Q u a n t u m D e s i g n

THERMAL-TRANSPORT

IN MEASURING THE THERMAL TRANSPORT PROPERTIES OF A MATERIAL SPECIMEN - SUCH AS THERMAL CONDUCTIVITY κ AND SEEBECK COEFFICIENT α - A RESEARCHER CAN LEARN CONSIDERABLE INFORMATION ABOUT THE ELECTRONIC AS WELL AS THE IONIC LATTICE STRUCTURE OF THAT SPECIMEN.

THERMAL TRANSPORT SAMPLE STATION

PPMS THERMAL TRANSPORT

The P670 Thermal Transport System (TTO) measures thermal conductivity, or the ability of a material to conduct heat, by monitoring the temperature drop along the sample as a known amount of heat passes through the sample. The TTO measures the thermoelectric Seebeck effect as an electrical voltage drop that accompanies a temperature drop across certain materials. The TTO system can perform these two measurements simultaneously by monitoring both the temperature and voltage drop across a sample as a heat pulse is applied to one end. The system can also measure electrical resistivity ρ by using the standard four-probe resistivity provided by the Model P600 AC Transport Measurement System (ACT). All three measurement types are essential in order to assess the so-called "thermoelectric figure of merit," $ZT = \alpha^2 T/\kappa\rho$, which is the quantity of main interest if you are investigating thermoelectric materials.

While the measurements taken with the TTO system are quite elementary in principle, they have eluded commercialization because the data was typically very error prone, time consuming, and laborious, due, for example, to problems in controlling heat flow and accurately measuring small temperature differentials in a convenient manner. The TTO system has solved or greatly reduced many of these experimental complications. The TTO uses convenient sample mounting, small and highly accurate Cernox chip thermometers, and sophisticated software that dynamically models an AC heat flow through the sample and corrects for any heat losses that occur. The PPMS with the High-Vacuum option (Model P640) provides an ideal environment for the specially designed TTO sample puck, and the ACT option (Model P600) powers the sample heater and takes resistivity measurements.

The TTO system is set up to measure four thermal transport properties:

- Thermal conductivity
- Seebeck coefficient
- Electrical resistivity
- Thermoelectric figure of merit

Thermal conductivity κ is measured by applying heat from the heater shoe in order to create a user-specified temperature differential between the two thermometer shoes. The TTO system dynamically models the thermal response of the sample to the low frequency, square-wave heat pulse, thus expediting data acquisition. TTO can then calculate thermal conductivity directly from the applied heater power, resulting ΔT, and sample geometry.

Seebeck coefficient (also called the thermopower) α is determined by creating a specified temperature drop between the two thermometer shoes—just as it does to measure thermal conductivity. However, for Seebeck coefficient the voltage drop created between the thermometer shoes is also monitored. The additional voltage-sense leads on these thermometer shoes are connected to the ultra-low-noise preamplifier of the ACT system.

Electrical resistivity ρ is measured by using a precision DSP current source and phase-sensitive voltage detection. The specifications for this AC resistivity measurement are essentially identical to those for the P600 AC Transport Measurement System (ACT) option, because both TTO and ACT use the same high-performance hardware.

The dimensionless thermoelectric **Figure of merit ZT** is determined here simply as the algebraic combination $ZT = \alpha^2 T/\kappa\rho$ of the three measured quantities—thermal conductivity, Seebeck coefficient, and electrical resistivity—discussed above.

Separate measurement protocols are provided for each of these measurements because these individual quantities maybe more accurately measured by using excitation currents and temperature differentials optimized for each situation. Limits for the parameters defining each measurement may be specified prior to running the measurement.

Each measured thermal transport property may be determined in either of the two measurement modes (continuous or single) supported by the TTO system. You select a measurement mode, and then you select the thermal properties to measure in that mode.

