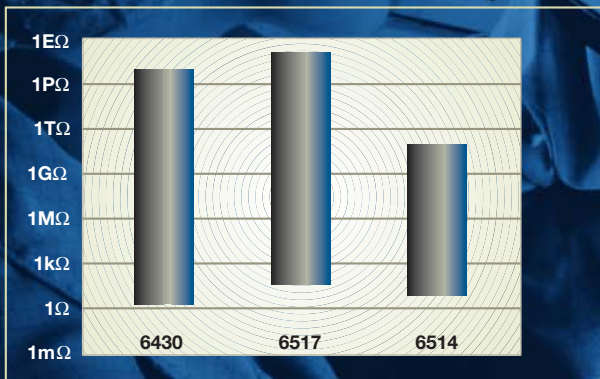


# High accuracy electrometers for low current/high resistance applications

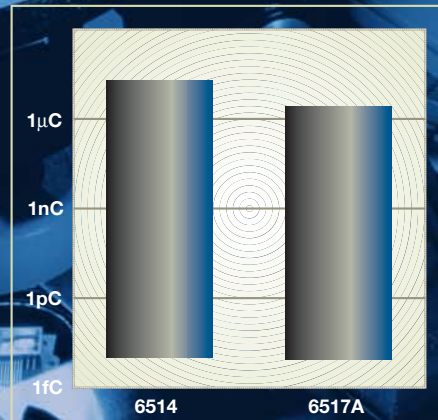


KEITHLEY

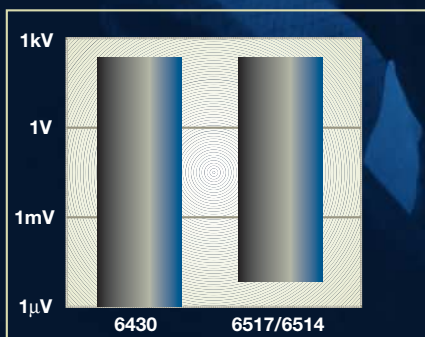
A GREATER MEASURE OF CONFIDENCE



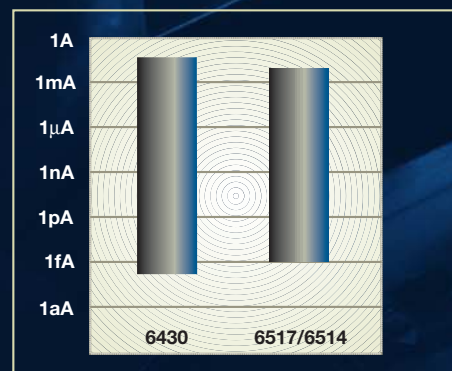
Resistance Measurement Ranges



Charge Measurement Ranges



Voltage Measurement Ranges



Current Measurement Ranges

# High performance electrometers

Keithley has more than a half-century of experience in designing and producing sensitive instrumentation. As new testing requirements have evolved, we've developed dozens of different models to address our customers' needs for higher resolution, accuracy, and sensitivity, as well as support for specific applications. Keithley electrometers are at work around the world in production test applications, industrial R&D centers, and university and government laboratories—wherever people need to make high precision current, voltage, resistance, or charge measurements.

## What is an electrometer?

Essentially, an electrometer is a highly refined digital multimeter (DMM). Electrometers can be used for virtually any measurement task that a conventional DMM can and offer the advantages of very high input resistance when used as voltmeters, and ultra-low current sensitivity with low voltage burden when used as ammeters. Electrometers are superior to DMMs by three to eight orders of magnitude in these respects. That makes them the instruments of choice for measuring voltages with high source impedance or currents with low source impedance (i.e., signals from non-ideal sources). Electrometers can also measure charge directly.

## Why is high input impedance necessary?

When measuring voltage, the input impedance of the meter must be many decades higher than the impedance of the voltage source. For example, if the meter's input impedance is only  $1\text{G}\Omega$  (typical of DMMs), and the source of voltage has  $10\text{M}\Omega$  of impedance, then the meter will introduce a 1% error due to its relatively low input impedance. In contrast, an electrometer with  $10^{14}\Omega$  input impedance will cause only a 0.00001% error. It's also important for the voltage measurement instrumentation to have a low bias current, because any current coming out of the meter input will be forced through the source, and change its voltage. Electrometers use active cancellation to reduce bias current to the single femtoamp level.

