT	3.15	1.00	1.60	117
C (diamond)	RT	10.40	1.70	5.50	117
CaF_2	298	1.6420	0.4398	0.8406	8
$CaLa_2S_4$	RT	0.98	0.47	0.50	117
CdTe	298	0.5351	0.3681	0.1994	9
CsBr	298	0.3063	0.0807	0.0750	11
CsCl	298	0.3644	0.0882	0.0804	11
CsI	298	0.2446	0.0661	0.0629	11
GaAs	298	1.1877	0.5372	0.5944	17
GaP	300	1.4120	0.6253	0.7047	18
GaSb	298	0.8839	0.4033	0.4316	16
$Gd_3Ga_5O_{12}$	RT	2.85	1.14	0.897	118
$Gd_3Sc_2Al_3O_{12}$	RT	2.99	1.01	0.89	119
$Gd_3Sc_2Ga_3O_{12}$	RT	2.77	1.049	0.8036	119

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Cubic Crystals—*continued*

Material	Temperature (K)	Elastic constants (10^{11} N/m^2) C_{11}	C_{12}	C_{44}	Ref.
Ge	298	1.2835	0.4823	0.6666	20
HgTe	290	0.548	0.381	0.204	36
InAs	293	0.8329	0.4526	0.3959	23
InP	RT	1.0220	0.5760	0.4600	24
InSb	298	0.6720	0.3670	0.3020	22
KBr	298	0.3468	0.0580	0.0507	11
KCl	298	0.4069	0.0711	0.0631	11
KCN	RT	0.1940	0.1180	0.0150	32
KF	295	0.6490	0.1520	0.1232	33
KI	300	0.2710	0.0450	0.0364	42
$KMgF_3$	RT	1.32	0.396	0.485	118
$KTaO_3$	RT	4.31	1.03	1.09	117
LiBr	RT	0.3940	0.1880	0.1910	32
LiCl	295	0.4927	0.2310	0.2495	33
LiF	RT	1.1397	0.4767	0.6364	34
LiI	RT	0.2850	0.1400	0.1350	32
$Lu_3Al_5O_{12}$	RT	3.39	1.14	1.13	119
$MgAl_2O_4$	298	2.9857	1.5372	1.5758	53
MgO	298	2.9708	0.9536	1.5613	20
MnO	298	2.23	1.20	0.79	35
NaBr	300	0.3970	0.1001	0.0998	33
$NaBrO_3$	RT	0.5450	0.1910	0.1500	32
NaCl	298	0.4947	0.1288	0.1287	11
$NaClO_3$	RT	0.4920	0.1420	0.1160	50
NaF	300	0.9700	0.2380	0.2822	51
NaI	300	0.3007	0.0912	0.0733	52
NH_4Br	300	0.3414	0.0782	0.0722	3
NH_4Cl	290	0.3814	0.0866	0.0903	4
$Pb(NO_3)_2$	293	0.3729	0.2765	0.1347	29
PbF_2	300	0.8880	0.4720	0.2454	28
PbS	RT	1.26	0.162	0.171	117
PbSe	RT	1.178	0.139	0.1553	117
PbTe	303.2	1.0795	0.0764	0.1343	30
RbBr	300	0.3152	0.0500	0.0380	45
RbCl	300	0.3624	0.0612	0.0468	45
RbI	300	0.2556	0.0382	0.0278	45
Si	298	1.6578	0.6394	0.7962	46
β-SiC	RT	3.50	1.42	2.56	117
$Sr(NO_3)_2$	293	0.4255	0.2921	0.1590	29
SrF_2	300	1.2350	0.4305	0.3128	54
SrO	300	1.601	0.435	0.590	55

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Cubic Crystals—*continued*

Material	Temperature (K)	Elastic constants (10^{11} N/m^2) C_{11}	C_{12}	C_{44}	Ref.
$SrTiO_3$	RT	3.4817	1.0064	4.5455	56
ThO_2	298	3.670	1.060	0.797	61
TiC	RT	5.00	1.13	1.75	107
TlBr	298	0.3760	0.1458	0.0757	59
TlCl	RT	0.403	0.155	0.0769	117
Tl[Br,I], KRS-5	RT	0.341	0.136	0.0579	117
Tl[Br,Cl], KRS-6	RT	0.397	0.149	0.0723	117
Y_2O_3	RT	2.33	1.01	0.67	117
$Y_3Al_5O_{12}$	RT	3.49	1.21	1.14	119
$Y_3Fe_2(FeO_4)_3$	298	2.680	1.106	0.766	19
$Y_3Sc_2Ga_3O_{12}$	RT	2.75	1.00	0.85	119
$Y_{2.25}Yb_{0.75}Al_5O_{12}$	RT	4.55	1.54	1.51	119
ZnS	298	1.0462	0.6534	0.4613	68
ZnSe	298	0.8096	0.4881	0.4405	68
ZnTe	298	0.7134	0.4078	0.3115	68
ZrC	298	4.720	0.987	1.593	63

Trigonal Crystals—Point Groups 32, 3m, –3m

Material	Temp. (K)	Elastic constants (10^{11} N/m^2) C_{11}	C_{12}	C_{13}	C_{14}	C_{33}	C_{44}	Ref.
Ag_3AsS_3	RT	0.570	0.318	—	—	0.364	0.090	117
Al_2O_3	300	4.9735	1.6397	1.1220	-0.2358	4.9911	1.4739	111
$AlPO_4$	RT	1.0503	0.2934	0.6927	-0.1271	1.3353	0.2314	73
β-$Ba_3B_6O_{12}$	RT	1.238	0.603	0.494	0.123	0.533	0.078	117
$CaCO_3$	300	1.4806	0.5578	0.5464	-0.2058	0.8557	0.3269	113
Fe_2O_3	RT	2.4243	0.5464	0.1542	-0.1247	2.2734	0.8569	82
$LiCaAlF_6$	RT	1.18	0.412	0.535	±0.192	1.07	0.504	119
$LiNbO_3$	RT	2.030	0.530	0.750	0.090	2.450	0.600	114
$LiSrAlF_6$	RT	1.17	—	—	—	0.94	—	119
LaF_3	RT	1.80	0.88	0.59	<0.005	2.22	0.34	117
$LiTaO_3$	RT	2.330	0.470	0.800	-0.110	2.750	0.940	114
$NaNO_3$	RT	0.8670	0.1630	0.1600	0.0820	0.3740	0.2130	12
Se	RT	0.198	0.066	0.202	|0.069|	0.836	0.183	117
α-SiO_2	298	0.8680	0.0704	0.1191	-0.1804	1.0575	0.5820	115
Te	RT	0.3257	0.0845	0.257	|0.1238|	0.717	0.3094	117
Tourmaline*	RT	2.7066	0.6927	0.0872	-0.0774	1.6070	0.6682	82

* $Na_3Al_6Si_6O_{18}(BO_3)_2(O,H,F)_4$

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Orthorhombic Crystals—Point Groups 222, m22, mmm

Material	Temp. (K)	Elastic constants (10^{11} N/m^2)									
		C_{11}	C_{12}	C_{13}	C_{22}	C_{23}	C_{33}	C_{44}	C_{55}	C_{66}	Ref.
$Al_2SiO_3(OH,F)_2$	RT	2.8136	1.2582	0.8464	3.8495	0.8815	2.9452	1.0811	1.3298	1.3089	82
$BaSO_4$	RT	0.8941	0.4614	0.2691	0.7842	0.2676	1.0548	0.1190	0.2874	0.2778	82
$BeAl_2O_4$	RT	4.32	—	—	4.64	—	5.11	1.45	1.52	1.42	120
$CaCO_3$	RT	1.5958	0.3663	0.0197	0.8697	0.1597	0.8503	0.4132	0.2564	0.4274	82
$CaSO_4$	RT	0.9382	0.1650	0.1520	1.845	0.3173	1.1180	0.3247	0.2653	0.0926	84
Cs_2SO_4	293	0.4490	0.1958	0.1815	0.4283	0.1800	0.3785	0.1326	0.1319	0.1323	81
HIO_3	RT	0.3030	0.1194	0.1169	0.5448	0.0548	0.4359	0.1835	0.2193	0.1736	73
K_2SO_4	293	0.5357	0.1999	0.2095	0.5653	0.1990	0.5523	0.195	0.1879	0.1424	81
$KB_5O_8{\cdot}4H_2O$	RT	0.582	0.229	0.174	0.359	0.231	0.255	0.164	0.046	0.057	71
$KNbO_3$	RT	2.26	0.96	—	2.70	—	2.80	0.743	0.250	0.955	117
$KTiOPO_4$	RT	1.59	—	—	1.54	—	1.75	—	—	—	117
$LiNH_4C_4H_4O_6{\cdot}4H_2O$	RT	0.3864	0.1655	0.0875	0.5393	0.2007	0.3624	0.1190	0.0667	0.2326	12
$(MgFe)SiO_3$	RT	1.876	0.686	0.605	1.578	0.561	2.085	0.700	0.592	0.544	78
$(MgFe)SiO_4$	RT	3.240	0.590	0.790	1.980	0.780	2.490	0.667	0.810	0.793	87
Mg_2SiO_4	298	3.2848	0.6390	0.6880	1.9980	0.7380	2.3530	0.6515	0.8120	0.8088	85
$MgSO_4{\cdot}7H_2O$	RT	0.325	0.174	0.182	0.288	0.182	0.315	0.078	0.156	0.090	86
$(Na,Al)SiO_3$	RT	0.716	0.261	0.297	0.632	0.297	1.378	0.196	0.248	0.423	78
$Na_2C_4H_4O_6{\cdot}2H_2O$	RT	0.461	0.286	0.320	0.547	0.352	0.665	0.124	0.031	0.098	12
$(NH_4)_2SO_4$	293	0.3607	0.1651	0.1580	0.2981	0.1456	0.3534	0.1025	0.0717	0.0974	81
$NaK(C_4H_4O_6)\cdot4H_2O$	RT	0.255	0.141	0.116	0.381	0.146	0.371	0.134	0.032	0.098	71
$NaNH_4C_4H_4O_6{\cdot}4H_2O$	RT	0.3685	0.2725	0.3083	0.5092	0.3472	0.5541	0.1058	0.0303	0.0870	12
$NiSO_4{\cdot}7H_2O$	RT	0.353	0.198	0.201	0.311	0.201	0.335	0.091	0.172	0.099	86
Rb_2SO_4	293	0.5029	0.1965	0.1999	0.5098	0.1925	0.4761	0.1626	0.1589	0.1407	81
$Sr(CHO_2)_2{\cdot}2H_2O$	RT	0.4391	0.1037	–0.149	0.3484	–0.014	0.3746	0.1538	0.1075	0.1724	12

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$SrSO_3$	RT	1.044	0.773	0.605	1.061	0.619	1.286	0.135	0.279	0.266	12
$TlSO_4$	293	0.4106	0.2573	0.2288	0.3885	0.2174	0.4268	0.1125	0.1068	0.0751	81
$ZnSO_4{\cdot}7H_2O$	RT	0.3320	0.1720	0.2000	0.2930	0.1980	0.3200	0.0780	0.1530	0.0830	86

Tetragonal Crystals—Point Groups 4, –4, 422, 4/m

Material	Temperature (K)	Elastic constants (10^{11} N/m^2)							Ref.
		C_{11}	C_{12}	C_{13}	C_{16}	C_{33}	C_{44}	C_{66}	
$CaMoO_4$	298	1.447	0.664	0.466	0.134	1.265	0.369	0.451	79
$CaWO_4$	RT	1.44	0.648	0.448	–0.142	1.26	0.369	0.461	117
$PbMoO_4$	RT	1.09	0.680	0.530	–0.140	0.920	0.267	0.335	117
$SrMoO_4$	RT	1.19	0.620	0.480	–0.120	1.04	0.349	0.420	117
$LiYF_4$	RT	1.21	0.609	0.526	–0.077	1.56	0.409	0.177	117

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Tetragonal Crystals—Point Groups 4mm, –42m, 422, 4/mmm

Material	Temperature (K)	Elastic constants (10^{11} N/m^2)						Ref.
		C_{11}	C_{12}	C_{13}	C_{33}	C_{44}	C_{66}	
$AgGaS_2$	RT	0.879	0.584	0.592	0.758	0.241	0.308	117
$BaTiO_3$	298	2.7512	1.7897	1.5156	1.6486	0.5435	1.1312	70
$CdGeAs_2$	RT	0.945	0.596	0.597	0.834	0.421	0.408	117
KH_2AsO_4	RT	0.530	–0.060	–0.020	0.370	0.120	0.070	12
KH_2PO_4	RT	0.7140	–0.049	0.1290	0.5620	0.1270	0.0628	71
MgF_2	RT	1.237	0.732	0.536	1.770	0.552	0.978	72
$NH_4H_2AsO_4$	298	0.6747	–0.106	0.1652	0.3022	0.0685	0.0639	69
$NH_4H_2PO_4$	293	0.6200	–0.050	0.1400	0.3000	0.0910	0.0610	69
$(NH_4)_3CO$	RT	0.217	0.089	0.24	0.532	0.0626	0.0045	117
$NiSO_4 \cdot 6H_2O$	RT	0.3209	0.2315	0.0209	0.2931	0.1156	0.1779	73
RbH_2PO_4	298	0.5562	–0.064	0.0279	0.4398	0.1142	0.0350	74
TeO_2	RT	0.5320	0.4860	0.2120	1.0850	0.2440	0.5520	76
TiO_2	298	2.7143	1.7796	1.4957	4.8395	1.2443	1.9477	75
$ZrSiO_4$	RT	2.585	1.791	1.542	3.805	0.733	1.113	78

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Monoclinic Crystals

Material	Temp. (K)	Elastic Constants (10^{11} N/m^2) C_{11}	C_{12}	C_{13}	C_{15}	C_{22}	Ref.
$(C_6H_5CH)_2$	RT	0.0930	0.0570	0.0670	-0.003	0.0920	94
$(CaMg)Si_2O_6$	RT	2.040	0.884	0.0883	-0.193	1.750	91
$C_{14}H_{10}$	RT	0.0852	0.0672	0.0590	-0.0192	0.1170	90
$CoSO_4 \cdot 7H_2O$	RT	0.335	0.205	0.158	0.016	0.378	86
$FeSO_4 \cdot 7H_2O$	RT	0.349	0.208	0.174	-0.020	0.376	86
$K_2C_4H_4O_6$	RT	0.3110	0.1720	0.1690	0.0287	0.3900	32
$KAlSi_3O_8$	RT	0.664	0.438	0.259	-0.033	1.710	92
$KHC_4H_4O_6$	RT	0.4294	0.1399	0.3129	-0.0105	0.3460	12
$Li_2SO_4 \cdot H_2O$	RT	0.5250	0.1715	0.1730	-0.0196	0.5060	32
$(NaFe)Si_2O_6$	RT	1.858	0.685	0.707	0.098	1.813	89
$(NH_2CH_2COOH)_3 \cdot H_2SO_4$ (TGS)	RT	0.4550	0.1720	0.1980	-0.030	0.3210	32
$Na_2S_2O_3$	RT	0.3323	0.1814	0.1875	0.0225	0.2953	12
Y_2SiO_5	RT	0.658	—	—	±0.706	1.85	119

Monoclinic Crystals—*continued*

Material	Elastic Constants (10^{11} N/m^2) C_{23}	C_{25}	C_{33}	C_{35}	C_{44}	C_{46}	C_{55}	C_{66}
$(C_6H_5CH)_2$	0.0485	-0.005	0.0790	-0.005	0.0325	0.0050	0.0640	0.0245
$(CaMg)Si_2O_6$	0.482	-0.196	2.380	-0.336	0.675	-0.113	0.588	0.705
$C_{14}H_{10}$	0.0375	-0.0170	0.1522	-0.0187	0.0272	0.0138	0.0242	0.0399
$CoSO_4 \cdot 7H_2O$	0.158	-0.018	0.371	-0.047	0.060	0.016	0.058	0.101
$FeSO_4 \cdot 7H_2O$	0.172	-0.019	0.360	-0.014	0.064	0.001	0.056	0.096
$K_2C_4H_4O_6$	0.1330	0.0182	0.5540	0.0710	0.0870	0.0072	0.1040	0.0826
$KAlSi_3O_8$	0.192	-0.148	1.215	-0.131	0.143	-0.015	0.238	0.361
$KHC_4H_4O_6$	0.1173	0.0176	0.6816	0.0294	0.0961	-0.0044	0.1270	0.0841
$Li_2SO_4 \cdot H_2O$	0.0368	0.0571	0.5400	-0.0254	0.1400	-0.0054	0.1565	0.2770
$(NaFe)Si_2O_6$	0.626	0.094	2.344	0.214	0.692	0.077	0.510	0.474
$(NH_2CH_2CO\text{-}OH)_3 \cdot H_2SO_4$	0.2080	-0.0036	0.2630	-0.0500	0.0950	-0.0026	0.1110	0.0620
$Na_2S_2O_3$	0.1713	0.0983	0.4590	-0.0678	0.0569	-0.0268	0.1070	0.0598
Y_2SiO_5	—	—	0.835	±0.330	0.465	±0.0014	1.87	0.656

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Hexagonal Crystals—Point Groups 6, –6, 622, 6mm, –62m, 6/mmm

Material	Temp. (K)	Elastic Constants (10^{11} N/m^2) C_{11}	C_{12}	C_{13}	C_{33}	C_{44}	Ref.
β-AgI	RT	0.293	0.213	0.196	0.354	0.0373	117
AlN	RT	3.45	1.25	1.20	3.95	1.18	117
$Be_3Al_2Si_6O_{18}$	RT	2.800	0.990	0.670	2.480	0.658	12
BeO	RT	4.70	1.68	1.19	4.94	1.53	96
$Ca_5(PO_4)3(OH,F,Cl)$	RT	1.667	0.131	0.655	1.396	0.663	12
CdS	298	0.8431	0.5208	0.4567	0.9183	0.1458	98
CdSe	298	0.7046	0.4516	0.3930	0.8355	0.1317	68
GaN	RT	2.96	1.30	1.58	2.67	2.41	117
$LiTiO_3$	RT	0.8124	0.3184	0.0925	0.529	0.1783	117
α-SiC	RT	5.02	0.95	056	5.65	1.69	117
TiB_2	RT	6.90	4.10	3.20	4.40	2.50	107
ZnO	298	2.0970	1.2110	1.0510	2.1090	0.4247	110
ZnS	298	1.2420	0.6015	0.4554	1.4000	0.2864	96

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1.4.2 Elastic Moduli

The mechanical response of a material to an applied force is described by various moduli. Young's modulus E (extension in tension) and the modulus of rigidity or shear G are related to Poisson's ratio μ (ratio of lateral to longitudinal strain under unilateral stress) by $\mu = E/2G) - 1$. The bulk modulus B (1/isothermal compressibility) is related to the above moduli by $B = E/3(1 - \mu)$.

Elastic Moduli

		Moduli		
Material	**Poisson's ratio**	**Young's E (GPa)**	**Rigidity G (GPa)**	**Bulk B (GPa)**
Ag_3AsS_3	0.38	28	10	37
AgBr	0.39	24.7	8.8	40.5
AgCl	0.41	22.9	8.1	44.0
$AgGaS_2$	0.37	52	19	67
β–AgI	0.4	12	4.4	24
AlAs	0.27	108	42.4	77.2
AlN	0.26	294	117	202
Al_2O_3	0.23	400	162	250
ALON	0.24	317	128	203
BaB_2O_4	0.41	30	11	60.6
BaF_2	0.31	65.8	25.1	57.6
$BaTiO_3$	0.36	145	53	174
$BeAl_2O_4$	—	469	—	—
BeO	0.23	395	162	240
$Bi_{12}GeO_{20}$	0.28	82	32	63.3
$Bi_{12}SiO_{20}$	0.28	84	33	63.1
BN	0.11	833	375	358
BP	0.19	324	136	172
C (diamond)	0.10	1100	500	460
$CaCO_3$	0.31	83	32	73.2
CaF_2	0.29	110	42.5	85.7
$CaLa_2S_4$	0.25	96	38.4	64
$CaMoO_4$	0.29	103	40	80
$CaWO_4$	0.29	96	37	78
$CdGeS_2$	0.32	74	28	70
CdS	0.38	42	15	59
CdSe	0.37	42	15.3	53
CdTe	0.35	8.4	14.2	42.9
CsBr	0.27	22	8.8	15.8
CsCl	0.27	25	10.0	18.2
CsI	0.26	18	7.3	12.6
CuCl	0.30	24.8	8.9	39.3
GaAs	0.24	116	46.6	75.0
GaN	0.25	294	118	195
GaP	0.24	140	56.5	89.3

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Elastic Moduli—*continued*

Material	Poisson's ratio	Moduli		
		Young's E (GPa)	Rigidity G (GPa)	Bulk B (GPa)
Ge	0.20	132	54.8	75.0
InAs	0.30	74	28	61
InP	0.30	89	34	72.7
KBr	0.30	18	7.2	15.2
KCl	0.29	22	8.5	18.4
KF	0.28	41	16	31.8
KH_2PO_4	0.26	38	15	28
KI	0.30	14	5.5	11.9
$KNbO_3$	0.22	250	71	95
$KTaO_3$	0.27	316	124	230
LaF_3	0.32	120	46	100
LiF	0.22	110	45	65.0
$LiIO_3$	0.23	55	22.4	33.5
$LiNbO_3$	0.25	170	68	112
$LiSrAlF_6$	0.3	109	—	—
$LiYF_4$	0.32	85	32	81
$MgAl_2O_4$	0.26	276	109	198
MgF_2	0.26	137	53.9	99.1
MgO	0.18	310	131	163
NaBr	0.26	29	11.6	19.9
NaCl	0.26	37	14.5	25.3
NaF	0.24	76	30.7	48.5
NaI	0.28	22	8.4	16.1
$[NH_4]_2CO$	0.41	~9	~3	17
$NH_4H_2PO_4$	0.32	29	11	27.9
PbF_2	0.33	59.8	22.4	60.5
$PbMoO_4$	0.35	66	24	72
PbS	0.28	70.2	27.5	52.8
PbSe	0.28	64.8	25.4	48.5
PbTe	0.26	56.9	22.6	39.8
Se	0.27	24	9	17
Si	0.22	162	66.2	97.7
α–SiC	0.16	455	197	221
β–SiC	0.17	447	191	224
β–SiC (CVD)	0.21	466	—	—
SiO_2, α–quartz	0.08	95	44	38
SrF_2	0.29	89	34.6	71.3
$SrMoO_4$	0.30	87	33	73
$SrTiO_3$	0.23	283	115	174
Te	0.25	35	14	24
TeO_2	0.33	45	17	46
TiO_2	0.27	293	115	215

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Elastic Moduli—*continued*

Material	Poisson's ratio	Moduli		
		Young's E (GPa)	Rigidity G (GPa)	Bulk B (GPa)
TlBr	0.32	24	8.9	22.4
Tl[Br,I] KRS-5	0.34	19.6	7.3	20.4
TlCl	0.33	25	9.3	23.8
Tl[Br,Cl], KRS-6	0.33	24	9.0	32.2
$Y_3Al_5O_{12}$	0.24	280	113	180
$Y_3Fe_5O_{12}$	0.29	200	—	—
Y_2O_3	0.30	173	67	145
ZnO	0.35	127	47	144
α-ZnS	0.30	87	33	74
β-ZnS	0.32	82.5	31.2	76.6
β-ZnS (CVD)	0.29	74.5	—	—
ZnSe	0.30	75.4	29.1	61.8
ZnSe (CVD)	0.28	70.3		
ZnTe	0.30	61.1	23.5	51.0
ZrO_2: 12%Y_2O_3	0.31	233	88.6	205

The above table was adapted from Tropf, W. J., Thomas, M. F., and Harris, T. J., Properties of crystals and glasses, *Handbook of Optics,* Vol. II (McGraw-Hill, New York, 1995), p. 33.48.

1.4.3 Engineering Data

The following engineering properties can depend on the production method and exhibit sample–to–sample variations. Material strength may also depend on subsurface damage resulting from grinding and polishing. Therefore, the data should be considered only as a guide.

