

100nm


**HUMMINGBIRD**  
 SCIENTIFIC

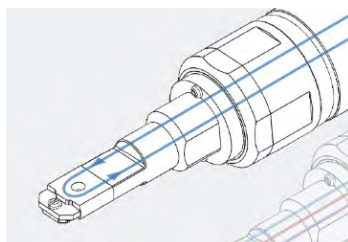
 > **Liquid TEM**

## Technical Specs



	1400 Series
<b>Number of Inlets</b>	1 or 2 depending on model, single outlet
<b>Biasing Contacts</b>	3 or 4 depending on model
<b>Tubing Type</b>	Replaceable microfluidic tubing
<b>Delivery System</b>	Variable speed liquid delivery system
<b>Tip Type</b>	Removable tip
<b>Flow Type</b>	Continuous flow or static liquid
<b>EDS Compatible</b>	Yes
<b>TEM Compatibility</b>	FEI, JEOL, Hitachi, Zeiss

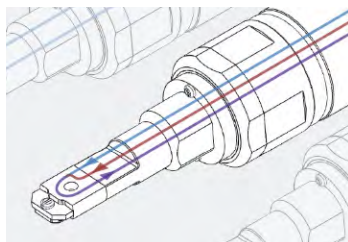
## Liquid TEM Holder System Options



### Continuous Flow

Our liquid specimen holder's unique liquid-cell assembly and safety features protect your microscope from contamination and damage. Interchangeable tips and user-replaceable tubing allow researchers to perform controlled and cross-contamination-free experiments and to easily upgrade the system to incorporate new capabilities.

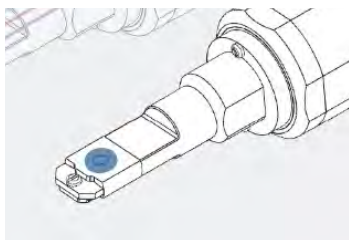
Once the sample is prepared, the system seals it within a microfluidic liquid cell in the holder tip, which is separated from the vacuum of the TEM via a patented sealing mechanism. The sample is then exposed to a continuous flow of liquid running through the environmental cell. Our two-chip fluid cell guarantees that once they are placed, samples remain within the viewing area.



### Dual Flow

Hummingbird Scientific's dual-flow mixing tip for the liquid TEM holder allows users to combine two liquids within a single environmental cell. The design supports liquids flowing at equal or varying rates. In addition to reagent mixing, the tip can be used for research requiring a traditional single-flow tip.

## Liquid TEM Holder System Options



### Static Cell

Hummingbird Scientific offers a sealed-cell liquid holder for static liquid applications. Once prepared, the sample is enclosed within a microfluidic liquid cell in the holder tip and separated from the vacuum of the TEM via a patented sealing mechanism. This tip can be paired with Hummingbird Scientific's wide range of liquid-cell chip configurations, each aimed at a specific set of experimental requirements. The continuous-flow and dual-flow configurations both also support static-liquid experiments for researchers interested in maximizing experimental flexibility.

### Electrochemistry

Hummingbird Scientific was the first company to provide a commercially-available holder capable of supporting liquid-electrochemical experiments conducted inside the TEM. In subsequent years, we have continued to refine the holder's capabilities. In its current configuration, the holder enables electrochemical research via integrated biasing contacts that connect to our specially-patterned electrochemical chips, which are available in a variety of materials. Among other topics, the system has been used for key research into battery materials.

The analytical electrochemistry tip features the sample basic capabilities of the standard electrochemistry liquid cell, but it also keeps the electrical contacts outside the experimental space. This option includes an optional low-noise potentiostat and fully shielded cabling for maximum analytical capabilities.



### Wiring Configurations

**Standard configuration:** In the standard configuration, the system's wires are not individually shielded. This configuration can connect to Hummingbird's heater control box as well as a variety of electronic source and measurement devices. The system can be configured for compatibility with a range of potentiostats and power supplies.