## Why is low voltage burden critical?

Voltage burden is the voltage that appears across the ammeter input terminals when measuring. As Figure 1 illustrates, a DMM uses a shunt ammeter that requires voltage (typically 200mV) to be developed across a shunt resistor in order to measure current. This voltage burden will reduce the actual current flowing in the circuit, and reduce accuracy. An electrometer uses a feedback ammeter to reduce this terminal voltage by several orders of magnitude. Some electrometers go a step further, adding a compensating voltage that eliminates any residual offset voltages at the ammeter input, down to as little as  $20\mu\text{V}$  (Figure 2).

Figure 1.

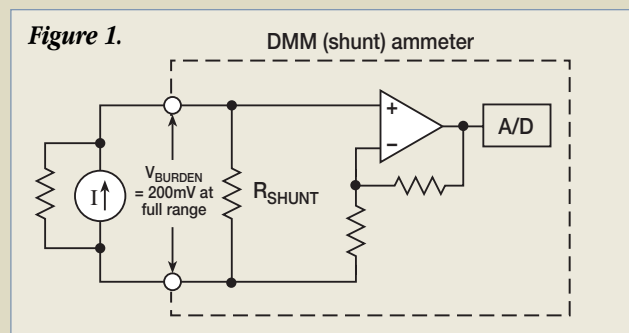
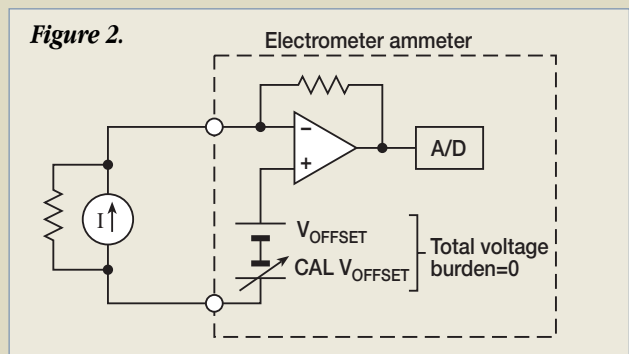


Figure 2.



# Model 6517A

## Packed with high performance functions

BUILT-IN  $\pm 1$ KV VOLTAGE SOURCE

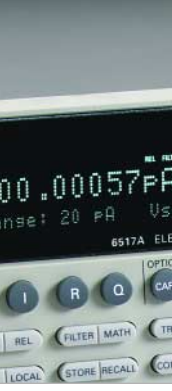


- Measures currents from 1fA to 20mA
- Voltage measurements from 10 $\mu$ V to 200V
- Measures resistances up to 10<sup>17</sup> $\Omega$
- Charge measurements from 10fC to 2 $\mu$ C
- <20 $\mu$ V burden voltage on the lowest current ranges
- 200T $\Omega$  input impedance
- <3fA bias current
- 0.75fA p-p noise
- Built-in  $\pm 1$ kV source

The Model 6517A Electrometer/High Resistance Meter combines exceptional accuracy and sensitivity with a variety of features that simplify measuring high resistances and the resistivity of insulating materials. Reading rates of up to 125 readings/second make it ideal for production test applications.

### Industry-Leading Performance

The Model 6517A's low current input amplifier has an input bias current of <3fA with just 0.75fA p-p (peak-to-peak) noise and <20 $\mu$ V burden voltage on the lower ranges. The input impedance for voltage measurements is >200T $\Omega$ , for near-ideal circuit loading. These specifications give the Model 6517A the accuracy and sensitivity needed for accurate low current, high impedance voltage, resistance, and charge measurements. A built-in  $\pm 1$ kV voltage source with a sweep capability simplifies leakage, breakdown, and resistance testing, as well as volume ( $\Omega$ -cm) and surface resistivity ( $\Omega$ /square) measurements on insulating materials.



## High Accuracy Resistance Measurements

Several instrument features help ensure the accuracy of high resistance measurements. For example, the built-in voltage source simplifies determining the relationship between an insulator's resistivity and the level of voltage applied. It is well suited for capacitor leakage and insulation resistance measurements, tests of the surface insulation of printed circuit boards, voltage coefficient testing of resistors, and diode leakage characterization.