Engineering Data

Material	Flexure strength (MPa)	Fracture toughness (MPa $m^{1/2}$)	Volume compressibility (Tpa^{-1})	Ref.
AgCl	26			1
AgSb			57.1	4
Al_2O_3	1200	3	1.36 || c	1
			1.22 || a	1
AlN	225	3		1
$Al_{23}O_{27}N_5$	310	1.4		1
α-AgI			41	4
BaB_2O_4		1.5		1
BaF_2	27			1
$Be_3Al_2Si_6O_{18}$			6.65	2
BeO	275			1
C (diamond)	2940	2.0		1

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Engineering Data—*continued*

Material	Flexure strength (MPa)	Fracture toughness (MPa $m^{1/2}$)	Volume compressibility (TPa^{-1})	Ref.
$Ca_5(PO_4)_3F$			13.2	2
CaF_2	90	0.5	11.64	1,2
$CaLa_2S_4$	81	0.68		1
$CaMoO_4$			12.5	2
$CaWO_4$			13.3	2
CdS	28			1
CdSe	21			1
$CdSiAs_2S_4$			4.3	4
CdTe	26			1
CsBr	8.4			1
CsI	5.6			1
GaAs	55		77.1	1,4
GaN	70			1
GaP	100	0.9	11.0	1,4
GaSbs			45.7	4
$Gd_2(MoO_4)_3$			27.2	2
$Gd_3Ga_5O_{12}$			5.88	2
$Gd_3Sc_2Ga_3O_{12}$		1.2		3
Ge	100	0.66		1
InAs			54.9	4
InP			73.5	4
InSb			44.2	4
KBr	11			1
KCl	10			1
$KMgO_3$			14.4	2
LaB_3O_6		1.9 (111)		
		0.38 (10–1)		
LaF_3	33			1
LiB_3O_5		2.0		
$LiCaAlF_6$		0.18 $\parallel$ c		3
		0.37 $\perp$ c		3
LiF	27		15.05	1,2
$LiNbO_3$			8.8	2
$LiSrAlF_6$		0.40 $\parallel$ c		3
$LiYF_4$	35			1
$Lu_3Al_5O_{12}$		1.1		3
$MgAl_2O_4$	170	1.5		1
MgF_2	100		10.1	1
MgO	130	1.0	6.2	1
MnF_2			4.3 $\parallel$ a	2
			2.0 $\perp$ c	2

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Engineering Data—*continued*

Material	Flexure strength (MPa)	Fracture toughness (MPa $m^{1/2}$)	Volume compressibility (TPa^{-1})	Ref.
NaCl	9.6			1
Si	130	0.95		1
β-SiC	250			1
β-SiC (CVD)		3.3		
$Sr_5(PO_4)_3F$		0.51		3
$Sr_5(VO_4)_3F$		0.36 || c		3
Te	11			1
Tl[Br,Cl], KRS-6	21			1
Tl[Br,I] KRS-5	26			1
$Y_{2.25}Yb_{0.75}Al_5O_{12}$		1.3		3
Y_2O_3	150	0.7		1
Y_2SiO_5		0.54 || a		3
		0.70 || b		3
		0.78 || c		3
$Y_3Al_5O_{12}$		1.0, 1.4		3
$Y_3Al_5O_{12}$			5.34	2
$Y_3Fe_5O_{12}$			6.15	2
$Y_3Ga_5O_{12}$			5.73	2
α-ZnS	69			1
β-ZnS (CVD)	60	0.8		1
ZnSe	55	0.32		1
ZnSe (CVD)	52	≈ 1		
ZnTe	24			1
ZrO_2: 12%Y_2O_3	200	2.0		1

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1.5 Thermal Properties

1.5.1 Melting Point, Heat Capacity, Thermal Expansion, and Thermal Conductivity

Values for the heat capacity and the thermal expansion coefficient are those at or near room temperature; thermal conductivity values are for the temperatures T indicated.

Thermal Properties

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
Ag_3AsS_3	763					1
AgBr	705	0.2790	33.8	1.11	250	2
				0.93	300	2
				0.57	500	2
AgCl	728	0.3544	32.4	1.25	250	2
				1.12	295	1
				1.1	373	4
$AgGaS_2$	1269	0.40	28.5 || a	1.5	300	1
			–18.7 || c			1
$AgGaSe_2$	1129	0.30	35.5 || a	1.1	300	1
			–15.0 || c			1
$AgGaTe_2$	990			1.0	300	3
β-AgI	423p	0.242		0.4	300	2
Al_2O_3	2319	0.777	6.65 || a	58	250	2
			7.15 || c	46	300	2
				24.2	500	2
$Al_6Si_2O_{13}$	2190	0.75				2
AlAs	2013	0.452	3.5			1
			3.1	84	300	3
AlN	3273	0.796	5.27 || a	500	250	2
			4.15 || c	320	300	2
				150	500	2
ALON	2323	0.830	5.66	12.6	300	2
				7.0	500	2
AlP	2820			92	300	3
$AlPO_4$	>1730		2.9	~6	300	1
AlSb	1330		4.2	60	300	3

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
BaB_2O_4	1200p	0.49	4 || a	1.2 || a	300	2
	1370		34 || c	1.6 || c	300	2
BaF_2	1550	0.4474	18.4	7.5	250	2
				12	300	2
				10.5	370	4
BaF_2-CaF_2	1330	0.13	21.0			1
$Ba_3Lu\ (BO_3)_3$	1540					
$BaTiO_3$	278p	0.439	16.8 || a	6	300	2
	406p		–9.07 || c			2
	1870					1
BaY_2F_8	1230		17 || a	6	300	5
			18.7 || b			5
			19.4 || c			5
$Ba_2NaNb_5O_{12}$	1710	28.5 || a	10.4 || a,b			5
		–18.7 || c	11.4 || c			5
$BeAl_2O_4$	2140	0.830	6.3 || a	23	300	5
			6.0 || b			5
			6.5 || c			5
Be_2SiO_4		0.84		3.3	300	2
$Be_3Al_2Si_6O_{18}$	1730	0.84	2.1 || a	5	300	1
			2.7 || c			1
BeO	2373p	1.028	5.64 || a	420	250	2
	2725		7.47 || c	350	300	2
				200	500	2
BiB_3O_6		0.5 (330 K)	48.1 (x)			
			44 (y)			
			–26.9 (z)			
$Bi_4Ge_3O_{12}$	1320		7			1
$Bi_{12}GeO_{20}$	1200		16.8			1
Bi_2Te_3	853			2.8	204	4
				3.6	303	4
				4.6	370	4
BN	1100p	0.513	3.5	760	300	2
	3240			36.2	1047	1,4
BP	1400d	0.71	3.65	460	250	2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
BP				360	300	2
C (diamond)	1770p	0.5169	1.25	2800	250	2
				2200	300	2
C (diamond)				1300	500	2
$Ca(NbO_3)_2$	1830					5
$Ca_2Al_2SiO_7$	1860		11.4 || a	3 || c	300	6
				4.4 ⊥ c	300	6
$Ca_3Gd_2(BO_3)_3$	1680					
$Ca_3Y_2(BO_3)_3$	1630					
$Ca_5(PO_4)_3F$	1920	0.745	9.4 || a			5
			10 || c			5
$CaCO_3$ (calcite)	323p	0.8820	–3.7 || a	5.1 || a	250	2
	1610		25.1 || c	6.2 || c	250	2
				4.5 || a	300	2
				5.4 || c	300	2
				3.4 || a	500	2
				4.2 || c	500	2
CaF_2	1424p	0.9113	18.9	39.0	83	5
	1630			13	250	2
				9.7	300	1,2
				5.5	500	2
$CaLa_2S_4$	2083	0.36	14.6	1.7	300	2
				1.5	500	2
$CaMoO_4$	1750	0.690	19 || a	3.95 || a	300	5
			25 || c	3.82 || c	300	5
CaO	2890	0.75		18	450	1
$CaTiO_3$	2250					7
$CaWO_4$	1855	0.396	6.35 || a	6	300	1,2
			12.38 || c	11.3	422	2,4
$CaY_4(SiO_4)O$	2320		7.1 || a			5
			5.1 || c			5
$CdCl_2$	781					1
CdF_2	1370		27			1
$CdGeS_2$	900p		8.4 || a			2
	943		0.25 || c			2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
CdI_2	760					1
CdS	1560	0.3814	4.6 || a	27	300	2
CdS			2.5 || c	13	500	2
CdSe	1580	0.272	4.9 || a	9	300	1,2
			2.9 || c			2
CdTe	1320	0.210	5.0	8.2	250	2
				6.3	300	2
CsBr	908	0.2432	47.2	1.2	223	4
				0.85	300	2
				0.77	373	4
CsCl	918	0.3116	45.0	0.84	360	3
CsF	955	0.33	32	4.2	300	2
CsI	898	0.2032	48.6	1.4	223	4
				1.05	300	2
				0.95	373	4
$CsLiB_6O_{10}$	1120					
Cu_2GeS_3	1210	0.51	7.2	1.2	300	3
Cu_2GeSe_3	1030	0.34	8.4	2.4	300	3
Cu_2SnS_3	1110	0.44	7.8	2.8	300	3
Cu_2SnSe_3	960	0.31	8.9	3.5	300	3
CuBr	777		19			1
CuCl	700	0.490	14.6	1.0	250	2
				0.8	300	2
				0.5	500	2
CuF	1181					3
$CuGaS_2$	1553	0.452	11.2 || a			2
			6.9 || c			2
$CuGase_2$	1970		5.4	4.2	300	3
$CuGaTe_2$	2400		6.9	2.7	300	3
$CuInSe_2$	1600		6.6	3.7	300	3
$CuInTe_2$	1660		7.1	4.9	300	3
$CuSnTe_3$	680			14.4	300	3
Ga_2O_3	2170	0.46				1

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
Ga_2Se_3	1020		8.9	50	300	3
Ga_2Te_3	1063			47	300	3
GaAs	1511	0.345	5.0	65	250	2
				54	300	2
				27	500	2
α-GaN	1160d	0.49	3.17 || a	130 || c	300	2
	2370		5.59 || c			2
GaP	1740	0.435	5.3	120	250	2
				100	300	2
				45	500	2
GaS	1240					7
GaSe	1235					7
GaSb	720	0.079	6.9	44	300	1,2
$Gd_2(MoO_4)_3$	1410	0.42				5
$Gd_3Ga_5O_{12}$	2100			60	70	5
				9.0	300	1
$Gd_3Sc_2Al_3O_{12}$	2110	0.424	6.9	5.6	300	6
$Gd_3Sc_2Ga_3O_{12}$	2130	0.4023	7.32	6.1	300	6
Ge	1211	0.3230	5.7	74.9	250	2
				59.9	300	2
				33.8	500	2
GeO_2	1360	0.54	4.5			1
HgI_2	532					7
Hg_2I_2	563					7
$Gd_2(MoO_4)_3$	1410	0.42				5
$Gd_3Ga_5O_{12}$	2100			60	70	5
				9.0	300	1
$Gd_3Sc_2Al_3O_{12}$	2110	0.424	6.9	5.6	300	6
$Gd_3Sc_2Ga_3O_{12}$	2130	0.4023	7.32	6.1	300	6
Ge	1211	0.3230	5.7	74.9	250	2
Ge				59.9	300	2
				33.8	500	2
GeO_2	1360	0.54	4.5			1

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
HgI_2	532					7
Hg_2I_2	563					7
HgInSe2	1053			3.0	300	3
HgInTe2	1053			3.0	300	3
HgS	857s	0.21				1
HgSe	Subl.		4.8	5.5	110	1
HgTe	943		4.8	12	100	1
InAs	1216	0.2518	4.4	50	250	2
				27.3	300	2
				15	500	2
α-InN	1373	0.32	2.9–3.8	55.6	300	3
InP	1345	0.3117	4.5	90	250	2
				68	300	2
				32	500	2
InSb	798	0.144	4.7	16	300	3
$KAl_3Si_3O_{10}(OH)_2$	1473–1573	0.87	27	0.25–0.59	293	8
KBr	1007	0.4400	38.5	5.5	250	2
				4.8	300	2
				2.4	500	2
KCl	104	0.6936	36.5	8.5	250	2
				6.7	300	2
				3.8	500	2
KF	1131	0.8659	31.4	8.3	300	2
KH_2PO_4	123p	0.88	22.0 || a	2.0	250	2
	450p		39.2 || c	2.1	300	2
	526					2
KI	954	0.3192	40.3	2.1	300	2
$KNbO_3$	223p		37			2
	498p					2
$KTaO_3$				0.2	250	2
$KTaO_3$				0.17	300	2
$KTiOPO_4$	1210p	0.728	11 || a	2.0 || a	300	2
	1423		9 || b	3.0 || b	300	2
			0.6 || c	3.3 || c	300	2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
K_2NaAlF_6	1210					6
$La_2B_6O_{10}$	1107p					2
$La_2Be_2O_5$	1630		7–7.9 ⊥	4.7	300	1
			9.50 || c			1
			10			
$LaAlO_3$	2350					
LaB_3O_6	1420					
LaF_3	1700	0.508	15.8 || a	5.4	250	2
			11.0 || c	5.1	300	2
$LaCl_3$	1130	0.422				5
La_2O_2S			6 || c			5
			3 || a			5
LiBr	823					1
$LiCaAlF_6$	1100	0.935	3.6 || c	5.14 || c	300	6
			22 || c	4.58 ⊥ c	300	6
LiCl	878	1.2	44			1
LiF	1115	1.6200	34.4	19	250	2
				14	300	2
				7.5	500	2
$LiGdF_4$	1010					
LiI	720		58			2
$LiIO_3$	520p		28 || a			2
	693		48 || c			2
$LiNbO_3$	1523	0.63	14.8 || a	5.6	300	2
			4.1 || c			2
$LiSrAlF_6$	1065		–10.0 || c	3.09 ||c		6
			18.8 || c			6
$LiTaO_3$	1932	0.42	4.1 || c			6
			16.1 || c			6
$LiYF_4$	1092	0.79	13.3 || a	6.3	300	2
$LiYF_4$			8.3 || c			2
$Lu_3Al_5O_{12}$	2260		8.8	31	300	6
$MgAl_2O_4$	2408	0.8191	6.97	30	250	2
				25	300	2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
Mg_2SiO_4	2160	0.74	8.7 || a			5
			15.4 || b			5
			13.3 || c			5
MgF_2	1536	1.0236	9.4 || a	30 || a	300	2
			13.6 || c	21 || c	300	2
MgO	3073	0.9235	10.6	73	250	2
				59	300	2
				32	500	2
MnF_2	1130	0.75	6.1			1
MnO	2112	0.67	13			1
Na_3AlF_6	1000					1
NaBr	1028	0.5046	41.8	5.6	300	2
NaCl	1074	0.8699	41.1	8	250	2
				6.5	300	2
				4	500	2
NaF	1266	1.1239	33.5	22	250	2
				17	500	2
NaI	934	0.3502	44.7	4.7	500	2
$NaNO_3$	580	1.05	11 || a			1
			12 || c			1
$[NH_4]_2CO$	408	1.551				1
$NH_4H_2PO_4$	148p	1.26	27.2 || a	1.26 || a	300	2
	463		10.7 || c	0.71 || c	300	1,2
$PbCl_2$	774	0.27	31			1
PbF_2	422p	0.3029	29.0	28	300	2
	1094					1
PbI_2	685	0.27	31			7
	1145d					
$PbMoO_4$	1338	0.326	8.7 || a			2
$PbMoO_4$			20.3 || c			2
PbO (massicot)	1160	2.0				1
PbS	1390	0.209	19.0	2.5	300	2
PbSe	1338	0.175	19.4	2	250	2
				1.7	300	2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
PbSe				1	500	2
PbTe	1190	0.151	19.8	2.5	250	2
				2.3	300	2
				1.8	500	2
$PbTiO_3$	763p			4	300	2
				2.8	500	2
RbBr	966	0.31		12.2	105	1
RbCl	991	0.42	36	7.6	124	1
RbI	920	0.24	39	9.9	84	1
Se	490	0.3212	69.0 || a	1.5 || a	250	2
			–0.3 || c	5.1 || c	250	2
				1.3 || a	300	2
				4.5 || c	300	2
Si	1680	0.7139	2.62	191	250	2
				140	300	2
				73.6	500	2
Si_3N_4	>2300		1.1 || a	33	300	1
			2.1 || c			1
SiO_2 (α-quartz)	845p	0.7400	12.38 || a	7.5 || a	250	2
			6.88 || c	12.7 || c	250	2
				6.2 || a	300	2
				10.4 || c	300	2
				3.9 || a	500	2
				6.0 || c	500	2
α-SiC	3110	0.690		450 || a	300	2
β-SiC	3103d	0.670	2.77	490	300	2
SrF_2	1710	0.6200	18.1	11	250	2
				8.3	300	2
$SrGaO_4$	1870					
$SrGdGa_3O_7$	1870					6
$SrLaAl\ O_4$	1920					
$SrMoO_4$	1763	0.619		4.0 || a	300	2
				4.2 || c	300	2
$SrTiO_3$	110p	0.536	8.3	12.5	250	2
	2358			11.2	300	2
$Sr_3Y(BO_3)_3$	1670					

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
$Sr_3Y_4(SiO_4)_3O$	2270					
$Sr_5(PO_4)_3F$	2040	0.50		2.0	300	6
$Sr_5(VO_4)_3F$	1920	0.513	7.3 || a			6
			10.8 ⊥ c			6
Ta_2O_5	2140					1
Te	621p	0.202	27.5 || a	2.5 || a	250	2
	723		–1.6 || c	4.9 || c	250	2
				2.1 || a	300	2
				3.9 || c	300	2
				1.5 || a	500	2
				2.5 || c	500	2
TeO_2	1006	0.41	15.0 || a	3	295	1,2
			4.9 || c			2
ThO_2	3600	0.24	7.8	15	300	1
TiO_2	2128	0.6910	6.86 || a	8.3 || a	250	2
rutile			8.97 || c	11.8 || c	250	2
				7.4 || a	300	2
				10.4 || c	300	2
				5.5 || a	500	2
				8.0 || c	500	2
Tl[Br,Cl]	697	0.201	51	0.50	300	2
Tl[Br,I]	687	0.16	58	0.32	300	2
Tl_3AsSe_3	583	0.19	28 || a	0.35	300	2
			18 || c			2
TlBr	740	0.1778	51	0.53	300	2
TlCl	703	0.2198	52.7	0.74	300	2
Y_2O_3	2650	0.4567	6.56	13.5	300	2
$YAlO_3$	2140	0.42	4.3–9.5 ⊥ c	11	323	1
			11 || c			1
$YCa_4O(BO_3)_3$			7.38 (ave)	2.60 || a	300	
				2.33 || b	300	
				3.01 || c	300	
YVO_4	~2100		11.4 || a	5.1 || a	300	1,6
			4.4 ⊥ c	5.2 || c	300	1,6
$Y_3Al_5O_{12}$	2220	0.625	7.7	14.5	226	6
				13.4	300	1,2

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Thermal Properties—*continued*

Material	Melting point (K)	Heat capacity (J/g K)	Thermal expansion (10^{-6} K)	Thermal conductivity (W/ m K)	T (K)	Ref.
				9.5	322	6
$Y_3Fe_5O_{12}$	1830		10.4	41.0	70	5
				7.4	300	5
$Y_3Ga_5O_{12}$	2100			39	70	5
				9.0	300	5
$Y_3Sc_2Al_3O_{12}$	2170	0.57	6.5	11	300	6
$Y_3Sc_2Ga_3O_{12}$	2180	0.534	8.1	7.3	300	6
$ZnCl_2$	563	0.525		0.313	562.9	8
ZnF_2	1140	0.63	9.8			1
$ZnGeAs_2$	1150			11	300	3
$ZnGeP_2$	1225p		7.8 || a	18	300	3
	1300		5.0 || c			3
ZnO	2248	0.495	6.5 || a	30	300	2
			3.7 || c	15	500	2
α-ZnS	2100	0.4723	6.54 || a			2
			4.59 || c			2
β-ZnS	1293p	0.4732	6.8	16.7	300	2
ZnSe	1790	0.339	7.1	13	300	2
$ZnSnAs_2$	1048			15	300	3
$ZnSnSb_2$	870			7.6	300	3
ZnTe	1510	0.218	8.4	10	300	1
ZrO_2	~3000	0.42	8.8	10.5	260	1
ZrO_2:	3110	0.46	10.2	1.8	300	2
$12\%Y_2O_3$				1.9	500	2
$ZrSiO_4$	2820	2.7		6.3	300	1

p – phase change, d – decomposes

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1.5.2 Temperature Dependence of Heat Capacity for Selected Solids

Temperature dependence of the molar heat capacity at constant pressure for representative crystalline solids and semiconductors in the range 200 to 600 K.

Molar Heat Capacity C_p in J/mol K

Name	200 K	250 K	300 K	400 K	500 K	600 K
Al_2O_3	51.12	67.05	79.45	88.91	106.17	112.55
$CaCO_3$	66.50	75.66	83.82	91.51	104.52	109.86
CaO	33.64	38.59	42.18	45.07	49.33	50.72
CsCl	50.13	51.34	52.48	53.58	56.90	59.10
Cu_2O	34.80	—	42.41	44.95	49.19	50.83
$CuSO_4$	77.01	89.25	99.25	107.65	127.19	136.31
Ge	—	—	23.25	23.85	24.96	25.45
KCl	48.44	50.10	51.37	52.31	54.71	56.35
LiCl	43.35	46.08	48.10	49.66	53.34	55.59
MgO	—	—	37.38	40.59	45.56	47.30
NaCl	46.89	48.85	50.21	51.25	53.96	55.81
Si	15.64	18.22	20.04	21.28	23.33	24.15
SiO_2	32.64	39.21	44.77	49.47	59.64	64.42

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1.5.3 Debye Temperature

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Material	Debye temperature (K)	Ref.
AgBr	145	1
AgCl	162	1
$AgGaS_2$	255	1
$AgGaSe_2$	156	1
$AgGaTe_2$	212	2
β-AgI	116	1
Al_2O_3	1030	1
AlAs	417	2
AlN	950	1
AlP	588	2
AlSb	292	2
BaF_2	283	1
BeO	1280	1
BN	1900	1
BP	985	1
C (diamond)	2240	1
CaF_2	510	1
$CdGeS_2$	253	1
CdS	215	1
CdSe	181	1
$CdSiP_2$	282	2
$CdSnP_2$	195	2
CdTe	160	1
CsBr	145	1
CsCl	175	1
CsI	124	1
Cu_2GeS_3	254	2
Cu_2GeSe_3	168	2
Cu_2SnS_3	214	2
Cu_2SnSe_3	148	2
Cu_3AsSe_4	169	2
Cu_3SbSe_4	212	2
CuCl	179	1
$CuGaS_2$	356	1
$CuInTe_2$	195	2
GaAs	344	1
GaP	460	1
GaSb	320	2
Ge	380	1
HgTe	242	2
InP	321	2
InAs	249	2
InSb	144	2
KBr	174	1
KCl	235	1
KF	336	1
KI	132	1
$KTaO_3$	311	1
LaF_3	392	1
LiF	735	1
$LiNbO_3$	560	1
$MgAl_2O_4$	850	1
MgF_2	535	1
MgO	950	1
NaBr	225	1
NaCl	321	1
NaF	492	1
NaI	164	1
PbF_2	225	1
PbS	227	1
PbSe	138	1
PbTe	125	1
Se	151	1
Si	645	1
β-SiC	1000	1
SiO_2, α-quartz	271	1
SrF_2	378	1
Te	152	1
TiO_2	760	1
Tl[Br,Cl], KRS-6	120	1
Tl[Br,I] KRS-5	110	1
TlBr	116	1
TlCl	126	1
Y_2O_3	465	1
$Y_3Al_5O_{12}$	754	1
$ZnGeAs_2$	271	2
$ZnGeP_2$	428	1
ZnO	416	1
α-ZnS	351	1
β-ZnS	340	1
ZnSe	270	1
ZnTe	225	1
ZrO_2:12%Y_2O_3	563	1

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1.6 Magnetooptic Properties

1.6.1 Diamagnetic Materials

Verdet Constants V of Diamagnetic Crystals (room temperature)*

Crystal	Wavelength (nm)	V (rad/(m T))	CTE α (10^{-6}/K)	(1/V)dVdT + α (10^{-4}/K)	Ref.
AgBr	633	26.8			1
AgCl	633	22.8	30	3.2	1
Al_2O_3	546	4.0			3
	589	3.5			3
BaF_2	633	3.75	19	–0.2	1
$Ba(NO_3)_2$	633	2.9	17.5	0.7	1
$BaTaO_3$ (403 K)	427	276			16
	496	111			16
	620	52.4			16
	826	21.0			16
$BaTiO_3$	620	–51.0			3
$Bi_4Ge_3O_{12}$	442	84.1			4
	633	30.1		2.0	2
	633	28.8			4
	1064	7.6			4
	1064	7.5			4
$Bi_{12}GeO_{20}$	633	60.3			1
C (diamond)	589	6.8		1.4	5
	633	5.81	0.87		1
$CaCO_3$	589	5.6		0	6
CaF_2	589	5.6			4
	633	2.49	19	0.9	1
CsBr	633	10.8	47	0.8	1
CsCl	633	8.3	46	0.7	1
CsCN	633	5.51		3	1
CsF	633	4.71	33	0.3	1
CsH_2AsO_4	633	6.49			7
CsI	633	17.4	49	2.5	1
$CsNO_2$	633	4.24			1
CuCl	546	58.1			8
	633	31.9	30	3.0	1
Cu_2O	633	147	0	5.2	1
GaP	633	154	5.81	3.3	1
GaSe	633	22			9

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Verdet Constants of Diamagnetic Crystals—*continued*

Crystal	Wavelength (nm)	V (rad/(m T))	CTE α (10^{-6}/K)	(1/V)dVdT + α (10^{-4}/K)	Ref.
$Gd_3Al_5O_{12}$	633	13.3	3.35	–2.2	1
$Hg_3Te_2Cl_2$	633	83			1
$KAl(SO_4)$•12 H_2O	589	3.6			13
KBr	546	14.5			10
	589	12.4			10
	633	10.1			1
KCl	633	6.68	38.4	1.0	1
KCN	633	3.89	36.2	2.1	1
KH_2PO_4	633	3.72	49	0.5	7
KH_2AsO_4	633	69.3			7
KI	546	24.1			10
	589	20.4			10
	633	17.5		2.2	1
$KTaO_3$	352	128			13
	413	55			13
	496	28			13
	620	–14	43		3
	826	6.4			13
LaF_3	325	16			4
(H || c)	442	8.1			4
	633	3.5			4
	1064	1.8			4
$LiBaF_3$	633	3.72	27	0.7	1
LiBr	633	14.2	38	2	1
LiCl	633	9.3	35	1.3	1
LiF	633	2.33	25	3.0	1
LiH	633	24.6	32	1.7	1
$MgAl_2O_4$	589	6.1			14
	633	7.6	8.82	0.9	1
MgO	633	9.2	13	1.7	1
NaBr	546	18.1			13
	633	13.2		1.8	1
NaCl	546	11.9			10
	589	10.0			10
	633	8.5	39.8	1.2	1
$NaClO_3$	546	3.1			13
	589	2.4			13
NaI	633	22.5	43	1.9	1
NH_4	633	12.6	53	2	1
$NH_4Al(SO_4)$•12 H_2O	589	3.7			13
NH_4Br	589	14.7			13
	633	8.9	48	0.9	1

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Verdet Constants V of Diamagnetic Crystals—*continued*

Crystal	Wavelength (nm)	V (rad/(m T))	CTE α (10^{-6}/K)	(1/V)dVdT + α (10^{-4}/K)	Ref.
NH_4Cl	546	11.9			13
	589	10.5			13
	633	6.60			7
$NH_4H_2AsO_4$	633	69.3			15
$NH_4H_2PO_4$	633	40.2			15
NH_4I	633	18.3	37	3.0	1
$NiSO_4 \cdot H_2O$	546	7.4			14
	589	6.4			14
RbH_2PO_4	633	3.72			7
RbH_2AsO_4	633	6.17			7
SiO_2	546	5.6			11
	589	4.9			11
$Sm_3Ga_5O_{12}$	633	11.8	6.39	1.24	1
$SrTiO_3$	413	227			16
	496	90.2			16
	633	–49.0	9.4	–1.8	1
	826	–19.2			3
TiO_2	620	–45			3
$Y_3Ga_5O_{12}$	633	11.7	5	1.23	1
ZnS	546	83.4			5
	589	65.8			5
	633	52.8		10.0	1
ZnSe	476	436			12
	496	302			12
	514	244			12
	587	154			12
	633	118			12
ZnTe	633	188		3.7	1

* The above table was adapted from Deeter, M. N., Day, G. W., and Rose, A. H., Magnetooptic materials: crystals and glasses, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 367, with additions.

