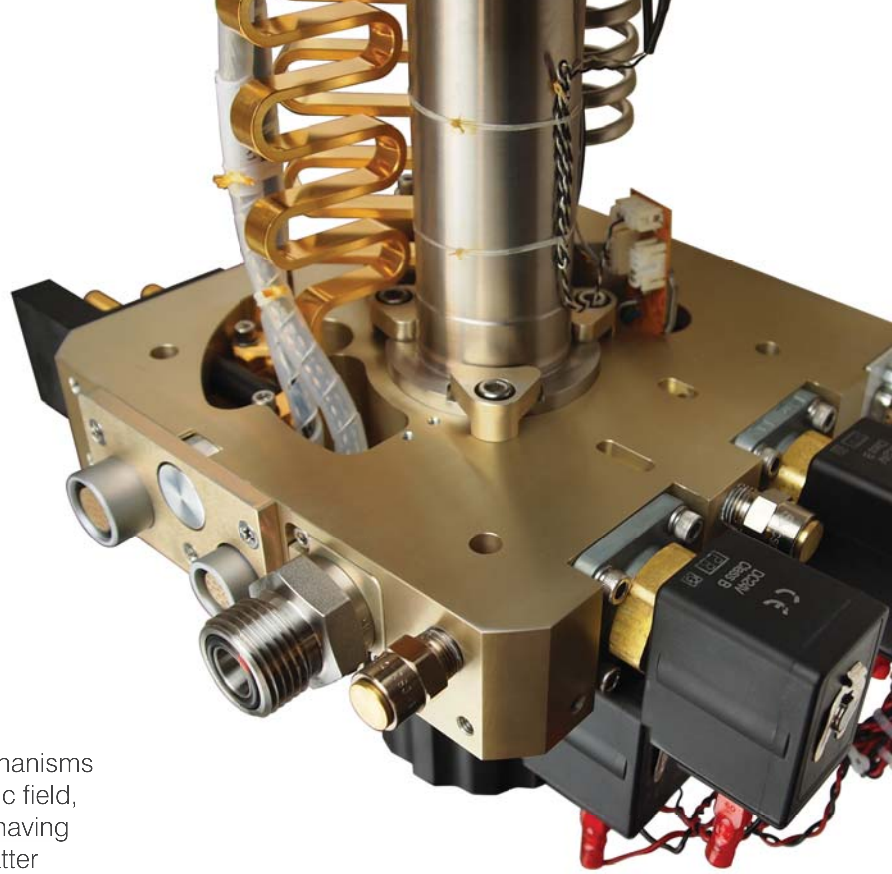
MPMS® 3

System Options



AC Susceptibility

Many materials display dissipative mechanisms when exposed to an oscillating magnetic field, and their susceptibility is described as having real and imaginary components – the latter being proportional to the energy dissipation in the sample. The key is resolving the component of the sample moment that is out of phase with the applied AC field. SQUID technology is the measurement system of choice because it offers a signal response that's virtually flat over a broad frequency range from 0.1 Hz to 1 kHz. In a SQUID system, the output voltage is proportional to the magnetic flux in the pick-up coil instead of its time derivative as in conventional AC systems. The MPMS 3 therefore is able not only to achieve unprecedented sensitivity in its base configuration, but also a minimal variation in sensitivity over the entire frequency range. The MPMS 3 AC option typically provides better than 5×10^{-8} emu sensitivity on the AC moment and better than $\pm 0.5°$ phase angle sensitivity over the entire AC measurement frequency spectrum.

The MPMS 3 AC option is comprised of a dedicated controller and software package which integrates seamlessly into the existing system and user interface.

AC Susceptibility Specifications

Model: M350

AC frequency range:	0.1 Hz to 1 kHz
AC Amplitude[1] (Peak)	0.1 Oe up to 10 Oe
AC Moment Sensitivity[2,3]	$\leq 5 \times 10^{-8}$ emu (typical)
AC Moment Accuracy[4]	$\leq \pm 1\%$ (typical)
Phase Angle Accuracy[3,5]	$\leq \pm 0.5°$ (typical)
Frequency[6] and Temperature[7] dependencies	
on AC Moment:	$\leq \pm 1\%$ (typical)
on Phase Angle:	$\leq \pm 0.5°$ (typical)

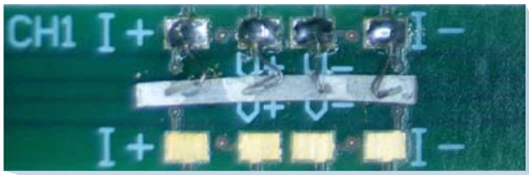
AC measurements can be performed in the full parameter space (temperature, dc magnetic field) of the base system as well as with the oven option, although to different specifications. For more details on using the oven and AC options together, visit www.qdusa.com/techsupport and refer to the MPMS 3 Application Note 1505-001.