Benefits of the design of the TTO system include the following:

- Four-terminal geometry minimizes the effects of thermal and electrical resistance of the leads.
- Continuous measurements while slewing in temperature provide high density of data.
- Novel Adaptive Analysis technology simplifies measurements of unknown materials.
- Careful attention to the removal of effects of temperature drift, thermal radiation, and other systematic errors.
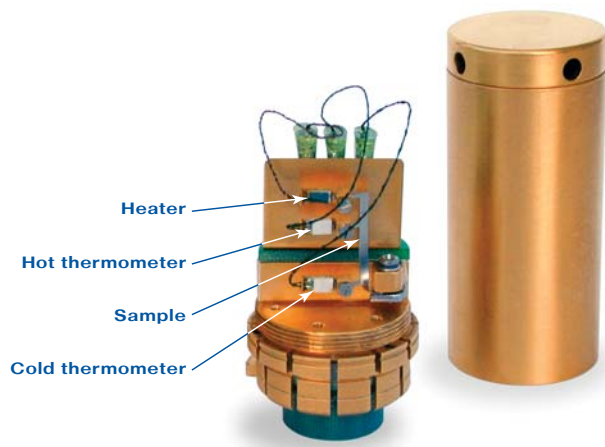- Robust, easy-to-use, fully automated measurements.

System Requirements for the Thermal Transport System*

The Thermal Transport System is comprised of the following components:

- One TTO Sample Puck, which plugs into the PPMS sample chamber connector.
- One set of calibrated plug-in thermometer (2) and heater (1) shoes (probes).
- One set of uncalibrated plug-in thermometer (2) and heater (1) shoes (probes).
- An Isothermal Radiation Shield which screws onto the TTO Puck.
- A software module which installs into MultiVu.
- A nickel calibration sample for demonstrating and verifying proper operation
- A user's kit with tools and accessories for sample mounting

COMPONENT	FUNCTION
Resistivity Option (Model P400)	Provides the user bridge board that reads the two thermometer shoes.
AC Transport Measurement System (Model P600)	Outputs current to heater and sample while providing low-noise, phase-sensitive detection.
High-Vacuum Option (Model P640)	Provides thermal isolation for measurements. Cryopump or Turbo Pump version may be used.
MultiVu Software Version 1.1.6 or Later	Provides single user interface for PPMS and PPMS options.

* In addition to the requirements in table1-1, the PPMS Continuous Low-Temperature Control (CLTC) option (Model P800) is highly recommended. CLTC provides extended low-temperature control.

Heater
Hot thermometer
Sample
Cold thermometer

➤ *Thermal Transport sample puck with radiation shield*

PRODUCT SPECIFICATIONS/FEATURES:

THERMAL CONDUCTANCE *(K)*

Typical Accuracy:

- ± 5 % or ± 2 µW/K, whichever is greater, for T < 15 K
- ± 5 % or ± 20 µW/K, whichever is greater, for 15 K < T < 200 K
- ± 5 % or ± 0.5 mW/K, whichever is greater, for 200 K < T < 300 K
- ± 5 % or ± 1 mW/K, whichever is greater, for T > 300 K

Estimated dynamic range:

- 1 - 25 mW/K for high T = 400 K
- 100 µW/K - 100 mW/K for intermediate T = 50 K
- 10 µW/K - 1 mW/K for low T = 1.9 K

Note: Dynamic range values are estimates. The dynamic range depends on the heat capacity of the leads and sample and thermal contact of leads to the sample, so results will depend on user samples.

Specifications subject to change without notice.

THERMAL CONDUCTIVITY
$\kappa = K(L/A)$

L = sample length [mm]
A = sample X-section [mm^2]
Estimated dynamic range, T = 300 K, for given sample geometries: L x (A)

- sample: 2.5 x (5 x 5) mm^3
  κ : 0.1 - 2.5 W/m-K
- sample: 8 x (2 x 2) mm^3
  κ : 2 - 50 W/m-K
- sample: 10 x (1 x 1) mm^3
  κ : 10 - 250 W/m-K

SEEBECK COEFFICIENT *(S)*

Typical Accuracy:

- Error in S = ± 5 % or,
- Error in S = ± 0.5 µV/K or,
- Error in V = ± 2 µV, whichever is greater

Approximate Range: 1 µV/K - 1 V/K

RESISTIVITY *(ρ)*

- AC Transport specifications for resistivity measurements apply in zero field.
- Maximum current: 200 mA
- Noise in field due to induction effects, 1 Hz measurement frequency:
  ± 1 mΩ, H = 9 T
  ± 3 mΩ, H = 14 T

THERMOELECTRIC FIGURE OF MERIT
$ZT = S^2T/(\rho\kappa)$

Typical Accuracy: ± 15 %
(When Seebeck coefficient and thermal conductivity 5 % specifications apply)

SPEED OF ACQUISITION:

Typically temperature slew rate:

± 0.5 K/min, T > 20 K
± 0.2 K/min, T < 20 K
14 hour run from 390 to 1.9 K

SYSTEM PARAMETERS:

- Temperature: 1.9 - 390 K
- Magnetic Field: 0 - 16 tesla*
- Pressure: High Vacuum (<10^{-4} torr)

*Note: If you require use of significant magnetic fields (H > 0.1 T) at temperatures below T ~ 20 K, it may be necessary to correct for the magnetoresistance of the TTO thermometers using the QD Magnetoresistance Calibration Wizard.