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1.6.2 Paramagnetic Materials

Verdet Constants for Representative Paramagnetic Crystals*

Crystal	Wavelength λ (nm)	Refractive index n	V (rad/(m T)	Ref.
$CaF_2:Ce^{3+}$(30%)	325	1.516	–278	1
	442	1.502	–86.4	1
	633	1.494	–32.3	1
	1064	1.489	–10.2	1
$CaF_2:Pr^{3+}$(5%)	266	1.471	–50.1	1
	325	1.461	–23.8	1
	442	1.451		1
	633	1.445	–4.9	1
	1064	1.441	–1.31	1
CeF_3	442	1.613	–306	1
	633	1.598	–118	1
	1064		–33	1
EuF_2	450		–1310	1
	500		–757	2
	550		–466	2
	600		–320	2
	633	1.544	–262	1
	650		–233	2
	1064	1.518	–55.3	1
$LiTbF_4$	325	1.493	–553	3
	442	1.481	–285	3
	633	1.473	–128	3
	1064	1.469	–38	3
NdF_3	442	1.60	–161	1
	633	1.59	–60.8	1
	1064	1.58	–28.2	1

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Verdet Constants for Representative Paramagnetic Crystals—*continued*

Crystal	Wavelength λ (nm)	Refractive index n	V (rad/(m T)	Ref.
KTb_3F_{10}	325	1.531	–633	3
	442	1.518	–272	3
	633	1.510	–112	3
	1064	1.505	–33.2	3
$Tb_3Ga_5O_{12}$	500		–278	4
	570		–169	4
	633	1.976	–134	1
	830		–61	4
	1064	1.954	–35	1

* The above table was adapted from Deeter, M. N., Day, G. W., and Rose, A. H., Magnetooptic materials: crystals and glasses, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 367, with additions.

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Rare Earth Aluminum Garnets

Material	Temp. (K)	Verdet constant V (rad/T m) at wavelength in nm 405	450	480	520	578	670	Ref.
$Tb_3Al_5O_{12}$	300	–659.4	–455.4	375.4	–302.3	–229	–158	1
	77	—	–29728	24284	–997	–757	–528	1
	4.2	—	—	—	–18860	–15650	–13140	2
	1.45	—	–58476	–50203	–40530	–32380	–27185	2
$Dy_3Al_5O_{12}$	300	–361	–274	–234	–194	–151	–104	1
$Ho_3Al_5O_{12}$	300	–206	–93.1	–75.7	–97.5	–87.0	–59.9	1
$Er_3Al_5O_{12}$	300	–55.0	–69.8	–44.8	–47.1	–42.2	–25.9	1
$Tm_3Al_5O_{12}$	300	43.9	30.0	27.1	22.1	17.2	—	1
$Yb_3Al_5O_{12}$	298	83.5	62.6	54.1	40.7	33.8	—	3
	77	209	157	140	114	87.9	—	3

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1.6.3 Ferromagnetic, Antiferromagnetic, and Ferrimagnetic Materials

The following symbols are used in the tables below:

T_c = Curie temperature
T_p = phase transition temperature
T_N = Neel temperature
T_∞ = compensation temperature
$4\pi M_S$ = saturation induction at 0 K, gauss
F = specific Faraday rotation, deg/cm
α = absorption coefficient (cm^{-1})
λ = measurement wavelength, nm

Transition Metals*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
Fe (bcc)	T_c = 1043	21800	4.4×10^5	6.5×10^5	300	500
			3.5×10^5	7.6×10^5	300	546
			6.5×10^5	5×10^5	300	1000
			7×10^5	4.2×10^5	300	1500
			7×10^5	3.5×10^5	300	2000
Co (hcp)	T_c = 1390	18200	2.9×10^5	—	300	500
			3.6×10^5	8.5×10^5	300	546
			5.5×10^5	6.1×10^5	300	1000
			5.5×10^5	4.5×10^5	300	1500
			4.8×10^5	3.6×10^5	300	2000
Ni (fcc)	T_c = 633	6400	0.8×10^5	—	300	500
			0.99×10^5	8.0×10^5	300	546
			2.6×10^5	5.8×10^5	300	1000
			1.5×10^5	4.8×10^5	300	1500
			1×10^5	4.1×10^5	300	2000
			7.2×10^5	4.2		4000

Binary Compounds*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
MnBi (NiAs)	T_c = 639	7700	4.2×10^5	6.1×10^5	300	450
		7500	5.0×10^5	5.8×10^5	300	500
		(300 K)	7.0×10^5	5.1×10^5	300	600
			7.7×10^5	4.5×10^5	300	700
			7.6×10^5	4.3×10^5	300	800
			7.5×10^5	4.2×10^5	300	900
			7.4×10^5	4.1×10^5	300	1000
MnAs (NiAs)	T_c = 313		0.44×10^5	5.0×10^5	300	500
			0.49×10^5	4.9×10^5	300	600

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Binary Compounds*—*continued*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
MnAs			0.78×10^5	4.5×10^5	300	800
			0.62×10^5	4.4×10^5	300	900
CrTe	$T_c = 334$		0.5×10^5	2.0×10^5	300	550
(NiAs)			0.4×10^5	1.2×10^5	300	900
			0.4×10^5	0.6×10^5	300	2500
FeRh	$T_p = 334$		0.9×10^5	3.3×10^5	348	700

Ferrites*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
$Y_3Fe_5O_{12}$	$T_N = 560$	2500	2400	1500	300	555
(garnet)			1750	1350	300	588
			1250	1400	300	625
			900	670	300	715
			800	1150	300	667
			750	450	300	770
			240	0.069	300	1200
			175	<0.06	300	5000–1500
$Gd_3Fe_5O_{12}$	$T_N = 564$	7300	–2000	6000	300	500
(garnet)	$T_\infty = 286$		–1050	900	300	600
			–450	400	300	700
			–300	100	300	800
			–220	230	300	900
			–80	70	300	1000
$NiFeO_4$	$T_N = 858$	3350	2.0×10^4	5.9×10^4	300	286
(spinel)			2.4×10^4	7.4×10^4	300	330
			-0.75×10^4	16×10^4	300	400
			-1.0×10^4	10×10^4	300	500
			0.12×10^4	1×10^4	300	660
			–120	38	300	1500
			40	32	300	2000
			75	15	300	3000
			110	15	300	4000
			110	32	300	5000
$CoFeO_4$	$T_N = 793$	4930	2.75×10^4	12×10^4	300	286
(spinel)			3.8×10^4	14×10^4	300	330
			3.6×10^4	17×10^4	300	400

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Ferrites*—*continued*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
			1.3×10^4	13×10^4	300	500
			-2.5×10^4	6×10^4	300	660
$MgFeO_4$			–60	100	300	2500
(spinel)			–40	40	300	3000
			0	12	300	4000
			30	4	300	5000
			35	6	300	6000
			50	13	300	7000
$BaFe_{12}O_{19}$			–50	38	300	2000
(hexagonal)			75	20	300	3000
			130	13	300	4000
			150	20	300	5000
			160	20	300	6000
			165	22	300	7000
$Ba_2Zn_2Fe_{12}O_{19}$			90	120	300	5000
(hexagonal)			80	70	300	6000
			75	65	300	7000
			70	85	300	8000

Halides*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
$RbNiF_3$	$T_N = 220$	1250	360	35	77	450
(perovskite)			210	12	77	500
			70	10	77	600
			–70	30	77	700
			310	70	77	800
			100	60	77	900
			75	25	77	1000
$RbFeF_3$	$T_p = 102$		3400	7	82	300
(perovskite)			160	3	82	400
			950	4.6	82	500
			620	1.5	82	600
			420	1.2	82	700
			300	2.5	82	800
FeF_3	$T_c = 365$	40	670	14	300	349
		(300 K)	415	8.2	300	404
			180	4.4	300	522.5

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Halides*—*continued*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
$CrBr_3$	$T_c = 32.5$	3390	3×10^5	3×10^3	1.5	478
(BiI_3)			1.6×10^5	1.4×10^4	1.5	500
$CrCl_3$	$T_c = 16.8$	3880	2000	20	1.5	410
(BiI_3)			–500	3	1.5	450
			–1000	30	1.5	590
CrI_3	$T_c = 68$	2690	1.1×10^5	6.3×10^3	1.5	970
(BiI_3)			0.8×10^5	3×10^3	1.5	1000

Borates*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
$FeBO_3$	$T_c = 115$	115	3200	140	300	500
(calcite)	(300 K)		2300	40	300	525
			1100	100	300	600
			450	38	300	700

Chalcogenides*

Material (structure)	Critical temp.	$4\pi M_S$ (gauss)	F (deg/cm)	Absorp. coeff. α (cm^{-1})	Temp. (K)	λ (nm)
EuO	$T_c = 69$	23700	-1.0×10^5	0.5×10^4	5	1100
(NaCl)		7500	3.2×10^5	7.5×10^4	5	800
			5×10^5	9.7×10^4	5	700
			3.6×10^5	9.7×10^4	5	600
			0.5×10^5	7.8×10^4	5	500
			3×10^4	$>0.5^5$	20	2500
			660	≥ 1.0	20	10600
EuS	$T_c = 16.3$		-1.6×10^5	~0	6	825
(NaCl)			-9.6×10^5	3.3×10^4	6	690
			5.5×10^5	1.2×10^5	6	563
			5.1×10^5	1.0×10^5	6	495
EuSe	$T_c = 7$	13200	1.45×10^5	80	4.2	750
(NaCl)			1.17×10^5	70	4.2	775
			0.95×10^5	60	4.2	800

* The data in the above tables are from Di Chen, Magnetooptical materials, *Handbook of Laser Science and Technology, Vol. IV, Optical Materials, Part 2* (CRC Press, Boca Raton, FL, 1986), p. 287.

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Room-Temperature Saturation Kerr Rotation Data for Ferromagnetic Materials

Material	T_c (K)	λ (nm)	θ_K (°)	Ref.
Fe	1043	633	–0.41	1
Co	1388	633	–0.35	1
Ni	627	633	–0.13	1
FeCo	NA	633	–0.54	1
MnBi	633	633	–0.70	2
PtMnSb	582	720	–1.27	3
CeSb[a]	16	2500	14	4

Measured at T = 2 K.

Faraday Rotation Data For Nonmetallic Ferro– and Antiferromagnetic Materials

Material	T_c (K)	$\mu_0 H$ (T)	λ (nm)	θ'_F (°/cm)	Ref.	Comments
EuO	69	2.1	660	4.9×10^5	5	1,4
EuSe	7	2.0	755	1.4×10^5	6	1,2,4,8
EuS	16	0.675	670	5.5×10^5	7	1,4
$CrBr_3$	36		493	1×10^5	8	1,5
$CdCr_2S_4$	84	0.6	1000	3800	9	1,5
$CdCr_2Se_4$	130	0.45	1050	5.5×10^4	10	1,4
$CoCr_2S_4$	221	0.4	10,600	320	11	ferri, 4
$YFeO_3$			600	$\sim 8 \times 10^3$	12	3,5,7
$FeBO_3$	348		525	2300	13	3,5,7
UO_2	30.8	4.0	276	4.8×10^4	14	2,4,8

Comments: (1) ferromagnetic; (2) antiferromagnetic; (3) canted antiferromagnetic; (4) electrically semiconducting; (5) electrically insulating; (6) electrically conducting; (7) birefringent; (8) measured in unsaturated state. (The ferrimagnet $CoCr_2S_4$ is included because of its chemical similarity to the ferromagnets $CdCr_2S_4$ and $CdCr_2Se_4$.)

Saturation Kerr Rotation/Ellipticity Data for Nonmetallic Ferromagnetic Materials

Material	T_c (K)	$\mu_0 H$ (T)	λ (nm)	$\theta_K[\varepsilon_K]$ (°)	Ref.	Comments
TmS	5.2	4	440	[–2.4]	15	1,6,8
TmSe	1.85	4	540	[–3.6]	15	1,6,8
US	177	4	350	[3.4]	16	1,6
USe	160	4	420	[4.0]	16	1,6
UTe	104	4	830	3.1	16	1,6
$CuCr_2Se_4$	432	2	1290	[–1.19]	17	1,6
$CoCr_2S_4$	221	1.5	1800	–4.6	18	ferri, 4

For materials which possess greater values of Kerr ellipticity than Kerr rotation, the ellipticity is reported in brackets [ ].

Comments: (1) ferromagnetic; (2) antiferromagnetic; (3) canted antiferromagnetic; (4) electrically semiconducting; (5) electrically insulating; (6) electrically conducting; (7) birefringent; (8) measured in unsaturated state.

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Room–Temperature Saturation Faraday Rotation and Absorption Data for Selected Iron Garnets at λ = 633 nm

Material	θ'_F(°/cm)	α (cm^{-1})	Growth technique	Ref.
$Y_3Fe_5O_{12}$	835	870	LPE	25
$Gd_3Fe_5O_{12}$	345	750	LPE	20
$Bi_3Fe_5O_{12}$	-5.5×10^4		sputtering	21
$Y_3Fe_{4.07}Ga_{0.93}O_{12}$	855	650	LPE	19
$Y_3Fe_{3.54}Ga_{1.46}O_{12}$	645	530	flux method	19
$Y_{2.3}Bi_{0.7}Fe_5O_{12}$	-1.25×10^4	1000	flux method	22
$Y_{0.5}Bi_{2.5}Fe_5O_{12}$	-7.5×10^4		MOCVD	23
$Y_{2.0}Ce_{1.0}Fe_5O_{12}$	2.2×10^4	540	sputtering	24

Room–Temperature Saturation Faraday Rotation and Absorption Data for Selected Iron Garnets at λ = 1064 nm

Material	θ'_F(°/cm)	α (cm^{-1})	Growth technique	Ref.
$Y_3Fe_5O_{12}$	280	9	flux method	25
$Pr_3Fe_5O_{12}$	65	10	flux method	26
$Nd_3Fe_5O_{12}$	535		flux method	26
$Sm_3Fe_5O_{12}$	15		flux method	25
$Eu_3Fe_5O_{12}$	107		flux method	25
$Gd_3Fe_5O_{12}$	65	10	flux method	25
$Tb_3Fe_5O_{12}$	535		flux method	25
$Dy_3Fe_5O_{12}$	310		flux method	25
$Ho_3Fe_5O_{12}$	135		flux method	25
$Er_3Fe_5O_{12}$	120		flux method	25
$Gd_{2.0}Bi_{1.0}Fe_5O_{12}$	–3300	< 10	flux method	27
$Y_{2.0}Ce_{1.0}Fe_5O_{12}$	–22000	1700	sputtering	24

Room–Temperature Saturation Faraday Rotation and Absorption Data for Selected Iron Garnets at λ = 1300 nm

Material	θ'_F(°/cm)	α (cm^{-1})	Growth technique	Ref.
$Y_3Fe_5O_{12}$	210	0.3	flux method	28
$Gd_3Fe_5O_{12}$	60	1.0	flux method	28
$Tb_3Fe_5O_{12}$	320		flux method	26
$Dy_3Fe_5O_{12}$	175		flux method	26
$Tm_3Fe_5O_{12}$	110		flux method	26
$Pr_3Fe_5O_{12}$	–1060	70	flux method	26
$Nd_3Fe_5O_{12}$	–690	< 50	LPE	26
$Y_{1.7}Bi_{1.3}Fe_5O_{12}$	–2100		LPE	29
$Gd_{2.0}Bi_{1.0}Fe_5O_{12}$	–2100	< 10	flux method	27
$Y_{2.0}Ce_{1.0}Fe_5O_{12}$	–120000	250	sputtering	24

LPE (liquid phase epitaxy), sputtering, and MOCVD (metal–organic chemical vapor deposition) are thin–film growth techniques. The flux method yields bulk crystals.

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The preceding tables were adapted from Deeter, M. N., Day, G. W., and Rose, A. H., Magnetooptic materials: crystals and glasses, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 367 (with additions).

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Faraday Rotation and Magnetooptic Properties of Orthoferrites[a]

		Intrinsic specific Faraday rotation (deg/cm) at 300 K						
Material	**$4\pi M_S$**[b] **(gauss)**	**600 nm**	**800 nm**	**1000 nm**	**1200 nm**	**1400 nm**	**1600 nm**	**Abs. coeff. (cm^{-1})** [c]
$EuFeO_3$	83							~38
$GdFeO_3$	94							~10
$TbFeO_3$	137							~29
$DyFeO_3$	128			|| c				~40
$HoFeO_3$	91	8000	2200	1000	800	700	600	~10
$ErFeO_3$	81							~15
$TmFeO_3$	140							~5
$YbFeO_3$	143							~12.5
$LuFeO_3$	119							~5
$SmFeO_3$	84							~50
$YFeO_3$	105			|| a				~10
$LaFeO_3$	83	3400	700	400	300	200	150	~10
$PrFeO_3$	71							~35
$NdFeO_3$	62							~10

[a] Strong natural birefringence interferes with the Faraday effect.
[b] Saturation induction.
[c] At a wavelength of 1250 nm.

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1.7 Electrooptic Properties

1.7.1 Linear Electrooptic Coefficients

The linear electrooptic effect occurs in acentric crystals. Only 21 acentric groups (those lacking a center of inversion) may have nonvanishing coefficients. Reduced electrooptic matrix forms are given in the two references below.

If the electrooptic coefficient r_{ij} is determined at constant strain (by making the measurement at high frequencies well above acoustic resonances of the sample) the crystal is clamped, as indicated by S. If the r_{ij} is determined at constant stress (at low frequencies well below the acoustic resonances of the sample) the sample is free, as indicated by T. The electrooptic coefficients are generally those for room temperature. Typical accuracies for r_{ij} are ±15%. Unless shown explicitly, the signs of r_{ij} have not been determined. As a rule, r_{ij} has little optical wavelength dependence in the transparent region of the crystal.

The following tables were adapted from:

> Kaminow, I. P., Linear Electrooptic Materials, *Handbook of Laser Science and Technology,* Vol. IV (CRC Press, Boca Raton, FL, 1986), p. 253.
>
> Holland, W. R. and Kaminow, I. P., Linear Electrooptic Materials, *Handbook of Laser Science and Technology, Suppl. 2* (CRC Press, Boca Raton, FL, 1995), p. 133.

A comprehensive table of electrooptic constants including extensive data on refractive indices and curves of wavelength and temperature dependence of electrooptic coefficients is given in Cook, W. R., Hearmon, R. F. S., Jaffe, H., and Nelson, D. F., Piezooptic and electrooptic coefficient constants, *Landolt-Börstein*, Group III, Vol. 11, Hellewege, K.-H. and Hellewege, A. M., Eds. (Springer-Verlag, New York, 1979), p. 495.

The following tables are divided according to the general structure of the electrooptic materials, i.e., tetrahedally coordinated binary AB compounds that are semiconductors, ABO_3-type compounds that are ferroelectric or pyroelectric, isomorphs of ferroelectric KH_2PO_4 and antiferroelectric $NH_4H_2PO_4$, other compounds that do not fit the previous categories, and organic compounds. Although nonlinear optic coefficients have been measured for many organic crystal and can be converted to equivalent electrooptic coefficients, only direct phase retardation measurements of the electrooptic effect are included in the last table.

AB-Type Compounds

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μm)
CdS	6mm	T	$r_c = 4$	0.589
		T	$r_{51} = 3.7$	0.589
		T	$r_c = 5.5$	10.6
		S	$r_{33} = 2.4$	0.633
		S	$r_{13} = 1.1$	
		T	$r_c = 4.8 \pm 0.2$	
		T	$r_{42} = 1.6 \pm 0.2$	

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AB-Type Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
CdS		T	$r_{33} = 3.2 \pm 0.2$	1.15
		T	$r_{13} = 3.1 \pm 0.2$	
		T	$r_c = 6.2 \pm 0.2$	
		T	$r_{42} = 2.0 \pm 0.2$	
		T	$r_{33} = 2.9 \pm 0.1$	3.39
		T	$r_{13} = 3.5 \pm 0.1$	
		T	$r_c = 6.5 \pm 0.2$	
		T	$r_{42} = 2.0 \pm 0.2$	
		T	$r_{33} = 2.75 \pm 0.08$	10.6
		T	$r_{13} = 2.45 \pm 0.08$	
		T	$r_c = 5.2 \pm 0.3$	
		T	$r_{42} = 1.7 \pm 0.3$	
CdSe	6mm	S	$r_{33} = 4.3$	3.39
		S	$r_{13} = 1.8$	
$CdS_{0.75}Se_{0.25}$	6mm	T	$n_1^3 r_c = 70$	0.63
CdTe	-43m	T	$r_{41} = 6.8$	3.39
		T	$r_{41} = 6.8$	10.6
		T	$r_{41} = 5.5$	23.35
		T	$r_{41} = 5.0$	27.95
		S	$n_0^3 r_{41} = 100 \pm 10$	10.6
CuBr	-43m	T	$r_{41} = 0.85$	0.525
		S	$r_{41} = -2.5$	0.63
		S	$r_{41} = -3.0$	1.15
		S	$r_{41} = -3.0$	3.39
CuCl	-43m	T	$r_{41} = 3.6$	0.633
		T	$r_{41} = 3.2$	10.6
		S	$r_{41} = 2.35$	0.633
		S	$r_{41} = 2.20$	3.39
		S	$r_{41} = -2.35$	0.63
		S	$r_{41} = -2.5$	3.39
		T	$r_{41} = -5$	0.55
CuI	-43m	T	$n_0^3 r_{41} = 30$	0.63
GaAs	-43m	S	$r_{41} = 1.2$	0.9–1.08
		S	$r_{41} = -1.5$	3.39
		S + T	$r_{41} = 1.2 – 1.6$	1.0 – 3.0
		T	$r_{41} = 1.0 – 1.2$	2.0 – 12.0
		T	$r_{41} = 1.6$	10.6
		S	$r_{41} = -1.33$	1.06

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AB-Type Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
GaAs		T	r_{41} = 1.24 ± 0.04	3.39
		T	r_{41} = 1.51 ± 0.05	10.6
GaP	-43m	S	r_{41} = -1.07 – -0.97	0.56 – 3.39
		T	r_{41} = 0.79–0.80 (200 Hz)	0.552 – 1.15
		S	r_{41} = 0.95–0.87 (9.45 GHz)	
GaSe	-6m2	T	r_{22} = 22	0.63
		T	$n_1^3 r_{22}$ = 27.5	1.06
HgS	32	S	r_{11} = 3.1	0.633
		S	r_{41} = 1.4	0.633
		S	r_{11} = 4.2	3.39
		S	r_{41} = 2.4	3.39
InP	-43m	S	r_{41} = -1.34	1.06
		S	r_{41} = -1.68	1.50
β-SiC	43m	T	$r_{41,52,63}$ = 2.7±0.5	0.633
ZnO	6mm	S	r_{33} = +2.6	0.633
			r_{13} = -1.4	0.633
		S	r_{33} = +1.9	3.39
			r_{13} = +0.96	3.39
			r_{51} = -3.1	0.4
		T	r_{31} - r_{33} = -1.4	0.4
ZnS	-43m	T	r_{41} = 1.2	0.4
		T	r_{41} = 2.1	0.65
		S	r_{41} = 1.6	0.633
		S	r_{41} = 1.4	3.39
		T	r_{41} = -1.9	0.63
ZnS	6mm	T	r_{41} = 2.0	0.546
		S	r_{41} = 2.0	0.633
		T	r_{41} = 2.2	10.6
		T	r_{41} = 1.9	0.55
ZnTe	-43m	T	r_{41} = 4.45 – 3.95	0.59 – 0.69
		T	r_{41} = 1.4	10.6
		S	r_{41} = 4.3	0.633
		S	r_{41} = 3.2	3.39
		T	r_{41} = 4.2 ± 0.3	3.41
		T	r_{41} = 3.9 ± 0.2	10.6