[1] Maximum drive amplitude is frequency dependent. Software will dynamically reduce the maximum amplitude at higher frequencies.
[2] Smallest moment change that can be detected.
[3] Specification defined for a moment of about 5×10^{-6} emu using reference sample at 300 K with 10 Hz ac frequency and 10s averaging.
[4] Reported ac susceptibility for reference sample agrees with measured dc susceptibility. Specification defined using reference sample at 300 K, dc susceptibility extracted from dc MvsH measurement between ± 100 Oe with 5 Oe field steps, ac susceptibility measured at 10 Hz with 10s averaging and an ac amplitude to give moment of at least 2×10^{-5} emu.
[5] Reported phase angle for reference sample agrees with expected value.
[6] Variation for frequencies between 0.1 Hz and 1 kHz for moments larger than 2×10^{-5} emu.
[7] Variation for Temperatures between 2 K and 400 K for moments larger than 2×10^{-5} emu.

Electrical Transport

The Electrical Transport Option (ETO) is designed to work in the MPMS 3 platform and allows users to perform AC resistance, Hall effect, I-V, Differential resistance (dV/dI vs. I_{bias} for 4-wire), and Differential conductance (dI/dV vs. V_{bias} for 2-wire) measurements on a sample using a Printed Circuit Board (PCB) sample holder.

Gadolinium Sample



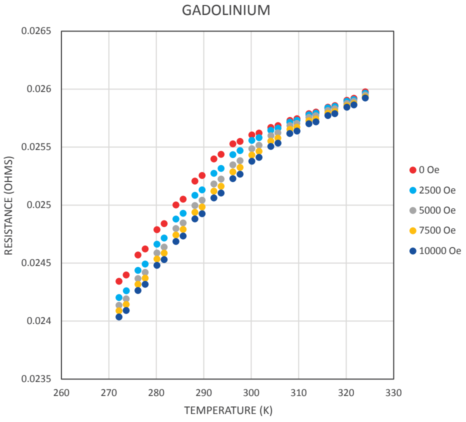
The primary operating mode of this 2-channel measurement system uses an AC current excitation and digital lock-in voltage detection to perform 4-wire measurements of electrical resistance or Hall effect in a sample with resistance up to several mega-ohms. For high impedance mode the stimulus-response circuit can operate voltage source and a nano-ammeter, thus allowing for 2-wire measurements of sample resistance up to 5 giga-ohms.

There are two types of PCB sample holders offered with this option: a 2-sample holder for measurements in a parallel magnetic field, and a single-sample holder for measurements in a perpendicular magnetic field. These specially designed sample holders allow users to measure magnetic moments by VSM or DC Scan using the same hardware, as well as conduct automated magnetic measurements while applying a voltage bias to the sample.

2-Sample Rod and Holder

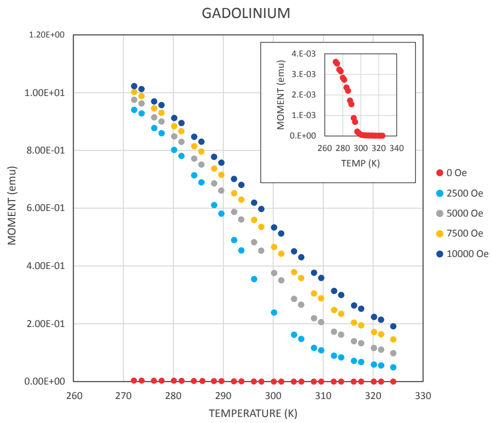
Two Types of Measurements for Single Set-up:

Resistance vs. Temperature, 18.3 Hz AC, 4 wire



Single-Sample Holder

Moment vs. Temperature, VSM



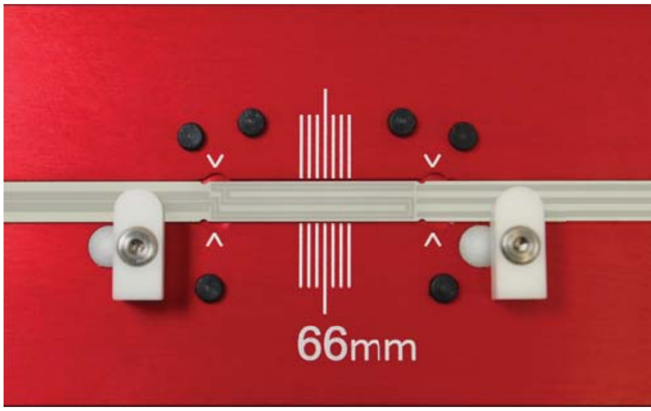
Electrical Transport (ETO) Specifications

