12 Appendix

12.1 List of Common Symbols

(multiple meanings possible!)

α_i	Angle of the crystallographic metric
a_i	Length of crystallographic basis vectors
a_{ij}	Components of the polarization tensor
α_{ij}	Components of the tensor of thermal expansion
B_i	Components of the magnetic induction vector
C_V, C_p	Specific heats at constant volume and constant hydrostatic pressure
c	Speed of light in vacuum
c_{ijkl}, c_{ij}	Components of the elastic tensor or elastic constants
δ_{ij}	Kronecker symbol
d_{ijk}	Components of the piezoelectric tensor
$\hat{d}_{ijk}$	Components of the electrostrictive tensor
D_i	Components of the dielectric displacement vector
ϵ_{ij}	Components of the dielectricity tensor
ϵ_0	Vacuum permittivity ($8.8542 \cdot 10^{-12}\,\mathrm{C\,V^{-1}\,m^{-1}}$)
ε_{ij}	Components of the deformation tensor
E_i	Components of the electric field vector
e_{ijk}	Components of the piezoelectric e tensor or the Levi-Civita tensor
F	Abrasive strength or Helmholtz energy
γ_{ij}	Components of the Grüneisen tensor
G	Gibbs energy
g_i	Components of the normalized propagation vector
g_{ijk}	Components of the gyration tensor
g_{ijkl}	Components of the electrogyration tensor
H_i	Components of the magnetic field vector

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h	Planck constant ($6.6262 \cdot 10^{-34}$ J s)
h_i	Miller indices
I_i	Components of the electric current density vector
k	Boltzmann constant ($1.380662 \cdot 10^{-23}$ J K^{-1})
K	Volume compressibility
k_i	Components of the propagation vector
K_i	Components of a force vector
κ_{ij}	Components of the magnetic susceptibility vector
k_t	electromecanical coupling constant for a longitudinal thickness vibration
λ	Wavelength
λ_{ij}	Components of the thermal conductivity tensor
L	Transmission path length
μ_{ij}	Components of the magnetic permeability tensor
μ_0	Vacuum permeability ($4\pi \cdot 10^{-7}$V s A^{-1}m^{-1})
ν	Frequency
n_i	Principal refractivities
π_i	Components of the pyroelectric tensor
p	Hydrostatic pressure
$P_{ij} = dc_{ij}/dp$	Piezoelastic constants
p_{ijkl}	Components of the elastooptic tensor
Q_i	Components of the heat flow density vector
q_{ijkl}	Components of the piezooptic tensor
ρ	Density
r_{ijk}, r_{ijkl}	Components of the first-and second-order electrooptic tensor
σ_{ij}	Components of the mechanical strain tensor
S	Entropy
s_{ij}	Elastic coefficients or components of the electrical conductivity tensor
s_{ijkl}	Components of the elastic s tensor
t	Time
T	Temperature
$T_{ij} = \frac{d \log c_{ij}}{\mathrm{d}T}$	thermoelastic constants
V	Volume
U	Internal Energy
v	Velocity of light or sound
$\omega = 2\pi\nu$	Angular frequency

12.2 Systems of Units, Units, Symbols and Conversion Factors

The continuing use of several systems of units has created substantial confusion particularly among beginners and laymen. The introduction of the SI sytem (Système International d'Unités) in 1960 has reduced this confusion to some extent. Today, the use of SI-compliant units, of which some are collected in Table 12.1, is strongly recommended. The definition of the base units is assumed to be known and will not be repeated here. Prefixes that may be used with a unit to indicate decimal multiples and submultiples are (symbol in parantheses):

10^{12}:	tera	(T)	10^{-1} :	deci	(d)
10^{9} :	giga	(G)	10^{-2} :	centi	(c)
10^{6} :	mega	(M)	10^{-3} :	milli	(m)
10^{3} :	kilo	(k)	10^{-6} :	micro	(μ)
10^{2} :	hecto	(h)	10^{-9} :	nano	(n)
10^{1} :	deka	(d)	10^{-12}:	pico	(p)

A number of outdated units are still encountered; their use is, however, not recommended. Some examples are:

Force :	$1\ \text{dyn} = 10^{-5}\ \text{N}$
Pressure:	$1\ \text{bar} = 10^{5}\ \text{Pa} = 10^{5}\ \text{N}\,\text{m}^{-2}$
Density :	$1\ \text{g}\,\text{cm}^{-3} = 10^{3}\ \text{kg}\,\text{m}^{-3}$
Energy :	$1\ \text{erg} = 10^{-7}\ \text{J}$,
:	$1\ \text{cal} = 4.187\,\text{J}$,
:	$1\ \text{kW}\,\text{h} = 3.6 \cdot 10^{6}\,\text{J}$,
:	$1\ \text{eV} = 1.602 \cdot 10^{-19}\ \text{J}$
Charge :	$1\ \text{esu} = \frac{1}{3} \cdot 10^{-9}\ \text{C}$

In some disciplines, the cgs system of units is still in use. For mechanical units, the conversion factors to SI units are always simple powers of ten. This is different for electric and magnetic quantities, where more complex factors arise because of the respective definitions of electrical charge in the different measurement systems. The conversion into other units thus requires particular care. To avoid these difficulties, the exclusive use of SI units is strongly recommended especially for electric and magnetic quantities. For theoretical derivations, however, the choice of a different measurement system may be appropriate if this allows for a more concise mathematical description; we have also taken this liberty in a few cases in this text.

The derived units for elastic, piezoelectric, electrooptical or magnetooptical quantities can be determined without difficulty. Some interesting remarks regarding units are given in *Pure and Applied Chemistry*, Vol. 21, pp. 1–113 (1970).

Table 12.1 SI units.

Quantity	Unit	Symbol
Length	meter	m
Area	square meter	m^2
Volume	cubic meter	m^3
Plane angle	degree or radian	° or rad ($360° = 2\pi$ rad)
Solid angle	steradian	sr
Mass	kilogram	kg
Density	kilogram per cubic meter	$kg\,m^{-3}$
Time	second	s
Frequency	hertz (one cycle per second)	Hz
Speed, velocity	meter per second	$m\,s^{-1}$
Acceleration	meter per second squared	$m\,s^{-2}$
Force	newton	N
Pressure, mech. stress	pascal	Pa (1 Pa = 1 $N\,m^{-2}$)
Energy	joule	J (1 J = 1 N m)
Power	watt	W ($1\,W = 1\,J\,s^{-1} = 1\,N\,m\,s^{-1}$)
Electric potential	volt	V
Resistance	ohm	Ω
Charge	coulomb	C
Electric displacement	coulomb per square meter	$C\,m^{-2}$
Electric current	ampére	A
Capacitance	farad	F
Electric field strength	volt per meter	$V\,m^{-1}$
Magnetic flux	weber	Wb
Magnetic induction	tesla	T
Magnetic field strength	ampére per meter	$A\,m^{-1}$
Inductance	henry	H
Temperature	kelvin (degree centigrade)	K (°C) ($T/K = 273.15 + T/°C$)

12.3
Determination of the Point Space Group of a Crystal From Its Physical Properties

Group A: acentric PSG (1, 2, m, 22, mm, 3, 32, 3m, 4, 42, 4m, $\bar{4}$, $\bar{4}2$, 6, 62, 6m, $\bar{6}$, $\bar{6}2$, 23, 43, $\bar{4}3$);

Group B: centrosymmetric PSG ($\bar{1}$, 2/m, mmm, $\bar{3}$, $\bar{3}$m, 4/m, 4/mm, 6/m, 6/mm, m3, 4/m3).

A preliminary investigation of a crystalline powder using optical frequency doubling (SHG test, see Section 4.4.4) and the piezoelectric effect (Giebe–Scheibe method, see Section 4.4.1) or the longitudinal piezoelectric effect (micro-miniaturized for small crystals) yields the classification of a crystal structure into group A or B except for the PSG 42, 62, and 43, provided the observed effects are large enough.

