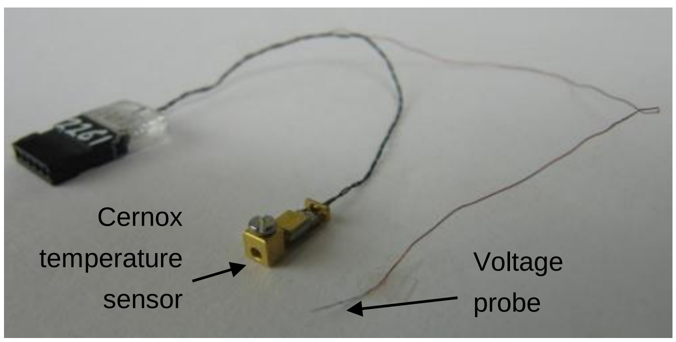
Application Note 1684-201

Measuring the Nernst-Ettingshausen Effect Using the Thermal Transport Option

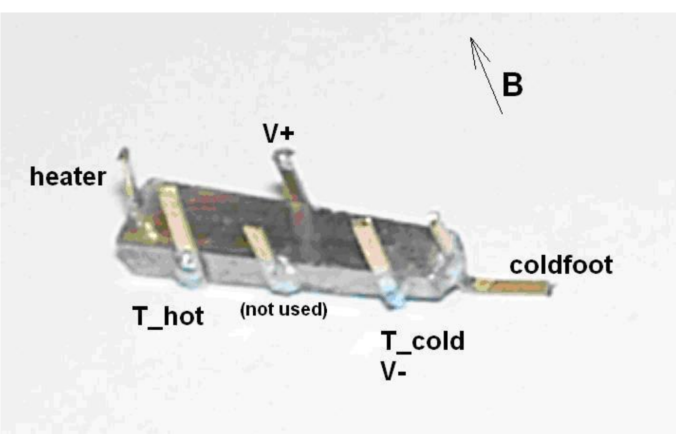
Quantum Design offers a part number 4084-581 "Nernst TTO shoe" to accommodate Nernst-Ettingshausen measurements on TTO, and consists merely of a normal TTO thermometer shoe (4084-580) but with the one modification that the voltage lead is separated from the body of the thermometer shoe, see photo below.

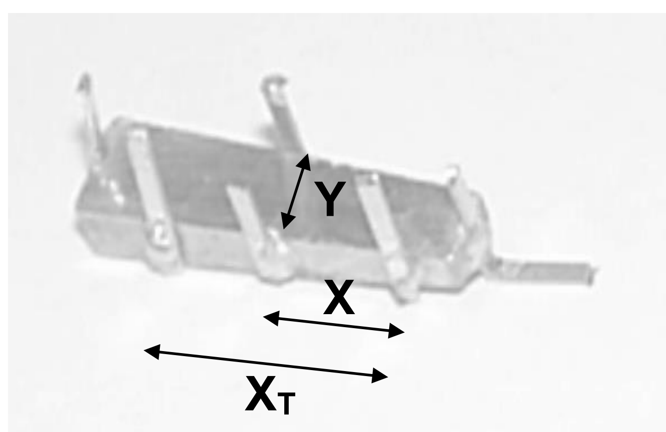


This application note explains how to measure Nernst effect in TTO and analyze the resulting data. We demonstrate the measurement using a single crystal of bismuth. In this material, there is a significant transverse voltage (V_Y) that accomanies a thermal gradient (ΔT_X) in the presence of a magnetic field (B_Z) . This is called the Nernst-Ettingshausen effect, and the coefficient is defined as:

$$N = \frac{1}{B_Z}\frac{E_Y}{dT/dx} = \frac{1}{B_Z}\frac{V_Y}{\Delta T_X}\left(\frac{X_{Th}}{Y}\right)$$

where X_{Th} and Y are the (longitudinal) thermometer probe separation and the (transverse) voltage lead separation, respectively. In this example with bismuth, we mounted the sample with transverse voltage leads that were purposefully offset by a distance X from each other so that a longitudinal (Seebeck) and transverse (Nernst) voltage would both be measured, see the diagrams below:





The heat flows from left to right, and the thermometers T_hot and T_cold are mounted on the left and right leads located on the lower side of the sample in the photo. The V+ and V- leads measure a diagonal voltage component, and by measuring as a function of magnetic field in both positive and negative fields we can employ symmetry arguments to separate the Seebeck from the Nernst-Ettingshausen coefficients. The validity of this approach rests on the truth of the following assumptions:

$\Delta V_X(B) = \Delta V_X(-B)$	Seebeck term is symmetric in field: this is true only when the "Umkehr" effect can be neglected. In the case of bismuth, this requires that the magnetic field B be parallel to the trigonal (c) axis of the crystal.
$\Delta V_Y(B) = -\Delta V_Y(-B)$	Nernst-related term is antisymmetric in field

Recall that TTO software simply reports Seebeck as:

$S_{TTO} = \Delta V/\Delta T$

So we define the field-symmetric and antisymmetric components as:

$S_{TTO,SYM} = ½*(S_{TTO}(B) + S_{TTO}(-B))$

$S_{TTO,ASYM} = ½*(S_{TTO}(B) - S_{TTO}(-B))$

So we use the above relations to obtain:

Seebeck [μV/K] = $\Delta V_X/\Delta T_X = S_{TTO,SYM} * (X_{Th}/X)$

Nernst-Ettinghausen [μV/K-tesla] = $1/B * S_{TTO,ASYM} * (X_{Th}/Y)$

The term (X_{Th}/X) in the Seebeck equation follows because the temperature and voltage are measured along different lengths of the sample and this has to be factored out as Seebeck assumes the temperature and voltage drops are measured at the same points.

For our sample,

X_{Th} = 8 mm (longitudinal distance between thermometer shoes)

X = 4.9 mm (longitudinal distance between voltage leads)

Y = 2.68 mm (transverse separation of the voltage leads, i.e., the width of the sample)

We recommend to use the conventional TTO shoes to check your Seebeck results obtained using the Nernst geometry. Below is a graph of Nernst and Seebeck vs. field up to 8 tesla: