Magnetic Property Measurement System – MPMS®-XL

The MPMS®-XL magnetism workcenter from Quantum Design

The fundamental study of magnetism is finding an ever-expanding role in the analysis and characterization of materials. From research applications in physics and chemistry, to geology and biology, to the development of the engineering materials of the future, Quantum Design’s MPMS (Magnetic Property Measurement System) family sets the performance and reliability standard for these exacting investigations.

Highest sensitivity

MPMS sample magnetometers employ SQUID (superconducting quantum interference device) technology, combined with patented enhancements. To achieve superior measurement sensitivity, dynamic range, and reproducibility otherwise unattainable.

Flexible operation

The MPMS is designed to fulfill the workcenter concept. It incorporates all the hardware and software needed for precise magnetic measurements in a fully integrated, modular system. For those favoring ease-of-use and short learning curves, windowing menus and color graphics simplify operation. For those requiring deeper involvement, a full suite of software tools allows customization of virtually every instrument parameter. This flexibility allows the user to decide what level of control the system will have when running a particular experiment.

Application versatility

In a multiple-user environment, the MPMS’s modular hardware and powerful software permits configuring the system quickly to each user’s specific needs, and easily reconfiguring it for the next user. A single MPMS can handle a full range of investigations including DC magnetization, AC susceptibility, Hall effect, resistivity and more, so that the space and cost overhead of multiple instruments is avoided.

MultiVu

MPMS MultiVu is a powerful software for the performance of complex measurements with a maximum of automatization. It allows both the measurement and evaluation of comprehensive data sets. Complex measurement sequences can be created by simply using click-and-drop.

Data can be viewed in a graphic, tabular, or raw data format. The raw data may either be processed directly by MultiVu or exported as an ASCII file to be processed by the user.

Third party instruments (e.g. external current sources) may easily be controlled via MultiVu. This allows the user to create customized setups without losing the automation of the measurements runs. Users who already work with LabView may also use this software for measuring with the MPMS.

The MPMS can also be controlled by remote access from any PC with internet access. If desired, the system automatically sends warnings by email if specific measurement values exceed limits set by the user.

MPMS®-XL

A new concept has been created with the flexible, powerful and easy-to-use MPMS design – the magnetism workcenter. The MPMS can resolve magnetic moment changes as small as 10⁻⁸ emu over a wide range of temperatures and applied magnetic fields. Yet its wide dynamic range permits measurements of moments up to 300 emu. It incorporates a minimal over-shoot healing mode for rapid warming. The result is an exceptionally stable control over the entire temperature range. A unique implementation of Quantum Design’s patented temperature control system permits operation in two modes: for rapid cooling it can either over-shoot the target temperature to minimize the time to stabilize after large changes, or never under-shoot the target by more than 0.5% (active from 4.5 to 350 kelvin to changes of 10 kelvin or less).

Continuous low temperature control (CLTC)

This patented, fully-automated feature offers capabilities not found in other instruments and systems. CLTC handles all procedures for setting and controlling temperatures below that of liquid helium. Operating range is between 1.9 and 400 kelvin. CLTC offers temperature stability of 0.01 kelvin, at 4.2 kelvin, and < 0.5% at 1.9 kelvin. Temperatures <4.2 kelvin can be kept for an indefinite period of time. The system solves the usual problems of temperature instability and hysteresis associated with rapid boil-off of liquid helium when warming through 4.2 kelvin. The results are smooth monotonic transitions across 4.2 kelvin during both warming and cooling temperature sweeps. All these capabilities
Magnetic Property Measurement System – MPMS®-XL

are fully automated for precise systems control and user friendly operation. No valves need to be operated.

System design

The MPMS family of magnetometers offers excellent sensitivity, field uniformity, repeatability and reliability. Two models are available with a magnetic field of ±5 or ±7 tesla, including ultra-low field options and AC/DC measurement capabilities. Powerful software makes measurements, data collection and analysis quick and easy. Window menu prompts and options lead the user through each step.

Reciprocating sample measurement system

In addition to the traditional AC/DC measurement modes, the MPMS features a reciprocating sample measurement system. This technique features small amplitude and periodic displacement of a sample inside the MPMS second-order gradiometer. The movement of the sample results in an oscillating AC signal that is detected by the SQUID sensor. This technique combines the higher sensitivity of performing phase-sensitive measurements with AC SQUID magnetometry to improve the overall sensitivity and noise rejection for DC magnetization measurements. With the reciprocating sample technique, sensitivities of 10⁻⁸ emu are available. For easy handling the system features automated sample centering methods.