Model 6521 and 6522 10-Channel Scanner Cards make it easy to scan and measure multiple signals rapidly and economically.

## Temperature and Humidity Stamping

Humidity and temperature can significantly influence the resistivity of materials. The Model 6517A has a built-in type K thermocouple and an optional Relative Humidity Probe to simplify making accurate comparisons of readings acquired under varying conditions. A built-in data storage buffer can record and recall readings stamped with the time, temperature, and relative humidity at which they were acquired.



## NIST-Traceable Calibration

An optional Model 5156 calibration unit provides all the NIST-traceable standards needed to calibrate the Model 6517A's 20pA–2 $\mu$ A current ranges and the 2nC– 2 $\mu$ C charge ranges.

The Model 65 High Resistivity Measurement Package includes the Model 6517A, the Model 6524 software, and the Model 8009 Resistivity Test Fixture. The software simplifies operating the 6517A via a computer controller and helps in optimizing the Alternating Polarity method resistance test parameters (delay time, voltage, etc.) for the specific material or device under test. The package also includes all meter and fixture cables. A built-in test sequence incorporates an Alternating Polarity method for measuring very high resistances, especially useful in materials and devices where the inherent background currents in the sample once made accurate measurements impossible.

# Model 6430

## The measurement industry's lowest noise



BEST LONG-TERM STABILITY OF ANY INSTRUMENT AVAILABLE

- Measures current, voltage, and resistance
- 0.4fA<sub>p-p</sub> noise
- Remote PreAmp minimizes cable noise
- $>10^{16}\Omega$  input resistance on voltage measurements
- 6½-digit resolution
- Up to 2000 source/measure readings/second
- Programmable digital I/O and GPIB interfaces for fast component characterization or selection

The design of the Model 6430 Sub-Femtoamp Remote SourceMeter® instrument builds on the advantages of Keithley's popular SourceMeter and Source-Measure Unit products, including full four-quadrant source/sink capability. These advantages are combined with sensitivity, noise, and input resistance specifications superior to an electrometer's. The Model 6430 also offers the lowest noise (just 400aA p-p) and best long-term stability of any instrument available.

### Remote PreAmp architecture

All these advantages are the result of a Remote PreAmp architecture, which provides a very sensitive bi-directional amplifier with sensitive feedback elements for measuring or sourcing currents at the DUT. The amplified signals the Remote PreAmp produces are not subject to cable noise as they are carried to the controlling mainframe. This architecture makes the Model 6430 the most sensitive current measurement instrument on the market.



# and drift

## High speed measurements

The Model 6430 is our fastest option for voltage, current and resistance measurements at up to 2000 source/measure readings per second. For example, it can measure currents less than 100 nanoamps in as little as five milliseconds, including setting time. For high speed component testing applications, a built-in IEEE-488 interface transmits up to 75 readings per second to an external computer controller, including pass/fail indication. The built-in component handler interface simplifies creating automated test systems. Simple pass/fail tests can be completed in less than 1.1ms per device.

## Broad resistance measurement range

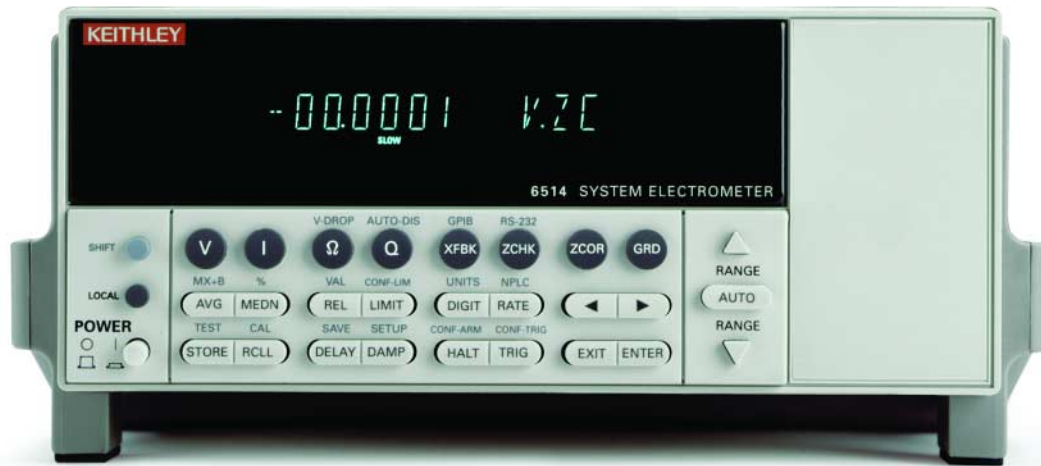
High resistances can be measured directly using either the Constant Current (for resistances up to  $10^{15}\Omega$ ) or the Constant Voltage technique (for higher resistances). This makes the Model 6430 a good choice for research on high resistance materials, calibration of high value precision resistors, and measuring a wide range of resistances on a single device. Its high input impedance and low input bias current on voltage measurements gives the Model 6430 the widest resistance measurement range in the industry. The constant current mode can be used for measuring resistances from  $1\Omega$  to  $10^{15}\Omega$ , much higher than any other instrument that uses this method. This eliminates the need to switch methods, avoiding the data discontinuities that can occur when two different measurement methods are used. The Model 6430 is equally useful for making four-terminal measurements of low resistance DUTs using current up to 100mA.