Investigations using polarization microscopy enable the classification intothe following groups:

	A:	B:
optically isotropic	23, 43, $\bar{4}3$	m3, 4/m3
optically uniaxial	3, 32, 3m, 4, 42, 4m $\bar{4}$, $\bar{4}2$, 6, 62, 6m, $\bar{6}$, $\bar{6}2$	$\bar{3}$, $\bar{3}$m, 4/m, 4/mm, 6/m, 6/mm
optically biaxial	1, 2, m, 22, mm	$\bar{1}$, 2/m, mmm

Crystals from group A can be further classified according to their optical activity. Cubic crystals display optical activity only in PSG 23 and 43. In 1, 2, 22, 3, 32, 4, 42, 6, and 62, a rotation of the plane of polarization along the optical axis is observed.

Other properties that can be described by polar tensors of rank two, such as thermal expansion, thermal conductivity, dielectric peoperties, exhibit the same symmetry as the optical properties.

A pyroelectric effect can occur in the following PSG of group A: 1, 2, m, mm, 3, 3m, 4, 4m, 6, 6m.

The form of the piezoelectric (or electrooptic) tensor allows a unique determination of the PSG of acentric crystals, except for PSG 43 (no effect) and the pairs 42 and 62, 4m and 6m, 23 and $\bar{4}3$m, which cannot be distinguished. If one analyzes, in addition, the elastic properties, the pairs 42 and 62 as well as 4m and 6m can be distinguished, but not 23 and $\bar{4}3$. Crystals from group B (Laue groups) can be distinguished from their elastic properties, with the exception of 6/m and 6/mm, and m3 and 4/m3. The pairs 23 and $\bar{4}3$, m3 and 4/m3, 6/m and 6/mm can be distinguished macroscopically only with the aid of certain 4th-rank tensors (such as the piezooptic effect, electrogyration, or 2nd-order electrostriction). The PSG 43 and 4/m3 can best be distinguished from an analysis of their optical activity. If this provides no clear distinction, higher-order effects must be employed. Note, however, that all properties that are described by tensors of even rank can at most indicate to which of the eleven Laue groups the crystal belongs.

This procedure can in most cases be avoided, however, by analyzing the morphological properties (particularly spherical growth and etching tests) and diffractograms (particularly Laue diagrams). Also, a complete structure determination provides almost always a clear indication of the space group and the PSG of the investigated crystal.

12.4
Electric and Magnetic Effects and Properties up to 4th-Rank Tensors

See Tables 12.2 and 12.3.

Table 12.2 Electric and magnetic effects. $\boldsymbol{D}$ electric displacement, $\boldsymbol{E}$ electric field strength, $\boldsymbol{B}$ magnetic induction, $\boldsymbol{H}$ magnetic field strength, $\boldsymbol{I}$ electric current density, T temperature, $\{\varepsilon_{ij}\}$ tensor of mechanical deformation, $\{\sigma_{ij}\}$ tensor of mechanical stress. In place of the relations used here with independent quantities $\boldsymbol{E}, \boldsymbol{H}, \sigma$, and T, corresponding relations between $\boldsymbol{D}, \boldsymbol{B}$, and ε as inducing quantities can also be used in many cases. p: polar tensor, a: axial tensor.

Quantity	Electric phenomena	Type
Pyroelectricity	$\Delta P_i = \pi_i \Delta T$	p
Dielectric susceptibility	$D_i = \epsilon_{ij} E_j = \epsilon_0(\delta_{ij} + \kappa_{ij}) E_j$	p
Magnetoelectric susceptibility	$D_i = \alpha_{ij} H_j$	a
Electric conductivity	$I_i = s_{ij} E_j$	p
Piezoelectricity	$P_i = d_{ijk} \sigma_{jk}$	p
1st-order electrostriction	$\varepsilon_{ij} = \hat{d}_{ijk} E_k$	p
1st-order nonlinear dielectric susceptibility	$D_i = \epsilon_{ijk} E_j E_k$	p
1st-order electrooptic effect (Pockels)	$\Delta a_{ij} = r_{ijk} E_k$	p
Optical activity	$D_i = \epsilon_{ij} E_j + g_{ijk} \dfrac{\partial E_j}{\partial x_k}$ $(g_{ijk} = -g_{jik})$	p
1st-order magnetoelectric effect	$D_i = \gamma_{ijk} H_j E_k$	a
1st-order electric resistance change	$\Delta s_{ij} = s_{ijk} E_k$	p
2nd-order magnetoelectric susceptibility	$D_i = \alpha_{ijk} H_j H_k$	p
Hall effect	$E_i = k_{ijk} I_j H_k$	a
2nd-order electrostriction	$\varepsilon_{ij} = \hat{d}_{ijkl} E_k E_l$	p
2nd-order electric resistance change	$\Delta s_{ij} = s_{ijkl} E_k E_l$	p
Magnetoelectrostriction	$\varepsilon_{ij} = v_{ijkl} H_k E_l$	a
2nd-order nonlinear dielectric susceptibility	$D_i = \epsilon_{ijkl} E_j E_k E_l$	p
higher-order magnetoelectric effects	$D_i = u_{ijkl} H_j E_k E_l$	a
higher-order magnetoelectric effects	$D_i = \gamma_{ijkl} H_j H_k E_l$	p
higher-order magnetoelectric effects	$D_i = \alpha_{ijkl} H_j H_k H_l$	a
Electrically induced piezoelectricity	$P_i =^e d_{ijkl} E_j \sigma_{kl}$	p
Electrically induced optical activity (electrogyration)	$D_i = g_{ijkl} E_j \dfrac{\partial E_k}{\partial x_l}$	p
Magnetically induced piezoelectricity	$P_i =^m d_{ijkl} H_j \sigma_{kl}$	a
2nd-order electrooptic effect (Kerr effect)	$\Delta a_{ij} = r_{ijkl} E_k E_l$	p
Magnetoelectrooptic effect	$\Delta a_{ij} = n_{ijkl} H_k E_l$	a
2nd-order piezoelectricity	$P_i = \ldots + d_{ijklm} \sigma_{jk} \sigma_{lm}$	p

Table 12.3 Electric and magnetic effects (continued from Table 12.2).

Quantity	Magnetic phenomena	Type
Pyromagnetism	$\Delta B_i = \beta_i \Delta T$	a
Magnetic susceptibility	$B_i = \mu_{ij} H_j = \mu_0(\delta_{ij} + \kappa_{ij}) H_j$	p
Electromagnetic susceptibility	$B_i = \beta_{ij} E_j$	a
Piezomagnetism	$B_i = q_{ijk} \sigma_{jk}$	a
1st-order magnetostriction	$\varepsilon_{ij} = f_{ijk} H_k$	a
Nonlinear magnetic susceptibility	$B_i = \mu_{ijk} H_j H_k$	a
1st-order magnetooptic effect	$\Delta a_{ij} = m_{ijk} H_k$	a
Faraday effect	$D_i = \epsilon_{ij} E_j + z_{ijk} E_j H_k$ $(z_{ijk} = -z_{jik})$	a
1st-order electromagnetic effect	$B_i = \eta_{ijk} E_j H_k$	p
1st-order magnetic resistance change	$I_i = s_{ij} E_j + t_{ijk} E_j H_k$ $\Delta s_{ij} = t_{ijk} H_k$	a
2nd-order electromagnetic susceptibility	$B_i = \beta_{ijk} E_j E_k$	a
2nd-order magnetostriction	$\varepsilon_{ij} = f_{ijkl} H_k H_l$	p
Magnetoelectric resistance change	$\Delta s_{ij} = w_{ijkl} H_k E_l$	a
2nd-order magnetic resistance change	$\Delta S_{ij} = u_{ijkl} H_k H_l$	p
2nd-order nonlinear magnetic susceptibility	$B_i = \mu_{ijkl} H_j H_k H_l$	a
higher-order electromagnetic effects	$B_i = \eta_{ijkl} E_j H_k H_l$	a
higher-order electromagnetic effects	$B_i = \zeta_{ijkl} E_j E_k H_l$	p
higher-order electromagnetic effects	$B_i = \beta_{ijkl} E_j E_k E_l$	a
Magnetically induced piezomagnetism	$B_i =^m q_{ijkl} H_j \sigma_{kl}$	p
Magnetically induced optical activity (electrogyration)	$D_i =^m g_{ijkl} H_j \frac{\partial E_k}{\partial x_l}$	a
Electrically induced piezomagnetism	$B_i =^e q_{ijkl} E_j \sigma_{kl}$	a
2nd-order magnetooptical effect (Cotton-Mouton-Effekt)	$\Delta a_{ij} = m_{ijkl} H_k H_l$	p
2nd-order piezomagnetism	$B_i = \ldots + q_{ijklm} \sigma_{jk} \sigma_{lm}$	a