Option M101A
Transverse moment detection system

The standard MPMS configuration employs a single SQUID sensor to measure magnetic moments aligned parallel with the applied field. To examine the anisotropic effects of moments with vector components perpendicular to the applied field, a transverse moment detection system option may be added. It incorporates a second SQUID detection system which can resolve transverse moments as small as 10⁻⁶ emu. The transverse superconducting coil array is wound in a second derivative configuration orthogonal to the longitudinal detection coils with both coil sets sharing a common center position. Thus, the user can easily specify whether he wants to use only the longitudinal, or both SQUID systems for programmed measurement sequences.

Specifications

| Dynamic range | 10⁻⁶ to >1.5 emu extendable to 300 emu |
| Detection loop (second derivative configuration) | d²Bx/dz² array |
| Calibration accuracy | 1% absolute |

Option M101B
Vertical sample rotator

This vertical sample rotator permits users of the transverse superconducting coil set to rotate samples ±360° degrees about the longitudinal axis of the solenoid under computer control, facilitating such activities as 3-axis measurements of a sample. Sample orientation can be specified within 0.1 degrees under either computer or manual control.

Specifications

| Range of motion | ±360° |
| Slew rate | 45°/s |
| Angular positioning resolution | ±0.5° |
Magnetic Property Measurement System – MPMS®-XL

**Option M101C**  
**Horizontal sample rotator**

The horizontal sample rotator is used for rotating a sample with respect to the magnetic field. This option, which requires the vertical sample rotator (M101B), will rotate a thin film (or other small sample) for measuring the magnetic moment versus angular position.

**Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>0 to 360° in 0.1° increments</td>
</tr>
<tr>
<td>Background</td>
<td>Linear &amp; diamagnetic</td>
</tr>
<tr>
<td></td>
<td>$&lt;1 \times 10^{-3}$ emu @ 5T</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>±1°</td>
</tr>
<tr>
<td>Sample size</td>
<td>$4 \times 4 \times 1$ mm$^3$</td>
</tr>
</tbody>
</table>

**Option M102**  
**Sample space oven**

MPMS magnetic moment measurements can be made at temperatures from ambient to 800 kelvin through use of the optional sample space oven. Operation is completely automated through control software which is fully integrated into the MPMS operating system. The oven is an insulated heater assembly which is introduced directly into the normal MPMS sample space. Its sample space is 3.5 mm in diameter. Because the oven employs a vacuum sleeve to isolate high temperatures from the standard MPMS temperature control system, the normal sample space remains below room temperature, thus minimizing helium requirements when operating the oven for extended experiments. The oven can quickly and easily be installed or removed as needed.

**Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample tube inner diameter</td>
<td>3.5 mm</td>
</tr>
<tr>
<td>Temperature range</td>
<td>Ambient to 800 K</td>
</tr>
<tr>
<td>Temperature accuracy</td>
<td>±0.5% (typical) at 800 K</td>
</tr>
<tr>
<td>Temperature uniformity</td>
<td>±0.5% (typical) over 6 cm length centered at coils</td>
</tr>
<tr>
<td>Sample run out</td>
<td>5 inches (center of measuring coils to oven bottom)</td>
</tr>
<tr>
<td>Thermometer element</td>
<td>Platinum</td>
</tr>
<tr>
<td>Helium usage</td>
<td>Approximately 0.1 l/h</td>
</tr>
</tbody>
</table>

**Option M104**  
**Magnet reset**

The magnetic field in the MPMS is produced by precisely controlling the current in the superconducting solenoid. Typically, a residual or remanent field of 3 to 5 gauss remains in the superconducting solenoid after operation at high fields – even when the current is oscillated to zero (this can be 10 times larger if the “no-overshoot” mode is used). The magnet reset option can be used to “quench” the superconducting magnet, reducing the remanent field to less than 2 gauss.

**Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remanent field after reset</td>
<td>&lt;2 G (typical)</td>
</tr>
<tr>
<td>Time to re-cool magnet</td>
<td>&lt;3.0 min</td>
</tr>
<tr>
<td>Dewar boil-off</td>
<td>&lt;0.5 l (typical)</td>
</tr>
</tbody>
</table>

**Option M105**  
**Extended dynamic range (EDR)**

This unique EDR option expands the MPMS full-scale measuring capabilities to ±300 emu. With this option, magnetic properties of materials can be examined over a dynamic range exceeding $10^{10}$ emu. The extended capability is particularly useful for single-instrument analysis of bulk ferromagnetic materials, and thin films of materials with inherently large magnetic moments. The EDA operating mode can be activated selectively, and doesn’t compromise the high sensitivity available for samples with much smaller moments.