Model: M605	
Current Source	
Current Range:	10 nA to 100 mA continuous operation
Frequency Range:	0.1 Hz to 200 Hz AC and DC
	0.1 Hz to 200 Hz for 1 μA to 100 mA
Resistance	0.1 Hz to 25 Hz below 1 μA
Measurement Accuracy:	
4-wire:	0.1% (typical for Resistance R $<$ 200 kΩ)
	0.2% (maximum for R $<$ 200 kΩ)
	0.2% (typical for R $=$ 1 MΩ)
2-wire:	2% (typical for R $<$ 1 GΩ)
	5% (typical for R $=$ 5 GΩ) for 0.1 to 10 Hz
Relative Sensitivity:	$\pm$ 10 nΩ RMS (typical) for 100 mA to short
Resistance Range:	Up to 10 MΩ in 4-wire mode (typical)
	2 MΩ to 5 GΩ in 2-wire mode (typical)
Preamp	
Noise:	
Low Noise Amp:	1 nV/√Hz @100 Hz (typical)
	2 nV/√Hz (maximum)
Programmable Gain Amp (100 X):	28 nV/√Hz @100 Hz (typical)
	30 nV/√Hz (maximum)
Voltage Input Range:	$\pm$ 4.5 Volts at 1 X Gain
Current Input Range for 2-Wire High Impedance Mode:	$\pm$ 250 nA
Common Mode Rejection:	-100 dB @100 Hz

Oven

The MPMS 3 Oven option allows sensitive magnetometry measurements at controlled temperatures from 300 K up to 1000 K. A heated sample holder allows reaching this temperature range while oscillating the sample inside the detection coils to perform measurements. With the AC Measurement option it is possible to measure AC susceptibility in the same temperature range during the same measurement, although with reduced specifications due to the oven sample holder. For more details visit www.qdusa.com/techsupport and refer to the MPMS 3 Application Note 1505-001.

The MPMS 3 Oven option incorporates additional electronics, a turbo pump unit for generating high vacuum in the sample chamber to minimize helium boil-off at high temperatures, and a dedicated sample holder allowing local temperature control directly at the sample.



Detail: MPMS 3 Oven Sample Mounting Platform with Oven Sample Holder.

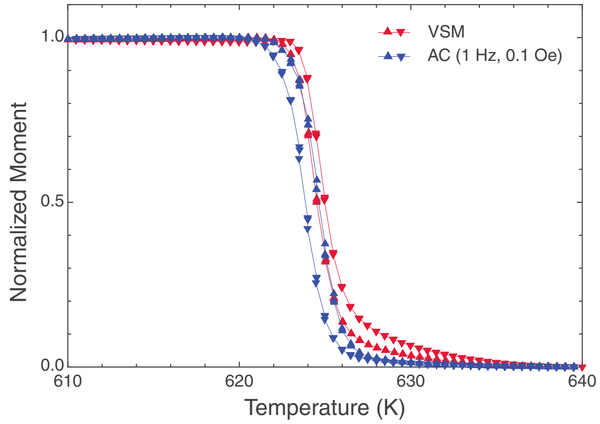


Figure 3. Measurement of the magnetization as a function of temperature for a small piece of nickel to examine the Curie temperature using both the VSM and AC measurement techniques with the oven option. 0.5K step sizes, stabilizing temperature and a 10Oe applied magnetic field were used to collect the data.

Oven Specifications

Model: M303

Temperature Range:	300 K – 1000 K
Temperature Accuracy:	Better than 2% after stabilizing
Temperature Stability:	+/- 0.5K
Moment Sensitivity:	1.0 x 10^{-6} emu @ H≤2500 Oe (300K, 10s averaging) 8.0 x 10^{-6} emu @ H>2500 Oe (300K, 10s averaging)

Sample Holder Specifications

Overall dimensions:	160mm (L) x 5mm (W) x 0.5mm (H)
Heater region:	25mm (L) x ~5mm (W) in center of holder
Sample mounting location:	66mm from bottom of holder
Max. sample size:	10mm (L) x 5mm (W) x 2mm (H)

Horizontal Rotator

The MPMS 3 Horizontal Sample Rotator allows samples to rotate around a horizontal axis. Samples are mounted on a small plate (rotor), which enables sample rotations of up to 360 degrees in 0.1 degree increments. The rotator is constructed of special materials to minimize magnetic contribution from the holders. Additionally, the new sample rod has the stepper motor fully integrated into the sample rod. Under normal operation, the MPMS 3 MultiVu software controls the sample holder plate with the rotator motor, allowing fully automated sample measurements as a function of angle.

