EXERCISE 3–44 Show that a nonsymmetric doubly contravariant or covariant second-rank tensor cannot be diagonalized by a linear transformation.

3–15 Magnitude of Second-Rank Tensor

If **T** is a second-rank tensor, and **u** is a unit vector, the operation **Tu** produces a new vector **v**; that is,

$$\mathbf{v} = \mathbf{T}\mathbf{u} \tag{3–134}$$

The magnitude $T(\mathbf{u})$ of the tensor **T** in the direction of the unit vector **u** is equal to the length of the projection of **v** onto **u**. That is,

$$T(\mathbf{u}) = \mathbf{u} \cdot \mathbf{v} = \tilde{\mathbf{u}}\mathbf{T}\mathbf{u} \tag{3–135}$$

In terms of components

$$T(\mathbf{u}) = T^{ij}u_i u_j = T_{ij}\, u^i u^j \tag{3–136}$$

If **u** is an eigenvector of **T**, T(**u**) is of course just the corresponding eigenvalue. A physical interpretation of the magnitude of a second-rank tensor will be described in Section 5–2.

EXERCISE 3–45 Derive a formula for the magnitude in the direction of reciprocal axis $\mathbf{a}^k$ of an anisotropic temperature factor tensor with components β^{ij}.

EXERCISE 3–46 Calculate the magnitude of the anisotropic temperature factor tensor of Exercise 3–38 in the crystal directions (a) [1, 0, 0]; (b) [0, 1, 0]; (c) [0, 0 ,1]; (d) [−0.1097, 0.0210, 0.0492].

3–16 Rigid-Body Motion

The thermal motion of atoms in a molecular crystal often may be resolved into the intermolecular movements of the molecules as units and the intramolecular movements of the atoms within the molecules relative to each other. Separation of the rigid-body molecular motion from the total movement is particularly clearcut if the amplitudes of molecular motion are large compared with the vibrational amplitudes within the molecules. Determination of the rigid-body motion from the observed anisotropic temperature factors was first described by Cruickshank (1956). A rigorous theory, which permitted noninter-

TABLE 5-1. CONDITIONS IMPOSED BY SYMMETRY UPON THE COMPONENTS OF A SYMMETRIC SECOND-RANK TENSOR REFERRED TO CRYSTAL AXES

Crystal system	σ^{11}	σ^{12}	σ^{13}	σ^{22}	σ^{23}	σ^{33}
Triclinic	σ^{11}	σ^{12}	σ^{13}	σ^{22}	σ^{23}	σ^{33}
Monoclinic	σ^{11}	0	σ^{13}	σ^{22}	0	σ^{33}
Orthorhombic	σ^{11}	0	0	σ^{22}	0	σ^{33}
Tetragonal	σ^{11}	0	0	σ^{11}	0	σ^{33}
Hexagonal, trigonal	σ^{11}	$\frac{1}{2}\sigma^{11}$	0	σ^{11}	0	σ^{33}
Cubic	σ^{11}	0	0	σ^{11}	0	σ^{11}

TABLE 5-2. CONDITIONS IMPOSED BY SYMMETRY UPON THE COMPONENTS OF A SYMMETRIC SECOND-RANK TENSOR REFERRED TO CARTESIAN AXES

Crystal system	σ^{11}	σ^{12}	σ^{13}	σ^{22}	σ^{23}	σ^{33}
Triclinic	σ^{11}	σ^{12}	σ^{13}	σ^{22}	σ^{23}	σ^{33}
Monoclinic	σ^{11}	0	σ^{13}	σ^{22}	0	σ^{33}
Orthorhombic	σ^{11}	0	0	σ^{22}	0	σ^{33}
Tetragonal	σ^{11}	0	0	σ^{11}	0	σ^{33}
Hexagonal, trigonal	σ^{11}	0	0	σ^{11}	0	σ^{33}
Cubic	σ^{11}	0	0	σ^{11}	0	σ^{11}

EXERCISE 5-1 The specific resistance of bismuth metal at 20°C is 109×10^{-6} ohm-cm perpendicular to $\mathbf{a}_3$ and 138×10^{-6} ohm-cm parallel to $\mathbf{a}_3$. Bismuth is rhombohedral, space group $R\bar{3}m$, with $a_1 = 4.537$, $a_3 = 11.838$ Å for the hexagonal cell.

(a) Calculate the components of the conductance tensor referred to cartesian coordinates with $\mathbf{e}_3$ along $\mathbf{a}_3$.

(b) Calculate the components of the conductance tensor referred to the hexagonal axes.

(c) Calculate the resistance of a single crystal bismuth rod 3.00 cm long and 1.00 cm in diameter cut with the cylinder axis along [001].

(d) Suppose that a single crystal of bismuth is cut into a cylinder 3.00 cm long and 1.00 cm in diameter with the cylinder axis along the [211] direction (a rhombohedral axis). Calculate the resistance to the flow of current along [211] when an electric field is applied to the ends of the rod.

EXERCISE 5-2 Calculate the specific conductance of bismuth (see Exercise 5-1) along the hexagonal [211], [$\bar{1}$11], and [$\bar{1}\bar{2}$1] directions.

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