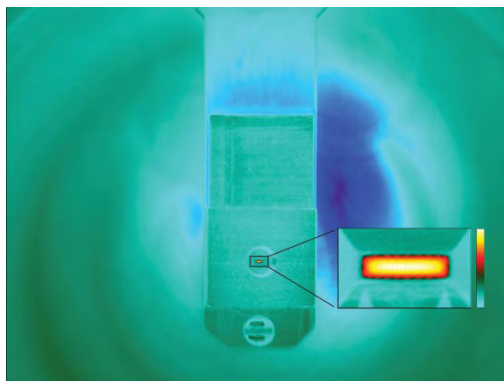
**Low current/noise:** For very small current or voltage values, we offer an individually-shielded, low-noise wiring system. In this system, a shielded coaxial cable runs through the holder shaft and connects through special micro-coax connectors in the holder. The system can be configured for compatibility with a range of potentiostats and power supplies. It is particularly well-suited for small-scale in-situ liquid electrochemistry measurements.



### Biologic SP-200 potentiostat

We are proud to offer the Biologic SP-200 potentiostat as a research-grade measurement tool for electrochemistry experiments. Hummingbird Scientific's electrochemistry tip and Biologic's SP-200 potentiostat can be used in combination for corrosion experiments, electrochemistry, electrolysis, and battery and photo-voltaic research.

## Liquid TEM Holder System Options



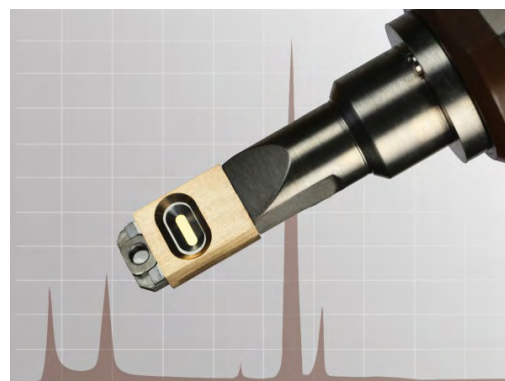
### Heating

Our heating system is optimized for moderate temperature requirements. Each chip features its own thin-film heater, which heats the contents of the liquid cell to the boiling point of your solution (max 200 °C).

The system's custom heating-control box features closed-loop temperature control and integrated protection against overheating and overpowering. Hummingbird's heating chips are specially calibrated for this system in order to ensure optimal capability.

### Spectroscopy

Hummingbird Scientific's liquid TEM holder includes an energy-dispersive X-ray spectroscopy (EDS) option for spectroscopic measurement. Our specialized chips ensure the thinnest possible liquid layer, allowing for electron energy loss spectroscopy (EELS) inside the liquid cell. This in turn allows researchers to perform direct elemental analysis and mapping at high magnifications. The EDS liquid-cell holder's large viewing angle ensures direct access from the sample to the EDS detector.



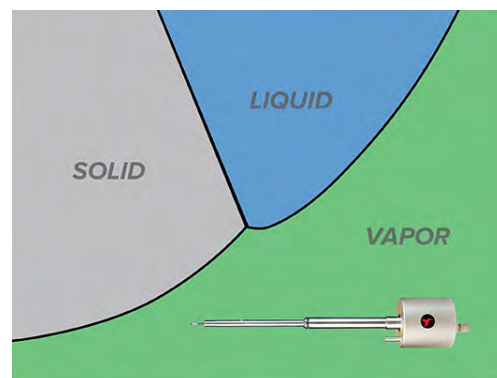
### Cross-Correlative Imaging

Our liquid system's unique removable holder tip allows for correlative imaging of transmission electron, scanning electron, X-ray, and optical microscopy of samples in liquid environments. Dedicated holders are available for each technique. All holders can interface with the same liquid-cell tip for site-specific imaging.

Correlative imaging allows researchers to acquire data across different length scales. It also allows for the acquisition of complementary data: high-resolution internal microstructure with TEM and X-ray, surface topography with high magnification and high depth of field in SEM, and lower magnification screening with optical microscopy. And it supports the use of different spectroscopy techniques, including fluorescence, X-ray absorption spectroscopy, energy-dispersive X-ray spectroscopy (EDS), and electron energy loss spectroscopy (EELS).