* $r_c = r_{33} - (n_1^3 / n_3^3) r_{33}$

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ABO_3-Type Compounds

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$Ba_xNaNb_5O_{15}$	mm2		$r_C = 34$	0.633
			$r_{33} = 48$	
			$r_{42} = 92$	
			$r_{13} = 15$	
			$r_{33} = +29$	
			$42 = 75$	
			$r_{13} = 6.1$	
			$n_3^3 r_{33} = 265$	
			$n_1^3 r_{13} = 76$	
$Ba_{2-y}Sr_yK_xNa_{1-x}Nb_5O_{15}$ (0.5<*x*<0.75) (0.6<*y*<1.8)	4mm		$n_o^3 r_o = 730$	0.561
$Ba_{1.5}Sr_{0.5}K_{0.75}Na_{0.25}Nb_5O_{15}$	4mm		$r_{33} = 110$	
			$r_{51} = 250$	
$Ba_{0.5}Sr_{1.5}K_{0.5}Na_{0.75}Nb_5O_{15}$	4mm		$r_{33} = 180$	
			$r_{51} = 300$	
$Ba_{0.5}Sr_{1.5}K_{0.25}Na_{0.75}Nb_5O_{15}$	4mm		$r_{33} = 200$	
$BaTiO_3$	4mm	T	$r_{13} = 19.5 \pm 1$	0.5145
		T	$r_{33} = 97 \pm 7$	
		T	$r_c = 76 \pm 7$	
		T	$r_c = 108$	0.546
		T	$r_{51} = 1640$	
		S	$r_c = 23$	
		S	$r_{51} = 820$	
		S	$r_c = 19$	0.633
		S	$r_{33} = 28$	
		S	$r_{13} = 8$	
$KNbO_5$	mm2	S	$r_{33} = 25 \pm 8$	0.633
		S	$r_{42} = 270 \pm 40$	
		S	$r_{13} = 10 \pm 2$	
		S	$r_{51} = 23 \pm 3$	
		S	$r_{23} = 2 \pm 1$	
		T	$r_{33} = 64 \pm 5$	
		T	$r_{42} = 380 \pm 50$	
		T	$r_{13} = 28 \pm 2$	
		T	$r_{51} = 105 \pm 13$	
			$r_{23} = +1.3 \pm 0.5$	
$KSr_xNb_5O_{15}$	4mm or 4	T	$r_c = 130$	0.633

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ABO_3-Type Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$LiIO_3$	6	S	$r_{33} = +6.4$	0.633
		S	$r_{41} = 1.4$	
		S	$r_{13} = +4.1$	
		S	$r_{51} = +3.3$	
$LiNbO_5$	3m	T	$r_c = 17.4$	0.633
		T	$r_{22} = 6.8$	
		T	$r_{51} = 32$	
		T	$r_{33} = +32.2$	
		T	$r_{13} = +10$	
		T	$r_c = 17$	1.15
		T	$r_{22} = 5.7$	
		T	$r_c = 16$	3.39
		T	$r_{22} = 3.1$	
		S	$r_{33} = +30.6$	0.633
		S	$r_{13} = +8.6$	
		S	$r_{51} = +28$	
		S	$r_{33} = 28$	3.39
		S	$r_{22} = 3.1$	
		S	$r_{13} = 65$	
		S	$r_{51} = 23$	
		S	$r_{33} = +28.8$	0.633
		S	$r_{51} = +18.2$	
		S	$r_{13} = +7.68$	
		S	$r_{33} = 27.2$	1.152
		S	$r_{13} = +6.65$	
		S	$r_{33} = +25.5$	3.391
		S	$r_{13} = +5.32$	
$LiTaO_5$	3m	T	$r_c = 22$	0.633
		S	$r_{33} = 30.3$	
		S	$r_{51} = 20$	
		S	$r_{33} = 27$	3.39
		S	$r_{51} = 15$	
		S	$r_{13} = 4.5$	
		S	$r_{22} = 0.3$	
		S	$r_{13} = 6.2$	
		S	$r_{33} = 26.7$	1.152
		S	$r_{51} = 8.9$	
		S	$r_{13} = 5.2$	
		S	$r_{33} = 25.2$	3.39
		S	$r_{13} = 4.4$	
		T	$r_{33} = 30.5 \pm 2$	0.633
		T	$r_{13} = 8.4 \pm 0.9$	

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ABO_3-Type Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.* r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$K_5Li_2Nb_5O_{15}$	4mm		$r_{33} = 78$	0.633
			$r_{13} = 8.9$	
$KTa_xNb_{1-x}O_5$	4mm	T	$r_c = 450$	0.633
		T	$r_{51} = +50$	
$La_y(Sr_{.5}Ba_{0.5})_{1-1.5y}Nb_2O_6$ (0<*y*<.03)	4mm		$r_c = 145\text{-}669$	0.6328
			$r_c = r_{33}–(n_1/n_3)^3 r_{13}$	
$PbTiO_5$	4mm	S	$r_{33} = 5.9$	0.633
		S	$r_{13} = 13.8$	
$Sr_{0.61}Ba_{.0.39}Nb_2O_6$	4mm	T	$r_{13} = 47 \pm 5$	0.5145
		T	$r_{33} = 235 \pm 21$	
$Sr_{0.75}Ba_{.0.25}Nb_2O_6$	4mm	T	$r_c = 1410$	0.633
		T	$r_{33} = 1340$	
		T	$r_{51} = 42$	
		T	$r_{15} = 67$	
		S	$r_c = 1090$	
$Sr_{0.5}Ba_{.0.5}Nb_2O_6$	4mm	T	$r_c = 218$	0.633
$Sr_{0.46}Ba_{.0.54}Nb_2O_6$	4mm	T	$r_{33} = 35 \pm 3$	0.633
		T	$r_{13} = 180 \pm 30$	
$Sr_{0.3}Ba_{.0.79}Nb_2O_6$	4mm	T	$r_{13} = -266$	0.633
			$r_{33} = +113$	

* $r_c = r_{33} - (n_1^3 / n_3^3) r_{33}$

KDP- and ADP-Type Compounds

Material	Symmetry*	T/S	Electrooptic coeff. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
KH_2PO_4 (KDP)	-42m	T	$r_{63} = 9.4 \pm 0.4$	0.633
		T	$r_{41} = +8.6$	
		S	$r_{63} = 8.8$	
KD_2PO_4 (DKDP)	-42m	T	$r_{63} = 23.8 \pm 0.6$	0.633
		T	$r_{41} = 8.8$	
		T	$r_{61} < 0$	
		S	$r_{63} = 24.0$	
KH_2AsO_4 (KDA)	-42m	T	$r_{63} = 10.9$	0.633
		T	$r_{41} = = 12.5$	
KD_2AsO_4 (DKDA)	-42m	T	$r_{63} = 18.2$	0.633

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KDP- and ADP-Type Compounds—*continued*

Material	Symmetry*	T/S	Electrooptic coeff. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
RbH_2PO_4 (RDP)	-42m	T	r_{63}= 15.5	0633
		S	r_{63} = 0.91	
RbH_2AsO_4 (RDA)	-42m	T	r_{63} = 13.0	0.633
RbD_2AsO_4 (DRDA)	-42m	T	r_{63} = 21.4	0633
CsH_2AsO_4 (CDA)	-42m	T	r_{63} = 18.6	0633
CsD_2AsO_4 (DCDA)	-42m	T	r_{63} = 36.6	0633
$NH_4H_2PO_4$ (ADP)	-42m	T	r_{63} = -8.5	0633
		T	r_{41} = 24.5	
		S	r_{63} = 5.5	
$NH_4D_2PO_4$ (DADP)	-42m	T	r_{63} = 11.9	0633
$NH_4H_2AsO_4$ (ADa)	-42m	T	r_{63} = 9.2	0633

* Above T_c

Other Compounds

Material	Symmetry	T/S	Electrooptic coeff.. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$AgGaS_2$	-42m	T	r_{63} = 3.0	0.633
		T	r_{41} = 4.0	
$AgGaSe_2$	-42m	T	r_{63} = 6.9	1.15
		T	r_{41} = 4.5	
		T	$n^3 r_{63}$ = 76	
		T	$n^3 r_{41}$ = 85	
$(CH_3NH_3)_5Bi_2Br_{11}$	mm2	T	$1/2(n_3^3 r_{33} - n_2^3 r_{23})$=5.8±0.8	0.6328
		T	$1/2(n_3^3 r_{33} - n_1^3 r_{13})$=3.5±0.7	
BaB_2O_4 (BBO)	3m	T	r_{22} = 2.7±0.4	0.6328
		T	r_{31} = 0	
		T	r_{61} = 0.055	
		T	r_{22} = 2.5±0.1	
		T	r_c = 0.17±0.02	
		S	r_{22} = 2.1±0.3	
		S	r_c = 0.11±0.02	
$Bi_4Ge_3O_{20}$ (BGO)	23	T	r_{41} = 1.03	0.45–0.62
		T	r_{41} = 0.95	0.63
$Bi_4Si_3O_{20}$	23	T	r_{41} = 0.54	0.63
$Bi_{40}Ga_2O_{63}$	23	T	$n_0^3 r_{41}$ = 54.9	0.633

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Other Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$Bi_{12}GeO_{20}$	23		$r_{41} = 3.67 \pm 0.11$	0.633
(BGO)			$r_{41} = 3.29 \pm 0.10$	0.850
$Bi_{12}SiO_{20}$	23	T	$r_{41} = 4.1 \pm 0.1$	0.650
(BSO)			$r_{41} = 4.25 \pm 0.13$	0.633
$Bi_{12}TiO_{20}$	23	T	$r_{41} = 5.75 \pm 0.10$	0.633
(BTO)			$r_{41} = 3.81 \pm 0.11$	
$Ca_2Nb_2O_7$	2	T	$r_{22} - (n_1/n_2)^3 r_{12} = 12$	0.63
		T	$r_{22} - (n_1/n_3)^3 r_{32} = 14$	
		S	$r_{22} - (n_3/n_2)^3 r_{32} = 0.6$	
		S	$r_{12} = 6.7$	
		S	$r_{22} = 25.5$	
		S	$r_{32} = 6.4$	
		S	$r_{13} = 0.37$	
		S	$r_{41} = 2.7$	
			$r_{52} = < 0.6$	
		S	$r_{63} = 0.9$	
$CdGaS_2$	-4	T	$r_{13} = 0.37$	0.50
		T	$r_{63} = 3.5$	
$CHI_3 \cdot 3S_8$	3m		$r_{12} = 4.4 \pm 2.5$	0.633
			$r_{13} = -0.512$	
			$r_{33} = 0.29 \pm 0.12$	
$Cs_3Sr[Cu_2(SCN)_9]$	42m	T	$r_{63} = +0.06 \pm .002$	0.633
$CuGaS_2$	-42m	S	$r_{63} = +1.35$	0.63
		S	$r_{41} = +1.76$	
		S	$r_{63} = +1.66$	1.15
		S	$r_{41} = +1.9$	
		S	$r_{63} n_0^3 r_{41}$	3.39
		S	$r_{41} = +1.1$	
$Gd_2(MoO_4)_3$ (450 K)	-42m	T	$n_1^3 r_{63} = 17$	0.633
$Gd_2(MoO_4)_3$ (30 K)	mm2	T	$n_1^3 r_{13} - n_3^3 r_{33} = 17.5$	0.633
$KTiOAsO_4$	mm2	T	$r_{33} = 40 \pm 1$	0.6328
(KTA)		T	$r_{33} = 21 \pm 1$	
		T	$r_{13} = 15 \pm 1$	
$KTiOPO_4$	mm2	T	$r_{13} = +9.5 \pm 0.5$	0.6328
(KTP)		T	$r_{23} = +15.7 \pm 0.8$	
		T	$r_{42} = 9.3 \pm 0.9$	
		S	$r_{13} = +8.8 \pm 0.8$	
		S	$r_{23} = +13.8 \pm 1.4$	

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Other Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$KTiOPO_4$		S	r_{33} = +35.0±3.5	
		S	r_{51} = 6.9±1.4	
		S	r_{42} = 8.8±1.8	
$K_2Mg_2(SO_4)_3$	23	T	r_{41} = 0.40	0.546
$K_2Mn_2(SO_4)_3$	23	T	r_{41} = 2.0	0.453–0.642
$K_2Ni_2(SO_4)_3$	23	T	r_{41} = 0.4	0.453–0.642
$K_2S_2O_6$	32	T	r_{11} = 0.26	0.546
$LiInS_2$	mm2	T	$r_{33} - (n_1^3/n_3^3)r_{13}$ = +0.67 $r_{33} - (n_2^3/n_3^3)r_{23}$ = +0.60	0.63
$LiInSe_2$	mm2	T	$r_{33} - (n_1^3/n_3^3)r_{13}$ = +1.39 $r_{33} - (n_2^3/n_3^3)r_{23}$ = +1.55	0.63
$LiKSO_4$	6	T	r_c = 1.6	0.546
$LiNaSO_4$	3m	T	r_{22} = <0.02	0.546
$NaClO_3$	23	T	r_{41} = 0.4	0.589
$NaNO_2$	mm2	T	$r_{22} - (n_1/n))^3 r_{32}$ = 4.1	0.546
		T	$r_{32} - (n_1/n))^3 r_{12}$ = 4.2	
		T	$r_{22} - (n_1/n_2)^3 r_{12}$ = 0.6	
		T	r_{43} = -1.9	
		T	r_{61} = -3.0	
$Na_2SbS_4 \cdot 9H_2O$	23	T	$n_1^3 r_{41}$ = 5.66	0.42
		T	$n_1^3 r_{41}$ = 5.62	1.08
		T	r_{22} = 0.82	0.52
		T	r_{22} = 0.77	0.60
$(NH_4)_3Cd_2(SO_4)_3$	23	T	r_{41} = 0.70	0.546
$(NH_2)_2CO$	-42m	T	r_{63} = 0.52	0.63
		T	r_{41} = 0.50	
$(NH_4)_3Mn_2(SO_4)_3$	23	T	r_{41} = 0.53	0.546
$Pb_5Ge_3O_{11}$	3	T	r_{11} = 0.27	0.63
		T	r_{22} = 0.23	
		T	r_{13} = 10.5	
		T	r_{33} = 15.3	
		T	r_{41} = 0.6	
		T	r_{51} = 6	
		T	r_c = 5.3	

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Other Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff.. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$Rb_2Mn_2(SO_4)_3$	23	T	r_{41} = 1.9	0.453–0.642
SbSI	mm2	T	r_{33} = 2x10^4 (293 K)	0.7
		T	r_{33} = 2000 (288 K)	
Se	32	S	$n_1^3 r_{11}$ = 89	1.15
		S	r_{11} = ~2.5	10.6
SiO_2	32	T	r_{11} = -0.47	0.409–0.605
		T	r_{41} = 0.20	
		S	r_{11} = 0.174	0.633
TeO_2	422	T	r_{41} = -0.76	0.63
		S	r_{41} = +0.62	
$Tl_2Mn_2(SO_4)_3$	23	T	r_{41} = 2.1	0.453–0.642
$Tl_2Cd_2(SO_4)_3$	23	T	r_{41} = 0.37	0.546
tourmaline	3m	T	r_{22} = 0.3	0.589
		S	r_{13} = 1.7	0.633
$ZnGeP_2$	-42m	S	r_{63} = -0.8	3.39
		S	r_{41} = +1.6	

Organic Compounds

Material	Symmetry	T/S	Electrooptic coeff. r_{ij} (10^{-12} m/V)	Wavelength λ (μ*m*)
$(CH_2)_6N_2$:HMT-	-43m	T	r_{41} = 0.72 ± 0.01	0.5
hexamethylenetetramine,		T	r_{41} = 0.78	0.633
hexamine		S	r_{41} = <0.14	
$C(CH_2OH)_4$	2	T	r_{52} = 1.45	0.46–0.70
		T	$\lvert r_{12} - r_{32} \rvert$ = 0.7	
$C_6H_4(NO_2)NH_2$	mm2	T	r_{33} = 16.7 ± 0.2	0.63
meta-nitroaniline		T	r_{23} = 0.1 ± 0.6	
		T	r_{13} = 7.4 ± 0.7	
$Cs_2C_4H_4O_6$	32	T	r_{11} = 1.0	0.546
DBNMNA	mm2	T	$n_a^3 r_{13} - n_c^3 r_{33}$ = 148	0.5145
2,6-dibromo-*N*-		T	r_{42} = 86	
methyl-4-nitroaniline		T	r_{51} = 83	
		T	$n_a^3 r_{13} - n_c^3 r_{33}$ = 32	0.6328
		T	r_{42} = 20.4	
		T	r_{51} = 41.4	

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Organic Compounds—*continued*

Material	Symmetry	T/S	Electrooptic coeff. r_{ij} (10^{-12} m/V)	Wavelength λ (μm)
DBNMNA		T	$n_a^3 r_{13} - n_c^3 r_{33} = 18.3$	0.810
		T	$r_{42} = 11.5$	
		T	$r_{51} = 31$	
MMONS	mm2	T	$r_{53} = 39.9 \pm 8$	0.6328
3-methyl-4-methoxy-		T	$r_{23} = 19.3 \pm 4$	
4;pr-nitrostilbene		T	$r_{c2} = 30.0 \pm 3$	
MNA	m	—	$r_{11} = 67 \pm 25$	0.6328
2-methyl-4-nitroaniline				
POM	222	*T*	$63 = 2.6 \pm 0.3$	0.63
3methyl 4-nitropyridine		T	$r_{52} = 5.1 \pm 0.4$	
1-oxide		T	$r_{41} = 3.6 \pm 0.6$	
PNP	2	T	$r_{12} = 20.2 \pm 0.3$	0.514
2-(*N*-Prolinol)-		T	$r_{22} = 28.3 \pm 0.4$	
5-nitropyridine		T	$r_{12} = 13.1 \pm 0.2$	
		T	$r_{22} = 13.1 \pm 0.2$	
SPCD	mm2	—	$r_{33} = 430$	0.6328
styrlpyridinium				
cyanine dye				

1.7.2 Quadratic Electrooptic Materials

Kerr Constants of Ferroelectric Crystals[1,2]

Material	T_{trans} (K)	λ (μm)	g_{11} (10^{10} esu)	g_{12} (10^{10} esu)	g_{11}-g_{12} (10^{10} esu)	g_{44} (10^{10} esu)
$BaTiO_3$	406	0.633	1.33	-0.11	1.44	—
$SrTiO_3$	—	0.633	—	—	1.56	—
$KTa_{0.65}Nb_{0.35}O_3$	330	0.633	1.50	-0.42	1.92	1.63
$KTaO_3$	13	0.633	—	—	1.77	1.33
$LiNbO_3$	1483	—	0.94	0.25	0.7	0.6
$LiTaO_3$	938	—	1.0	0.17	0.8	0.7
$Ba_{0.8}Na_{0.4}Nb_2O_6$	833	—	1.55	0.44	1.11	—

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2. Gray, D. E., Ed., *AIP Handbook of Physics*, McGraw Hill, New York, 1972, p. 6-241.

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1.8 Elastooptic Properties

1.8.1 Elastooptic Coefficients

The following tables of elastooptic coefficients (photoelastic constants) are from the *CRC Handbook of Chemistry and Physics*, 82nd edition, Lide, D. R., Ed. (CRC Press, Boca Raton, FL, 2001), p. 12–180. Materials are listed alphabetically by chemical composition. Data have been measured at room temperature, except for rare gas crystals.

Cubic Crystals; Point Groups 43m, 432, m3m

Material	Wavelength (μm)	Elastooptic coefficients				Ref.
		p_{11}	p_{12}	p_{44}	$p_{11}-p_{12}$	
C (diamond)	0.540–0.589	–0.278	0.123	–0.161	–0.385	13
CaF_2	0.55–0.65	0.038	0.226	0.0254	–0.183	11
CdTe	1.06	–0.152	–0.017	–0.057	–0.135	10
CuBr	0.633	0.072	0.195	–0.083	–0.123	12
CuCl	0.633	0.120	0.250	–0.082	–0.130	12
CuI	0.633	0.032	0.151	–0.068	–0.119	12
GaAs	1.15	–0.165	–0.140	–0.072	–0.025	15
GaP	0.633	–0.151	–0.082	–0.074	–0.069	15
$Gd_3Ga_5O_{12}$	0.514	–0.086	–0.027	–0.078	–0.059	23
Ge	3.39	–0.151	–0.128	–0.072	–0.023	14
KBr	0.589	0.212	0.165	–0.022	0.047	5
KCl	0.633	0.22	0.16	–0.025	0.06	4
KF	0.546	0.26	0.20	–0.029	0.06	1
KI	0.590	0.212	0.171	—	0.041	6
LiCl	0.589	—	—	–0.0177	–0.0407	3
LiF	0.589	0.02	0.13	–0.045	–0.11	5
NaBr	0.589	0.148	0.184	–0.0036	–0.035	1
NaCl	0.589	0.115	0.159	–0.011	–0.042	2
NaF	0.633	0.08	0.20	–0.03	–0.12	1
NaI	0.589	—	—	0.0048	–0.0141	3
NH_4Cl	0.589	0.142	0.245	0.042	–0.103	9
RbBr	0.589	0.293	0.185	–0.034	0.108	7,8
RbCl	0.589	0.288	0.172	–0.041	0.116	7,8
RbI	0.589	0.262	0.167	–0.023	0.095	7,8
SrF_2	0.633	0.080	0.269	0.0185	–0.189	16
$SrTiO_3$	0.633	0.15	0.095	0.072	—	17
Tl(Br,Cl)	0.633	–0.451	–0.337	–0.164	–0.114	19,20
Tl(Br,I)	0.633	–0.140	0.149	–0.0725	–0.289	18,20
$Y_3Al_5O_{12}$	0.633	–0.029	0.0091	–0.0615	–0.038	15
$Y_3Fe_5O_{12}$	1.15	0.025	0.073	0.041	—	15
$Y_3Ga_5O_{12}$	0.633	0.091	0.019	0.079	—	17
ZnS	0.633	0.091	–0.01	0.075	0.101	15

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Cubic Crystals; Point Groups 23, m3

Material	Wavelength (μm)	Elastooptic coefficients				Ref.
		p_{11}	p_{12}	p_{44}	p_{13}	
$Ba(NO_3)_2$	0.589	—	$p_{11}-p_{22}$ = 0.992	–0.0205	$p_{11}-p_{13}$ = 0.713	13
$NaBrO_3$	0.589	0.185	0.218	–0.0139	0.213	26
$NaClO_3$	0.589	0.162	0.24	–0.0198	0.20	26
$Pb(NO_3)_2$	0.589	0.162	0.24	–0.0198	0.20	24,25
$Sr(NO_3)_2$	0.41	0.178	0.362	–0.014	0.316	27

Trigonal Crystals; Point Groups 3m, 32, –3m

Material	Wavelength (μm)	Elastooptic coefficients				
		p_{11}	p_{12}	p_{13}	p_{14}	p_{31}
Ag_3AsS_3	0.633	±0.10	±0.19	±0.22		±0.24
Al_2O_3	0.644	–0.23	–0.03	0.02	0.00	–0.04
$CaCO_3$	0.514	0.062	0.147	0.186	–0.011	0.241
HgS	0.633			±0.445		
$LiNbO_3$	0.633	±0.034	±0.072	±0.139	±0.066	±0.178
$LiTaO_3$	0.633	–0.081	0.081	0.093	–0.026	0.089
$NaNO_3$	0.633		±0.21	±0.215	±0.027	±0.25
SiO_2	0.589	0.16	0.27	0.27	–0.030	0.29
Te	10.6	0.155	0.130	—	—	—

Trigonal Crystals; Point Groups 3m, 32, 3m —*continued*

Material	Wavelength (μm)	Elastooptic coefficients			Ref.
		P_{33}	P_{41}	P_{44}	
Ag_3AsS_3	0.633	±0.20	—	—	38
Al_2O_3	0.644	–0.20	0.01	–0.10	15,32
$CaCO_3$	0.514	0.139	–0.036	–0.058	33
α–HgS	0.633	±0.115	—	—	36
$LiNbO_3$	0.633	±0.060	±0.154	±0.300	15,34
$LiTaO_3$	0.633	–0.044	–0.085	0.028	15,35
$NaNO_3$	0.633		0.055	–0.06	39
α–SiO_2	0.589	0.10	–0.047	–0.079	37
Te	10.6	—	—	—	15

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Tetragonal Crystals; Point Groups 4/mmm, –42m, 422

Material	Wavelength (μm)	Elastooptic coefficients p_{11}	p_{12}	p_{13}	p_{31}
$(NH_4)H_2PO_4$	0.589	0.319	0.277	0.169	0.197
$BaTiO_3$	0.633	0.425	—	—	—
CsH_2AsO_4	0.633	0.267	0.225	0.200	0.195
MgF_2	0.546	—	—	—	—
Hg_2Cl_2	0.633	±0.551	±0.440	±0.256	±0.137
KH_2PO_4	0.589	0.287	0.282	0.174	0.241
RbH_2AsO_4	0.633	0.227	0.239	0.200	0.205
RDP	0.633	0.273	0.240	0.218	0.210
$Sr_{0.75}Ba_{0.25}Nb_2O_6$	0.633	0.16	0.10	0.08	0.11
$Sr_{0.5}Ba_{0.5}Nb_2O_6$	0.633	0.06	0.08	0.17	0.09
TeO_2	0.633	0.0074	0.187	0.340	0.090
TiO_2 (rutile)	0.633	0.017	0.143	–0.139	–0.080