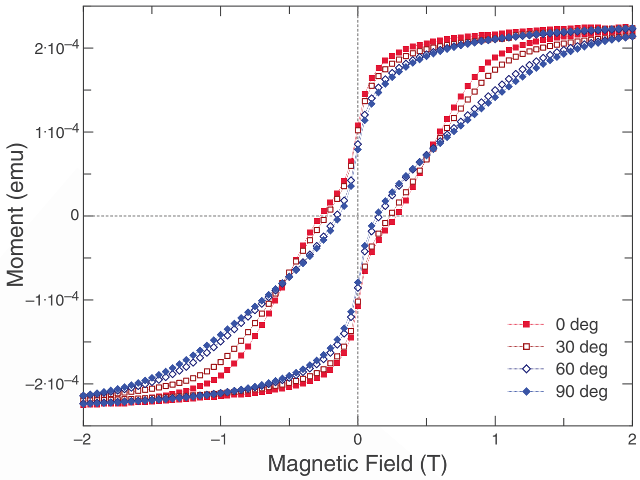


Figure 1. Measurement of a ferromagnetic thin film sample with perpendicular anisotropy on a substrate. Results are shown for ±2T moment versus field loop at 4 different angles from 0 to 90 degree sample rotation.

Horizontal Rotator Specifications

Model: M301

Sample Area Size:	4 mm x 4 mm x 2 mm (with the standard stage)
Range:	-10° to 370° (one direction)
Angular Step Size:	0.1° (typical)
Reproducibility:	<1.0° with <10° backlash (typical)

Magneto-Optic Measurement

The Magneto-Optic Measurement option for the MPMS 3 is a powerful tool used for investigations of photo-induced magnetization and related phenomena in samples. In practice, this option is designed to allow a sample to be illuminated by an external light source while conducting magnetic measurements. This turnkey option includes all the necessary parts and components to generate light of a certain wavelength and couple it in a Fiber Optic Sample Holder (FOSH) specifically designed for the MPMS3.

At the heart of the Magneto-Optic Measurement option is a Monochromatic Light Source (MLS) that uses a Xenon lamp bulb and a filter to generate light with a specific wavelength. The wavelengths of available filters range between 360 nm and 845 nm. The typical output power at the sample for a filter with a 50 nm bandwidth is in the range of 1 to 10 mW depending on the selected wavelength. In general, Xenon lamps have the highest radiation power in UV and VIS, which is why this source is used in this option.

The fiber optic components of the FOSH consist of a 2-meter long flexible, multimode fiber optic bundle that is connected to a solid fiber optic rod by a SMA connector.

The fiber optic bundle and the fiber optic rod have a diameter of 1.5 mm and a numerical aperture of approximately 0.2. The solid fiber optic rod is fixed inside of the MPMS 3 sample rod, and extends beyond the lower end of the sample rod into a FOSH sample holder. The sample holder for the FOSH consists of a spring-loaded slide assembly constructed of nested quartz tubes.

The components of the sample holder are made almost entirely of quartz to minimize the magnetic noise produced by the sample holder. Samples are mounted in a small quartz bucket, which has an inner diameter of 1.6 mm and a depth of 1.6 mm, and are held in place by a quartz lid. The small volume of the quartz bucket limits the size of samples that may be inserted, and a different sample holder may be needed depending on the specific measurement being performed. The entire bucket assembly loads into the center of a quartz sample holder, and rests on a second piece of solid fiber optic rod.

MPMS 3 shown with Quantum Design light source and controller for FOSH.

A beryllium-copper spring mounted on the bottom of the sample holder maintains an upward pressure on the bottom of the bucket via the solid fiber optic rod in order to ensure that the quartz lid is always flush against the upper solid fiber optic rod.

The standard fiber optic components of the FOSH are optimized for wavelengths in the near UV spectrum. The fiber bundle has an operating wavelength of 180 nm to 1100 nm, and the standard solid fiber optic rod has an operating wavelength of 180 nm to 700 nm. Other fiber optic rods can be used in place of the standard UV rod. The free end of the fiber optic bundle is bare without any connector for connection to the user's light source. The user can use any connector, including SMA, which is appropriate for his light source or available at his laboratory.

Some of the sample-holder materials will not withstand high temperatures, so the FOSH cannot be used above 300 K or with the MPMS 3 Oven. In addition, the available base temperature is limited when using the VSM option.