### Vapor Delivery System

Hummingbird Scientific's low-pressure vapor system allows researchers to introduce water vapor into the sample chamber of our fluid TEM sample holders, thus providing greater control over in-situ reaction conditions and protecting delicate biological samples. The system is available as an add-on to Hummingbird's liquid and gas holders and can be used with all existing environmental cell systems.





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## Liquid TEM Holder System Options

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### TEM Safety

Careful preparation of your samples and system are essential for effective use of environmental holders. A critical component of any holder system is a high-vacuum leak check station.

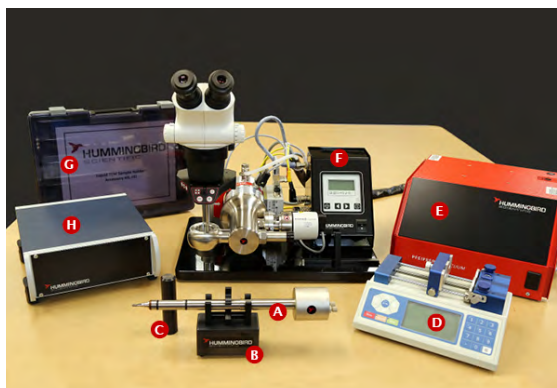
Our high-vacuum pumping station is a compact, all-in-one vacuum storage and seal-checking mechanism for TEM specimen holders. The station features short pumping and venting times, a low base pressure (10-6mbar), and a glass viewing port for the holder tip. The integrated stereo-microscope allows researchers to inspect and test the seal of a liquid or gas cell assembly before loading it into the TEM, crucial for protecting vacuum quality. A convenient, easy-to-use control-panel and a compact design make the check station a worthwhile addition to your electron microscopy laboratory.



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### System Components

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- A.** Liquid-Flow Holder
- B.** Liquid Holder Stand
- C.** Liquid Holder Tip Cover
- D.** Microfluidics Syringe Pump
- E.** High-Vacuum Pump
- F.** Seal Checking Station with Integrated Microscope
- G.** Accessory Kit and Liquid Cell Starter Batch. More accessories, along with a wide array of specialty chips, are available at our Web Store.
- H.** Optional Thin Film Heater Controller Power Supply
- I.** Optional Biologic Potentiostat (see page 2)

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### Available For

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TECNAI/TITAN/CMX00 SUPER TWIN, X-TWIN, ULTRA-TWIN



HITACHI



2010/2100/ARM, HR/ARP POLE, URP/UHR POLE, GRAND ARM



ZEISS

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### Award Winning

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Hummingbird Scientific's Liquid flow holder allows scientists to image samples in flowing or static liquids, at atomic resolution. This system is a complete, all-in-one solution, opening up exciting new avenues for materials characterization.

This ground-breaking product was the winner of the Tibbets Award (pictured) for Small Business Innovation Research in 2010 and the Federal Lab Consortium Award in 2011. The Microanalysis Society of America awarded the 2011 Birks Award for the first in-situ liquid TEM electrochemical study performed with the patented **Hummingbird Scientific Liquid Flow TEM Holder**.

Our award-winning liquid ElectroChemistry holder was the first commercial holder to allow liquid electrochemical experiments inside the TEM.



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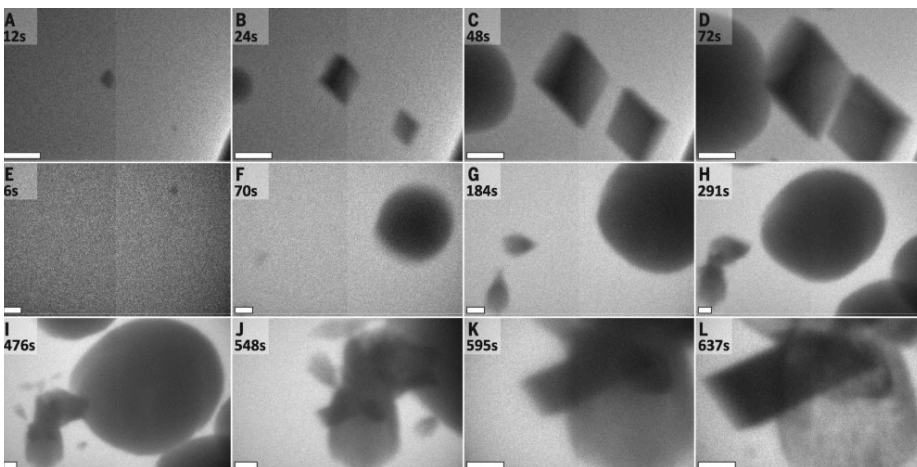
## Application Example