Tetragonal Crystals; Point Groups 4/mmm, –42m, 422—*continued*

Material	Wavelength (μm)	Elastooptic coefficients p_{33}	p_{44}	p_{66}	Ref.
$(NH_4)H_2PO_4$	0.589	0.167	–0.058	–0.091	40
$BaTiO_3$	0.633	—	—	—	41
CsH_2AsO_4	0.633	0.227	—	—	42
MgF_2	0.546	—	±0.0776	±0.0488	43
Hg_2Cl_2	0.633	–0.010	—	±0.047	44
KH_2PO_4	0.589	0.122	–0.019	–0.064	45
RbH_2AsO_4	0.633	0.182	—	—	41
RDP	0.633	0.208	—	—	41
$Sr_{0.75}Ba_{0.25}Nb_2O_6$	0.633	0.47	—	—	46
$Sr_{0.5}Ba_{0.5}Nb_2O_6$	0.633	0.23	—	—	46
TeO_2	0.633	0.240	–0.17	–0.046	47
TiO_2 (rutile)	0.633	–0.057	–0.009	–0.060	48

Tetragonal Crystals; Point Groups 4, –4, 4/m

Material	Wavelength (μm)	Elastooptic coefficients p_{11}	p_{12}	p_{13}	p_{16}	p_{31}
$CdMoO_4$	0.633	0.12	0.10	0.13	—	0.11
$PbMoO_4$	0.633	0.24	0.24	0.255	0.017	0.175
$NaBi(MoO_4)_2$	0.633	0.243	0.205	0.25	—	0.21

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Tetragonal Crystals; Point Groups 4, –4, 4/m —*continued*

Material	Wavelength (μm)	Elastooptic coefficients p_{33}	p_{44}	p_{45}	p_{61}	p_{66}	Ref.
$CdMoO_4$	0.633	0.18	—	—	—	—	49
$PbMoO_4$	0.633	0.300	0.067	–0.01	0.013	0.05	52
$NaBi(MoO_4)_2$	0.633	0.29	—	—	—	—	—

Hexagonal Crystals; Point Groups mmc, 6mm

Material	Wavelength (μm)	Elastooptic coefficients p_{11}	p_{12}	p_{13}	p_{31}	p_{33}	p_{44}	Ref.
$Be_3Al_2Si_6O_{18}$	0.589	0.0099	0.175	0.191	0.313	0.023	–0.152	28
CdS	0.633	–0.142	–0.066	–0.057	–0.041	–0.20	–0.099	2,15
ZnO	0.633	±0.222	±0.099	–0.111	±0.088	–0.235	0.0585	30
ZnS	0.633	–0.115	0.017	0.025	0.0271	–0.13	–0.0627	31

Orthorhombic Crystals; Point Groups 222, m22, mmm

Material	Wavelength (μm)	Elastooptic coefficients p_{11}	p_{12}	p_{13}	p_{21}	p_{22}	p_{23}
$Al_2SiO_4(OH,F)_2$	—	–0.085	0.069	0.052	0.095	–0.120	0.065
$BaSO_4$	0.589	0.21	0.25	0.16	0.34	0.24	0.19
HIO_3	0.633	0.302	0.496	0.339	0.263	0.412	0.304
$NaKC_4H_4O_6$	0.589	0.35	0.41	0.42	0.37	0.28	0.34
NH_4ClO_4	0.633	—	0.24	0.18	0.23	—	0.20
$(NH_4)_2SO_4$	0.633	0.26	0.19	±0.260	±0.230	±0.27	±0.254

Orthorhombic Crystals; Point Groups 222, m22, mmm —*continued*

Material	Elastooptic coefficients p_{31}	p_{32}	p_{33}	p_{44}	p_{55}	p_{66}	Ref.
$Al_2SiO_4(OH,F)_2$	0.095	0.085	–0.083	–0.095	–0.031	0.098	28
$BaSO_4$	0.28	0.22	0.31	0.002	–0.012	0.037	55
HIO_3	0.251	0.345	0.336	0.084	–0.030	0.098	54
$NaKC_4H_4O_6$	0.36	0.35	0.36	–0.030	0.0046	–0.025	53
NH_4ClO_4	0.19	0.18	±0.02	<±0.02	—	±0.04	51
$(NH_4)_2SO_4$	0.20	±0.26	0.26	0.015	±0.0015	0.012	52

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Rare Gas Crystals

Rare Gas	Elastooptic coefficients				Ref.
	p_{11}	p_{12}	p_{44}	$p_{11} - p_{12}$	
Ne (T = 24.3 K)	0.157	0.168	0.004	–0.011	59
Ar (T = 82.3 K)	0.256	0.302	0.015	–0.046	60
Kr (T = 115.6 K)	0.34	0.34	0.037	—	59
Xe (T = 160.5 K)	0.284	0.370	0.029	–0.086	60

Measured made at a wavelength of 488 nm.

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1.8.2 Acoustooptic Materials

A figure of merit for an acoustooptic material is $M = n^6p^2/\rho v^3$, where n is the refractive index, p is the photoelastic constant, ρ is the density, and ν is the sound velocity.

Properties of Selected Acoustooptic Materials

Material	Transparency range (μm)	Acoustic mode/ direction	Acoustic velocity ((km/s)	Figure of merit
Ge	2–20	L <111>	5.5	840
Hg_2Br_2	0.40–30	S <110>	0.273	2600
Hg_2Cl_2	0.36–20	S <110>	0.347	700
Hg_2I_2	0.45–40	S <110>	0.254	3200
$LiNbO_3$	0.35–5.0	L <100>	6.5	4.6
$PbBr_2$	0.36–60	S <010>	2.30	550
$PbCl_2$	0.35–20	S <001>	2.51	136
$PbMoO_4$	0.42–5.5	L <001>	3.63	36.3
SiO_2	0.12–4.5	L <100>	5.72	2.38
TeO_2	0.35–5.0	L <001>	4.2	34.5
		S <110>	0.62	793
Tl_3AsS_3	1.3–17	L <001>	2.15	416

All measurements at 0.633 μm, except for Ge at 10.6 μm; L = longitudinal, S = shear.

Reference:

Gottlieb, M. and Singh, N. B., Elastooptic materials*, Handbook of Laser Science and Technology*, *Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 416.

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1.9 Nonlinear Optical Properties

1.9.1 Nonlinear Refractive Index*

Nonlinear refraction is commonly defined either in terms of the optical field intensity I

$$n = n_0 + \gamma I$$

or in terms of the average of the square of the optical electric field $\langle E^2 \rangle$

$$n = n_0 + n_2 \langle E^2 \rangle,$$

where n_0 is the ordinary linear refractive index, γ is the nonlinear refractive coefficient, and n_2 is the nonlinear refractive index. The conversion between n_2 and γ is given by

$$n_2[\text{cm}^3/\text{erg}] = (cn_0/40\pi)\,\gamma[\text{m}^2/\text{W}] = 238.7\, n_0\, \gamma[\text{cm}^2/\text{W}],$$

where c is the speed (in m/s) of light in vacuum.

In terms of third-order susceptibility tensor $\chi^{(3)}(-\omega,\omega,\omega,-\omega)$ of the medium, the nonlinear refractive indices for a linearly polarized wave and a circularly polarized wave in an isotropic material are

$$n_2(\text{LP}) = (12\pi/n_0)\chi^{(3)}_{1111}(-\omega,\omega,\omega,-\omega)$$

and

$$n_2(\text{CP}) = (24\pi/n_0)\chi^{(3)}_{1122}(-\omega,\omega,\omega,-\omega).$$

Whereas in a cubic material the linear refractive index is isotropic, n_2 is not. If θ is the angle made by the electric field vector with the [100] axis for a wave propagating along, say, [001], the effective value of $\chi^{(3)}$ is given by

$$n_2(\theta) = 12\pi/n_0\{\chi^{(3)}_{1111}[1 + \sigma\sin(\theta)^2/2]\},$$

where

$$\sigma = [\chi^{(3)}_{1111} - \chi^{(3)}_{1122} + 2\chi^{(3)}_{1212}]/\chi^{(3)}_{1111}.$$

For a circularly polarized beam propagating along [100]

$$n_2(\text{CP},100) = 6\pi/n_0[\chi^{(3)}_{1111} + 2\chi^{(3)}_{1122} - \chi^{(3)}_{1212}]$$

and for a circularly polarized beam propagating along [111]

$$n_2(\text{CP},111) = 4\pi/n_0[\chi^{(3)}_{1111} + 4\chi^{(3)}_{1122} - \chi^{(3)}_{1212}].$$

The nonlinear refractive index is not a unique quantity for a given material because several physical mechanisms contribute to the polarization that is cubic in the applied optical elect-

* This section was adapted from Chase, L. L. and Van Stryland, E. W., Nonlinear Refractive index: inorganic materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 269.

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ric field. These physical mechanisms require a material response that can take place on various time scales. The mechanisms that contribute most strongly to n_2, and their characteristic time scales (in parentheses) are bound electrons (10^{-15} s), optically created free carriers (>10^{-12} s), Raman-active optical phonons (10^{-12} s), electrostriction (>10^{-9} s), and thermal excitation (~10^{-9} s).

Several methods listed below have been employed to measure n_2. The details of the measurements determine the relative contributions from the various possible physical mechanisms to the measured n_2. In general, experiments done with picosecond pulses and nondegenerate mixing are less likely to be affected by the "slow" electrostrictive or thermal effects than those done in the nanosecond pulse regime and with degenerate mixing. Most of the measurements include the effects of both electronic and vibrational (Raman) contributions to n_2.

Techniques for Measuring the Nonlinear Refractive Index

	Method	Ref.
DFWM	Degenerate four-wave mixing	2
DHG	Dynamic holographic grating	3
DTLC	Damage threshold for linear vs. circular polarization	4
ER	Ellipse rotation	5
KE	DC Kerr effect	6
NDFWM	Nondegenerate four-wave mixing	7,8
OKE	Optical Kerr effect	9
PDF	Power-dependent focus	10
PST	Power for self-trapping	11
RSS	Raman scattering spectroscopy	12
SFL	Self-focal length	13
SPA	Spatial profile analysis	14
SPM	Self-phase modulation	15
SSMG	Small-scale modulation growth	16
TBI	Two-beam interferometry	17
TII	Time-integrated interferometry	18
TRI	Time-resolved interferometry	19
TWR	Temporal waveform reshaping	20
WFC	Wavefront conjugation	21
ZS	Z-scan	22

In the following tables of nonlinear refractive parameters, values in parentheses were calculated by Chase and Van Stryland[1] from the quantities reported in the original references. Refractive indices in parentheses were obtained from extrapolation of available data. For noncubic crystals, or for cubic crystals where the polarization is not along a cube axis or is not specified in the original reference, the value tabulated for $\chi^{(3)}{}_{1111}$ is an effective value of $\chi^{(3)}$. Unless noted otherwise, measurements were made at room temperature.

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Measured Nonlinear Refractive Parameters

Crystals	Method	Pulse duration (ns)	Wavelength (nm)	Linear refractive index	χ_{1111} (10^{-13} cm^3 erg)	$n_{2,LP}$ (10^{-13} cm^3 erg)	γ_{LP} (10^{-16} cm^2/W)	Ref.
AgCl	NDFWM	3	1064	2.02	(1.25)	23.3	(48.3)	23[a]
Al_2O_3	PDF	0.17	308	(1.814)	(0.088)	(1.82)	4.2	24
Al_2O_3	ZS	0.02	532	1.8	(0.066)	(1.4)	3.3	25
Al_2O_3	ZS	0.028	1064	1.75	(0.056)	(1.2)	2.9	25
Al_2O_3	ZS	0.016	355	1.8	(0.076)	(1.6)	3.7	25
Al_2O_3	NDFWM	3	560, 590	(1.76)	(0.11)	2.4	(5.7)	8
Al_2O_3	PDF	0.030	1064	(1.76)	(0.060)	1.3	(3.1)	26
Al_2O_3 (E‖c)	NDFWM	3	1064	1.75	(0.060)	1.3	(3.11)	7
Al_2O_3 (E⊥c)	NDFWM	3	1064	1.75	(0.057)	1.23	(2.94)	7
Al_2O_3:Cr	TRI	~1	1064	1.76	(0.069)	1.48	(3.52)	27
AlGaAs	TRI	—	850–810	NA	—	–(2.2–3.3) × 10^4	—	28[b]
BaF_2	ZS	0.027	532	(1.476)	(0.031)	0.8	(2.27)	29
BaF_2	PDF	0.017	308	(1.500)	(0.077)	(1.94)	5.42	24
BaF_2	NDFWM	4	592, 575	(1.47)	0.069	(1.8)	(5.0)	30
BaF_2	TRI	0.125	1064	1.47	(0.39)	(1.00)	2.85	32
BaF_2 (100)	DFWM	0.3	1064	1.468	(0.026)	0.67	(1.91)	7
BaF_2 (100)	ZS	0.028	1064	1.47	0.019	(0.5)	1.4	25
BaF_2 (100)	ZS	0.02	532	1.48	0.029	(0.73)	2.1	25
BaF_2 (100)	ZS	0.016	355	1.5	0.039	(0.97)	2.7	25
$BeAl_2O_4$	NDFWM	3	1064	1.73	(0.67)	1.46	(3.54)	7
$Bi_{12}SiO_{20}$	OKE	1.5 × 10^{-4}	532	—	—	5	—	33
C (diamond)	NDFWM	4	545, 545-ε	(2.42)	0.46	(7.2)	(12.6)	31[n]
$CaCO_3$	NDFWM	3	560, 590	(1.66)	(0.14)	3.2	(8.1)	28[c]

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Measured Nonlinear Refractive Parameters—*continued*

Crystals	Method	Pulse duration (ns)	Wavelength (nm)	Linear refractive index	χ_{1111} (10^{-13} cm^3 erg)	$n_{2,LP}$ (10^{-13} cm^3 erg)	γ_{LP} (10^{-16} cm^2/W)	Ref.
$CaCO_3$ (E ‖ c)	NDFWM	3	1064	1.48	(0.033)	0.83	(2.35)	23
$CaCO_3$ (E ⊥c)	NDFWM	3	1064	1.643	(0.048)	1.11	(2.83)	23
CaF_2	PDF	0.017	308	(1.453)	(0.026)	(0.67)	1.92	24
CaF_2	NDFWM	4	592, 575	(1.43)	0.04	(1.1)	(3.1)	30
CaF_2	NDFWM	3	560, 590	(1.43)	(0.055)	1.46	(4.3)	8
CaF_2	TRI	0.125	1064	1.43	(0.025)	0.65	1.90	32,34
CaF_2	PDF	0.030	1064	1.43	0.105	2.8	(8.1)	10
$CaMg_2Si_2O_6$	NDFWM	3	1064	1.67	(0.077)	1.73	(4.34)	7
CaO (100)	NDFWM	3	1064	1.83	(0.25)	5.2	(11.9)	7
$CaWO_4$ (E ⊥ c)	NDFWM	3	1064	1.89	(0.25)	4.2	(9.3)	7
$CaWO_4$ (E ‖ c)	NDFWM	3	1064	1.91	(0.28)	5.6	(12.3)	7
CdF_2	NDFWM	4	575, 575-ε	(1.57)	0.145	(3.48)	(9.29)	31
CdF_2	TRI	0.125	1064	1.57	(0.061)	(1.46)	3.87	32
CdF_2 (100)	NDFWM	3	1064	1.56	(0.16)	3.95	(10.6)	7
CdS	ZS	0.03	532	2.34	(–211)	–3400	(–6090)	35
CdS	SPA	20	694	(2.42)	(130)	2×10^3	(3.5×10^3)	36
CdS (E‖c)	NDFWM	3	1064	2.34	(17.5)	283	(507)	7
CdS(E⊥c)	NDFWM	3	1064	2.33	(18.8)	304	(547)	7
$CdS_{0.18}Se_{0.82}$	SPA	20	694	(2.6)	(1500)	2.2×10^4	(3.5×10^4)	36
$CdS_{0.5}Se_{0.5}$	ZS	0.03	1064	2.45	(65)	1000	(1710)	35
$CdS_{0.5}Se_{0.5}$	SPA	20	694	(2.5)	(230)	3.5×10^3	(5.9×10^3)	36
CdSe	ZS	0.03	1064	2.56	(–6.1)	–90	(–147)	35
CdTe	ZS	0.04	1064	2.84	(–150)	–2000	(–3000)	35

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CdTe	DFWM	0.04	1064	2.84	±150	±2100	±3100	37[d]
CdTe	WFC	15	1064	~3	2.5×10^5	(3.1×10^6)	(4.4×10^6)	38
CeF_3	NDFWM	3	1064	~1.6	(0.055)	1.3	(3.4)	7
CeF_3	TRI	0.125	1064	~1.6	(0.066)	(1.55)	4.06	32
CsCl	NDFWM	0.006	1064, 532	(1.64)	0.086	(2.0)	(5.1)	39
CsCl	NDFWM	0.006	1064, 532	—	0.029	—	—	39[e]
CuCl	NDFWM	—	773, 694	(1.94)	33	640	1400	40[m]
Er_2O_3	NDFWM	3	1064	1.96	(0.24)	4.53	(9.7)	7
Ga_2O_3	NDFWM	3	1064	1.96	(0.30)	5.8	(12.4)	7
GaAs	ZS	0.03	1064	3.47	(~249)	~2700	(~3260)	35
GaAs	NDFWM	~200	9200–11800	(3.3)	120	(1.4×10^3)	(1.7×10^3)	41
GaP	TDFWM	2.7×10^{-3}	577	(3.396)	2.1×10^3	(2.33×10^4)	(2.87×10^4)	42
$Gd_3Ga_5O_{12}$	NDFWM	3	1064	1.945	(0.30)	5.8	(12.5)	7
$Gd_3Sc_2Al_3O_{12}$	NDFWM	3	1064	1.891	(0.20)	4.0	(8.9)	7
$Gd_3Sc_2Ga_3O_{12}$	NDFWM	3	1064	1.943	(0.28)	5.5	(11.9)	7
Ge	ZS	0.06	10600	3.47	(290)	2700	(2800)	35
Ge	NDFWM	~200	9200–11800	4.	1000	(9.4×10^3)	(9.9×10^3)	41
Ge	ER	2.3	10590	(4.)	250	(2.3×10^3)	(2.5×10^3)	43
Ge	NDFWM	—	10600	4.	—	—	—	44[f]
Ge	WFC	300	38000	4.0	400	(3.8×10^3)	(3.9×10^3)	45
HgCdTe	SPA	CW	10640	4.25	—	$[n = -7 \times 10^{-3}\ I^{1/3}]$	—	46[g]
InSb	SPA	CW	5313	(4)	$(-6. \times 10^{10})$	$(-6. \times 10^{11})$	-6×10^{11}	47[l]
InSb	SPA	CW	5405–5714	(4)	—	100	—	48[h]
InSb	NDFWM	—	10600	(4)	$\sim 2 \times 10^6$	$(\sim 2 \times 10^7)$	$(\sim 2 \times 10^7)$	49[i]
KBr	NDFWM	3	1064	1.544	(0.12)	2.93	(8.0)	7
KBr	PDF	0.030	1064	1.544	0.58	14.2	(38.5)	10
KCl	NDFWM	3	1064	1.479	(0.079)	2.01	(5.7)	7
KCl	PDF	0.030	1064	1.479	0.13	3.3	(9.3)	59

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Measured Nonlinear Refractive Parameters—*continued*

Crystals	Method	Pulse duration (ns)	Wavelength (nm)	Linear refractive index	χ_{1111} (10^{-13} cm^3 erg)	$n_{2,LP}$ (10^{-13} cm^3 erg)	γ_{LP} (10^{-16} cm^2/W)	Ref.
KF	NDFWM	0.006	1064, 532	(1.36)	0.014	(0.39)	(1.2)	39
KF	NDFWM	0.006	1064, 532	—	0.020	—	—	39[e]
KH_2PO_4	TRI	0.10	1064	(1.49)	(0.040)	1.0	(2.8)	34
KH_2PO_4	PDF	0.030	1064	1.49	0.14	3.6	(10)	7
KH_2PO_4 (‖c)	NDFWM	3	1064	1.460	(0.028)	0.72	(2.1)	7
KH_2PO_4 (⊥c)	NDFWM	3	1064	1.494	(0.031)	0.78	(2.2)	7
KI	NDFWM	0.006	1064, 532	(1.7)	0.38	(8.4)	(20)	39
KI	NDFWM	0.006	1064, 532		0.13	—	—	39[e]
KI	PDF	0.030	1064	1.638	0.49	11.2	(29)	10
$KTaO_3$	NDFWM	3	1064	2.25	(1.73)	29	(54)	7
$KTiOPO_4$	NDFWM	3	1064	1.74	(0.26)	5.73	(13.8)	7
$KTiOPO_4$	ZS	0.04	1064	1.78	(0.47)	(10)	24	50
$La_2Be_2O_5$:Nd	PDF	0.030	1064	(1.98)	(0.11)	2.1	(4.4)	26
$La_3Lu_2Ga_3O_{12}$	NDFWM	3	1064	1.930	(0.30)	5.8	(12.6)	10
LaF_3	TRI	0.125	1064	1.60(o)	(0.064)	1.51	3.95	86
LaF_3 (‖c)	NDFWM	3	1064	1.60	(0.059)	1.4	(3.7)	7
LAP, x + z	NDFWM	3	1064	1.51	(0.12)	3.0	(8.4)	7
LAP,y	NDFWM	3	1064	1.559	(0.077)	1.87	(5.0)	7
LiCl	NDFWM	0.006	1064,532	(1.67)	0.069	(1.56)	(3.9)	39
LiCl	NDFWM	0.006	1064,532	—	0.027	—	—	39[e]
LiF	ZS	0.028	1064	1.39	(0.01)	(0.27)	(0.81)	51
LiF	ZS	0.02	532	1.4	(0.011)	(0.3)	0.9	51
LiF	NDFWM	3	560, 590	(1.39)	(0.034)	0.92	(2.8)	8
LiF	TRI	0.125	1064	1.39	(0.013)	0.35	1.05	32,34

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$LiNbO_3$	NDFWM	5	577	(2.31(o))	—	—	—	52
$LiYF_4$	TRI	0.125	1064	1.45(o)	(0.023)	0.60	1.72	32
$MgAl_2O_4$	NDFWM	3	1064	1.72	(0.068)	1.5	(3.65)	7
MgF_2	NDFWM	3	1064	1.374	(0.0091)	0.25	(0.76)	7
MgF_2	ZS	0.028	1064	1.38	(0.0073)	(0.20)	0.61	51
MgF_2	ZS	0.02	532	1.38	(0.008)	(0.22)	0.67	51
MgF_2	ZS	0.016	355	1.4	(0.0085)	(0.23)	0.69	25
MgF_2	TRI	0.125	1064	1.37(o)	(0.011)	0.30	0.92	32,34
MgO	NDFWM	3	1064	1.72	(0.073)	1.61	(3.92)	7
NaBr	NDFWM	3	1064	1.623	(0.14)	3.26	(8.41)	7
NaBr	PDF	0.030	1064	1.62	0.41	9.6	(25)	10
NaCl	NDFWM	3	1064	1.531	(0.065)	1.59	(4.35)	7
NaCl	PDF	0.030	1064	1.532	0.26	6.5	(18)	10
NaF	NDFWM	3	1064	1.321	(0.012)	0.34	(1.1)	7
NaF	TRI	0.125	1064	1.32	(0.015)	0.43	1.37	32
NaF	PDF	0.030	1064	1.321	0.03	0.9	(2.9)	10
PbF_2	TRI	0.125	1064	1.76	(0.23)	4.94	11.7	32
Si	NDFWM	~200	9200–11800	(3.4)	60	660.	(820)	41
SiC	SPA,TWR	20	694	2.68	(36)	510	(800)	53
SiO_2 ($\perp$c)	NDFWM	3	1064	1.534	(0.046)	1.12	(3.06)	7
SiO_2 ($\parallel$c)	NDFWM	3	1064	1.543	(0.047)	1.16	(3.15)	7
SrF_2	NDFWM	3	1064	1.433	(0.019)	0.50	(1.46)	7
SrF_2	NDFWM	4	592, 575	(1.43)	0.052	(1.4)	(4.0)	30
SrF_2	TRI	0.125	1064	1.43	(0.023)	0.60	1.76	32
SrO (110)	NDFWM	3	1064	1.81	(0.24)	5.07	(11.7)	7
$SrTiO_3$	NDFWM	3	1064	2.31	(1.63)	26.7	(48)	7
TiO_2	NDFWM	3	1064	2.48	(3.67)	55.8	(94)	7
TiO_2	DFWM	0.08	1064	(2.48)	(7.75)	(118)	200	2

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Measured Nonlinear Refractive Parameters—*continued*

Crystals	Method	Pulse duration (ns)	Wavelength (nm)	Linear refractive index	χ_{1111} (10^{-13} cm^3 erg)	$n_{2,LP}$ (10^{-13} cm^3 erg)	γ_{LP} (10^{-16} cm^2/W)	Ref.
Y_2O_3	NDFWM	3	1064	1.92	(0.27)	5.33	(11.6)	7
$Y_3Al_5O_{12}$	TRI	0.15	1064	(1.83)	(0.15)	3.16	(7.2)	54[i]
$Y_3Al_5O_{12}$	NDFWM	3	560,590	(1.83)	(0.22)	4.5	(10)	8
$Y_3Al_5O_{12}$	TRI	~1	1064	1.83	(0.17)	3.47	(7.9)	27
$Y_3Al_5O_{12}$	ER	13	694	1.829	(0.21)	4.27	(9.8)	5[k]
$Y_3Al_5O_{12}$:Nd	PDF	0.030	1064	1.82	0.17	3.5	(8.1)	7
$Y_3Ga_5O_{12}$	NDFWM	3	1064	1.912	(0.26)	5.2	(11.4)	7
$YAlO_3$	NDFWM	3	1064	1.933	(0.17)	3.37	(7.3)	7
ZnO (E⊥χ)	NDFWM	3	1064	1.99	(1.32)	25	(53)	7
ZnO (E‖c)	NDFWM	3	1064	1.96	(1.20)	23	(49)	7
ZnS	ZS	0.03	1064	2.40	(3.1)	48	(84)	35
ZnS (E‖c)	NDFWM	3	1064	2.29	(2.98)	49	(90)	7
ZnS (E⊥c)	NDFWM	3	1064	2.29	(2.85)	47	(87)	7
ZnSe	ZS	0.03	1064	2.48	(11)	170	(290)	35
ZnSe	DFWM	0.04	1064	2.48	18	(270)	(460)	37
ZnSe	ZS	0.03	532	2.70	(–29)	–400	(–621)	35
ZnSe	DFWM	0.03	532	2.70	±30	(±420)	(±650)	37[d]
ZnTe	ZS	0.03	1064	2.79	(61)	830	(1250)	35
ZrO_2	SFL	0.045	1064	(1.92)	(0.41)	8	(17)	55
ZrO_2	SFL	0.03	1064	(1.92)	(0.31)	6	(12.9)	56
ZrO_2	NDFWM	3	1064	2.12	(0.33)	5.8	(11.5)	7

[a] polycrystalline sample; [b] wavelength dependent; [c] E ‖ optic axis; [d] absolute values measured; [e] in 5 mol/O acq. sc; [f] relative spect; impurity; 175 K, I in W/cm^2; [g] 175 K, I in W/cm^2; [h] 77 K, free electrons; [i] 4 K, free electrons; [j] 4 K ‖ [111]; [k] E ‖ [100]; [l] 5 K, free electrons; [m] 15 K; [n] dispersion also given.