**Specifications**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range of measurement</td>
<td>1.25 to &gt;300 emu</td>
</tr>
<tr>
<td>Helium usage</td>
<td>0.4 l in 12 h when option is activated</td>
</tr>
</tbody>
</table>

**Option M106**  
**External device control (EDC)**

EDC is a powerful yet easy-to-use programming language for selecting devices, evoking device functions, and sending or receiving data as well as accessing such MPMS functions as temperature and magnetic field control. EDC also supports real and string variables and allows mathematical and string operations. This versatile option provides access to MPMS precision temperature and magnetic field controls, which serve as an experimental platform for the measurement of resistivity, magnetoresistance, Hall effect and other subtle physical properties. EDC is fully integrated with the MPMS control software.
Resistivity & Hall effect package

Resistivity and Hall effect equipment is also available for use with the MPMS to facilitate these measurements. Each consists of a voltmeter, current source, external device control (M106), and the manual insertion utility probe (MIUP).

Option M107
Environmental magnetic shield (EMS)

The EMS allows very sensitive MPMS measurements to be made in locations with excessive magnetic noise by creating a locally quiet environment. The EMS also serves as a return path for the MPMS superconducting solenoid, permitting use of the system in close proximity to other sensitive instruments. The installed shield does not require degaussing after repeated full-field operation. It fits around the dewar inside the standard MPMS dewar cabinet and both are suspended to provide vibration isolation. The EMS is available as upgrade for both new and existing systems.

Option M120
AC susceptibility measurement

This option turns an MPMS into a complete magnetism workcenter. All phases of research into both magnetism and magnetic properties of materials are possible. 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 that is out of phase with the applied AC field. The SQUID technology of the MPMS is the measurement system of choice because it offers a signal response that is virtually flat over a broad frequency range from 0.01 Hz to 1 kHz. In a SQUID system, the output voltage is proportional to the magnetic flux in the pickup coil instead of its time derivative. Therefore the MPMS shows only a minimal variation in sensitivity over the entire frequency range, thus opening up new regimes for scientific study. This is in contrast to conventional AC systems where signal sensitivity depends on the measurement frequency. The AC measurement option adds the ability to evaluate AC susceptibility by upgrading the system controller and incorporating a programmable waveform synthesizer plus a high-speed analog-to-digital converter. AC susceptibility is measured automatically by (1) applying an AC field to the sample, (2) digitizing the SQUID system's output, (3) programming the waveform synthesizer to generate the proper compensation feedback, and (4) digitally recording the sample's AC response. AC response voltage readings can be recorded in a data file, or processed using the system’s advanced digital techniques to determine the real and imaginary components of the sample’s susceptibility. The MPMS’s SQUID detection system provides full $10^{-8}$ emu sensitivity through the entire AC measurement frequency spectrum – a significant advantage over non-SQUID systems. The EMS is a recommended option.

<table>
<thead>
<tr>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
</tr>
</tbody>
</table>

Option M125
Ultra-low field capability

This option actively cancels residual magnetic flux in the MPMS superconducting solenoid so samples can be cooled in a very low field – typically less than 0.05 gauss. This capability is extremely important for measurements of high-temperature superconductors and spin glass materials. It can also be used in concert with the external device control option for the measurement of resistivity and other transport property measurements. The low field option incorporates additional electronics for the system’s controller and a custom magnetometer specifically designed for this application. In operation, the MPMS measures the residual field and then nulls it by setting a compensating DC field, using a drive coil installed in the superconducting solenoid. The ultra low field option requires use of the environmental magnetic shield (EMS) option which both reduces excessive environmental magnetic noise by creating locally quiet conditions and screens out the earth’s ambient field.

Note: option M125 includes option C020 an M104.

<table>
<thead>
<tr>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual field</td>
</tr>
</tbody>
</table>

Typical comparison of SQUID-AC measurement with conventional induction technology
Magnetic Property Measurement System – MPMS®-XL

Option C010
Fiber optic sample holder

The fiber optic sample holder provides a convenient way to study the magnetization of a sample under the influence of light. It connects easily to an optical fiber from a laser or another high powered light source, so the user can illuminate a sample in the sample space. During and after illumination, the MPMS can measure magnetization over a wide range of temperatures and magnetic fields.