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### The Origins of a Mineral

In a study published recently in *Science*, researchers at Lawrence Berkeley, Pacific Northwest National Laboratories, and the University of Washington used Hummingbird Scientific's dual-flow liquid TEM sample holder to observe calcium carbonate crystal nucleation directly. Their research reveals the presence of multiple simultaneously-operating nucleation pathways and calls into question traditional assumptions about the nature of the nucleation process.

"For a decade, we've been studying the formation pathways of carbonates using high-powered microscopes," explains Dr. Jim DeYoreo, the project lead, in a PNNL press release. "But we hadn't had the tools to watch the crystals form in real time. Now we know the pathways are far more complicated than envisioned in the models established in the twentieth century."



Concurrent formation of multiple phases. All scale bars are 500nm

Reference: M.H. Nielsen, S. Aloni, J.J. De Yoreo. "In situ TEM imaging of  $\text{CaCO}_3$  nucleation reveals coexistence of direct and indirect pathways," *Science* vol. 345 iss. 6201 (2014) pp. 1158-1162. Image courtesy of M.H. Nielson et al. Copyright © 2014, American Association for the Advancement of Science.

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## Selected Publications

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**Continuous Flow:** J.M. Miller, D.H. Alsem, N. Salmon, N.E. Johnson and J.E. Hutchison. "Functionalized Surfaces to Improve Imaging Conditions in Liquid Cell Transmission Electron Microscopy." *Microscopy and Microanalysis*, 20:Suppl. 3 (2014), pp. 1140-1141

**Dual Flow/Mixing:** P. J. M. Smeets, K. R. Cho, R. G. E. Kempen, N. A. J. M. Sommerdijk, and J. J. De Yoreo. "Calcium carbonate nucleation driven by ion binding in a biomimetic matrix revealed by in situ electron microscopy", *Nature Materials Letters*, Published Online 01/26/2015

**Static Cell:** M.H. Nielsen, J.R.I. Lee, Q. Hu, T. Yong-Jin Han, and J.J. De Yoreo. "Structural evolution, formation pathways and energetic controls during template-directed nucleation of  $\text{CaCO}_3$ ." *Faraday Discuss.* 159 (2012) pp. 105-121.

**Electrochemistry:** P. Abellan, B. L. Mehdi, L.R. Parent, M. Gu, C. Park, W. Xu, Y. Zhang, I. Arslan, J.G. Zhang, C.M. Wang, J.E. Evans, and N.D. Browning "Probing the Degradation Mechanisms in Electrolyte Solutions for Li-Ion Batteries by in Situ Transmission Electron Microscopy" *Nano Lett.* 14:3 (2014) 1293-1299

**Spectroscopy:** Jungjohann, Katherine L., J. E. Evans, J. A. Aguiar, I. Arslan, and N.D. Browning. "Atomic-Scale Imaging and Spectroscopy for In Situ Liquid Scanning Transmission Electron Microscopy." *Microscopy and Microanalysis* 18, no. 03 (May 2, 2012): 621-627

**Cross-Correlative:** T.J. Woehl, S. Kashyap, E. Firlar, T. Perez-Gonzalez, D. Faivre, D. Trubitsyn, D.A. Bazylinski and T. Prozorov. "Correlative Electron and Fluorescence Microscopy of Magnetotactic Bacteria in Liquid: Toward In Vivo Imaging" *Scientific Reports* 4, 6854 (2014)

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