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Dispersion of the Nonlinear Refractive Index*

Material	Energy gap (eV)	n_2 x 10^{-14} esu			
		266 nm	355 nm	532 nm	1064 nm
LiF	13.6	4.0 ± 1.0	1.9 ± 0.4	1.9 ± 0.4	2.5 ± 0.5
MgF_2	10.8	5.0 ± 1.0	2.2 ± 0.4	1.9 ± 0.4	1.9 ± 0.4
BaF_2	9.1	11 ± 2	9.7 ± 1.9	7.5 ± 1.5	5.0 ± 1.0
SiO_2	8.4	28 ± 6	8.5 ± 1.7	7.8 ± 1.6	7.4 ± 1.5
Al_2O_3	9.9	26 ± 5	16 ± 3	14 ± 3	13 ± 3
BaB_2O_4	6.2	1 ± 0.3	14 ± 3	21 ± 4	11 ± 2
KBr	7.6	—	—	47 ± 9	29 ± 6
$CaCO_3$	5.9	46 ± 9	14 ± 3	11 ± 2	11 ± 2
$LiNbO_3$	4.0	—	—	440 ± 70	48 ± 7
$KTiOPO_4$	3.5	—	—	98 ± 15	100 ± 20

* DeSalvo, R., Said, A. A., Hagan, D. J., Van Stryland, E. W., and Sheik-Bahae, M., Infrared to ultraviolet measurements of two-photon absorption and n_2 in wide bandgap solids, *IEEE J. Quantum Electron.* 32, 1324 (1996).

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1.9.2 Two-Photon Absorption*

Two-photon absorption (2PA) occurs in all materials at sufficiently high irradiance when the combined energy of two quanta of light matches a transition energy between two states of the same parity. The fundamental equation describing this loss of irradiance I with depth z in a material is

$$dI/dz + \beta I^2,$$

where β is the two-photon absorption coefficient. The coefficient β is proportional to the imaginary part of $\chi^{(3)}(-\omega,\omega,\omega,-\omega)$. The relationship between n_2, β, and $\chi^{(3)}$ is analogous to the relationship between n_0, the linear absorption coefficient α, and the linear susceptibility χ.

The two-photon absorption coefficient β depends not only on the frequency arguments but also on the state of polarization, propagation direction, and crystal symmetry as β is derived from the imaginary part of the third-order susceptibility tensor $\chi^{(3)}$. Relations for $\chi^{(3)}$ for cubic crystals for several polarization orientations are presented in reference 1. These relations are valid for both the real and imaginary parts of $\chi^{(3)}$. For a linear or circularly polarized wave:

$$\beta(\mathrm{LP}) = (32\pi^2\omega/n^2c^2)3\chi^{(3)}{}_{1111}$$

and

$$\beta(\mathrm{CP}) = (64\pi^2\omega/n^2c^2)3\chi^{(3)}{}_{1122}.$$

Because these equations are in cgs units (esu), β is in cm s/erg rather than the more common mixed unit of cm/W.

Several methods have been used to measure the two-photon absorption coefficient in solids. Direct transmission measurements as a function of irradiance have been the primary method to determine absolutely calibrated values of β as well as two-photon absorption spectra. Several other techniques have been utilized to obtain calibrated as well as relative measurements and two-photon absorption spectra. These are listed in the table to follow. Many of these methods require calibration. Direct transmission experiments are best suited for absolute calibration. Because to give a value for β a measurement of the absolute irradiance is needed, single-beam experiments are most easily calirated. Once absolute calibration is obtained at a single wavelength, relative measurements and spectral measurements can be calibrated.

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* This section was adapted from Van Stryland, E. W. and Chase, L. L., Two-photon absorption: inorganic materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 299.

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Techniques for Measuring Two-Photon Absorption

	Method	Ref.
AI1	Attenuation vs. irradiance for a single beam	3, 4
AI2	Attenuation vs. irradiance; two beams, usually one scanned in ω	5
AIS	Attenuation vs. irradiance; broad spectrum treated simultaneously	6
C	Calorimetry	7
CR	Comparison of 2-photon loss and Raman gain	8, 9
EPR	Elliptical polarization rotation	10
FCC	F-center coloration	11
GTA	Gain measurement in a 2-photon-pumped amplifier	12
IA	Intracavity absorption	13
L	Luminescence or fluorescence	14, 15
HGE	Harmonic generation efficiency	16
PA	Photoacoustics	17
PC	Photoconductivity or photo-Hall effect	18, 19
TCN	Two-channel normalization	20
TL	Thermal lensing	21
TRT	Time-resolved transmission	22
Z-scan	A propagation method to measure β and n_2	23

The experimental data on two-photon absorption coefficients (β in cm per GW) are presented in the following table. Materials are listed alphabetically. The method of measurement (using the above table), the pulse duration t_p, the input two-photon excitation energy $2\hbar\omega$ (or range of energies if spectra are given), band gap energy E_g (if given in the reference) or absorption cutoff energy for wide-gap materials, and linear index $n_0(\hbar\omega)$ are listed. The linear refractive indices are taken from reference 2.

The following shorthand notation is used in the table: Anisot. = anisotropy; β_l and $\beta_c = \beta$ measured with linearly or circularly polarized light, respectively; Cleartran = brand name of heat-treated ZnS that makes it water clear and is grown by CVD = chemical vapor deposition; Dir. = direct; K = Kelvin; L = length; Mag. = magnetic; Pol. = polarized; SHG = second harmonic generation; *T* = temperature; t = time; *E* for SHG, means that the electric field and propagation direction are aligned for SHG phase matching.

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Two-Photon Absorption Data

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
Ag_3AsS_3	AI2	10	2.1	2.7–3.2	~2.7	Abs. spectr. (10 @ 3.1 eV)	24, 25	
Ag_3AsS_3	AI1	25		3.56	~2.7	20	26	
Ag_3AsS_3	AI1	20		2.34	~2.7	<3	26	
AgCl	L		3.2	4.0–4.4	2.0	Abs. spectr. (0.5 @ 4.3 eV)	27	Indirect gap
AgCl	L	9		6.6–7.6	2.07	Relative spectrum	28	77 K
AgCl	L	9		3.3–4.2		Relative spectrum	28	80 K
$AgGaSe_2$	AI1	~0.01	1.1	2.33	2.7	1.4	29	
α-AgI	A12		2.9	3.0–3.06		Relative spectrum	30	1.6 K
A1As-GaAs	L		1.7	1.65–1.8		Relative spectrum	191	
Al_2O_3	AI1	0.017	9.9	6.99	~1.79	<0.0016	3	
Al_2O_3	AI1	0.015		9.32	~1.84	0.27	3	
Al_2O_3	AI1	0.12		8.05	~1.8	0.0276	31	
As_2S_3	AI2	30	2.5	2.4–3.6	~2.6	Abs. spectr. (25 @ 3.4 eV)	32	
BaF_2	AI1	0.017	9.1	6.99	1.49	<0.0036	33	
BaF_2	AI1	0.015		9.32	~1.5	<0.0040	33	
BaF_2	AI1	0.0007		10.0	~1.5	0.11	34	
$BaTiO_3$	AI2	17	3.5	3.4–4.2		Abs. spectr. (4 @ 4 eV)	35	392 K
$BaTiO_3$	AI2	0.0012		4.16	~2.4	0.1	36	Photorefraction
$Bi_4Ge_3O_{12}$	L	~10	4.2	4.1–5.1	2.1	Relative spectrum	37	
$Bi_4Ge_3O_{12}$	L	9		4.27–4.83	2.1	Abs. spectr. (50 @ 4.5eV)	38	80 K
$Bi_4Ge_3O_{12}$	L	9		4.2–5	2.1	Relative spectrum	39	80 K
$Bi_4Ge_3O_{12}$	AI2	10		4.8–5.7		Abs. spectr. (10 @ 5.6 eV)	40	80 K
C (diamond)	CR	4.0	5.47	4.55	2.42	<0.003	9	
C (diamond)	AI1	0.021		4.66	2.42	<0.26	41	

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C (diamond)	AI1	0.000135		8.0	~2.5	0.74	42	Indirect gap
C (diamond)	Z-scan	0.015		6.99	~2.5	0.3	43	k ‖ [001]
$CaCO_3$	AI1	0.015	5.9	9.32	~1.5–1.8	0.24	3	
CaF_2	CR	4.0	10	4.31	1.43	<0.004	9	
CaF_2	AI1	0.015		9.32	1.46	<0.02	3	
CaF_2	AI1	0.0007		10.0	1.47	0.0083	34	
CaF_2	AI1	0.12		8.05	1.46	0.00092	31	
CdF_2	CR	4.0	6	4.31		<0.03	9	
CdF_2	AI1	0.017		6.99		<0.042	33	
CdF_2	AI1	0.015		9.32		1.6	33	
CdI_2	L	9	3.9	3.5–4.4		Relative spectrum	39	Indirect gap
CdP_2	TRT			2.34		160	44	
CdP_2	TRT			3.56		800	44	
CdP_2	AI2	15		2.4–3.2		Abs. spectr. (11 @ 2.9 eV)	45	
CdS	L	3×10^5	2.42	3.56	~2.42	12	46	123 K
CdS	AI2	30		2.5–3.5	2.35–2.42	Abs. spectr. (20 @ 2.8 eV)	47	
CdS	AI2	40		2.5–3.4	2.35–2.4	Abs. spectr. (14.7 @ 3.4 eV)	48	
CdS	AI1	30		3.56	~2.42	30	49	
CdS	AI2	30		2.5–3.5	2.3–2.4	Relative spectrum	50	Anisotropy
CdS	AI2			2.54–3.6	2.35–2.44	Abs. spectr. (30 @ 3.0 eV)	51	77 K
CdS	AI2			2.54–3.6	2.35–2.44	Abs. spectr. (30 @ 3.0 eV)	51	77 K
CdS	AI1	30		3.56	~2.42	100	52	β vs. length
CdS	AI2	30		2.65–3.45	2.35–2.4	Abs. spectr. (35 @ 4 eV)	53	
CdS	AI1	5		2.54–2.55	~2.35	Relative spectrum	54	
CdS	AI2	0.006		2.5–3.5	2.35–2.42	Abs. spectr. (18 @ 3.35 eV)	55	
CdS	L			2.550–2.554	~2.35	Relative spectrum	56	1.6 K
CdS	AI1	30		3.56	~2.42	15; 20	57	E ‖ c; E ⊥ c
CdS	AI2	300		2.5–2.6	~2.35	Abs. spect. (4000 @2.54 eV)	58	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
CdS	L	~25	2.5	2.56–2.62	~2.35	Relative spectrum	107	
CdS	AI1	20	2.4	3.56	~2.42	56	106	Self-focusing
CdS	AI1	45	2.5	3.56	~2.42	120; 56	82	E ‖ c; E ⊥ c
CdS	AI2			2.5–3.6		Abs. spectr. (20 @ 3.2 eV)	62	β vs. pol.
CdS	PC	~10	2.58	~5.1–5.2	~2.8	Magnetospectra 0 < B < 10 Tesla	63	A-excitons 1.8 K
CdS	CR	8		3.91	~2.5	120; k ‖ c; 110 k ⊥ c, E ⊥ c 140 k ⊥ c, E ⊥ c	65	β vs. T and resistance
CdS	AI1			4.66		0.9; 1.8	66	E ‖ c; E ⊥ c
CdS	AI1	0.027		4.66	~2.64	5.5	67	
$CdS_{.25}S_{e.75}$	AI1	0.038	1.78	2.33	2.51	15	67	
$CdS_{0.5}Se_{0.5}$	C	11; 26		2.33		32;135	7	
$CdS_{0.5}Se_{0.5}$	AI1	0.038	1.93	2.33	2.45	10	67	
$CdS_{0.8}Se_{0.2}$	AI1	30		3.56		130	49	
$CdS_{0.9}Se_{0.1}$	AI1	30		3.56		70	49	
CdSe	AI1		1.7	2.33	2.56	950	68	
CdSe	AI1			2.33	2.56	900; 390	69	E ⊥ z; E ‖ z
CdSe	AI1			2.33	2.56	200	70	
CdSe	AI1	20		2.33	2.56	60–140	71	
CdSe	AI1	15		2.33	2.56	40	72	
CdSe	AI1	0.030		2.33	2.56	30	73	
CdSe	TRT	~20		1.88; 2.33	2.5; 2.56	2; <20	26	
CdSe	C	16		2.33	2.56	50	74	

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CdSe	C	11; 26		2.33	2.56	25; 38	7	
CdSe	PA	0.040		2.33	2.56	35	75	
CdSe	C	79		1.88	~2.5	67	7	
CdSe	AI1	0.038		2.33	2.56	18	67	
CdSe	AI1	~200		3.65	~2.6	$\sim 10^6$	76	4.2K, t resol.
CdSe	AI1	0.006		2.36	2.56	18	77	No dep. SHG
CdS_xSe_{1-x}	AI1	30	1.9–2.4	3.56		100–1700	78	300 K, 77 K
CdS_xSe_{1-x}	AI1			2.33, 3.56		Relative spectrum	79	
CdTe	AI1		1.56	2.33	2.84	200	70	
CdTe	AI1			2.33	2.84	180	80	300 K, 85 K,
CdTe	AI1	0.030		2.33	2.84	25	73	E ‖ z
CdTe	TCN	0.030		2.33	2.84	$\beta_{CdTe}/\beta_{GaAs} = 0.78$	20	
CdTe	C	16		2.33	2.84	130	74	
CdTe	C	11; 38		2.33	2.84	53; 78	7	
CdTe	C	79		1.88	~2.7	120	7	
CdTe	PA	0.040		2.33	2.84	50	75	
CdTe	TCN	20		2.33	2.84	170	81	
CdTe	AI1	0.005		2.34	2.84	12; 8	82	270 K; 100 K
CdTe	AI1	0.038		2.33	2.84	22; 15	67	Cryst., polycryst.
CdTe	AI1	0.035		2.33	2.84	8	83	
CdTe	Z-scan	0.040		2.33	2.84	26	84	Polycrystal
CsBr	AI2	~10	6.9	7.2–8.0	~1.8–1.9	Abs. spectr. (10 @ 7.5 eV)	85	20 K
CsD_2AsO_4	AI1	0.017		6.99	1.6	0.051; 0.080	3	E ‖ z; E ⊥ z
CsH_2AsO_4	AI1	0.017		6.99	1.6	0.028	3	
CsI	AI2	$\sim 10^6$	6.2	5.7–6.8	~1.8–1.9	Relative spectrum	86,87	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
CsI	AI2	~10		6.2–6.8	~1.8–1.9	Abs. spectr. (40 @ 6.5 eV)	85	20 K
CsI	AI2			6.0–6.8	~1.8–1.9	Relative spectrum	88	20 K
CsI	L	5		7.0	1.89	Relative spectrum	89	
CsI	AI1	6		6.99	1.89	6	90	
CsI	AI1	0.00035		8.05	~1.9	4.5	91	3×10^{18} Na^+
Cu_2O	AI2	40	2.1	2.0–2.8		Relative spectrum	92	
Cu_2O	AI2	0.0005		3.4–3.9		Relative spectrum	93	20 K
Cu_2O	AI2			2.03–2.17		Relative spectrum	94	Excitons
CuBr	AI2	30	3	2.97–3.10	2.1	Relative spectrum	95	
CuBr	AI1	45		3.56	2.1	200	62	
CuCl	AI2	~10	3.3	3.2–4.25	~2	Relative spectrum	96	20 K
CuCl	AI2			3.21–3.56	1.97	Relative spectrum	97	4.2 K
CuCl	AI1	16		3.16–3.20	1.95	1×10^6	98	4 K, 77 K
CuCl	AI2	~5		3.16–3.18	1.95	~3×10^6	4	4.2 K
CuCl	AI1	45		3.56	1.97	45	62	
CuCl	AI2	~10		3.2–5.4	~2	Relative spectrum	99	
CuCl	AI2			3.2–5.4	~2	Relative spectrum	100	4.3 K, β vs Pol
CuCl	EPR	5		3.18–3.19	1.95	Relative spectrum	10	4 K
CuCl	L	9		3.34–4.1	1.92	Abs. spectr. (30 @ 3.5 eV)	38	80 K
CuCl	L	9		3.34–4.1	1.92	Relative spectrum	39	80 K
CuI	AI1	45	3.1	3.56	1.97	89	62	
$FeBO_3$	AI2	12	~2.5	2.6–3.6		Abs. spectr. (5 @ 3.4 eV)	101	108 K
GaAs	AI1		1.42	2.33	3.43	300	68	
GaAs	AI1			2.33	3.43	20	70	

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GaAs	AI1			2.33	3.43	800	49	n-type
GaAs	AI1, PC	22		2.33	3.43	360	102	
GaAs	AI1	~125		1.88	~3.4	33	103	
GaAs	AI1	30		2.33	3.43	230	104	
GaAs	AI1			2.33	3.43	80	80	300 K, 85 K
GaAs	AI1	~50		1.5–2.33	~3.4	Abs. spectr. (1100 @ 1.5eV)	105	
GaAs	AI1	15		2.33	3.43	60	72	
GaAs	AI1	0.030		2.33	3.43	28	46	E ‖ z
GaAs	AI1	~10		2.33	3.43	35; 78	106	
GaAs	L			1.4–1.8	~3.35	Abs. spectr. (5.1 @ 1.6eV)	107	
GaAs	L	5		2.33	3.43	70	108	
GaAs	AI1	0.008		2.33	3.43	15	109	
GaAs	C	0.030		2.33	3.43	30	7	
GaAs	AI1	30		2.33	3.43	100	110	
GaAs	AI1	~0.035		1.3–1.7		Relative spectrum	111	100 K
GaAs	AI1	0.038		2.33	3.43	23	67	
GaAs	AI1	0.045		2.33	3.43	26	112	
GaAs	AI2, L	0.005		2.34	3.43	45	113	295 K, 103 K
GaAs	AI2	0.035		2.33	3.43	27	114	Cross-pol.
GaAs	AI1	0.05		2.33	3.53	29	115	In Chinese
GaAs	A12	0.027		2.33	3.43	18, 22	116	
GaAs	AI1	0.08		2.33	3.43	26	117	
GaAs	Z-scan	0.040		2.33	3.43	26	84	No anisotropy
GaP	AI1	50	2.26	2.33	3.12	1.7	118	Indirect gap
GaP	AI1	0.030		2.33	3.12	0.2	73	E ‖ [110]
GaP	TCN			3.92	3.35	250	119	
GaP	CR			3.18	3.18	250	59	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
GaS	AI1	20	2.8	3.56		100	120	Direct gap
GaS	PC	20	2.3	2.33		0.05	120	Indirect gap
GaSe	AI1	20	2.0	2.33		110	120	
Ge	AI1	80	0.66	1.06	~4	50	121	
Ge	AI1	100		0.8–1.0	~4	2500	122	
Ge	AI1; PC	~480		0.916	4.05	160	19	
$Hg_{0.78}Cd_{0.22}Te$	TRT	~200	0.17	0.233		14000	123	
$Hg_{0.78}Cd_{0.22}Te$	TRT	300		0.233		1×10^4, 3×10^4	124	300 K; 150 K
Hg_2Cl_2	L	2	3.9	4.7–5.2		Relative spectrum	125	8.5 K, E || *c*
Hg_2Cl_2	L, AI1	2		4.1–5.7		Relative spectrum	126	8.5 K
Hg_2Cl_2	L			4–5.5		Polarization dependence	127	8.5 K
InP	TRT	200	1.34	2.33	3.33	210	104	
InP	AI1, PC	22		2.33	3.33	260	102	
InP	AI1	30		2.33	3.33	1800	110	
InP	AI1	100		2.34	3.33	60	128	$\beta_l/\beta_c = 1.8$
InSb	PC	~200	0.17	0.233	3.95	59.6–119	129	77 K
InSb	PC	~200		0.233	3.95	0	129	2 K
InSb	PC	~200		0.257	3.95	1151–1419	129	77 K
InSb	AI1	~10		0.233	3.95	16000	130	
InSb	PC	~200		0.257	3.95	946–1850	129	2 K
InSb	AI1	30		0.233	3.95	15000	104	
InSb	AI1; PC	~150		0.233	3.95	220	19	
InSb	TRT	~200		0.233; 0258	3.95	8000; 14000	123	
InSb	TRT	300		0.233	3.95	4800	124	

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InSb	TRT	300		0.233	3.95	220	124	77 K
InSb	AI2	130		0.233	3.95	2000–5600	130	
InSb	PC	CW		0.26	3.95	2900	131	Magnetic field
InSb	AI1	0.045		0.234; 0.258	3.95	2500; 1700	132,133	300 K
KBr	AI1	15	7.6	7.12	~1.6	3.3	134	
KBr	AI2	~10		7.0–8.0	~1.6	Relative spectrum	135	20 K, 80 K
KBr	AI1	0.015		9.32	~1.6	2.0	3	
KBr	CR	15		6.7	~1.6	8.0	136	
KBr	AI1	10		7.18	~1.6	$\beta_{KBr} = 0.64\ \beta_{KI}$	137	
KCl	FCC	8	8.5	9.32	1.6	1.5	11	
KCl	AI1	0.015		9.32	1.6	2.2	3	
KCl	AI2	10		8.1–8.5	1.6	Abs. spectr. (400 @ 8.5eV)	138	20 K
KD_2AsO_4	AI1	0.017		6.99	~1.6	0.027	3	
KD_2PO_4	AI1	0.030		9.32	1.57–1.51	0.027	139	
KD_2PO_4	AI1	0.030	7.0	9.32	1.57–1.51	0.027	140	$k \perp c$
KD_2PO_4	AI1	0.017		6.99	1.53–1.49	0.0054	3	
KH_2AsO_4	AI1	0.017		6.99	~1.6	0.048	3	
KH_2PO_4	AI1	0.017	7.0	6.99	1.53–1.49	0.0059	3	
KH_2PO_4	AI1	0.015		9.32	1.57–1.51	0.27	3	
KH_2PO_4	Model	0.5		9.32	1.57–1.51	0.5	141	$E \perp$ opt.axis
KI	AI1	15		7.12	~1.9	4.4	134	
KI	AI2			6.0–7.5	~1.7–1.9	Relative spectrum	142	
KI	AI2			6.1–7.7	~1.7–1.9	Relative spectrum	88	20 K
KI	AI2			6.23–6.36	~1.7–1.8	Relative spectrum	143	
KI	PC	20		7.12	~1.9	10	144	
KI	AI1	0.017		6.99	~1.9	7.3	3	
KI	AI1	0.015		9.32	2.0	3.7	3	
KI	CR	15		6.7	~1.9	18	136	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
KI	AI1	0.024		7.12	~1.9	8	145	
KI	AI1	10		7.12	~1.9	Relative value	137	
KI	AI2	10		6.0–6.7		Abs. spectr. (300 @ 6.5 eV)	138	20 K
KRS-V	C	38		2.33	2.44	1.6	7	
$KTa_{0.7}Nb_{0.3}O_3$	AI1	0.010		4.66		14	146	
$KTaO_3$	AI2	17	3.5	3.9–4.6		Abs. spectr. (1 @ 4.4 eV)	35	
KTP	Z-scan	0.019	3.5	4.66	1.8	0.1	147	E for SHG
LiF	AI1	0.015	13.6	9.32	1.4	<0.02	3	
$LiIO_3$	AI2	10	4.0	4.4–4.8	1.75–1.9	<0.4	148	
$LiNbO_3$	AI1	30	4.0	3.56	~2.2	10.	49	
$LiNbO_3$	AI1	0.025		4.66	2.3–2.2	3.4	149	
$LiNbO_3$	AI2	10		4.4–4.8	2.3–2.2	Abs. spectr. (1.5 @ 4.66 eV)	148	
$LiYF_4$	AI1	0.015	~11	9.32	1.5	<0.004	33	
MgF_2	AI1	0.017	10.8	6.99	1.4	<0.0062	33	
MgF_2	AI1	0.015		9.32	1.4	<0.0028	33	
NaBr	AI1	0.015	7.5	9.32	1.8	2.5	3	
NaCl	AI1	0.015	9.0	9.32	~1.64	3.5	3	
NaCl	AI2	10		8.1–8.6	~1.6	Abs. spectr. (200 @ 8.5 eV)	138	20 K
$NH_4H_2AsO_4$	AI1	0.017		6.99		0.035	3	
$NH_4H_2PO_4$	AI1	0.030	6.8	9.32	1.59–1.53	0.11	139	No pol., k ⊥ c
$NH_4H_2PO_4$	AI1	0.015		9.32	1.59–1.53	0.24	3	
$NH_4H_2PO_4$	AI1	0.017		6.99	1.55–1.50	0.0068	3	
$NH_4H_2PO_4$	Model	0.5		9.32	1.59–1.53	0.35	141	E ⊥ opt. axis
$NH_4H_2PO_4$	Model	0.5		4.67 + 5.83	~1.6	1	141	E for 5th harmonic