12.5 Tables of Standard Values

Data for more crystals can be obtained from the tables in "Landolt–Börnstein". Digits in parentheses indicate error intervals for the last digit given. All values are for approximately 293 K and standard pressure. Where the PSG is not indicated, the crystal is cubic.

Table 12.4 Density and specific heat.

	Density ρ [$\mathrm{g\,cm^{-3}}$]	Specific heat C_p [$\mathrm{J\,g^{-1}K^{-1}}$]
Diamond	3.5150(3)	0.511
Si	2.3283(2)	0.712
LiF	2.6406(2)	1.616
NaCl	2.1644(2)	0.870
CaF_2	3.1804(4)	0.912
$KAl(SO_4)_2 \cdot 12H_2O$	1.7530(3)	1.47
$CsAl(SO_4)_2 \cdot 12H_2O$	1.9995(3)	1.09
α-Quartz (32)	2.6481(3)	0.744
Calcite ($CaCO_3$) ($\bar{3}$m)	2.7102(3)	0.829
Quartz glass (Spectrosil)	2.200(1)	0.73(2)
Air (dry)	0.00121(1)	1.02(1)

Table 12.5 Pyroelectric effect.

	π_i^σ [$\mu\mathrm{C\,m^{-2}K^{-1}}$]
Turmaline (3m)	$\pi_3^\sigma = 4.3$
Li_2GeO_3 (mm2)	$\pi_3^\sigma = -21.4$
$(CH_2NH_2COOH)_3 \cdot H_2SO_4$, TGS (2)	$\pi_2^\sigma = 350$
$(CH_2NH_2COOH)_3 \cdot H_2SeO_4$ (2)	$\pi_2^\sigma = 4200$
$BaTiO_3$ (4m)	$\pi_3^\sigma = 280$

Table 12.6 Relative permittivities of non-ferroelectric crystals at about 10 MHz at constant mechanical stress.

	$\epsilon_{\mathrm{rel},11}$
LiF	9.036(4)
NaCl	5.895(2)
CaF_2	6.799(2)
$KAl(SO_4)_2 \cdot 12H_2O$	6.55(5)
$CsAl(SO_4)_2 \cdot 12H_2O$	5.50(5)
α-Quartz (32)	$\epsilon_{\mathrm{rel},11} = 4.520(2)$, $\epsilon_{\mathrm{rel},33} = 4.640(2)$

Table 12.7 Relative permittivities of ferroelectric crystals at about 1 kHz close to the Curie temperature T_c. The asterisk * denotes the direction of the ferroelectric polarization P_s.

	T_c $[K]$	$\epsilon_{\text{rel},11}$	$\epsilon_{\text{rel},22}$	$\epsilon_{\text{rel},33}$	P_s $[10^4 \mu\text{Cm}^{-2}]$
$NaKC_4H_4O_6 \cdot 4H_2O$	297	$\approx 3 \cdot 10^{3*}$	≈ 8.8	≈ 9.4	0.25
(Seignette salt, $22 \to 2$ and $2 \to 22$)[1]	255	$\approx 3 \cdot 10^{3*}$	≈ 8.8	≈ 9.4	
$(CH_2NH_2COOH)_3 \cdot H_2SO_4$ (TGS, $2/m \to 2$)	322	≈ 9.0	$\approx 5 \cdot 10^{5*}$	≈ 8	2.8
$BaTiO_3$ ($4/m3 \to 4m$)	408	$\approx 10^4$	$\approx 10^4$	$\approx 10^{4*}$	26.0
KH_2PO_4 (KDP, $\bar{4}2 \to m2$)	123	≈ 50	≈ 50	$\approx 10^{5*}$	4.75

[1] Seignette salt is ferroelectric in the interval between the Curie temperatures 297 K and 255 K.

Table 12.8 Refractivities for $\lambda_0 \approx 589$ nm.

	$n_1 = n_2$	n_3
Diamond	2.4190(1)	
Silicon	4.21(2)	
LiF	1.3915(1)	
NaCl	1.5443(1)	
$KAl(SO_4)_2 \cdot 12H_2O$	1.4564(1)	
CaF_2	1.43385(5)	
$MgAl_2O_4$	1.7274(1)	
$Y_3Al_5O_{12}$ (YAG)	1.823(1)	
α-Quartz (32)	1.54426(3)	1.55337(3)
Calcite $CaCO_3$ ($\bar{3}m$)	1.65835(5)	1.48640(5)
$NaNO_3$ ($\bar{3}m$)	1.5848(2)	1.3360(2)
Air (dry)	$n = 1.000272(2)$; $dn/dT = -0.93(2) \cdot 10^{-6}\ \text{K}^{-1}$	

Table 12.9 Specific optic rotation for $\lambda_0 = 589$ nm.

	α [grad mm^{-1}]
$NaBrO_3$ (23)	2.12
$Na_3SbS_4 \cdot 9H_2O$ (23)	2.35
α-Quartz (32)	21.72
Benzil $C_6H_5CO \cdot COC_6H_5$ (32)	24.84
$LiIO_3$ (6)	99.3
$Al(IO_3)_3 \cdot 2HIO_3 \cdot 6H_2O$ (6)	34.9

Table 12.10 Coefficients of thermal expansion.

	α_{11} [10^{-6}K^{-1}]		
Diamond	0.87		
Si	3.08(5)		
Cu	16.9(2)		
LiF	32.0(3)		
NaCl	39.1(3)		
$KAl(SO_4)_2 \cdot 12H_2O$	13.6(2)		
$CsAl(SO_4)_2 \cdot 12H_2O$	27.3(3)		
CaF_2	19(1)		
α-Quartz (32)	13.3(3)	$\alpha_{33} = 7.07(7)$	
Calcite ($\bar{3}$m)	−3.7(1)	$\alpha_{33} = 24.7(3)$	
$NaNO_3$ ($\bar{3}$m)	8.8(3)	$\alpha_{33} = 107(3)$	
$Ca(HCOO)_2$ (mmm)	−16.5(5)	$\alpha_{22} = 68.6(5)$	$\alpha_{33} = 29.8(5)$
Quartz glass (Spectrosil, $\rho = 2.200$)	0.5(1)		

Table 12.11 Magnetic susceptibilities in SI units.

	κ_{11} [10^{-6}]	κ_{33}
Diamond	−21.6	
Si	−3.3	
LiF	−12.9	
NaCl	−14.0	
CaF_2	−14.3	
$KAl(SO_4)_2 \cdot 12H_2O$	−11.7	
$KCr(SO_4)_2 \cdot 12H_2O$	+280	
$NH_4Al(SO_4)_2 \cdot 12H_2O$	−11.1	
$NH_4Fe(SO_4)_2 \cdot 12H_2O$	+650	
α-Quartz (32)	−15.6	−15.3
Calcite ($\bar{3}$m)	−12.1	−13.5

Table 12.12 Coefficients of electric conductivities (a definitive indication of errors is not possible because of the large contributions from crystal defects).

	s_{11} [Ω^{-1}cm^{-1}]	s_{33}
Al	$4 \cdot 10^5$	
Fe	$1.16 \cdot 10^5$	
Cu	$6.45 \cdot 10^5$	
Si (high-purity)	$5 \cdot 10^{-2}$	
NaCl	$2 \cdot 10^{-8}$	
Zn (6/mm)	$1.72 \cdot 10^5$	$1.62 \cdot 10^5$
$LiIO_3$ (50 Hz) (6)	10^{-9}	$0.5 \cdot 10^{-6}$
Bi ($\bar{3}$m)	$0.917 \cdot 10^4$	$0.725 \cdot 10^4$

Table 12.13 Coefficients of thermal conductivity.

