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Effect of pressure on temperature measurements using WRe thermocouple and its impact on geophysics

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Our understanding of the Earth's interior highly depends on physical and chemical properties of the Earth materials which were determined based on high-pressure and high-temperature experiments.
Temperature in these experiments is mostly determined using a thermocouple without any pressure correction. This may lead to erroneous results in estimated temperature and thus physical and chemical properties of the Earth materials due to significant pressure effects of the thermocouple electromotive force (EMF). However, knowledge of the absolute pressure effect on the EMF has been limited to relatively low pressures (<3.5 GPa) for more than 40 years (Getting and Kennedy, 1970).
Recently, we have developed a new method to determine the absolute pressure effect on thermocouple EMF at higher pressures based on a single wire method using Kawai-type multi-anvil apparatus (Nishihara et al., 2016). In this method, testing wires are subjected to higher and lower pressures by containing them in semi-sintered MgO and dense Al_2O_3 insulating tubes, respectively. The temperature along the single wires is calibrated by separate experiments employing multiple thermocouples. Pressure conditions along the wires are evaluated based on in situ X-ray diffraction using synchrotron X-ray radiation and their thermal equations of state. The pressure effect of the Seebeck coefficients is determined by the analyses of single wire EMFs and pressure-temperature profiles along the wires.
Based on this method, we have measured pressure effect on the EMF of W3Re-W25Re (type D) thermocouple up to 16 GPa and 900˚C. The difference of the nominal temperature from the real temperature was calculated to be −27˚C at 16 GPa and 900˚C. This absolute temperature correction may be underestimated due to influence of uniaxial stress during measurements. An extrapolation of the raw results suggest the temperature difference of −70˚C at 23 GPa and 1500˚C. *P-T* condition of the post-spinel phase boundary in Mg_2SiO_4 determined using type D thermocouple (Irifune et al., 1998; Katsura ae al., 2003) shifts to higher pressure by 0.5–0.7 GPa when temperature values are corrected. This corresponds to 12–16 km change of depth of the 660 km discontinuity. The temperature correction also has significant influence on the activation volumes for thermally activated processes such as element diffusion and rheology. The real values of activation volume determined at 0–10 GPa and 1500˚C is calculated to be ~1.3 cm^3/mol higher than nominal values when they are determined by experiments using type D thermocouple and the activation energy is 500 kJ/mol. This means that element diffusion and rheology are getting more sluggish with increase of depth in the Earth's mantle than previously estimated.

Keywords: temperature measurement, high-pressure and high-temperature, thermocouple, 660 km discontinuity