## Model 6430 Applications

- Low current measurements.
  - Particle beam experiments, including precision mass spectrometry.
  - Single-electron tunneling and other quantum experiments.
- High resistance measurements.
  - Research on insulators, dielectrics, polymers, etc.
  - Precise measurements of high resistances.
- Four-terminal low resistance measurements.
- Semiconductor research and characterization.
  - Measuring sub-femtoamp gate currents.
  - Characterizing sub-threshold I-V curves.
  - Characterizing probe performance.
- Component testing.
  - Development labs.
  - Production facilities.

# Model 6514

## Easy to use, even easier to afford



- 6½-digit resolution
- Up to 1200 readings/second
- Uncomplicated user interface
- <1fA noise
- >200TΩ input impedance on voltage measurements
- Built-in constant current source
- Active cancellation of voltage and current offsets
- IEEE-488 and RS-232 interfaces
- Digital I/O and handler interface for automated test

The Model 6514 Programmable Electrometer is ideal for applications that demand fast, yet precise measurements of low currents, voltages from high resistance sources, charges, and high resistances. For applications that don't require the use of a voltage source, it offers exceptional measurement performance at an affordable price. While its cost is comparable to many high-end DMMs, the Model 6514 offers far greater current sensitivity and significantly lower voltage burden (as low as 20μV) than DMMs can provide.

The Model 6514 offers the flexibility and sensitivity needed for a wide array of experiments. A built-in constant current source simplifies measuring resistance. The 2V analog output can be used with strip-chart data recorders.

### High speed component testing

While earlier electrometers couldn't keep up with the high throughput that production test applications demand, the Model 6514 is designed for fast, sensitive measurements. Its affordable price makes it suitable for a wide array of low current measurement applications, such as testing resistance and leakage current in switches, relays, and other components. Built-in IEEE-488, RS-232, and digital I/O interfaces make it simple to configure fully automated, high speed systems for low level testing. The Model 6514 provides speeds up to 1200 readings per second with fast integration or 17 measurements per second with 60Hz linecycle integration. It offers 10fA resolution on 2nA signals, settling to within 10% of the final value in just 15ms.

### Low burden voltage and input bias current

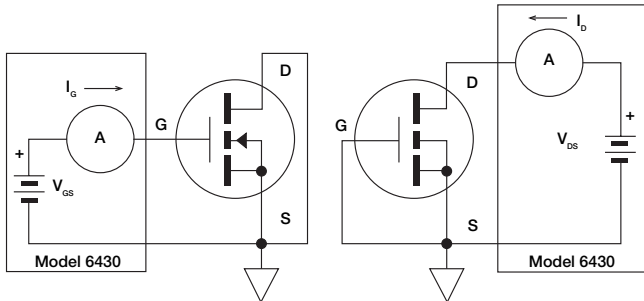
The Model 6514's feedback ammeter design minimizes the voltage drops (burden voltage) that can interfere with making accurate current measurements. With less than 20μV of burden voltage on the lowest current measurement ranges and less than 3fA of input bias (offset) current, the Model 6514 can provide superior low current measurement accuracy. It does this by active cancellation of input voltage and current offsets, and can be adjusted either manually or over the bus.