	λ_{11} [$Jm^{-1}s^{-1}K^{-1}$]		
Diamond (type I)	900(50)		
NaCl	6.2(2)		
$KAl(SO_4)_2 \cdot 12H_2O$	0.605(6)		
$CsAl(SO_4)_2 \cdot 12H_2O$	0.677(6)		
KH_2PO_4 ($\bar{4}2$)	$\lambda_{11} = 1.78(5)$	$\lambda_{33} = 1.36(4)$	
α-Quartz (32)	$\lambda_{11} = 6.2(3)$	$\lambda_{33} = 10.4(5)$	
$NaNO_3$ ($\bar{3}$m)	$\lambda_{11} = 1.64(3)$	$\lambda_{33} = 2.14(7)$	
$Ca(HCOO)_2$ (mmm)	$\lambda_{11} = 1.35(2)$	$\lambda_{22} = 0.561(5)$	$\lambda_{33} = 0.99(1)$

Table 12.14 Adiabatic piezoelectric constants for low frequencies (about 10 kHz).

	d_{ijk} [pCN^{-1}] ($= [10^{-12}mV^{-1}]$)		
$NaBrO_3$ (23)	$d_{123} = 1.21(1)$		
KH_2PO_4 ($\bar{4}2$)	$d_{123} = 0.65(2)$,	$d_{312} = -10.5(2)$	
α-Quartz (32)	$d_{111} = 2.31(1)$,	$d_{123} = -\ 0.37(1)$	
$LiNbO_3$ (3m)	$d_{113} = 37.0(3)$,	$d_{222} = 20.8(1)$	$d_{311} = -0.86(2)$
	$d_{333} = 16.2(2)$		

Table 12.15 Adiabatic electrooptic constants for low frequencies (about 10 kHz) and $\lambda =$ 633 nm (except for GaAs).

	r_{ijk} [$pm\,V^{-1}$]	
$NaBrO_3$ (23)	$r_{123} = 0.57(3)$	
$NaClO_3$ (23)	$r_{123} = 0.40(2)$	
GaAs ($\bar{4}3$)	$r_{123} = 1.43(7)$ (1150 nm)	
Hexamethylenetetramine ($\bar{4}3$)	$r_{123} = 0.80(5)$	
KH_2PO_4 ($\bar{4}2$)	$r_{123} = 10.3(2)$	$r_{231} = 8.6(2)$
α-Quartz (32)	$r_{111} = 0.48(1)$	$r_{231} = 0.23(1)$
$LiNbO_3$ (3m)	$r_{113} = 9.6$	$r_{222} = 6.8$
	$r_{311} = 32.6$	$r_{333} = 30.9$

Table 12.16 Nonlinear optical coefficients $\epsilon^*_{ijk} = \epsilon_0^{-1}\epsilon_{ijk}$ for the vacuum wavelength of the primary wave $\lambda = 1064$ nm (Nd glass laser).

	ϵ^*_{ijk} [$10^{-12}V^{-1}m$]		
GaAs ($\bar{4}3$)	$\epsilon^*_{123} = 134$		
$LiIO_3$ (6)	$\epsilon^*_{311} = -7.1$;	$\epsilon^*_{333} = -7.0$;	$\epsilon^*_{123} = 0.31$
KH_2PO_4 ($\bar{4}2$)	$\epsilon^*_{312} = 0.63$		
$NH_4H_2PO_4$ ($\bar{4}2$)	$\epsilon^*_{312} = 0.76$		
$LiNbO_3$ (3m)	$\epsilon^*_{311} = 5.9$;	$\epsilon^*_{333} = -34$;	$\epsilon^*_{222} = 4.0$
α-Quartz (32)	$\epsilon^*_{111} = 0.50$;	$\epsilon^*_{123} = -0.005$	
α-HIO_3 (22)	$\epsilon^*_{123} = 8.3$		

Table 12.17 Elastic constants c_{ij} $[10^{10}\mathrm{N\,m^{-2}}]$.

	c_{11}	c_{12}	$c_{44} = c_{66}$
Diamond	104	17	55
Si	16.5(1)	6.4(1)	7.92(3)
LiF	11.37(2)	4.76(3)	6.35(3)
NaCl	4.944(8)	1.29(2)	1.266(5)
γ-NaCN	2.534(2)	1.444(6)	0.033(1)
CsCl	3.64(1)	0.92(2)	0.80(1)
CaF_2	16.357(20)	4.401(16)	3.392(13)
$Y_3Ga_5O_{12}$	28.70(1)	11.60(6)	9.04(4)
$KAl(SO_4)_2 \cdot 12H_2O$	2.465(3)	1.021(8)	0.867(5)
$CsAl(SO_4)_2 \cdot 12H_2O$	3.118(5)	1.541(9)	0.840(5)
$NaBrO_3$	5.478(5)	1.628(6)	1.505(5)
KH_2PO_4 ($\bar{4}2$)	$c_{11} = 7.165(5)$	$c_{33} = 5.640(5)$	$c_{12} = -0.627(6)$
	$c_{13} = 1.494(8)$	$c_{66} = 0.621(4)$	$c_{44} = 1.248(6)$
α-Quartz (32)	$c_{11}^E = 8.674$	$c_{33}^E = 10.72$	$c_{12}^E = 0.698$
	$c_{13}^E = 1.19$	$c_{44}^E = 5.79$	$c_{14}^E = -1.79$
Ga (mmm)	$c_{11} = 10.16(1)$	$c_{22} = 9.156(10)$	$c_{33} = 13.64(1)$
	$c_{12} = 4.601(10)$	$c_{13} = -3.057(10)$	$c_{23} = 2.804(10)$
	$c_{66} = 4.079(10)$	$c_{55} = 4.155(10)$	$c_{44} = 3.499(10)$

Table 12.18 Thermoelastic constants $T_{ij} = d \log c_{ij}/dT$ $[10^{-3}\mathrm{K^{-1}}]$.

	T_{11}	T_{12}	$T_{44} = T_{66}$
Diamond	-0.0137	-0.057	-0.0125
Si	-0.081	-0.11	-0.063
LiF	-0.66	$+0.01$	-0.28
NaCl	-0.80	$+0.17$	-0.266
γ-NaCN	$+0.47$	-1.38	$+27$
CsCl	-0.42	-0.93	-1.29
CaF_2	-0.205	-0.291	-0.343
$Y_3Ga_5O_{12}$	-0.113	-0.092	-0.092
$KAl(SO_4)_2 \cdot 12H_2O$	$+0.108$	$+1.91$	-0.95
$CsAl(SO_4)_2 \cdot 12H_2O$	-0.517	-0.69	-0.43
$NaBrO_3$	-0.72	-0.45	-0.58
KH_2PO_4 ($\bar{4}2$)	$T_{11} = -0.635$	$T_{33} = -0.49$	$T_{12} = -0.62$
	$T_{13} = -0.185$	$T_{66} = -0.53$	$T_{44} = -0.57$
α-Quartz (32)	$T_{11} = -0.0443$	$T_{33} = -0.160$	$T_{12} = -2.69$
	$T_{13} = -0.55$	$T_{44} = -0.175$	$T_{14} = +0.11$
Ga (mmm)	$T_{11} = -0.47$	$T_{22} = -0.42$	$T_{33} = -0.38$
	$T_{12} = -0.029$	$T_{13} = +0.05$	$T_{23} = +0.115$
	$T_{66} = -0.72$	$T_{55} = -0.43$	$T_{44} = -0.59$

Table 12.19 Piezoelastic constants $P_{ij} = dc_{ij}/dp$ (dimensionless).