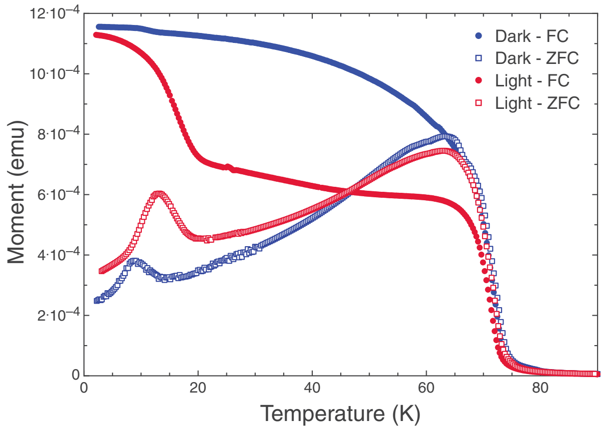


Figure 2. Zero-field-cooled and Field-cooled FOSH data, collected using DC scan mode at 100 Oe applied field, on a sample consisting of core shell particles of Prussian blue analogues, which is ferromagnetic with $T_c \sim 70$ K, and surrounding cores which are photoactive and ferrimagnetic with $T_c \sim 20$ K.

Measurements were accomplished in collaboration with Elisabeth S. Knowles and Mark W. Meisel (UF Physics and NHMFL). FOSH sample was prepared by Carissa H. Li and Daniel R. Talham (UF Chemistry).

Manual Insertion Utility Probe (MIUP)

The Manual Insertion Utility Probe (MIUP) is a multifunction sample mounting platform, which is easily integrated into the base MPMS3.
A micro-connector at the top of the sample rod connects 5 phosphor bronze wires to the sample mounting location. These 5 wires can be attached to the sample at the user's discretion. The MIUP may be used for any application that necessitates up to 5 leads. Its design also allows users to perform a variety of resistivity measurements within the automated field and temperature environment that the MPMS 3 provides.

MIUP Specifications

Model: M311

- Low current (<100mA Full temperature range accessible*)
- High current (Base temperature not accessible*)

**We do not guarantee temperature accuracy with this option*

Magneto-Optic Measurement Option

Magneto-Optic Measurement Specifications

Model: M310

- **Monocromatic Light Source with wavelength ranges between 360 and 845 nm.**
- **Optional Electronic Shutter**
- **Fiber Optic Sample Holder (FOSH) for samples up to 1.6 mm**
- **Moment Sensitivity:**

  1.0×10^{-6} emu @ H≤2500 Oe (300K, 10s averaging)
  8.0×10^{-6} emu @ H>2500 Oe (300K, 10s averaging)

MPMS®3

System Options

Ultra-Low Field (ULF) Capability

This MPMS 3 option actively cancels residual magnetic flux in the superconducting solenoid so samples can be cooled in a very low field – typically less than ±0.05 Gauss. The capability is extremely important for measurements of high temperature superconductors and spin glass materials. Besides allowing zero-field measurements, the option also allows one to set fields up to ±20 Gauss with a resolution improved by two orders of magnitude over the standard system.

The Ultra-Low Field option incorporates additional electronics and a custom fluxgate specifically designed for this application. In basic operation, the MPMS 3 measures the residual field profile along the solenoid's longitudinal axis using the fluxgate and then nulls it by setting a DC field using compensation coils installed in the superconducting solenoid.

Ultra-Low Field Specifications

Model: M355

Nulling Specifications:

Field nulling window[1]	Up to ±10 mm
Field uniformity[2]	±0.05 Gauss
Target field range[3]	±5 Gauss
Field stability[4]	24 hours

Fluxgate Specifications:

Fluxgate range[5]	±10 Gauss
Sensitivity[6]	±0.002 Gauss
Accuracy:	±(0.02 Gauss + 0.5% measured field)

Additional Specifications:

Magnet profiling length[7]	Up to 50 mm
High resolution field range[8]	±20 Gauss
Field resolution:	Better than 0.002 Gauss
Field accuracy:	+(0.002 Gauss + 0.5% set field)

[1] Window in which field is nulled (distance from magnet center).
[2] Maximum field at any point along the magnet axis inside the nulling window.
[3] Any target field within this range can be set with quoted uniformity and verified with fluxgate.
[4] Stability (within uniformity specification) over time of the applied field.
[5] Field range which can be read by the fluxgate.
[6] Intrinsic noise on fluxgate reading.
[7] Maximum length along magnet axis which can be profiled using the fluxgate.
[8] High resolution field range which can be applied by the option.

Quantum Design's Wire Access Port (WAP) allows connectivity to the FOSH, Oven and MIUP options.

Quantum Design

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