Effects of metal protection coils on thermocouple EMF in multi-anvil high-pressure experiments

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ABSTRACT

Metallic coils (in most cases Cu coils) are often used in high-pressure experiments to protect thermocouple wires. In this paper we show that these coils have important influences on thermocouple EMF and therefore on the temperature measurements. We tested this effect by measuring EMF from Cu coiled single wires of chromel and alumel, and, further, we conducted experiments to compare the EMF from W5Re-W26Re thermocouples with and without Cu coils attached to them. The results show systematic differences in thermocouple readings; the EMFs from W-Re thermocouples with Cu coils give systematically lower values than EMFs from thermocouples without Cu coils. The results were analyzed using a simple model. The difference in thermocouple EMFs between thermocouples with and without protection coils is given by

\[ \Delta E_{TC} = E_i - E_{i-1} - \frac{R_i}{R_{i-1}} \left( E_i - E_{i-1} \right) \]

where \( E_i \) and \( R_i \) are the EMF and the electrical resistance of metal \( i \) in the portion of the Cu coil, and the subscripts 1+, 1−, and 2 indicate positive thermocouple metal, negative thermocouple metal, and coil metal, respectively. The addition of a coil with different metal has a large effect — the \( \Delta E_{TC} \) will be close to \( -(E_{i-1} - E_i) < 0 \) when the resistance of the coil is significantly smaller than that of a thermocouple wire. For a Cu coil and W-Re thermocouple, \( R_{i-1} \gg R_i \) and therefore thermocouple readings with a Cu coil will lead to underestimation of the real temperature. Under common experimental conditions with a multi-anvil apparatus, the error in the temperature estimate caused by Cu protection coils is \( \sim 100–150 \) K for a peak temperature of \( 1600–2000 \) K.

Keywords: High-pressure and high-temperature studies, thermocouple EMF, electrical properties, tungsten-rhenium alloy, chromel-alumel

INTRODUCTION

A thermocouple is widely used to measure temperatures. Temperature measurements using thermocouples are based on the Seebeck effect of metals. Because different metals have different thermoelectric power (Seebeck coefficient, \( \sigma \)), connected metals with different compositions generate an electric potential difference between the ends corresponding to the temperature difference between the junction and the ends. By measuring the thermally induced potential difference (electromotive force, EMF), we can determine the temperature at the junction.

In high-pressure and high-temperature experiments with a multi-anvil apparatus temperature is usually monitored by a thermocouple. To prevent breakdown of the thermocouple in multi-anvil experiments a thermocouple wire is often protected with a binding metal coil. The use of a protection coil may influence the EMF reading and hence the temperature measurements, but there have been no systematic studies on this issue. The purpose of this study is to determine the influence of protection coils on the thermocouple EMF reading.

THE MODEL

The configuration of a thermocouple wire with a metal protection coil is shown in Figure 1. The thermocouple wire is in a temperature gradient and a protection coil is attached to a portion of the thermocouple. The thermocouple wire and the protection coil are made of different metals with different Seebeck coefficients. Consequently, different voltage differences will be created in each part which correspond to the temperature difference between the two ends of a coil. This difference in voltage causes a local electrical current. The equivalent circuit is also shown in which the electric current could flow either through the thermocouple wire or the protection coil where current going through the voltmeter is ignored because of the much higher resistance of a voltmeter compared to those of thermocouple wires and coil materials.

Using Kirchhoff’s law, the difference in total voltage, \( \Delta V \), between two ends of a protection coil (potential difference between \( A \) and \( B \) between coil-free and a composite made up of thermocouple wires with a coil, can be calculated as

\[ \Delta V = \frac{E_2 - E_1}{1 + \frac{R_1}{R_i}} \]

with

\[ E_i = \int_{T_A}^{T_B} \sigma_i(T) \, dT \]

where \( R_i, E_i, \) and \( \sigma_i(T) \) are the electrical resistance, the EMF, and the Seebeck coefficient of metal \( i (i = 1, 2) \), respectively, and \( T_A \) and \( T_B \) are the temperatures at points \( A \) and \( B \).

For a thermocouple for which two coils are bound symmetri-