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Numerical aperture</td>
<td>0.22 ±0.02, 1.5 mm core</td>
</tr>
<tr>
<td>Fiber VIS/UV and VIS/NIR fiber available</td>
<td>Flexible bundle: SMA</td>
</tr>
<tr>
<td>Connector</td>
<td>Flexible bundle: SMA</td>
</tr>
<tr>
<td>Length</td>
<td>Flexible bundle: 2 m</td>
</tr>
</tbody>
</table>

Option C020
Low field profiling option

The low field profiling option measures the remanent magnetic field in the MPMS superconducting solenoid. This allows the user to establish controlled measurement conditions before introducing a field-sensitive sample, like high temperature superconductors or spin glasses into the MPMS. The low field profiling option allows the user to map the field uniformity at low magnetic fields and to measure the absolute field at a given position. Using the low field profiling option and manually setting the magnetic field, very low field conditions (given the high resolution field setting precision of the MPMS), or precisely set fields up to ±10 gauss can be achieved. A wall-mounted holder with a μ-metal shield, for zeroing the fluxgate before each use, is part of this option.

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature range</td>
<td>0.5 - 18 K</td>
</tr>
<tr>
<td>Temperature stability</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Cool down time</td>
<td>&lt; 6 h</td>
</tr>
</tbody>
</table>

The gas handling system contains a high-vacuum system with a turbo molecular pump and a hermetically-sealed rotary-vane pump for automated helium3 gas recovery. The vacuum jacket and sample space are ingeniously accommodated within an 8.6 mm diameter probe that mounts within the MPMS sample space. The inner diameter of the helium3 insert is 6.4 mm, allowing the standard MPMS straws to be used for sample mounting.

Pressure cells

Different pressure cells for pressures up to 1.5 GPa are available for the MPMS. Those can either be used with the RSO or with the AC measurement option. The pressure is applied by a hydraulic press.

Option C050
EverCool dewar

The EverCool dewar was designed to eliminate the need for liquid helium transfers and to virtually eliminate all helium losses from the Quantum Design MPMS magnetometer system under most operating conditions. The EverCool system features an integrated cryocooler-dewar system that recondenses the helium directly within the EverCool dewar. Because the cold helium gas is recondensed at low temperatures before it leaves the dewar, the EverCool system is much more efficient in power consumption and cooling requirements than helium liquefying systems that recover the helium gas at room temperature.

Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature range</td>
<td>0.5 - 18 K</td>
</tr>
<tr>
<td>Temperature stability</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Cool down time</td>
<td>&lt; 6 h</td>
</tr>
</tbody>
</table>

The gas handling system contains a high-vacuum system with a turbo molecular pump and a hermetically-sealed rotary-vane pump for automated helium3 gas recovery. The vacuum jacket and sample space are ingeniously accommodated within an 8.6 mm diameter probe that mounts within the MPMS sample space. The inner diameter of the helium3 insert is 6.4 mm, allowing the standard MPMS straws to be used for sample mounting.
Magnetic Property Measurement System – MPMS®-XL

<table>
<thead>
<tr>
<th>Pressure cell model</th>
<th>Type</th>
<th>Sample space diameter</th>
<th>Max. applied pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPC-5</td>
<td>Uniaxial</td>
<td>3 mm</td>
<td>500 MPa</td>
</tr>
<tr>
<td>LPC-15</td>
<td>Hydrostatic</td>
<td>2.6 mm</td>
<td>1.25 GPa</td>
</tr>
<tr>
<td>MLPC-15</td>
<td>Hydrostatic</td>
<td>2.6 mm</td>
<td>1.50 GPa</td>
</tr>
</tbody>
</table>

**Additional advantages of the EverCool system**

1. Only minimal additional space is required for the cryocooler compressor.
2. All EverCool functions are fully integrated into the new MPMS MultiVu software for Windows™, allowing virtually automatic operation of all functions, including helium level control in the MPMS EverCool dewar.
3. Use of a single cold head minimizes power consumption, cooling water requirements, and cost of regularly scheduled maintenance.
4. Under typical MPMS operating conditions [with the sample chamber at temperatures below 200 kelvin and the magnet in persistent mode], the EverCool cryocooler operates at a reduced duty cycle (~60% run time), extending the time between maintenance cycles for both the cold head and compressor. This minimizes downtime and reduces operating costs.
5. Cryocooler operation can be controlled automatically by the MPMS operating system or manually by the user to minimize any interference with sensitive magnetic measurements from vibrations of the cryocooler.
6. The EverCool dewar includes the option to hook up an external helium gas supply for the purpose of automatically replenishing helium gas that is lost under certain conditions (e.g., purging the sample tube, using the standard sample transport and using the system under extreme conditions).
7. The EverCool dewar is available as an option to all Quantum Design MPMS systems.

