CHAPTER 11

SOME PHILOSOPHICAL IMPLICATIONS
OF CHEMICAL SYMMETRY

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INTRODUCTION

This paper deals with a fundamental insight that was long in development and slow in diffusion—but which has deep philosophical implications. The insight is that the symmetry properties of any object are not mutually independent—they generally come in bundles. The collection of symmetries of some object (those that preserve aspects of the object’s structure that are relevant to the problem at hand) is considered to constitute a group. The branch of mathematics that deals with such bundles of symmetries is designated group theory.

Philosophers have often discussed symmetry (and group theory) in systems treated by quantum mechanics, but have shown less interest in systems mainly considered by chemists. This paper deals with two types of chemical symmetry, and suggests that closure (the feature that distinguishes groups from other sets) may deserve increased philosophical attention.

Symmetry may be defined as “immunity to a possible change” (Rosen 1995). If a planar BF$_3$ molecule (on the left in Figure 1) were to undergo a rotation of 120° around a line that passes through the B atom and is perpendicular to the plane of the molecule, the molecule would assume a configuration indistinguishable from the original configuration. The BF$_3$ molecule is immune to the possible change of rotation about that “threefold” axis. In contrast, if the BClF$_2$ molecule (on the right in Figure 1) were to undergo a similar rotation, the resulting configuration of atoms would be quite different from the original one. Every statement about molecular symmetry must include specification of an operation and of some geometric entity—rotation and a line (symmetry axis) in the example.

Since all four atoms lie in the same plane in the lowest energy form of the BF$_3$ molecule, the molecule is also symmetric with respect to three other rotations (one about each of the B–F bonds) and it is also symmetric with respect to reflection through the plane of the molecule. These six symmetries (as a group) specify much of the structure of the molecule.¹
Astrophysicist Arthur Eddington made a remarkable claim:

What sort of thing is it that I know? The answer is structure. To be quite precise, it is structure of the kind defined and investigated by the mathematical theory of groups (1939, p. 147).

That is to say, whatever Eddington—and presumably the rest of us as well—might possibly know is said to be somehow covered by group theory. Group theoretical reasoning was first applied to physics only in the years just before this claim was made—at that time, many physicists did not share Eddington’s enthusiasm for that approach (see below). Each subsequent decade has seen an expansion of the applicability of group theoretic reasoning. The recent revival of philosophical structuralism (in several versions) (French and Ladyman 2003) may be seen as a further expansion of appreciation for the power of group theoretic approaches. This chapter introduces some basic concepts of group theory in the section on Some Concepts of Group Theory; the section on Development of Group Theoretical Concepts gives an account of the origin and spread of group theoretic ideas; the section on Chemical Substances: What “Is” Might Mean deals with chemical substances of the usual sort; and the section on Groups of Processes and Chemical Reaction Networks concerns consequences of symmetries in collections of chemical reactions.

SOME CONCEPTS OF GROUP THEORY

Formally, any collection of elements (of whatever sort) constitutes a set. (Let $X_n$ designate the set of $n$ elements, $x_i$.) A groupoid involves a set $S$ (the carrier) and a binary operation, · (some procedure that can be applied to two elements of the carrier set to yield a single result). If the operation is associative, i.e., $a \cdot (b \cdot c) = (a \cdot b) \cdot c$, the groupoid merits the designation semi-group. Semi-groups may or may not contain an identity element, a unique element that, when coupled with a second element (via the group-defining operation ·), regenerates the same (second) element, i.e., $e \cdot a = a = a \cdot e$. The identity element is often designated as 1 (Baumslag and Chandler 1985).

Elements of sets can be of any sort whatsoever. Some sets have elements that are mappings (transformations) of other sets. A particularly interesting kind of mapping, when applied to members of a set $X$, generates results that are themselves members of the same set $X$. (This is a mapping of $X$ onto itself, sometimes called an endomap.) If, for a certain set $X$, several different mappings (endomaps) of this sort (p, q, r, . . . )