# Keithley electrometers are at work in a wide range of applications



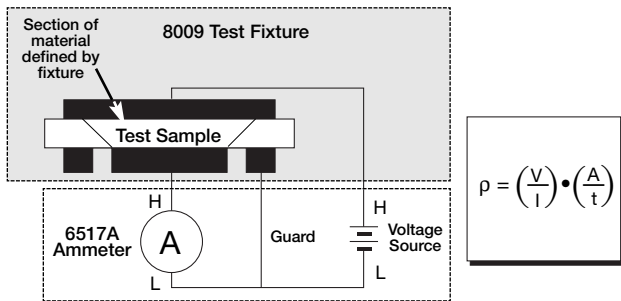
Measuring FET Gate Leakage & Channel Currents



## Semiconductor measurements

Gate leakage or channel leakage in FET-based components can generate errors in MOSFETs, JFETs, analog switches, and many other circuits. By allowing researchers to measure extremely low-level currents and voltages, the Model 6430 can help them understand the design limitations of these components, and investigate alternative device structures or materials.

even more crucial. This figure illustrates how the Model 6514's CAL  $V_{\text{OFFSET}}$  can be adjusted to cancel  $V_{\text{BURDEN}}$  to within a few microvolts, so the applied bias is precisely the intended value, and the measurement reflects the true dark current of the photodiode.

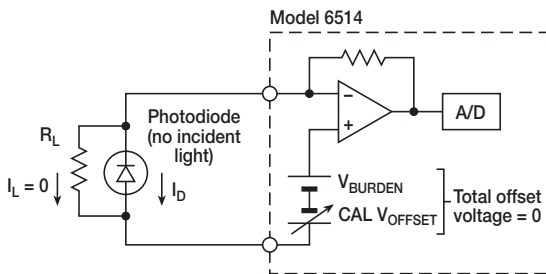


## Resistivity measurements

Volume resistivity measurements are used to characterize a material's dielectric purity, dissipation factor, moisture content, mechanical continuity, etc. Determining volume resistivity requires measuring the resistance of a sample of known physical dimensions. A voltage is applied, the current through the sample is measured, and the resistivity is calculated. The Model 8009 Resistivity Test Fixture defines the cross-sectional area of the sample, so the researcher only needs to know its thickness. The fixture also supports surface resistivity measurements.

## Dark current measurements

Dark current ( $I_n$ ) from a device such as a photodiode is the current generated by the detector with no light falling on the device. Dark current measurements to characterize the detector are usually performed with a voltage bias applied or sometimes with a variety of bias voltages. Any voltage that the ammeter presents across its input terminals is added to the applied bias, reducing accuracy. If the photodiode bias is fairly small (on the order of a few volts), the voltage burden of a DMM (up to 200mV) will have a substantial effect. In the case of solar cells, dark current is measured with 0V bias, so a low voltage burden is



## SET research

The Model 6430's superior low current measurement ability ( $<0.4\text{fAp-p}$ ) makes it extremely useful for single electron transistor (SET) and quantum-dot research. Using a technique similar to a lock-in, the 6430 can measure currents with 1aA sensitivity ( $10^{-18}\text{ A} = 6\text{e}^-/\text{Sec}$ ).

# Keithley offers a broad range of low solutions in addition to electrometers.

Keithley has a wide range of low current, high resistance test solutions, which span the most often needed measurement ranges. For the most demanding applications, electrometers offer the best combination of functionality, sensitivity, and accuracy. Find the solution that offers the best combination of measurement range and capabilities for your application.