	P_{11}	P_{12}	P_{44}	$\frac{dK^{-1}}{dp}$
Diamond	5.72	4.18	3.19	4.69
Si	4.32	4.22	0.80	4.26
LiF	9.86	2.76	1.40	5.12
NaCl	11.85	2.06	0.37	5.32
γ-NaCN	5.55	5.98	−0.36	5.84
CsCl	6.77	5.13	3.52	5.68
CaF_2	6.11	4.55	1.32	5.07
$KAl(SO_4)_2 \cdot 12H_2O$	6.73	7.15	2.77	7.01
$CsAl(SO_4)_2 \cdot 12H_2O$	5.83	6.05	1.17	5.98
$MgAl_2O_4$	5.08	4.93	0.86	4.98
$K_2Hg(CN)_4$	−6.51	−6.23	−1.22	−6.32
α-Quartz (32)	$P_{11} = 3.30$	$P_{33} = 10.93$	$P_{12} = 83.7$	$\frac{dK^{-1}}{dp} = 19.8$
	$P_{13} = 5.95$	$P_{44} = 2.66$	$P_{14} = 2$	

Table 12.20 Piezooptic constants q_{ij} $[10^{-12}\text{m}^2\text{N}^{-1}]$ and elastooptic constants q_{ij} (dimensionless) for $\lambda_0 = 589$ nm. Abbreviations: $q_{11} = q_{1111}$; $q_{12} = q_{1122}$; $q_{44} = 2q_{2323}$ etc.; $p_{11} = p_{1111}$; $p_{12} = p_{1122}$; $p_{44} = p_{2323}$ etc.

	q_{11}	q_{12}	q_{44}	p_{11}	p_{12}	p_{44}
LiF (4/m3)	−0.40	1.12	−0.83	0.061	0.161	−0.053
NaCl (4/m3)	1.27	2.58	−0.84	0.129	0.177	−0.011
RbI (4/m3)	9.23	4.99	−7.92	0.275	0.181	−0.022
CaF_2 (4/m3)	−0.33	1.10	0.74	0.038	0.226	0.0254
Hexamethylenetetramine ($\bar{4}3$)	11.95	8.42	7.56	0.259	0.227	0.039
$KAl(SO_4)_2 \cdot 12H_2O$ (m3)	2.43	6.66	−0.55	0.199	0.260	−0.005
	$q_{13} = 6.99$			$p_{13} = 0.265$		
$CsAl(SO_4)_2 \cdot 12H_2O$ (m3)	−0.63	4.25	−1.82	0.124	0.201	−0.015
	$q_{13} = 5.05$			$p_{13} = 0.214$		
α-Quartz (32)	$q_{11} = 1.25$			$p_{11} = 0.15$		
	$q_{12} = 2.60$			$p_{12} = 0.26$		
	$q_{13} = 1.95$			$p_{13} = 0.265$		
	$q_{14} = -0.10$			$p_{14} = -0.029$		
	$q_{31} = 2.94$			$p_{31} = 0.27$		
	$q_{33} = 0.12$			$p_{33} = 0.10$		
	$q_{41} = -0.33$			$p_{41} = -0.045$		
	$q_{44} = -1.07$			$p_{44} = -0.074$		

Table 12.21 Nonlinear elastic coefficients c_{ijk} $[10^{10}\,\mathrm{N\,m^{-2}}]$; definition according to Brugger (1964).

	c_{111}	c_{112}	c_{113}	c_{123}	c_{144}	c_{155}	c_{166}	c_{456}
Si (4/m3)	−81.5	−44.8	−44.8	−7.0	−31	−31	−31	−7.5
LiF (4/m3)	−142	−26.4	−26.4	15.6	8.5	−27.3	−27.3	9.4
NaCl (4/m3)	−84.3	−3.3	−3.3	−3.6	2.0	−6.0	−6.0	2.0
CaF_2 (4/m3)	−124.6	−40	−40	−25.4	−12.4	−21.4	−21.4	−7.5
$KAl(SO_4)_2 \cdot 12H_2O$ (m3)	−22.2	−7.1	−8.6	−13.4	−2.3	−8.0	−7.44	−2.0
$CsAl(SO_4)_2 \cdot 12H_2O$ (m3)	−21.2	−11.1	−12.6	−9.0	−2.7	−5.90	−5.36	−1.6
α-Quartz (32)	$c_{111} = -21.4$;		$c_{112} = -34.1$;		$c_{113} = +1.9$;		$c_{114} = -15.5$;	
	$c_{123} = 28.2$;		$c_{124} = -2.0$;		$c_{133} = -31.8$;		$c_{134} = +35$;	
	$c_{144} = -15.8$;		$c_{155} = -17.9$;		$c_{222} = -33.6$;		$c_{333} = -82.6$;	
	$c_{344} = -12.9$;		$c_{444} = -22.6$;					

12.6 Bibliography

12.6.1 Books

M. Berek Anleitung zu optischen Untersuchungen mit dem Polarisationsmikroskop (Rinne-Berek). E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart 1953.

S. Bhagavantam Crystal symmetry and physical properties. Academic Press, New York 1966.

S. Bhagavantam, T. Venkatarayudu Theory of groups and its application for physical problems. Academic Press, New York, London 1969.

A. R. Billings Tensor properties of materials. Wiley-Interscience, London, New York, Sydney, Toronto 1969.

R. R. Birss Symmetry and magnetism. North-Holland, Amsterdam 1964.

N. Bloembergen Nonlinear optics. Benjamin, New York 1965.

F. D. Bloss An introduction to the methods of optical crystallography. Holt, Rinehart and Winston, New York 1961.

M. Born, K. Huang The dynamical theory of crystal lattices. Clarendon Press, Oxford 1954.

M. Born, E. Wolf Principles of optics. Macmillan, New York 1959.

F. C. Brown The physics of solids. Benjamin, New York 1967.

E. Buchwald Einführung in die Kristalloptik. Walter de Gruyter, Berlin 1937.

J. J. Burkhardt Die Bewegungsgruppen in der Kristallographie. Birkhäuser, Basel 1947.

W. G. Cady Piezoelectricitiy. McGraw-Hill, New York 1946.

A. P. Cracknell Applied group theory. Pergamon Press, Oxford 1967.

J. P. Elliott, P. G. Dawber Symmetry in physics. Vols. 1 and 2. Macmillan, London 1979.

J. C. Erdmann Wärmeleitung in Kristallen, theoretische Grundlagen und fortgeschrittene experimentelle Methoden. Springer, Berlin, Heidelberg, New York 1969.

L. Eyraud Diélectriques solides anisotropes et ferroélectricité. Gauthiers-Villars, Paris 1967.

F. I. Fedorov Theory of elastic waves in crystals. Übers. aus d. Russ. Plenum Press, New York 1968.

S. Flügge (ed.) Handbuch der Physik. Vol. XXV/2a (L. Genzel ed.) Licht und Materie, Springer, Berlin 1967.

A. J. Freeman, H. Schmid (eds.) Magnetoelectric interaction phenomena in crystals. Gordon and Breach, London 1975.

H. Fröhlich Theory of dielectrics. Clarendon Press, Oxford 1958, 1968 (2nd ed.).

W. Gebhardt, U. Krey Phasenübergänge und kritische Phänomene. Vieweg, Braunschweig, Wiesbaden 1980.

H. Geiger, K. Scheel (eds.) Handbuch der Physik.Vol. XXIV, 2. Aufl., Aufbau der zusammenhängenden Materie (A. Smekal ed.). Springer, Berlin 1933.

