

# Nickel-Titanium Memory Metal

## Overview

Nickel-titanium (NiTi) is a remarkable metal alloy that is representative of “smart materials” that respond to a stimulus in a predictable manner. The wire sample of NiTi used in this unit can be bent at room temperature, but will return to its linear shape when heated by hot air or water as its atoms move in a kind of “atomic ballet.” Moreover, the wire can be heated to the much higher temperature of a candle flame (~500 degrees C), where it can be trained to “remember” a new shape. Subsequently, when the wire is distorted at room temperature and heated by hot air or water, it will return to this new shape. Rods of NiTi can be used to show that the flexibility, hardness, and even its acoustic characteristics are all affected by its temperature.

The unusual properties of this smart material are derived from the two crystal structures that can be interconverted by changes in temperature or pressure. At temperatures between about 0 and 100 degrees Celsius, there are two important phases or crystal structures of NiTi that can be referred to as the high temperature and low temperature phase, or as austenite and martensite, respectively. The austenite phase has the symmetry of a cube and is characterized by hardness and rigidity.

When cooled, the austenite phase transforms to martensite, which is less symmetric and in fact can have 24 different relative orientations (called variants) of groups of atoms comprising the crystal. When pressure is applied to this low temperature phase, groups of atoms can change their relative orientation to accommodate the pressure, causing the material to be softer and more flexible than the austenite phase. Furthermore, when a rod of NiTi in the austenite phase is dropped, a sound wave propagates relatively unimpeded through the material, yielding a ringing sound; in contrast, when a rod of NiTi in the martensite phase is dropped, its different orientations of groups of atoms act as sound absorbing boundaries and will create a muffled thud sound.

Because martensite is also slightly denser than austenite, by LeChatelier’s principle, which states that an increase in pressure favors the denser phase of multiple phases at equilibrium, pressure can be used to convert austenite to martensite. This is analogous to the pressure from ice skates helping to melt the ice: application of pressure from the skate helps transform the less dense ice to denser liquid water.

The ability to change the shape of this “smart” material stems from defects, irregularities in the packing of atoms, that occur in samples of the material. The defects, which can be altered at the high temperature of a candle flame where NiTi is in the austenite phase, are used to create the shape to be “remembered” by forcing groups of atoms to have particular positions relative to one another.

This collection of unusual properties possessed by NiTi has enabled it to be used in a wide variety of applications. Some of the more common uses are as the arch wires of orthodontic braces, bendable eyeglass frames, and anti-scald faucets.