	Typical Applications	Summary
Electrometers	<b>Model 6517A Electrometer/High Resistance Meter</b> <ul style="list-style-type: none"> <li>• Low current and high impedance voltage, resistance, and charge measurements</li> <li>• Solar cell experiments</li> <li>• Leakage, breakdown, and resistance testing</li> <li>• Volume and surface resistivity measurements</li> </ul>	<ul style="list-style-type: none"> <li>• 1kV source</li> <li>• &lt;20<math>\mu</math>V burden voltage on the lowest current ranges</li> <li>• &lt;3fA bias current</li> <li>• 0.75fA p-p noise</li> </ul>
	<b>Model 6514 Programmable Electrometer</b> <ul style="list-style-type: none"> <li>• Radiation detector, photo detector, and photodiode current measurements</li> <li>• Leakage current measurements on opto-isolators and photo-sensitive semiconductors</li> <li>• Dark current characterization</li> <li>• Component evaluation tasks</li> <li>• Troubleshooting high impedance circuits</li> <li>• Tracing circuit board leakages</li> </ul>	<ul style="list-style-type: none"> <li>• 6½-digit resolution</li> <li>• Up to 1200 readings/second</li> <li>• Uncomplicated user interface</li> <li>• &lt;1fA noise</li> <li>• Built-in constant current source</li> <li>• Active cancellation of voltage and current offsets</li> <li>• IEEE-488 and RS-232 interfaces</li> </ul>
	<b>Model 6430 Sub-Femtoamp Remote SourceMeter® Instrument</b> <ul style="list-style-type: none"> <li>• Low current measurements</li> <li>• High resistance measurements</li> <li>• Four-terminal low resistance measurements</li> <li>• Semiconductor research and characterization</li> <li>• Component testing</li> <li>• I-V measurements</li> </ul>	<ul style="list-style-type: none"> <li>• Measures current, voltage, and resistance</li> <li>• 0.4fA p-p noise</li> <li>• Remote PreAmp minimizes cable noise</li> <li>• 6½-digit resolution</li> <li>• Up to 2000 source/measure readings/second</li> <li>• Programmable digital I/O and GPIB interfaces</li> </ul>
Picoammeters	<b>Model 6485 Picoammeter</b> <ul style="list-style-type: none"> <li>• Beam monitoring and radiation monitoring</li> <li>• Leakage current testing</li> <li>• Optoelectronic device testing and characterization</li> <li>• Optical fiber alignment</li> <li>• Sensor characterization</li> </ul>	<ul style="list-style-type: none"> <li>• Cost-effective low current measurement solution</li> <li>• 10fA resolution</li> <li>• 5½-digit resolution</li> <li>• Up to 1000 readings/second</li> <li>• IEEE-488 and RS-232 interfaces</li> <li>• Analog output</li> </ul>
	<b>Model 6487 Picoammeter/Voltage Source</b> <ul style="list-style-type: none"> <li>• Resistivity measurements</li> <li>• I-V characterization</li> <li>• Component leakage tests</li> <li>• Insulation resistance testing</li> </ul>	<ul style="list-style-type: none"> <li>• Combination picoammeter and voltage source</li> <li>• Resistance measurements, including Alternating Voltage method</li> <li>• Floating measurements up to 500V</li> </ul>
	<b>Model 428 Current Amplifier</b> <ul style="list-style-type: none"> <li>• Surface science studies</li> <li>• Laser and light measurements</li> <li>• Transient phenomena</li> <li>• Front-end amplifier/converter for oscilloscopes or waveform digitizers</li> <li>• Optical fiber alignment</li> </ul>	<ul style="list-style-type: none"> <li>• Converts fast, small currents to a voltage</li> <li>• Selectable rise times from 2<math>\mu</math>s to 300ms</li> <li>• 1.2fA rms noise</li> <li>• IEEE-488 interface</li> </ul>
Source-Measure Units	<b>Series 236/7/8 Source-Measure Units</b> <ul style="list-style-type: none"> <li>• Characterization of semiconductor devices</li> <li>• Leakage current measurements</li> <li>• Insulation resistance measurements</li> </ul>	<ul style="list-style-type: none"> <li>• Four instruments in one: V-source, V-measure, I-source, I-measure</li> <li>• 10fA, 10<math>\mu</math>V measurement sensitivity</li> <li>• 1000 source/measurements/second</li> <li>• Four-quadrant source operation</li> </ul>
	<b>Series 2400 SourceMeter® Instruments</b> <ul style="list-style-type: none"> <li>• Resistance measurements at a specified current or voltage</li> <li>• Breakdown voltage, leakage current, basic insulation resistance measurements</li> <li>• Electrical characterization of a wide range of components</li> </ul>	<ul style="list-style-type: none"> <li>• 20 to 1000W source capability</li> <li>• 4-quadrant operation</li> <li>• 0.012% basic accuracy with 5-½ digit resolution</li> <li>• 1000 readings/second at 4-½ digits via GPIB</li> </ul>