C. Giacovazzo (ed.) Fundamentals of crystallography. International Union of Crystallography and Oxford University Press, New York 1992.

P. Groth Elemente der physikalischen und chemischen Kristallogrophie. R. Oldenbourg, München, Berlin 1921.

C. Hamann, J. Heim, H. Burghardt Organische Leiter, Halbleiter und Photoleiter. Fr. Vieweg & Sohn, Braunschweig 1981.

W. A. Harrison Solid state theory. McGraw-Hill, New York 1970.

R. F.S. Hearmon Applied anisotropic elasticity. University Press, Oxford 1961.

K.-H. Hellwege Einführung in die Festkörperphysik, 2. Aufl. Springer, Berlin 1981.

R. Houwink Elastizität-Plastizität und Struktur der Materie, 3. Aufl. Theodor Steinkopff, Dresden, Leipzig 1958.

H. B. Huntington The elastic constants of crystals. Academic Press, New York, London 1958.

H. Jaffe Crystal chemistry and refractivity. Cambridge University Press, Cambridge 1988.

H. Jagodzinski Kristallographie. In: Handbuch der Physik (S. Flügge ed.). II, 1. Springer, Berlin 1955.

F. Jona, G. Shirane Ferroelectric crystals. Pergamon Press, Oxford, London 1962.

H. J. Juretschke Crystal physics. Benjamin, London, Amsterdam 1974.

C. Kittel Introduction to solid state physics. 4. Aufl. Wiley, New York 1971.

W. Kleber Angewandte Gitterphysik, 3. Aufl. Walter de Gruyter, Berlin 1960.

W. Kleber Einführung in die Kristallographie, 13. Aufl. VEB Verlag Technik, Berlin 1977.

W. Kleber, K. Meyer, W. Schoenborn Einführung in die Kristallphysik. Akademie-Verlag, Berlin 1968.

R. S. Knox, A. Gold Symmetry in the solid state. Benjamin, New York, Amsterdam 1964.

E. Kordes Optische Daten zur Bestimmung anorganischer Substanzen. Verlag Chemie, Weinheim 1960.

R. S. Krishnan (ed.) Progress in crystal physics. Vol. 1: thermal, elastic and optical properties. Viswanathan, Madras 1958.

R. S. Krishnan, R. Srinivasan, S. Devanarayanan Thermal expansion of crystals. Pergamon Press, Oxford, New York 1979.

E. Kröner Elastizität und Plastizität der Vielkristalle. In: Mechanische Anisotropie p. 149 (H. P. Stüwe, ed.). Springer, Wien, New York 1974.

W. D. Kusnezow Einfluß der Oberflächenenergie auf das Verhalten fester Körper. Akademie-Verlag, Berlin 1961.

L. D. Landau, E. M. Lifshitz Statistical physics (Vol. 5 Course of theoretical physics). Übers. aus d. Russ. Pergamon Press, Oxford, New York 1968. (2., verbess. Aufl.).

G. Leibfried Gittertheorie der mechanischen und thermischen Eigenschaften der Kristalle. In: Handbuch der Physik VII/1, pp. 104–324. Springer, Berlin 1955.

G. Leibfried, W. Ludwig Theory of anharmonic effects in crystals. In: Solid State Physics, Vol. 12, pp. 275–444 (F. Seitz, D. Turnbull eds.). Academic Press, New York, London 1961.

M. Levy, H. E. Bass, R. R. Stern Handbook of elastic properties of solids, liquids, and gases. Vols. I–IV. Academic Press, San Diego 2001.

Th. Liebisch Physikalische Kristallographie. Veit, Leipzig 1891.

M. E. Lines, A. M. Glass Principles and applications of ferroelectrics and related materials. Clarendon Press, Oxford 1977.

G. J. Ljubarski Anwendungen der Gruppentheorie in der Physik. VEB Deutscher Verlag der Wissenschaften, Berlin 1962.

A. E.H. Love A treatise of the mathematical theory of elasticity. Dover, New York 1944.

W. Ludwig Recent developments in lattice theory. Springer tracts in modern physics, Vol. 43 (G. Höhler ed.). Springer, Berlin 1967.

W. Ludwig Festkörperphysik. 2nd ed. Akademische Verlagsgesellschaft, Wiesbaden 1978.

B. Lüthi Interaction of magnetic ions with phonons. In: Dynamical Properties of Solids. Vol. 3, pp. 245–292 (G. K. Horton, A. A. Maradudin eds.). North-Holland, Amsterdam 1980.

B. Lüthi, W. Rehwald Ultrasonic studies near structural phase transitions. In: Structural phase transitions I, pp. 131–184 (K. A. Müller, H. Thomas eds.). Springer, Berlin 1981.

O. Madelung Festkörpertheorie I & II. Springer, Berlin 1972.

A. A. Maradudin, E. W. Montroll, G. H. Weiss Theory of lattice dynamics in the harmonic approximation. Solid State Physics, Suppl. 3 (F. Seitz, D. Turnbull eds.). Academic Press, New York, London 1963.

A. S. Marfunin Physics of minerals and inorganic materials. Übers. aus d. Russ. Springer, Berlin 1979.

H. J. Martin Die Ferroelektrika. Tech. phys. Monographien. Vol. 15. Akad. Verlagsgesellschaft Geest & Portig, Leipzig 1964.

W. P. Mason Piezoelectric crystals and their application to ultrasonics. Van Nostrand, Princeton, NJ 1950.

W. P. Mason (ed.) Physical acoustics, Vols. I–XII. Academic Press, New York, London 1964–1976.

W. P. Mason Crystal physics of interaction processes. Academic Press, New York 1966.

H. D. Megaw Ferroelectricity in crystals. Methuen, London 1957.

A. Migliori, J. L. Sarrao Resonant ultrasound spectroscopy. Wiley, New York 1997.

B. W. Mott Die Mikrohärteprüfung. Berliner Union, Stuttgart 1957.

M. J.P. Musgrave Crystal acoustics. Holden-Day, San Francisco 1970.

T. S. Narasimhamurty Photoelastic and electro-optic properties of crystals. Plenum Press, New York, London 1981.

R. E. Newnham Structure-property relations. Springer, Berlin 1975.

A. Nowick Crystal properties via group theory. Cambridge University Press, Cambridge 1995.

J. F. Nye Physical properties of crystals. Oxford University Press, London, New York 1957.

P. Paufler Phasendiagramme. Akademie-Verlag, Berlin 1981.

P. Paufler Physikalische Kristallographie. Akademie-Verlag, Berlin 1986.

P. Paufler, G. E.R. Schulze Physikalische Grundlagen mechanischer Festkörpereigenschaften I u. II. Vieweg, Braunschweig 1978.

F. Pockels Lehrbuch der Kristalloptik. Teubner, Leipzig 1906.

H. Poulet, J. P. Mathieu Vibration spectra and symmetry of crystals. Gordon and Breach, New York 1976.

H. Rabin, C. L. Tang (eds.) Quantum electronics: a treatise. Vol. I, Nonlinear Optics, Parts A and B. Academic Press, New York 1975.

G. N. Ramachandran, S. Ramaseshan Crystal optics. In: Handbuch der Physik (S. Flügge ed.). Vol. XXV/1. Springer, Berlin 1967.

R. Rath Theoretische Grundlagen der allgemeinen Kristalldiagnose im durchfallenden Licht. Springer, Berlin 1969.

Lord Rayleigh The theory of sound. Dover, New York 1945.

C. Z. Rosen, B. V. Hiremath, R. Newnham (eds.) Key papers in physics: Piezoelectricity. American Institute of Physics, New York 1992.

A. Seeger Kristallplastizität. In: Handbuch der Physik (S. Flügge ed.) Vol. VII/2 Kristallphysik II, pp. 1–210. Springer, Berlin 1958.

J. N. Sherwood (ed.) The plastically crystalline state. Wiley, Chichester 1979.

L. A. Shuvalov (ed.) Modern Crystallography IV (Physical properties of crystals). Übers. aus d. Russ. Springer, Berlin 1983.