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$NH_4H_2PO_4$	Model	0.5		11.66	~1.6	9.5	141	E for 5th harmonic
PbI_2	AI1	20	2.4	3.56		250	120	
PbI_2	AI2	~10		2.46–2.55		Relative spectrum	150	1.6–300 K
$PbMoO_4$	AI2	50	3.6	3.2–4.2		Abs. spectr. (5 @ 4 eV)	151–52	80 K, 300 K
RbBr	AI2	~10	7.25	7.0–8.0	~1.6	Relative spectrum	135	20 K, 80 K
RbBr	AI1	0.017		6.99	1.6	2.43	3	
RbBr	AI1	0.015		9.32	1.7	2.18	3	
RbBr	CR	15		6.7	1.6	11	136	
RbBr	AI1	10		7.12	1.6	$\beta_{RbBr} = 0.55\ \beta_{KI}$	137	
RbCl	AI1	0.015	8.3	9.32	1.6	1.1	3	
RbH_2AsO_4	AI1	0.017		6.99		0.050	3	
RbH_2PO_4	AI1	0.017		6.99		0.059	3	
RbI	AI2	~10	5.83	6.1–7.0	1.7	Relative spectrum	135	20 K
RbI	AI1	0.017		6.99	1.73	5.1	3	
RbI	AI1	0.015		9.32	2.0	2.5	3	
RbI	AI1	10		7.12	1.73	$\beta_{RbBr} = 0.51\ \beta_{KI}$	137	
Si	AI1	200	1.12	2.33	3.52	40	153	
Si	AI1		“1.1”	2.33	3.52	7300	70	T dependence
Si	AI2	25		1.62–2.2	~3.5	Relative spectrum	154	
Si	AI1	0.020		2.33	3.52	1.9; 1.5	155	20 K; 100 K
Si	C	79		1.88	~3.5	21	7	
Si	AI1	0.004–0.1		2.33–2.34	3.52	1.5	156	
Si	AI2	0.00009		4–4.5; 4.0	~3.8	15–36; 34.6	156,157	Dir. $E_g = 3.43$
SiC	AI1	30	2.6	3.56	2.6	200	49	
SiC	L	20		3.0–4.6	~2.6	Relative spectrum	159	E || c; E $\perp$ c
SiO_2 (quartz)	AI1	0.015	8.4	9.32	1.6	<0.045	3	
SnO_2	AI2	~10	3.4	3.555–3.573		Relative spectrum	160	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
SnO_2	AI1	45		3.56		300; 34	62	E ‖ c; E ⊥ c
SrF_2	AI1	0.017	9.4	6.99	1.45	<0.0057	33	
SrF_2	AI1	0.015		9.32	1.47	<0.0054	33	
SrF_2	AI1	0.0007		10.0	1.47	0.011	34	
$SrTiO_3$	AI1	~30	4.1	3.56	2.38	2.9	161	
$SrTiO_3$	CR			3.92	2.4	3	119	
$SrTiO_3$	AI2	17		3.2–4.4	~2.4	Abs. spectr. (4 @ 4.2 eV)	35,162	
$SrTiO_3$	AI2			4.1; 4.7; 5.0	2.4–2.5	1.3; 4.1; 10.2	163	
$SrTiO_3$	PA	5		3.2–5.5	~2.4–2.5	Abs. spectr. (5 @ 5.0 eV)	17	
$SrTiO_3$	AI2			3.3–4.2	~2.4	Abs. spectr (2 @ 4.1 eV)	164	
Te	AI2	200	0.33	0.342	~5–6	800	140	
TiO_2	AI2		3.5	3.3–4.1	~2.5–2.9	Abs. spectr. (300 @ 4 eV)	166	
TiO_2	AI1	0.004		4.66	~2.6–3	14	167	
TiO_2	AI1	0.004		3.96	~2.6–2.9	6.5	167	
TiO_2	CR			3.92	~2.6–2.9	23	119	
TiO_2	CR			4.1; 4.7; 5.0	~2.6–3	12.7; 87; 170.	163	
TiO_2	AI1	45		3.56	~2.5–2.9	150; 120	62	E ‖ c; E ⊥ c
TlCl	AI2	20	3.6	3.4–4.4	2.2–2.26	Abs. spectr. (0.45 @ 3.8 eV)	165	
TlCl	AI2	20		3.4–4.4	2.2–2.26	Abs. spectr. (4.7 @ 4.0 eV)	169	
TlCl	AI2	~10		3.39–3.56	2.2	Relative spectrum	170	4, 20, 77 K
V_2O_5	AI1	60	~2.3	3.56		720	171	E ‖ [001]
$Y_3Fe_5O_{12}$	AI2	17	2.66	2.5–3.5		Abs. spectr. (300 @ 3.51 eV)	172	T dep., β vs. pol.
$Zn_{.0.85}Cd_{0.15}Se$	AI1	10	2.65	3.56		56	173	
$Zn_{0.12}Cd_{0.88}Se$	AI1	10	1.92	3.56		620; 260	173	E ⊥ z; E ‖ z

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$Zn_{0.5}Cd_{0.5}S$	AI1	45	~3	3.56		60	62	
$Zn_{0.5}Cd_{0.5}S$	AI2	35	2.62	2.6–3.6		Abs. spectr. (20 @ 3.4 eV)	174	
$Zn_{0.5}Cd_{0.5}S$	AI2			2.6–3.4		Abs. spectr. (10 @ 3 eV)	63	β vs. pol.
ZnO	AI2	20	3.35	3.42–3.45	2.0	Relative spectrum	175	
ZnO	AI1:AI2			3.56		26; 21	176	$k \perp c$
ZnO	AI2			3.42–3.43	2.0	Abs. spectr. (2 @ 3.4 eV)	177	4.2 K in 42 kG field
ZnO	AI2	~10		3.42–3.48	2.0	Relative spectrum	88	1.6 K
ZnO	CR			4.1; 4.7; 5.0	2.0–2.1	19.8; 20.9; 47.8	163	
ZnO	AI1	45		3.56	2.0	34; 16	62	E ‖ c; E⊥c
ZnO	AI2	50		3.4–4.2	2.0	Abs. spectr. (10 @ 3.8 eV)	133	β vs. pol.
ZnO	AI1	0.027		4.67	2.05	5.0	67	
ZnO	L	9		3.4–4.2	2.0	Abs. Spectr. (10 @ 3.5 eV)	28,38	80 K
ZnP_2	TRT			2.34		120	44	
ZnP_2	TRT			3.56		650	44	
ZnP_2	AI2	15		2.4–3.2		Abs. spectr. (10 @ 2.9 eV)	45	
ZnP_2	AI2	25	2.22	2.2–2.7		Abs. spectr. (10 @ 2.6 eV)	179	
ZnP_2	AI2	15		2.4–3.4		Relative spectrum	180	Impurities
ZnS	AI2		3.68	3.7–4.2	~2.36	Abs. spectr. (2.3 @ 4.0 eV)	154	
ZnS	AI2			3.6–4.0	~2.35	Relative spectrum	181	
ZnS	PC	20		3.56	~2.35	4.3	18	Cu-doped
ZnS	AI1	45		3.56	~2.35	20; 0	62	E ‖ c; E ⊥ c
ZnS	PA	5		3.65–5.5	2.35–2.5	Relative spectrum	17	E ‖ z
ZnS	AI2			3.7–5.3		Abs. spectrum (2 @ 4.1 eV)	63	β vs. pol
ZnS	AI1	0.027		4.67	2.4	2.0; 3.5	67	Cleartran, CVD
ZnSe	AI1	30	2.71	3.56	~2.6	40	49	
ZnSe	AI1	10		3.56	~2.6	45	173	
ZnSe	AI2	40		2.6–3.6	~2.5–2.6	Abs. spectr. (4 @ 3.0 eV)	182	

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Two-Photon Absorption Data—*continued*

Material	Method	Pulse τ_p (ns)	Bandgap E_g (eV)	$2\hbar\omega$ (eV)	Index n_0 ($\hbar\omega$)	2PA coefficient (cm/GW)	Ref.	Additional information
ZnSe	AI2	40		2.75–3.45	~2.5–2.6	Abs.spectr. (13 @ 3.45 eV)	183	Impurity resonances
ZnSe	CR			3.18	~2.53	60	59	
ZnSe	AI1	45		3.56	~2.6	17000	62	300 K, cubic
ZnSe	AI2	15		2.7–3.75	~2.5–2.6	Abs. spectr. (10 @ 3.5 eV)	45	
ZnSe	TCN	20		3.56	~2.6	80	81	
ZnSe	AI2			2.7–3.8	~2.5–2.6	Abs. spectr. (10 @ 3.4 eV)	63	β vs. pol
ZnSe	AI2	15		2.9–3.7	~2.5–2.6	Abs. spectr. (10 @ 3.4 eV)	184	β vs Cu doped
ZnSe	AI1	20		3.56	~2.6	4–15	185	β vs Cu doped
ZnSe	AI1	0.027		4.67	2.7	5.5	67	
ZnSe	Z-scan	0.03		4.67	2.7	5.8	84	
ZnTe	AI1	30	2.3	2.33	2.79	34	104	
ZnTe	AI1			3.56	2.91	500	186	77 K
ZnTe	AI1	0.030		2.33	2.79	8.0	73	E || z
ZnTe	AI1, TCN	20		2.34; 3.56	2.79; 2.91	20; 300	187	T-tuned band gap
ZnTe	AI1	45		3.56	2.91	8000	62	Arb. pol.
ZnTe	AI2	30		2.8–4	~3	Abs. spectr. (4 @ 3.1 eV)	188	Time resolved
ZnTe	AI1	0.038		2.33	2.79	4.5	67	
ZnTe	Z-scan	0.040		2.33	2.79	4.2	84	
$Zn_xCd_{1-x}Se$	AI1		2.45–3.55	3.56		50–1	189	Anistropy
$Zn_{0.12}Cd_{0.88}Se$	AI1	10	1.92	3.56		620, 260	173	
$Zn_{0.5}Cd_{0.5}Se$	AI1	45	~3	3.5		60	62	
$Zn_{0.85}Cd_{0.15}Se$	AI1	10	2.65	3.56		56	173	
ZrO_2-(Y_2O_3)	AI1	0.03	~4.1	4.66	2.12	0.013	190	Independent of Y_2O_3

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1.9.3 Second Harmonic Generation Coefficients

Crystal System—Cubic

Cubic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$NaBrO_3$	23	$d_{14} = 0.19$	0.6943
$NaClO_3$	23	$d_{14} = 0.46$	0.6943
AlSb	–43m	$d_{14} = 49 \pm 36$	1.058
$Bi_4Ge_3O_{12}$	–43m	$d_{14} = 1.28$	1.064
CdTe	–43m	$d_{14} = 167.6 \pm 63$	10.6
		$d_{14} = 59.0 \pm 24$	28.0
CuBr	–43m	$d_{14} = 8.04 \pm 30\%$	10.6
		$d_{14} = -4.38 \pm 20\%$	1.318
		$d_{14} = -6.37 \pm 20\%$	1.064
		$d_{14} = -6.53 \pm 20\%$	0.946
CuCl	–43m	$d_{14} = 6.7 \pm 30\%$	10.6
		$d_{14} = -4.0 \pm 20\%$	1.318
		$d_{14} = -3.97 \pm 20\%$	1.064
		$d_{14} = -3.47 \pm 20\%$	0.946
CuI	–43m	$d_{14} = 8.04 \pm 30\%$	10.6
		$d_{14} = -5.47 \pm 20\%$	1.318
		$d_{14} = -6.08 \pm 20\%$	1.064
		$d_{14} = -6.04 \pm 20\%$	0.946
GaAs	–43m	$d_{14} = 134.1 \pm 41.9$	10.6
		$d_{14} = 209.5 \pm 13.3$	1.058
		$d_{14} = 256.5$	0.694
GaP	–43m	$d_{14} = 71.8 \pm 12.3$	1.058
		$d_{36} = 59.5 \pm 6.0$	1.318
		$d_{14} = +70.6$	3.39
GaSb	–43m	$d_{14} = +628 \pm 6.3$	10.6
InAs	–43m	$d_{14} = 364 \pm 47$	1.058
		$d_{14} = 249 \pm 62$	10.6
InP	–43m	$d_{14} = 143$	1.058
InSb	–43m	$d_{14} = 520 \pm 47$	1.058
		$d_{14} = 16345 \pm 503$	10.6
		$d_{14} = 560 \pm 230$	28
$N_4(CH_2)_6$	–43m	$d_{14} = 4.1$	1.06
β-ZnS	–43m	$d_{14} = 30.6 \pm 8.4$	10.6
		$d_{36} = 20.7 \pm 1.3$	1.058

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Crystal System—Cubic—*continued*

Cubic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
ZnSe	–43m	$d_{14} = 78.4 \pm 29.3$	10.6
		$d_{36} = 26.6 \pm 1.7$	
ZnTe	–43m	$d_{14} = 92.2 \pm 33.5$	10.6
		$d_{14} = 83.2 \pm 8.4$	1.058
		$d_{36} = 89.6 \pm 5.7$	1.058

Crystal System—Hexagonal

Hexagonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$LiIO_3$	6	$d_{31} = \pm 10.17 \pm 0.32$	0.5145
		$d_{33} = -5.15 \pm 0.32$	1.064
		$d_{31} = -4.96 \pm 0.32$	1.064
		$d_{33} = -5.54 \pm 0.61$	1.318
		$d_{31} = -6.82$	1.318
$LiKSO_4$	6	$d_{31} = 0.38$	0.6943
		$d_{33} = 0.71$	0.6943
GaS	6m2	$d_{16} = 135$	0.6943
GaSe	6m2	$d_{22} = 75.4 \pm 10.8$	10.6
		$d_{16} = 972$	0.6943
InSe	6m2	$d_{16} = 281$	0.6943
AgI	6mm	$d_{31} = +8.2 \pm 20\%$	1.318
		$d_{33} = -16.8 \pm 22\%$	1.318
AlN	6mm	$d_{31} = \leq 0.30$	1.064
		$d_{33} = 7.42 \pm 35\%$	1.064
BeO	6mm	$d_{33} = -0.20 \pm 0.01$	1.064
		$d_{31} = -0.15 \pm 0.01$	1.064
CdS	6 mm	$d_{33} = 25.8 \pm 1.6$	1.058
		$d_{31} = -13.1 \pm 0.8$	1.058
		$d_{15} = 14.4 \pm 0.8$	1.058
		$d_{33} = +44.0 \pm 12.6$	1.064
		$d_{31} = -26.4 \pm 6.31$	1.064
		$d_{15} = 28.9 \pm 7.1$	1.064
CdSe	6 mm	$d_{33} = 66.9 \pm 4.2$	1.064
		$d_{31} = -26.8 \pm 2.7$	1.064
		$d_{33} = 54.5 \pm 12.6$	1.064

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Crystal System—Hexagonal System—*continued*

Hexagonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$LiClO_4 \cdot 3H_2O$	6mm	$d_{31} = +0.22 \pm 20\%$	1.064
		$d_{33} = +0.25 \pm 20\%$	1.064
		$d_{15} = +0.25 \pm 20\%$	1.064
SiC	6mm	$d_{31} = +8.6 \pm 0.9$	1.064
		$d_{33} = -14.4 \pm 1.3$	1.064
		$d_{15} = +8.0 \pm 0.9$	1.064
Zn_3AgInS_5	6mm	$d_{31} = +7.2 \pm 20\%$	1.064
		$d_{33} = \pm 15.9 \pm 20\%$	1.064
Zn_5AgInS_7	6mm	$d_{31} = +9.22 \pm 20\%$	1.064
		$d_{33} = +20.95 \pm 20\%$	1.064
ZnO	6mm	$d_{33} = -5.86 \pm 0.16$	1.058
		$d_{31} = 1.76 \pm 0.16$	1.058
		$d_{15} = 1.93 \pm 0.16$	1.058
α-ZnS	6mm	$d_{33} = 11.37 \pm 0.07$	1.058
		$d_{33} = 37.3 \pm 12.6$	10.6
		$d_{31} = -18.9 \pm 6.3$	10.6
		$d_{15} = 21.37 \pm 8.4$	10.6
		$d_{15} = 6.7 \pm 1.0$	1.064
		$d_{31} = -7.6 \pm 1.5$	1.064
		$d_{33} = +13.8 \pm 1.7$	1.064

Crystal System—Tetragonal

Tetragonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$BaTiO_3$	4mm	$d_{33} = 6.8 \pm 1.0$	1.064
		$d_{31} = 15.7 \pm 1.8$	1.064
		$d_{15} = 17.0 \pm 1.8$	1.064
$Ba_6Ti_2Nb_8O_3$	4mm	$d_{31} = 9.7 \pm 1.8$	1.064
		$d_{33} = 13.2 \pm 1.8$	1.064
$K_3Li_2Nb_5O_{15}$	4mm	$d_{33} = 11.2 \pm 1.6$	1.064
		$d_{31} = 6.18 \pm 1.28$	1.064
		$d_{15} = 5.45 \pm 0.54$	1.064
$K_{0.8}Na_{0.2}Ba_2Nb_5O_{15}$	4mm	$d_{31} = 13.6 \pm 1.6$	1.064
$PbTiO_3$	4mm	$d_{33} = 7.5 \pm 1.2$	1.064
		$d_{31} = 37.6 \pm 5.6$	1.064
		$d_{15} = 33.3 \pm 5$	1.064

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Crystal System—Tetragonal System—*continued*

Tetragonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$SrBaNb_5O_{15}$	4mm	$d_{33} = 11.3 \pm 3.3$	1.064
		$d_{31} = 4.31 \pm 1.32$	1.064
		$d_{15} = 5.98 \pm 2$	1.064
$AgGaS_2$	-42m	$d_{36} = 18 \pm 2.7$	10.6
		$d_{36} = 23.36 \pm 3.52$	1.064
$AgGaSe_2$	-42m	$d_{36} = 37.4 \pm 6.0$	10.6
		$d_{36} = 67.7 \pm 13$	2.12
$AgInSe_2$	-42m	$d_{36} = 55.9 \pm 10\%$	10.6
$CdGeAs_2$	-42m	$d_{36} = 351 \pm 105$	10.6
$BeSO_4 \cdot 4H_2O$	-42m	$d_{36} = 0.30$	0.6328
		$d_{36} = 0.29 \pm 0.03$	0.5321
$CdGeP_2$	-42m	$d_{36} = 162 \pm 30\%$	10.6
CsD_2AsO_4	-42m	$d_{36} = 0.40 \pm 0.05$	1.064
CsH_2AsO_4	-42m	$d_{36} = 0.22$	0.6943
		$d_{36} = 0.40 \pm 0.05$	1.064
$CuGaSe_2$	-42m	$d_{36} = 44.2 \pm 10\%$	10.6
$CuGaS_2$	-42m	$d_{36} = 14.5 \pm 15\%$	10.6
$CuInS_2$	-42m	$d_{36} = 10.6 \pm 15\%$	10.6
KD_2PO_4 (KD*P)	-42m	$d_{36} = 0.38 \pm 0.016$	1.058
		$d_{36} = 0.34 \pm 0.06$	0.694
		$d_{14} = 0.37$	1.058
KH_2PO_4 (KDP)	-42m	$d_{36} = 0.44$	1.064
		$d_{36} = 0.47 \pm 0.07$	0.694
KD_2AsO_4 (KD*A)	-42m	$d_{36} = 0.39$	1.064
KH_2AsO_4 (KDA)	-42m	$d_{36} = 0.43 \pm 0.025$	1.06
		$d_{36} = 0.39 \pm 0.4$	0.694
$ND_4H_2PO_4$ (AD*P)	-42m	$d_{36} = 0.495 \pm 0.07$	0.6943
$NH_4H_2PO_4$ (ADP)	-42m	$d_{36} = 0.762$	1.064
		$d_{36} = 0.85$	0.6943
		$d_{36} = 0.85$	0.694
$(NH_2)_2CO$ (urea)	-42m	$d_{36} = 1.35$	1.06
RbH_2AsO_4 (RDA)	-42m	$d_{36} = 0.39 \pm 0.04$	0.6943

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Crystal System—Tetragonal System—*continued*

Tetragonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
RbH_2PO_4 (RDP)	-42m	$d_{36} = 0.414 \pm 0.045$	0.6943
		$d_{36} = 0.38 \pm 0.04$	1.064
$ZnGeP_2$	-42m	$d_{36} = 111.2 \pm 30\%$	10.6
TeO_2	422	$d_{14} = 0.34 \pm 0.05$	1.318
		$d_{14} = 0.38 \pm 0.03$	1.064
		$d_{14} = 4.13 \pm 1.03$	0.659
$CdGa_2S_4$	-4	$d_{36} = 25.6 \pm 3.8$	1.064
$HgGa_2S_4$	-4	$d_{36} = 25.6 \pm 7.7$	1.064
$InPS_4$	-4	$d_{36} = 20.1 \pm 2.1$	1.064
		$d_{31} = 26.3 \pm 2.58$	1.064

Crystal System—Trigonal

Trigonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$PbGe_3O_{11}$	3	$d_{11} = 0.96 \pm 0.16$	1.064
		$d_{22} = -2.1 \pm 0.3$	1.064
		$d_{31} = +0.51 \pm 0.07$	1.064
		$d_{33} = -0.79 \pm 0.12$	1.064
$AlPO_4$	32	$d_{11} = 0.35 \pm 0.03$	1.058
		$d_{14} < 0.008$	1.058
HgS	32	$d_{11} = 50.3 \pm 17$	10.6
		$d_{11} = 47.2 \pm 4$	1.32
$Nd_{0.2}Y_{0.8}Al_3(BO_3)_4$	32	$d_{11} = d_{12} = 1.36 \pm 0.16$	1.32
		$d_{14} = d_{12} < 0.01$	1.32
$PbS_2O_6 \cdot 4H_2O$	32	$d_{11} = 0.096$	1.0645
		$d_{11} = 0.15$	0.694
RbS_2O_6	32	$d_{11} = 0.081 \pm 0.03$	0.6943
Se	32	$d_{11} = 79.6 \pm 42$	10.6
$SrS_2O_6 \cdot 4H_2O$	32	$d_{11} = 0.06 \pm 0.02$	0.6943
Te	32	$d_{11} = 650 \pm 30$	10.6
SiO_2 (quartz)	32	$d_{11} = 0.335$	1.064
$(C_6H_5CO)_2$ (benzil)	32	$d_{11} = 3.6 \pm 0.5$	1.064

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Crystal System—Trigonal—*continued*

Trigonal material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
Ag_3AsS_3 (proustite)	3m	$d_{31} = 16.8 \pm 1$	10.6
		$d_{22} = 26.8 \pm 4$	10.6
		$d_{22} = 20.0$	1.152
		$d_{31} = 12.0$	1.152
Ag_3SbS_3 (pyrargerite)	3m	$d_{31} = 12.6 \pm 4$	10.6
		$d_{22} = 13.4 \pm 4$	10.6
β-BaB_2O_4 (BBO)	3m	$d_{22} = 13.4 \pm 4$	1.06
		$d_{31} = 12.6 \pm 4$	1.06
$(CN_3H_6)As(SO_4)_2$-•$6H_2O$ (GASH)	3m	$d_{22} = -1.05 \pm 0.017$	1.064
		$d_{31} = +0.008 \pm 0.017$	1.064
		$d_{33} = +0.020 \pm 0.003$	1.064
$LiNbO_3$	3m	$d_{33} = -34 \pm 8.6$	1.058
		$d_{31} = -4.88 \pm 0.7$	1.058
		$d_{22} = +2.58 \pm 0.25$	1.058
		$d_{31} = -4.35 \pm 0.4$	1.152
		$d_{22} = +2.1 \pm 0.8$	1.152
		$d_{33} = -31.8$	1.318
		$d_{31} = -29.1$	1.318
$LiTaO_3$	3m	$d_{33} = -16.4 \pm 2$	1.058
		$d_{31} = -1.07 \pm 0.2$	1.058
		$d_{22} = +1.7 \pm 0.2$	1.058
(Na,Ca)(Mg,Fe)$(BO_3)_3$-Al_6Si_6(OH,O,F) (tourmaline)	3m	$d_{15} = 0.24 \pm 0.04$	1.064
		$d_{31} = 0.14 \pm 0.03$	1.064
		$d_{22} = 0.07 \pm 0.01$	1.064
		$d_{33} = 0.50 \pm 0.06$	1.064
$TlIO_3$	3m	$d_{15} = 3.49 \pm 20\%$	1.064
		$d_{31} = 3.36 \pm 20\%$	1.064
		$d_{23} = 1.11 \pm 20\%$	1.064
		$d_{24} = 3.85 \pm 20\%$	1.064
		$d_{32} = 3.98 \pm 20\%$	1.064
		$d_{33} = 6.85 \pm 20\%$	1.064
SbI_3•$3S_8$	3m	d22 = 5.2	1.064
		d33 = 7.23	1.064
		d31 = 4.8	1.064