**Specifications**

- Estimated helium liquefaction capacity: ~2 liquid l/day with sample space at 5 K, ~1 liquid liter/day with sample space at 300 K. (These values represent the amount of liquid helium that can be generated in excess of the normal daily system usage. This is equivalent to an external liquifier running at 6-7 l/day)

- Potential effect on system sensitivity: Using the reciprocating sample measurement system (RSO), an MPMS with an EverCool dewar can make measurements to ~1 x 10⁻⁷ emu without stopping the cryocooler. For very sensitive measurements, entering a command into the measurement sequence can stop the cryocooler during the measurement. The DC sample transport can be used for an MPMS EverCool system. Magnetic measurement with the DC sample transport system will result in a decreased sensitivity.

<table>
<thead>
<tr>
<th></th>
<th>Maintenance time on compressor</th>
<th>Maintenance time on cold head</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After 20,000 operational hours</td>
<td>After approximately 10,000 operational hours</td>
</tr>
</tbody>
</table>
# Magnetic Property Measurement System – MPMS®-XL

## Specifications

<table>
<thead>
<tr>
<th>Description</th>
<th>MPMS-XL5</th>
<th>MPMS-XL7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field range</td>
<td>±5 T</td>
<td>±7 tesla</td>
</tr>
<tr>
<td>Field stability</td>
<td>1 ppm/h</td>
<td>1 ppm/h</td>
</tr>
<tr>
<td>Field uniformity</td>
<td>0.01% over 4 cm</td>
<td>0.01% over 4 cm</td>
</tr>
<tr>
<td>Field setting resolution</td>
<td>0.1 G to 5.000 G; 1 G to 50.000 G</td>
<td>0.2 G to 6.000 G; 2 G to 70.000 G;</td>
</tr>
<tr>
<td>Residual field</td>
<td>&lt;5 G typical (Oscillation mode)</td>
<td>&lt;5 G typical (Oscillation mode)</td>
</tr>
<tr>
<td></td>
<td>&lt;20 G typical (No-overshoot mode)</td>
<td>&lt;30 G typical (No-overshoot mode)</td>
</tr>
<tr>
<td>Diameter sample chamber</td>
<td>9 mm</td>
<td>9 mm</td>
</tr>
<tr>
<td>DC sensitivity</td>
<td>&lt;1 x 10^8 emu to 250 mT &lt;2 x 10^7 emu to 5 T</td>
<td>&lt;1 x 10^8 emu to 250 mT &lt;6 x 10^7 emu to 7 T</td>
</tr>
<tr>
<td>Range of measurement</td>
<td>±5 emu (±300 emu optional)</td>
<td>±5 emu (±300 emu optional)</td>
</tr>
<tr>
<td>Temperature range</td>
<td>1.9 - 400 K (up to 800 K with optional oven)</td>
<td>1.9 - 400 K (up to 800 K with optional oven)</td>
</tr>
<tr>
<td>Temperature accuracy</td>
<td>±0.5% typical</td>
<td>±0.5% typical</td>
</tr>
<tr>
<td>Temperature stability</td>
<td>±5% default (user-selectable from 0.015 - 1%)</td>
<td>±5% default (user-selectable from 0.015 - 1%)</td>
</tr>
<tr>
<td>Temperature homogeneity</td>
<td>±0.1 K over 8 cm; ±1.0 K over 15 cm @ 235 K</td>
<td>±0.1 K over 8 cm; ±1.0 K over 15 cm @ 235 K</td>
</tr>
<tr>
<td>Temperature sweep rate</td>
<td>10 K/min (300 K -10 K) 2 K/min (10 K -2 K)</td>
<td>10 K/min (300 K -10 K) 2 K/min (10 K -2 K)</td>
</tr>
<tr>
<td>Helium capacity</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Helium usage*</td>
<td>5.5 l/day</td>
<td>6.1/day</td>
</tr>
<tr>
<td>Software</td>
<td>MultiVu software for Windows</td>
<td></td>
</tr>
<tr>
<td>Sample transport</td>
<td>RSO, DC</td>
<td></td>
</tr>
</tbody>
</table>

### Reciprocating sample measurement system (RSO)

- Frequency range: 0.5 Hz - 4.0 Hz
- Amplitude range: 0.5 mm - 50 mm (p - p)
- Absolute sensitivity: 1 x 10^6 emu at 0 T - 1 T