1 FVMI method only  
 2 Highest resistance measurement capability  
 3 Highest charge measurement capability

4 Lowest current measurement capability  
 5 Widest resistance measurement range  
 6 Highest impedance

7 With addition of Model 2400 SourceMeter® Instrument

# current/high resistance measurement

Capabilities							Key Specifications					
I-V Curves	Low Current Measurements (tens of fAs)	Ultra Low Current Measurements ( $\leq 1fA$ )	High Resistance Measurements	Charge Measurements	High Impedance Voltage Measurements	Input Impedance in V Measure Mode	Current Measurement Range	Resistance Measurement Range	Charge Measurement Range	Built-in Voltage Source	Special Features	
● <sup>1</sup>	●	●	● <sup>2</sup>	●	●	200T $\Omega$	1fA-20mA	50 $\Omega$ -100,000-T $\Omega$	10fC-2 $\mu$ C	1000V	<ul style="list-style-type: none"> <li>• Temperature/RH measurements</li> <li>• Alternating polarity method for HI-R</li> <li>• Plug-in switch cards available</li> </ul>	
	●	●		● <sup>3</sup>	●	200T $\Omega$	1fA-20mA	5 $\Omega$ -200G $\Omega$	10fC-20 $\mu$ C	-	<ul style="list-style-type: none"> <li>• Digital I/O and handler interface for automated test</li> </ul>	
●	●	● <sup>4</sup>	● <sup>5</sup>		● <sup>6</sup>	10,000T	0.4fA-100mA	0.5 $\Omega$ -10,000T $\Omega$	-	210V	<ul style="list-style-type: none"> <li>• 4-quadrant sourcing of up to 2.2W</li> </ul>	
● <sup>7</sup>	●					-	20fA-20mA	-	-	-	<ul style="list-style-type: none"> <li>• 5½ digits</li> <li>• Autoranging</li> <li>• 2500 point storage buffer</li> </ul>	
	●		●			-	20fA-20mA	200 $\Omega$ -10,000T $\Omega$	-	500V	<ul style="list-style-type: none"> <li>• Suitable for performing ASTM's D257 test procedure</li> <li>• Source from 200<math>\mu</math>V to 505V</li> <li>• Digital I/O</li> </ul>	
	●					-	1.2fA-10mA	-	-	-	<ul style="list-style-type: none"> <li>• Up to 10<sup>11</sup>V/A gain</li> </ul>	
●	●		●		●	100T $\Omega$	20fA-1A	0.05 $\Omega$ -1000T $\Omega$	-	110V-1100V	<ul style="list-style-type: none"> <li>• High speed</li> <li>• Built-in waveforms</li> <li>• Internal 1000-reading memory</li> </ul>	
●						Depends on model chosen. Visit <a href="http://www.keithley.com">www.keithley.com</a> for detailed Series 2400 specifications.						

# A greater measure of confidence

## Informative reference materials

Visit our web site, [www.keithley.com](http://www.keithley.com), to access our reference library, including:

**Low Level Measurements** This informative handbook describes the theoretical and practical considerations involved in measuring low DC currents, high resistances, low DC voltages, and low resistances.

**Application Notes** Discover practical, real-world answers to many low level measurement applications questions.

**Lab Exercises** Keithley engineers have developed these lab exercises to help students learn about making electrical and physical measurements by giving their instructors the information they need to create a hands-on experience. These lab exercises can be downloaded for free from our website:

- Energy Gap in a Semiconductor
- Digital Multimeter and Oscilloscope
- Linear Op Amp Circuits
- Step Response of Passive Circuits
- The Electric Field
- Field Effect Transistors
- Non-Linear Op Amp Circuits
- Frequency Domain Analysis of Signals

## Service you can depend on

When you need help with low level measurement applications, contact us at [www.keithley.com](http://www.keithley.com) or call us at 1-888-KEITHLEY (534-8453). Whatever measurement challenge you're facing, Keithley's application engineers are ready to help, before and after the sale. They can suggest the most effective system configurations and provide prompt, reliable applications support once your system is in place. The next time you need help or applications guidance, give us a call. We'll help you find an accurate, cost-effective solution.

## A greater measure of confidence

With more than a half-century of experience in designing low level measurement solutions, we offer our customers a greater measure of testing confidence on the production floor, in the QA lab, and in R&D. To learn how Keithley test solutions can help you keep pace with changing technologies, call your local Keithley sales engineer or visit our website.

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