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Crystal System—Orthorhombic

Orthorhombic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$Ba(COOH)_2$	222	$d_{14} = 0.11 \pm 11\%$	1.064
		$d_{25} = 0.11 \pm 14\%$	1.064
		$d_{36} = 0.13 \pm 11\%$	1.064
α–HIO_3	222	$d_{36} = 5.15 \pm 0.16$	1.064
NO_2•$CH_3NOC_5H_4$ (POM)	222	$d_{36} = 6.4 \pm 1.0$	1.064
$Sr(COOH)_2$	222	$d_{34} = 0.51$	1.064
$BaMgF_4$	mm2	$d_{31} = 0.023 \pm 20\%$	1.064
		$d_{32} = \pm 0.035 \pm 12\%$	1.064
		$d_{33} = 0.0094 \pm 14\%$	1.064
		$d_{24} = 0.025 \pm 17\%$	1.064
$Ba_2NaNb_5O_{15}$	mm2	$d_{33} = -17.6 \pm 1.28$	1.064
		$d_{32} = -12.8 \pm 0.64$	1.064
		$d_{31} = -12.8 \pm 1.28$	1.064
$BaZnF_4$	mm2	$d_{32} = 0.08 \pm 20\%$	1.06
		$d_{15} = 0.011 \pm 20\%$	1.06
		$d_{33} = 0.035 \pm 20\%$	1.06
$C_6H_4(NO_2)_2$ [MDB]	mm2	$d_{33} = 0.74$	1.064
		$d_{32} = 2.7$	1.064
		$d_{31} = 1.78$	1.064
$Gd_2(MoO_4)_3$	mm2	$d_{33} = -0.044 \pm 0.008$	1.064
		$d_{32} = +2.42 \pm 0.36$	1.064
		$d_{31} = -2.49 \pm 0.37$	1.064
KB_5O_8•$4H_2O$	mm2	$d_{31} = 0.046$	0.4342
		$d_{32} = 0.003$	0.4342
KIO_2F_2	mm2	$d_{31} = \pm 0.57 \pm 25\%$	1.064
		$d_{32} = \pm 0.16 \pm 25\%$	1.064
		$d_{33} = \pm 2.79 \pm 25\%$	1.064
		$d_{15} = 0.49 \pm 25\%$	1.064
		$d_{24} = 0.25 \pm 25\%$	1.064
$K_2La(NO_3)_4$•$2H_2O$	mm2	$d_{31} = d_{15} = -1.13 \pm 0.15$	1.064
		$d_{32} = d_{24} = -1.10 \pm 0.1$	1.064
		$d_{33} = 0.13 \pm 0.1$	1.064
$KNbB_2O_6$	mm2	$d_{24} = 6.10$	1.064
		$d_{32} = 3.00$	1.064
		$d_{33} = 1.44$	1.064

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Crystal System—Orthorhombic—*continued*

Orthorhombic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$KNbO_3$	mm2	$d_{33} = -19.58 \pm 1.03$	1.064
		$d_{32} = +11.34 \pm 1.03$	1.064
		$d_{31} = -12.88 \pm 1.03$	1.064
$KTiOPO_4$ [KTP]	mm2	$d_{33} = 13.7$	1.06
		$d_{32} = \pm 5.0$	1.06
		$d_{31} = \pm 6.5$	1.06
		$d_{24} = 7.6$	1.06
		$d_{15} = 6.1$	1.06
LiB_3O_5	mm2	$d_{15} = +0.85$	1.064
		$d_{24} = -0.67$	
		$d_{33} = +0.04$	
$LiGaO_2$	mm2	$d_{31} = d_{15} = -1.13 \pm 0.15$	1.064
		$d_{33} = -0.59 \pm 0.06$	1.064
LiH_2PO_3	mm2	$d_{31} = 0.03$	1.064
		$d_{32} = 0.16$	1.064
		$d_{33} = 0.43$	1.064
		$d_{15} = 0.035$	1.064
		$d_{24} = 0.17$	1.064
$LiInO_2$	mm2	$d_{31} = 9.9 \pm 15\%$	1.064
		$d_{32} = 8.58 \pm 15\%$	1.064
		$d_{33} = 15.8 \pm 15\%$	1.064
Na(COOH)	mm2	$d_{15} = -0.22 \pm 0.11$	1.064
		$d_{32} = d_{15} \approx 0.22$	1.064
		$d_{33} = 0.33 \pm 0.16$	1.064
$NaNO_2$	mm2	$d_{31} = 0.074 \pm 0.008$	1.064
		$d_{32} = 1.89 \pm 0.25$	1.064
		$d_{33} = 0.094 \pm 0.008$	1.064
		$d_{15} = 0.04 \pm 0.008$	1.064
		$d_{24} = 1.80 \pm 0.25$	1.064
		$d_{31} = d_{15} = 0.18$	1.153
		$d_{32} = d_{24} = 0.76$	1.153
$NO_2 \cdot C_6H_4NH_2$ [mNA]	mm2	$d_{33} = 13.12 \pm 1.28$	1.064
		$d_{32} = 1.02 \pm 0.22$	1.064
		$d_{31} = 12.48 \pm 1.28$	1.064
$PbNb_2O_{11}$	mm2	$d_{31} = +6.5 \pm 0.97$	1.064
		$d_{32} = -5.87 \pm 0.88$	1.064
		$d_{33} = -8.88 \pm 1.32$	1.064
		$d_{15} = +5.89 \pm 0.88$	1.064
		$d_{24} = -5.42 \pm 0.39$	1.064

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Crystal System—Orthorhombic—*continued*

Orthorhombic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$RbNbB_2O_6$	mm2	$d_{24} = 2.40$	1.064
		$d_{32} = 2.30$	
		$d_{33} = 0.94$	
$Sr(COOH)_2$	222	$d_{34} = 0.51$	1.064
$SbNbO_4$	mm2	$d_{32} = 4.72 \pm 0.82$	1.058
$SbTaO_4$	mm2	$d_{32} = 4.1 \pm 0.82$	1.058
$Tb_2(MoO_4)_3$	mm2	$d_{31} = -2.99 \pm 0.35$	1.064
		$d_{32} = +2.22 \pm 0.33$	1.064
		$d_{33} = -0.11 \pm 0.03$	1.064
$Tb_2(MoO_4)_3$		$d_{15} = -2.52 \pm 0.38$	1.064
		$d_{24} = +2.55 \pm 0.35$	1.064

Crystal System—Monoclinic

Monoclinic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$GdCa_4O(BO_3)_4$	Cm	$d_{11} = 0.04$	1.064
		$d_{12} = 0.128$	1.064
		$d_{13} = -0.17$	1.064
		$d_{31} = 0.148$	1.064
		$d_{32} = 0.64$	1.064
		$d_{33} = 0.58$	1.064
$GdCa_4O(BO_3)_4$	Cm	$d_{11} = -0.104$	1.064
		$d_{12} = 0.015$	1.064
		$d_{13} = -0.253$	1.064
		$d_{31} = 0.12$	1.064
		$d_{32} = 1.36$	1.064
		$d_{33} = -0.93$	1.064
CH_3-NH_2–NO_2-C_6H_4 [MNA]	m	$d_{11} = 160 \pm 40$	1.064
		$d_{12} = 24 \pm 6$	1.064
4-$(CH_3)_2N$-C_6H_4 [DAST]	m	$d_{11} = 600 \pm 200$	1.064
		$d_{22} = 10 \pm 30$	1.064
		$d_{12} = 30 \pm 10$	1.064
$C_{10}H_{12}N_3O_6$ [MAP]	2	$d_{23} = 10.67 \pm 1.3$	1.064
		$d_{22} = 11.7 \pm 1.3$	1.064
		$d_{21} = 2.35 \pm 0.5$	1.064
		$d_{25} = -0.35 \pm 0.3$	1.064

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Crystal System—Monoclinic—*continued*

Monoclinic material	Symmetry class	d_{im} (pm/V)	Wavelength λ (μm)
$C_{14}H_{17}NO_2$ [DMC]	2	$d_{21} = 4.1$	1.06
		$d_{22} = 1.6$	1.06
		$d_{23} = 0.53$	1.06
N'-(4-nirophenyl)-(s)-proplinol (NPP)	2	$d_{21} = \sim 84$	1.06
		$d_{22} = 29$	1.06
$Li_2SO_4 \cdot H_2O$	2	$d_{22} = 0.4 \pm 0.06$	1.064
		$d_{23} = 0.29 \pm 0.04$	1.064
		$d_{34} = 0.25 \pm 0.04$	1.064
$(NH_2CH_2COOH)_3$-H_2SO_4 [TGS]	2	$d_{23} = 0.32$	0.694
$PbHPO_4$	2	$d_{31} = 0.11$	1.064
		$d_{11} = 0.4$	1.064
		$d_{33} = 0.23$	1.064

The above data are from tables of S. Singh, Nonlinear optical materials, *Handbook of Laser Science and Technology, Vol. III: Optical Materials, Part 1* (CRC Press, Boca Raton, FL, 1986), p. 54 ff and S. Singh, Nonlinear optical materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL 1995), p. 237 ff. These references list the original sources of the data; they also contain additional nonlinear coefficients for other organic materials and powders.

1.9.4 Third-Order Nonlinear Optical Coefficients

Crystal	Nonlinear optical process	Coefficient $C_{jn} \times 10^{20}$ m^2 V^{-2}	Wavelength (μm)
$Al_{0.2}Ga_{0.8}As$	$(-2\omega_2 - \omega_1; \omega_1, \omega_1, -\omega_2)$	$\chi^{(3)} = 116.7$	0.84
Al_2O_3	$(-2\omega_1 + \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0159 \pm 0.002$	0.5250
	$(-\omega; \omega, \omega, -\omega)$	$C_{11} \leq 0.28$	0.6943
BaF_2	$(-2\omega_1 + \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0387 \pm 0.00042$	0.5750
		$C_{18} = 0.0159 \pm 0.00014$	0.5750
$Bi_{1-x}Sb_x$	$(-2\omega_2 - \omega_1; \omega_1, \omega_1, -\omega_2)$	$\chi^{(3)} = 4.18 \times 10^8$	10.6
C (diamond)	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} + 3C_{18} = 0.1456 \pm 10\%$	1.06
	$(-2\omega_1 + \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} + 3C_{18} = 0.163 \pm 0.046$	1.06
		$C_{11} + 3C_{18} = 0.0738 \pm 0.0019$	0.407
		$C_{18} = 0.01218 \pm 0.0009$	0.407
		$C_{11} = 0.02147$	0.545
		$C_{18} = 0.00803 \pm 0.0003$	0.545

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Third-Order Nonlinear Optical Coefficients—*continued*

Crystal	Nonlinear optical process	Coefficient $C_{jn} \times 10^{20}$ m^2 V^{-2}	Wavelength (μm)
$CaCO_3$	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0084 \pm 0.0037$	0.530
		$C_{11} = 0.0078 \pm 0.00033$	0.556
		$C_{33} = 0.0047 \pm 0.0009$	0.530
CaF_2	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.002 \pm 0.0006$	0.575
		$C_{18} = 0.00089 \pm 0.00023$	0.575
		$C_{11} = 0.005$	0.6943
		$C_{18} = 0.0025$	0.6943
CdF_2	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0068 \pm 0.0010$	0.5750
		$C_{18} = 0.0022 \pm 0.0003$	0.5750
$CdGeAs_2$	$(-3\omega;\ \omega, \omega, \omega)$	$C_{11} = 182 \pm 84$	10.6
		$C_{16} = 175$	10.6
		$C_{18} = -35$	10.6
CdS	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 2.24$	0.6943
GaAs	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 16.80 \pm 10\%$	10.6
		$C_{18} = 4.2 \pm 0.168$	10.6
Ge	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 140 \pm 50\%$	10.6
		$C_{18} = 85.4 \pm 2.8$	10.6
	$(-3\omega;\ \omega, \omega, -\omega)$	$C_{11} = 42.8 \pm 80\%$	10.6
		$C_{18} = 12 \pm 3.6$	10.6
HgCdTe	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 1.75$	10.6
InAs	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 63$	10.6
KBr	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.042$	0.6943
		$C_{18} = 0.0154$	0.6943
	$(-3\omega;\ \omega, \omega, -\omega)$	$C_{11} = 0.0392$	1.06
KCl	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0266$	0.6943
		$C_{18} = 0.0081$	0.6943
	$(-3\omega;\ \omega, \omega, -\omega)$	$C_{11} = 0.0168$	1.06
KH_2PO_4	$(-3\omega;\ \omega, \omega, -\omega)$	$C_{11} - C_{18} = 0.04$	1.06
KI	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0035$	0.6943
		$C_{18} = 0.00216$	0.6943
LiF	$(-2\omega_1+\omega_2;\ \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0048 \pm 0.0008$	0.5250
		$C_{11} = 0.0028$	0.6943
		$C_{18} = 0.00126$	0.6943
	$(-3\omega;\ \omega, \omega, -\omega)$	$C_{11} = 0.0014 \pm 0.00002$	1.89
		$C_{11} = 0.0042$	1.06

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Third-Order Nonlinear Optical Coefficients—*continued*

Crystal	Nonlinear optical process	Coefficient $C_{jn} \times 10^{20}$ $m^2 V^{-2}$	Wavelength (μm)
$LiIO_3$	$(-3\omega; \omega, \omega, -\omega)$	$C_{12} = 0.2285$	1.06
		$C_{35} = 6.66 \pm 1$	1.06
MgO	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.014$	0.6943
		$C_{18} = 0.0077$	0.6943
	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} = 0.0336$	1.06
NaCl	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.0238$	0.6943
		$C_{18} = 0.0101$	0.6943
	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} = 0.0168$	1.06
		$C_{18}/C_{11} = 0.4133$	1.06
NaF	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} = 0.0035$	1.06
$NH_4H_2PO_4$	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} = 0.0104$	1.06
		$C_{18} = 0.0098$	1.06
Si	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 8.4 \pm 10\%$	10.6
		$C_{18} = 4.03 \pm 0.252$	10.6
	$(-3\omega; \omega, \omega, -\omega)$	$C_{11} = 60.7 \pm 9.7$	1.06
α–SiO_2	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.014$	0.6943
		$C_{11} = 0.0059 \pm 50\%$	1.89
SrF_2	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.00205 \pm 0.0005$	0.575
		$C_{18} = 0.0014 \pm 0.00019$	0.575
$SrTiO_3$	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 5.6$	0.6943
		$C_{18} = 2.63$	0.6943
$Tb_3Al_5O_{12}$	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = (3.1 \pm 0.62) \times 10^6$	4.0
		$C_{18} = (0.95 \pm 0.2) \times 10^6$	4.0
$Y_3Al_5O_{12}$	$(-2\omega_1+ \omega_2; \omega_1, \omega_1, -\omega_2)$	$C_{11} = 0.03052 \pm 0.0018$	0.5250
		$C_{18} = 0.0084$	0.694

The above data are from tables of S. Singh, Nonlinear optical materials, *Handbook of Laser Science and Technology, Vol. III: Optical Materials, Part 1* (CRC Press, Boca Raton, FL 1986), p. 54 ff and S. Singh, Nonlinear optical materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials*, (CRC Press, Boca Raton, FL, 1995), p. 237 ff. These references list the original sources of the data; they also contain additional nonlinear coefficients for other organic materials and powders.

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1.9.5 Optical Phase Conjugation Materials*

Photorefractive and semiconducting media are widely used for optical phase conjugation. Photorefractive materials are electrooptic photoconductors in which a refractive index grating can be written by charge generation, transport, and trapping. The most general interaction used to produce phase conjugation in photorefractive materials is degenerate four–wave mixing (DFWM).

Photorefractive materials may be classified into several major structural categories.[1]

Ferroelectric oxides, including $LiNbO_3$, $BaTiO_3$, $KNbO_3$, and $Sr_{1-x}Ba_xNb_2O_6$ (SBN). These materials have large electrooptic coefficients and are thus characterized by large values of diffraction efficiency, gain coefficient, and phase conjugate reflectivity. They are not effective photoconductors;, thus the response times in these materials with typical CW beams are slow.

Cubic oxides or sillenites, including $Bi_{12}SiO_{20}$ (BSO), $Bi_{12}GeO_{20}$ (BGO) and $Bi_{12}TiO_{20}$ (BTO). These materials have relatively small electrooptic coefficients, but they are good photoconductors, thus their response times are fast. In order to improve the phase conjugate reflectivity of the sillenites, applied DC or AC electric fields are generally used.

Bulk compound semiconductors, including GaAs, InP, and CdTe. These materials have small electrooptic coefficients but they are excellent photoconductors, with response times approaching the fundamental limit for bulk photorefractive materials. As with the sillenites, both DC and AC electric fields have been used to enhance the gain and phase conjugate reflectivity of semiconductor conjugators.

Other photorefractive materials include multiple quantum wells in the GaAs/AlGaAs or CdZnTe/ZnTe systems. These materials require an applied AC electric field; the periodic space charge field is due to periodic screening of the applied field. Photorefractive multiple quantum wells are faster than bulk semiconductors, but are relatively inefficient, because of the small thickness (typically 1 mm) of the active layers.

Organic crystals. Organic crystals are in principle easier to grow than inorganics, but they are also more difficult to handle. Only limited work on these materials has been performed.

Polymer films. These materials are simple and inexpensive to fabricate. In addition, there is great flexibility in modifying the structure to separately optimize the electro–optic properties and the charge transport properties.

[1] Fisher, R. A., Phase conjugation materials, *Handbook of Laser Science and Technology,* vol. V, *Optical Materials*, Part 3, (CRC Press, Boca Raton, FL 1987), p. 261.

* This section was adapted from Pepper, D. M., Minden, M. L., Bruesselbach, H. W., and Klein, M. B., Nonlinear optical phase conjugation materials, *Handbook of Laser Science and Technology, Suppl. 2: Optical Materials* (CRC Press, Boca Raton, FL, 1995), p. 467.

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Semiconducting media possess a wide range of nonlinearities and materials are available at wavelengths from the visible spectral region to 10.6 μm and beyond. The variety of nonlinearities in semiconductors results from the presence of free carrier states, as well as the bound carrier states which are present in all optical materials. Large concentrations of free carriers can be created through doping or through optical excitation. Semiconductors are particularly useful materials in the infrared spectral region because in most cases the nonlinear susceptibility increases rapidly as the operating wavelength increases. In addition, the susceptibility is larger in materials with smaller values of band gap energy.

Nonlinear processes in semiconductors can be broadly divided into two categories: resonant and nonresonant. In general, nonresonant nonlinearities involve virtual transitions and are quite fast. By contrast, resonant nonlinearities involve real transitions (usually involving free carrier generation), and are thus slower. Nonlinear processes used for phase conjugation via DFWM in semiconductors include anharmonic response of bound electrons, nonlinear motion of free carriers, plasma generation by valence–to–conduction band transitions, interband population modulation through optically induced carrier temperature fluctuations, saturation of exciton absorption in multiple quantum wells, and saturation of intersubband transitions in multiple quantum wells.

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Semiconductor Phase Conjugate Materials

Material	Wavelength (μm)	Nonlinearity mechanism	Temp. (K)	Pulse width (ns)	Pump intensity (W/cm^2)	Reflectivity	$\chi^{(3)}$ (esu)	Ref.
Ge	10.6	AMBE	300	50	4×10^7	2%	2×10^{-10}	1
Ge	10.6	NLPlasma	300	1.5	1.2×10^8	800%	—	7
Ge	3.8	AMBE	300	—	1.2×10^7	0.14%	4×10^{-11}	3
Si	1.06	Plasma	300	10	10^6	1%**	—	4
Si	1.06	Plasma	300	15	10^7	150%	10^{-7}	5,6
Si	1.06	Plasma	300	15	7×10^6	100%	—	7
InAs	10.6	3PA-Plasma	300	~200	1.8×10^6	13%	2.5×10^{-7}	8,9
InSb	5.3	Plasma	5	CW	40	1%	—	10
InSb	5.3	Plasma	80	CW	1	20%	1.1	11
InSb	10.6	2PA-Plasma	300	~200	10^5	30%	2×10^{-5}	8,12,13
n-$Hg_{0.768}Cd_{0.232}Te$	10.6	CBNP	295	200	10^7	9%	4×10^{-8}	14
n-$Hg_{0.78}Cd_{0.22}Te$	10.6	Plasma	77	CW	1	8%	3×10^{-2}	15
n-$Hg_{0.78}Cd_{0.22}Te$	10.6	Plasma	120	CW	12	2%	5×10^{-2}	16
HgTe	10.6	Plasma*	300	~200	5×10^5	—	2×10^{-4}	17
CdTe	1.06	TSA-Plasma	300		10^7	200%		18
CdS	0.53	Plasma	300	15	2×10^7	—	3×10^{-9}	19
ZnSe	0.69	TSA-Plasma	300	15	5×10^7	200%	—	20

AMBE, anharmonic motion of bound electrons; Plasma, nonlinearity due to index change from free carriers; also known as band filling nonlinearity; NL Plasma, plasma nonlinearity induced by high-order nonlinear absorption; 2PA-Plasma, plasma nonlinearity induced by two-photon absorption; 3PA-Plasma, plasma nonlinearity induced by three-photon absorption; SIA, saturation of intersubband absorption; SEA, saturation of exciton absorption; CBNP, conduction band nonparabolicity; TSA-Plasma, plasma nonlinearity induced by two-step absorption via impurity states; *Fast (5 ps) interband population modulation; **Diffraction efficiency.

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Photorefractive Phase Conjugation Materials

Structural category and material	Wavelength (μm)	Gain coeff. (cm^{-1})	Response time(s)	Intensity (W/cm^2)	Interaction	Reflectivity	Ref.	Notes
Ferroelectric oxide								
$BaTiO_3$	0.515	—	—	—	DFWM	100 (10^4%)	1	
	1.09		500	1	Ring	17%	2	
	0.532	15	10^{-8}	2×10^6	TWM	—	3	b
	0.532		3×10^{-11}	3×10^8	—	3×10^{-6}	4	c
	0.515	—	10^{-3}	4	—	—	5	d
$BaTiO_3$:Co	0.515	—	—	—	SPBS	60%	6	
	0.85	—	—	—	Internal	70%	7	a
	0.515	38	0.021	1	—	—	8	e
SBN:Ce	0.442	—	0.3	0.5	Internal	30%	9	
SBN:Rh	0.532	—	10^{-8}	10^6	Internal	29%	10	
	0.515	60	10	1	TWM	—	11	f
BSKNN:Ce	0.458		100	1	Internal	28%	12	g
$KNbO_3$:Fe	0.488	—	5×10^{-5}	1	—	—	13	h
$KNbO_3$:Fe	0.488	14	10^{-3}	300	Ring	60%	14	i
Sillenite								
BSO	0.568		0.2	0.1	DFWM	270%	15	j
	0.568	12	0.2	0.1	TWM	—	16	k
BTO	0.633	9	—		Mutual	40%	17	l
	0.633	35	—	0.1	Ring	7%	18	m
	0.633	35	10	0.1	TWM	—	19	n

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Bulk semiconductor

InP:Fe	1.32	2.5	10^{-3}	0.1	Ring	11%	20	o
	1.064	11	0.1	0.07	Mutual	74%	21	p
	0.970	31	0.1	0.023	Ring	0.3%	18	q
GaP	0.633	0.4				0.3%	22	r
CdTe:V	1.32	10	10^{-3}	0.075	TWM	—	23	s
	1.5	2.4	2×10^{-3}	0.003	TWM	—	24	t
GaAs:Cr	1.064	6	0.040	0.050	TWM		25	u
GaAs	1.064	7.7	—	0.02	DFWM	500%	26	u
	1.064		—		Ring	3%	27	v
ZnTe:V	0.633	0.4	1.5×10^{-5}	4.7	TWM	—	28	

Organic crystal

COANP	0.676	0.1%	10^3	3.2	—	—	29	

[a] Reflectivity constant from 0.6–0.9 μm; [b] Experiment performed with 10-ns pulses; [c] Experiment performed with 30-ps pulses; [d] Samples operated at 120°C; [e] 45-degree cut sample; [f] Rhodium concentration = 0.07 wt %; [g] $Ba_{1.5}Sr_{0.5}K_{0.75}Na_{0.25}Nb_5O_{15}$ (BSKNN-1) and $Ba_{0.5}Sr_{1.5}K_{0.50}Na_{0.50}Nb_5O_{15}$ (BSKNN-2); [h] Electrochemically reduced sample; [i] Reflection grating geometry; [j] DC electric field (E=10 kV/cm) with moving grating; beam ratio=10^4; [k] DC electric field (E=10 kV/cm) with moving grating; beam ratio=10^5; [l] AC square-wave electric field (E=20 kV/cm; f=50 Hz); [m,n] AC square-wave electric field (E=10 kV/cm; f=60 Hz); beam ratio=10^5; [o] AC square-wave electric field (E=10 kV/cm); [p] DC electric field (E=13 kV/cm); temperature/intensity resonance; [q] DC electric field (E=10 kV/cm); beam ratio=10^6; [r] band edge resonance and temperature/intensity resonance; [s] AC square-wave electric field (E=23 kV/cm; f=230 kHz); [t] beam ratio=10^4; [u] DC electric field (E=5 kV/cm) with moving grating; beam ratio=10^4; [v] DC electric field (E=12 kV/cm).

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