G. A. Smolenskij, N. N. Krajnik Ferroelektrika und Antiferroelektrika. Teubner, Leipzig 1972.

U. Stille Messen und Rechnen in der Physik. Fr. Vieweg & Sohn, Braunschweig 1955.

G. Szivessy Kristalloptik. In: Handbuch der Physik. Vol. XX. Springer, Berlin 1928.

H. Tertsch Die Festigkeitserscheinungen der Kristalle. Springer, Wien 1947.

J. Tichý, G. Gautschi Piezoelektrische Meßtechnik. Springer, Berlin 1980.

H. F. Tiersten Linear piezoelectric plate vibrations. Plenum Press, New York 1969.

R. Truell, C. Elbaum, B. B. Chick Ultrasonic methods in solid state physics. Academic Press, New York, London 1969.

W. Voigt Lehrbuch der Kristallphysik. B. Teubner, Leipzig 1910 (2. Aufl. 1928).

D. C. Wallace Thermoelastic theory of stressed crystals and higher-order elastic constants. In: Solid State Physics, Vol. 25, pp. 301–404. Academic Press, New York, London 1970.

D. C. Wallace Thermodynamics of crystals. Wiley, New York 1972.

L. M. Wasiliev Physikalische Kristallographie (in Russian). Metallurgia, Moscow 1981.

W. A. Wooster A text-book on crystal physics. Cambridge University Press, Cambridge 1949.

W. A. Wooster Experimental crystal physics. Oxford University Press, New York 1957.

W. A. Wooster Diffuse X-ray reflections from crystals. Clarendon Press, Oxford 1962.

W. A. Wooster Tensors and group theory for the physical properties of crystals. University Press, Oxford 1973.

G. S. Zhdanov Crystal physics. Oliver & Boyd, Edinburgh, London 1965.

I. S. Zheludev Physics of crystalline dielectrics, I & II. Plenum Press, New York, London 1971.

J. M. Ziman Prinzipien der Festkörpertheorie. Harri Deutsch, Zürich, Frankfurt a.M., 1975.

12.6.2 Articles

K. Aizu Possible species of "ferroelastic crystals" and of simultaneously ferroelectric and ferroelastic crystals. J. Phys. Soc. Japan **27** (1969) 387–396.

C. Andeen, J. Fontanella, D. Schuele Low-frequency dielectric constants of the alkaline earth fluorides by the method of substitution. J. Appl. Phys. **42** (1971) 2216–2219.

R. Bechmann Contour modes of square plates excited piezoelectrically and determination of elastic and piezoelectric coefficients. Proc. Phys. Soc. (London) **B64** (1951) 323–337.

P. S. Bechthold Quantitative Interpretation der Maker-Interferenzen bei der Frequenzverdopplung in optisch zweiachsigen Kristallen. Diss. University Köln 1976.

L. Bohatý, S. Haussühl Quadratic electrostrictive effects in LiF, NaF, NaCl, NaBr, KCl, KBr, KI, RbCl, RbBr and RbI. Acta Crystallogr. **A33** (1977) 114–118.

K. Brugger Thermodynamic definition of higher order elastic coefficients. Phys. Rev. **A133** (1964) 1611–1612.

M. J. Buerger Crystallographic aspects of phase transformations. In: Phase Transformations in Solids, pp. 183–209. Wiley, New York 1951.

M. J. Buerger Phase transformations. Sov. Phys. Crystallography **16** (1972) 959–968.

C. F. Buhrer, L. Ho, J. Zucker Electrooptic effect in optically active crystals. Appl. Optics **3** (1964) 517–521.

S. Chandra, M. P. Hemkar Evaluation of the elastic constants of 1,3,5-triphenylbenzene from thermal diffuse scattering of X-rays. Acta Cryst. **A29** (1973) 25–28.

H. H. Demarest Cube-resonance method to determine the elastic constants of solids. J. Acoust. Soc. Am. **49** (1969) 768–775.

R. W. Dixon Acoustic diffraction of light in anisotropic media. IEEE J. Quant. Electron. **QE-3** (1967) 85–93.

H. J. Eichler Forced light scattering at laser induced gratings–a method for investigation of optically excited solids. Adv. Solid State Phys. **XVIII** (1978) 241–263.

W.v. Engelhardt, S. Haussühl Schleiffestigkeit und spezifische freie Grenzflächenenergie der Alkalihalogenide vom NaCl-Typus. Kolloid Zeitschr. **173** (1960) 20–35.

W.v. Engelhardt, S. Haussühl Festigkeit und Härte von Kristallen. Fortschr. Miner. **42** (1965) 5–49.

P. P. Ewald, C. Hermann Strukturbericht 1913–1928. Z. Kristallogr. Ergänzungsband 1931. Akad. Verlagsgesellschaft, Leipzig 1931.

R. L. Forgacs Improvements in the sing-around technique for ultrasonic velocity measurements. J. Acoust. Soc. Amer. **32** (1960) 1697–1698.

J. Gahm Ein neuer Mikrohärteprüfer. Zeiss Informationen 14. Jahrgang (1966) 120–127.

M. W. Guinan, A. D. Ritchie Evaluation of third-order elastic constants for cubic crystals. J. Appl. Phys. **41** (1970) 2256–2258.

U. Hauser, V. Oestreich, M. D. Rohrweck On optical dispersion in transparent molecular systems. Z. Physik **A280** (1977) 17–25, 125–130 et ibid. **A284** (1978) 9–19.

S. Haussühl Physikalische Kristallographie von Calcium- und Cadmiumformiat. Z. Kristallogr. **118** (1963) 33–50.

S. Haussühl Die Abweichungen von den Cauchy-Relationen. Phys. kondens. Materie **6** (1967) 181–192.

S. Haussühl Elastische und thermoelastische Konstanten von Benzil $C_6H_5COCOC_6H_5$, gemessen mit dem Schaefer-Bergmann-Verfahren. Acta Cryst. **23** (1967) 666–667.

S. Haussühl Elastic and thermoelastic properties of 1,3,5-triphenyl-benzene derived from ultrasonic wave velocities. Acta Cryst. **A30** (1974) 106–107.

S. Haussühl Ferroelasticity and phase transformation in $Rb_2Hg(CN)_4$ spinel. Acta Cryst. **A34** (1978) 965–968.

S. Haussühl Pyroelectric, dielectric, piezoelectric, elastic, and thermoelastic properties of triclinic lithium hydrogen oxalate hydrate, $LiHC_2O_4 \cdot H_2O$. VII. Intern. Conf. on Crystal Growth, Stuttgart 1983.

S. Haussühl, W. Müller Zur Auflösungsgeschwindigkeit von Kristallen in Wasser. Kristall und Technik **7** (1972) 533–554.

S. Haussühl, H. Siegert Bestimmung des Elastizitätstensors trikliner Kristalle: Beispiel $CuSO_4 \cdot 5H_2O$. Z. Kristallogr. **129** (1969) 142–246.

S. Haussühl, K. Uhl Die Bestimmung des piezooptischen Tensors monokliner Kristalle: Beispiel Taurin. Z. Kristallogr. **128** (1969) 418–423.

M. V. Hobden Phase-matched second-harmonic generation in biaxial crystals. J. Appl. Phys. **38** (1967) 4365–4372.

A. R. Hutson, D. L. White Elastic wave propagation in piezoelectric semiconductors. J. Appl. Phys. **33** (1962) 40–47.

J. Jerphagnon A contribution to the study of certain non-linear optical phenomena. Ann. Telecommunications **23** (1968) 203–232.

J. Jerphagnon, S. K. Kurtz Maker Fringes: a detailed comparison of theory and experiment for isotropic and uniaxial crystals. J. Appl. Phys. **41** (1970) 1667–1681.

R. C. Jones A new calculus for the treatment of optical systems. VII. Properties of the N-matrices. J. Opt. Soc. Amer. **38** (1948) 671–685.

S. K. Joshi, B. M.S. Kashyap Determination of elastic constants of benzalazine from thermal diffuse scattering of X-rays. Acta Cryst. **17** (1964) 629–632.

D. A. Kleinman Theory of second harmonic generation of light. Phys. Rev. **128** (1962) 1761–1775.

E. Kröner Calculation of the elastic constants of a polycrystalline material from the elastic constants of the single crystal. Z. Physik **151** (1958) 504–518.

H. Küppers Die Messung von Schallgschwindigkeiten in optisch anisotropen Medien mit dem Schaefer-Bergmann-Verfahren. Acta Cryst. **A27** (1971) 316–322.

J. J. Kyame Wave propagation in piezoelectric crystals. J. Acoust. Soc. Amer. **21** (1949) 159–167.

R. G. Leisure, F. A. Willis Resonant ultrasound spectroscopy. J. Phys. Condens. Matter **9** (1997) 6001–6029.

P. D. Maker, E. W. Terhune, M. Nisenoff, C. M. Savage Effects of dispersion and focussing on the production of optical harmonics. Phys. Rev. Letts. **8** (1962) 21–22.

H. J. McSkimin Pulse superposition method for measuring ultrasonic wave velocities in solids. J. Acoust. Soc. Amer. **33** (1961) 12–16.

R. Meier, K. Schuster Zur Theorie der Schallausbreitung in piezoelektrischen Kristallen. Ann. Physik **11** (1953) 397–406.

H. Mueller Determination of elasto-optical constants with supersonic waves. Z. Kristallogr. **99** (1938) 122–141.

D. F. Nelson, M. Lax New symmetry for acousto-optic scattering. Phys. Rev. Letters **24** (1970) 379–380.

D. F. Nelson, M. Lax Theory of the photoelastic ineraction. Phys. Rev. **B3** (1971) 2778–2794.

R. Nitsche, V. Krämer, M. Schuhmacher, A. Bussmann Preparation and properties of ferroelastic/ferroelectric polytypes of antimony(III) oxide iodide Sb_5O_7I. J. Cryst. Growth **42** (1977) 549–559.

I. Ohno Free vibration of a rectangular parallelepiped crystal and its application to determination of elastic constants of orthorhombic crystals. J. Phys. Earth **24** (1976) 355-379.

M. Onoe, H. F. Tiersten, A. H. Meitzler Shift in the location of resonant frequencies caused by large electromechanical coupling in thickness-mode resonators. J. Acoust. Soc. Amer. **35** (1963) 36–42.

P. Preu, S. Haussühl Dielectric properties and phase transition in $Li_2Ge_7O_{15}$. Solid State Comm. **41** (1982) 627–630.

P. Preu, S. Haussühl Quadratic electrostrictive effects in NaCl and $KAl(SO_4)_2 \cdot 12H_2O$ derived from stress dependence of dielectric constants. Solid State Comm. **45** (1983) 619–623.

N. W. Schubring, J. P. Nolta, R. A. Dork Ferroelectric hysteresis tracer featuring compensation and sample grounding. J. Sci. Instr. **35** (1964) 1517–1521.

A. Seeger, O. Buck Die experimentelle Ermittlung der elastischen Konstanten höherer Ordnung. Z. Naturforsch. **15a** (1960) 1056–1067.

L. A. Shuvalov Symmetry aspects of ferroelectricity. J. Phys. Soc. Japan **28** (1970) 38–51.

R. N. Thurston, K. Brugger Third-order elastic constants and the velocity of small amplitude elastic waves in homogenously stressed media. Phys. Rev. **A133** (1964) 1604–1610.

R. W. Whatmore New polar materials: their application to SAW (surface acoustic waves) and other devices. J. Cryst. Growth **48** (1980) 530–547.

H. Wondratschek Über Tensorsymmetrien in den einzelnen Kristallklassen. N. Jahrbuch Miner. Jahrgang 1952, 217–234.

I. S. Zheludev The change of complete symmetry of the crystals during the phase transitions in ferroelectrics and ferromagnetics. Proc. Ind. Acad. Sci. **LIX** (1964) 168–184.

12.6.3 Data Sources

Th.J. Ahrens (ed.) Mineral physics & crystallography: A handbook of physical constants. American Geophysical Union, Washington 1995.

S. L. Altmann, P. Herzig Point-group theory tables. Clarendon Press, Oxford 1994.

B. P. Belikov, K. S. Alexandrov, T. V. Ryshova Elastische Eigenschaften von gesteinsbildenden Mineralen und Gesteinen. In russ. Sprache. NAUK publishing, Moscow 1970.

M. G. Graham, H. E. Hagy (eds.) Thermal Expansion—1971. AIP Conf. Proceed. No. 3. American Institute of Physics, New York 1972.

P. Groth Chemische Krystallographie. Vol. I-V. V. W. Engelmann, Leipzig 1906–1919.

Landolt-Börnstein, 6. Aufl. Springer, Berlin 1959–1971

Vol. II/1 : Mechanisch-thermische Zustandsgrößen (1971).
Vol. II/4 : Kalorische Zustandsgrößen (1961).
Vol. II/6 : Elektrische Eigenschaften I (1959).
Vol. II/8 : Optische Konstanten (1962).
Vol. II/9 : Magnetische Eiegnschaften I (1962).
Vol. II/10 : Magnetische Eigenschaften II (1967).

Landolt-Börnstein, New Series. Springer, Berlin 1966–2000

Vol. III/1 : Elastic, piezoelectric, piezooptic and electrooptic constants of crystals (1966).
Vol. III/2 : Supplement and extension to III/1 (1969).
Vol. III/3 : Ferro and antiferroelectric substances 1969).
Vol. III/4a,b : Magnetic and other properties of oxides and related compounds (1970).
Vol. III/9 : Ferro and antiferroelectric substances (1975).
Vol. III/11 : Elastic, piezoelectric, pyroelectric, piezooptic, electrooptic constants, and nonlinear dielectric susceptibilities of crystals (1979).
Vol. III/12a,b,c : Magnetic and other properties of oxides and related compounds (1978-1981).
Vol. III/16a,b : Ferroelectrics and related substances (1981, 1982).
Vol. III/17a,b,c : Semiconductors (1981, 1982).
Vol. III/18a,b : Ferroelectrics and related substances (1990).
Vol. III/29a : Low frequency properties of dielectric crystals: Second and higher order elastic constants (1992).
Vol. III/29b : Low frequency properties of dielectric crystals: Piezoelectric, pyroelectric and related constants (1993).
Vol. III/30a : High frequency properties of dielectric crystals: Piezooptic and electrooptic coefficients and nonlinear dielectric susceptibilities (1996).
Vol. III/30b : High frequency properties of dielectric crystals: Nonlinear dielectric susceptibilities (2000).
Vol. IV/4 : High-pressure properties of matter (1980).
Vol. V/1 : Physical properties of minerals and rocks (1981).

R. E. Taylor, G. L. Denman (eds.) Thermal expansion—1973. AIP Conf. Proceed. No. 17. American Institute of Physics, New York 1974.

Y. S. Touloukian, C. Y. Ho (eds.) Thermophysical properties of matter. Vols. 1–6, 12 and 13. The TPRC Data Series. IFI/Plenum, New York, Washington 1970 and 1972.

A. N. Winchell The optical properties of organic compounds. Academic Press, New York 1954.

A. N. Winchell, H. Winchell The microscopic character of artificial inorganic solid substances. Academic Press, New York 1964.

12.6.4 Journals

Acta Crystallographica
Crystal Research and Technology
Journal of Applied Crystallography
Journal of Crystal Growth
Kristallografiya (Soviet Physics Crystallography)
physica status solidi
Solid State Communications
Zeitschrift für Kristallographie

In addition, almost all Journals in physics and physical chemistry contain articles on crystal physics.