Table 3.2.2.2
Polar axes and nonpolar directions in the 21 noncentrosymmetric crystal classes

All directions normal to an evenfold rotation axis and along rotoinversion axes are nonpolar. All directions other than those in the column 'Nonpolar directions' are polar. A symbol like $[u0w]$ refers to the set of directions obtained for all possible values of u and w, in this case to all directions normal to the b axis, *i.e.* parallel to the plane (010). Symmetry-equivalent sets of nonpolar directions are placed between semicolons; the sequence of these sets follows the sequence of the symmetry directions in Table 2.1.3.1.

System	Class	Polar (symmetry) axes	Nonpolar directions
Triclinic	1	None†	None
Monoclinic Unique axis b	2	[010]	$[u0w]$
	m	None†	[010]
Monoclinic Unique axis c	2	[001]	$[uv0]$
	m	None†	[001]
Orthorhombic	222	None	$[0vw]$; $[u0w]$; $[uv0]$
	$mm2$	[001]	$[uv0]$
Tetragonal	4	[001]	$[uv0]$
	$\bar{4}$	None	[001]; $[uv0]$
	422	None	$[uv0]$; $[0vw]$ $[u0w]$; $[uuw]$ $[u\bar{u}w]$
	$4mm$	[001]	$[uv0]$
	$\bar{4}2m$	None	$[uv0]$; $[0vw]$ $[u0w]$
	$\bar{4}m2$	None	$[uv0]$; $[uuw]$ $[u\bar{u}w]$
Trigonal (Hexagonal axes)	3	[001]	None
	321	[100], [010], $[\bar{1}\bar{1}0]$	$[u2uw]$ $[\overline{2u}\bar{u}w]$ $[u\bar{u}w]$
	312	$[1\bar{1}0]$, [120], $[\bar{2}\bar{1}0]$	$[uuw]$ $[\bar{u}0w]$ $[0\bar{v}w]$
	$3m1$	[001]	[100] [010] $[\bar{1}\bar{1}0]$
	$31m$	[001]	$[1\bar{1}0]$ [120] $[\bar{2}\bar{1}0]$
Trigonal (Rhombohedral axes)	3	[111]	None
	32	$[1\bar{1}0]$, $[01\bar{1}]$, $[\bar{1}01]$	$[uuw]$ $[uvv]$ $[uvu]$
	$3m$	[111]	$[1\bar{1}0]$ $[01\bar{1}]$ $[\bar{1}01]$
Hexagonal	6	[001]	$[uv0]$
	$\bar{6}$	None	[001]
	622	None	$[u2uw]$ $[\overline{2u}\bar{u}w]$ $[u\bar{u}w]$ $[uuw]$ $[\bar{u}0w]$ $[0\bar{v}w]$
	$6mm$	[001]	$[uv0]$
	$\bar{6}m2$	$[1\bar{1}0]$, [120], $[\bar{2}\bar{1}0]$	$[uuw]$ $[\bar{u}0w]$ $[0\bar{v}w]$
	$\bar{6}2m$	[100], [010], $[\bar{1}\bar{1}0]$	$[u2uw]$ $[\overline{2u}\bar{u}w]$ $[u\bar{u}w]$
Cubic	23	Four threefold axes along ⟨111⟩	$[0vw]$ $[u0w]$ $[uv0]$
	$\bar{4}3m$	Four threefold axes along ⟨111⟩	$[0vw]$ $[u0w]$ $[uv0]$
	432	None	$[0vw]$ $[u0w]$ $[uv0]$; $[uuw]$ $[uvv]$ $[uvu]$; $[u\bar{u}w]$ $[uv\bar{v}]$ $[\bar{u}vu]$

† In class 1 any direction is polar; in class m all directions except [010] (or [001]) are polar.

Enantiomorphic crystals can also be built up from achiral molecules or atom groups. In these cases, the achiral molecules or atom groups form chiral configurations in the structure. The best known examples are quartz and $NaClO_3$. For details, reference should be made to Rogers (1975).

3.2.2.1.4. *Polar directions, polar axes, polar point groups*

A *direction* is called *polar* if its two directional senses are geometrically or physically different. A *polar symmetry direction* of a crystal is called a *polar axis*. Only proper rotation or screw axes can be polar. The polar and nonpolar directions in the 21 noncentrosymmetric point groups are listed in Table 3.2.2.2.

The terms *polar point group* or *polar crystal class* are used in two different meanings. In crystal physics, a crystal class is considered as polar if it allows the existence of a permanent dipole moment, *i.e.* if it is capable of pyroelectricity (*cf.* Section 3.2.2.5). In crystallography, however, the term *polar crystal class* is frequently used synonymously with *noncentrosymmetric crystal class*. The synonymous use of polar and acentric, however, can be misleading, as is shown by the following example. Consider an optically active liquid. Its symmetry can be represented as a right-handed or a left-handed sphere (*cf.* Sections 3.2.1.4 and 3.2.2.4). The optical activity is isotropic, *i.e.* magnitude and rotation sense are the same in any direction and its counterdirection. Thus, no polar direction exists, although the liquid is noncentrosymmetric with respect to optical activity.

According to Neumann's principle, information about the point group of a crystal may be obtained by the observation of physical effects. Here, the term 'physical properties' includes crystal morphology and etch figures. The use of any of the techniques described below does not necessarily result in the complete determination of symmetry but, when used in conjunction with other methods, much information may be obtained. It is important to realize that the evidence from these methods is often negative, *i.e.* that symmetry conclusions drawn from such evidence must be considered as only provisional.

In the following sections, the physical properties suitable for the determination of symmetry are outlined briefly. For more details, reference should be made to the monographs by Bhagavantam (1966), Nye (1957) and Wooster (1973).

3.2.2.2. Morphology

If a crystal shows well developed faces, information on its symmetry may be derived from the external form of the crystal. By means of the optical goniometer, faces related by symmetry can be determined even for crystals far below 1 mm in diameter. By this procedure, however, only the eigensymmetry (*cf.* Section 3.2.1.2.2) of the crystal morphology (which may consist of a single form or a combination of forms) can be established. The determination of the point group is unique in all cases where the observed eigensymmetry group is compatible with only one generating group.

Column 6 in Table 3.2.1.3 lists all point groups for which a given crystal form (characterized by its name and eigensymmetry) can occur. In 19 cases, the point group can be uniquely determined because only one entry appears in column 6. These crystal forms are always characteristic general forms, for which eigensymmetry and generating point-group symmetry are identical. They belong to the 19 point groups with more than one symmetry direction.

If a crystal exhibits a combination of forms which by themselves do not permit unambiguous determination of the point group, those generating point groups are possible that are common to all crystal forms of the combination. The mutual orientation of the forms, if variable, has to be taken into account, too.

Example

Two tetragonal pyramids, each of eigensymmetry $4mm$, rotated with respect to each other by an angle $\neq 45°$, determine the point group 4 uniquely because the eigensymmetry of the *combination* is only 4.

In practice, however, unequal or incomplete development of the faces of a form often simulates a symmetry that is lower than the actual crystal symmetry. In such cases, or when the