Nickel 201 alloy
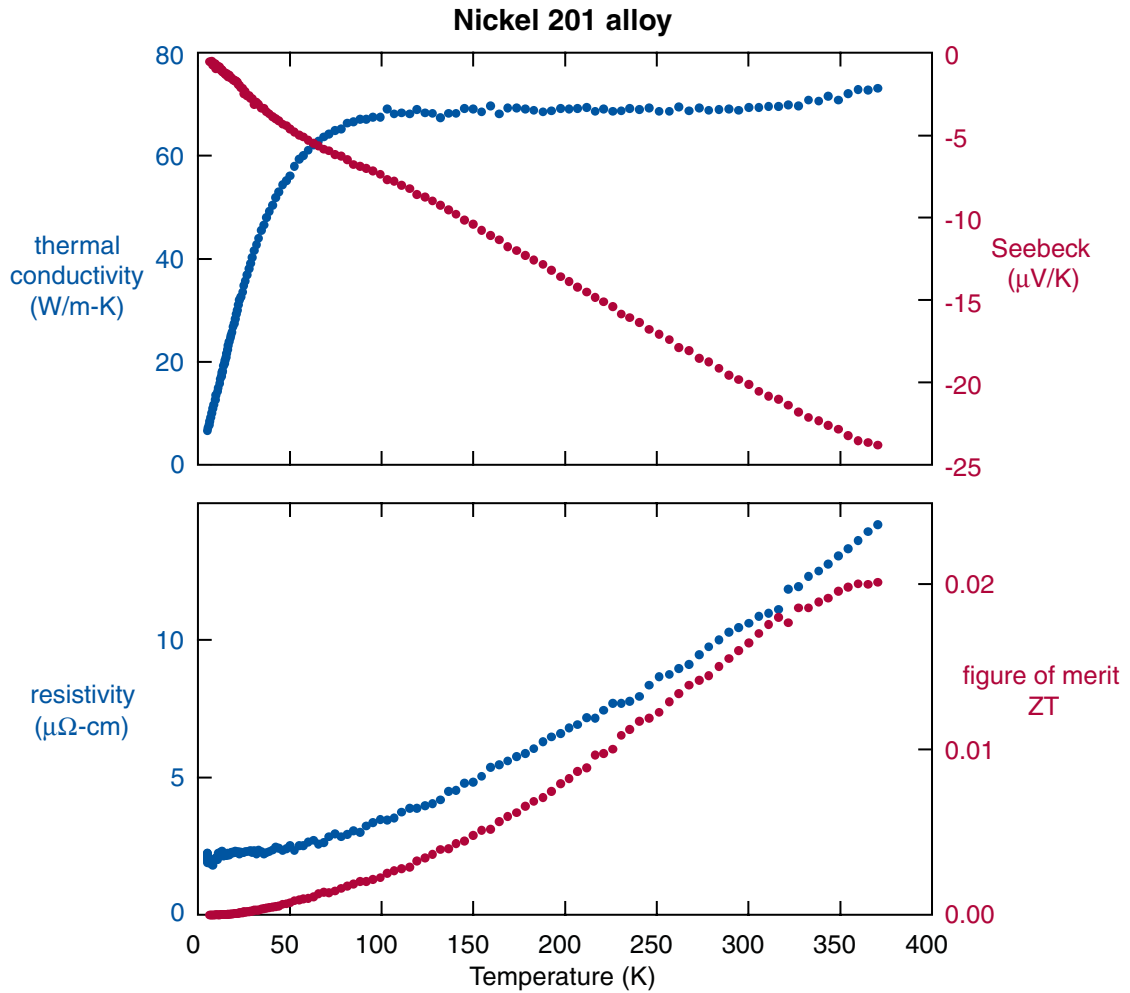
> ➤ *Thermal conductivity, Seebeck coefficient, and electrical resistivity are measured simultaneously to determine the thermoelectric figure of merit. The nickel standard sample is supplied with the Thermal Transport Option.*