Forecast:
Storm clouds dispersing?

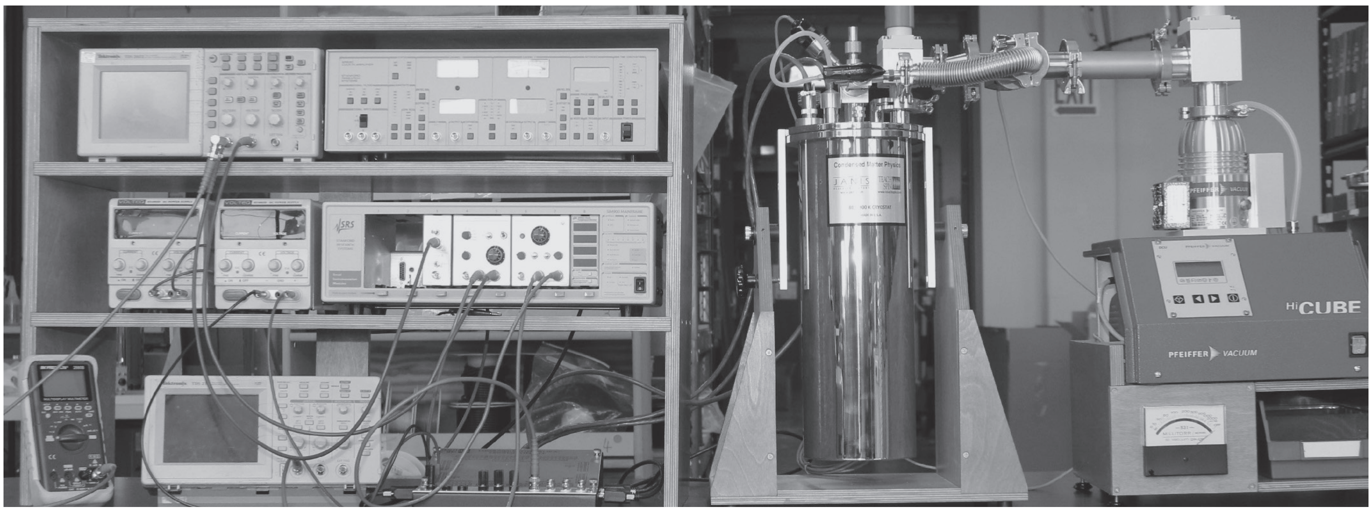
The Relaxation Times

2495 Main Street
Buffalo, NY 14214
(716) 885-4701
www.teachspin.com

VOL.V NO. 11 ***NEWSLETTER OF TEACHSPIN, INC.*** ***February 2022***

Your students' journey into Condensed-Matter Physics

Here's hoping that you've managed to stay healthy and productive in these turbulent times! We thought we might remind you of our popular CMP offerings, aimed at bringing to you, and to your students, the possibility of conducting student-directed explorations in condensed-matter physics.



Fitting a whole condensed-matter physics lab-station in 1.9 meters of shelf space – dewar right of center, vacuum system at right.

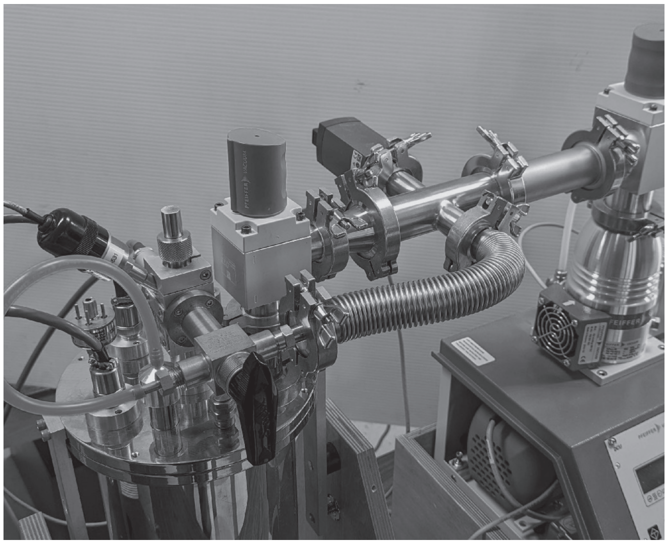
Our CMP innovations came to market in 2017, and have continued to develop since then. We started with the realization that whole classes of CMP experiments only needed access to moderately low temperatures, plus careful temperature control of samples. After some agonizing, we decided to keep costs low, and reliability and accessibility high, by choosing liquid nitrogen (LN2) as a cryogen, and by contenting ourselves with coverage in the 80 - 350 K temperature range. Now let's review how the project grew from there:

The cryogen needed a dewar, and the dewar needed a vacuum space, and the vacuum space needed mechanical and electrical access; from there the project 'designed itself', even before we decided what physics packages and experiments to put into this 'infrastructure'. Reflecting on five years of our production, and of customers' experiences, with these cryostat systems, we can share some points-of-pride with you:

We offer a classy and robust dewar, made exclusively for us by Janis, Inc. out of stainless steel. It has a size and holding capacity neatly matched to the needs of undergraduate student laboratories, and it's been wholly reliable for our users. We decided early on to offer it with a modern oil-free vacuum-pumping system from Pfeiffer, Inc. (though users may supply their own high-vacuum systems, if they wish). And we designed and built the right sort of temperature-measurement, and temperature-control, capabilities into our supporting electronics.

Quite apart from the physics results, think of what such a package offers in the way of *experiential learning* for your students. They encounter the least-expensive cryogen, locally available to nearly all our customers, and easily handled safely. They learn to assemble a vacuum system out of modern ISO fittings, with genderless O-ring connections, that serves the vacuum needs of the dewar, and of the internal experimental space inside it. They encounter an oil-free diaphragm forepump, and a modern (and air-cooled) turbomolecular high-vacuum pump, and will routinely obtain working pressures (under 10^{-5} Torr) within half an hour of a warm startup. We've included a wide-ranging gas-pressure gauging system, integrated with the pumping system. For those of you who cut your teeth on oil-dripping forepumps and water-cooled diffusion pumps, it will come as a welcome surprise to encounter 'turn-key vacuum' capability without tears. Note too that this versatile pumping-system is reconfigurable, and likely has other applications in your laboratory.

continued on p.2



The vacuum 'plumbing' joining the dewar's top flange to the pump system. Note two right-angle valves; note vacuum gauge at back.

Turn now to the experiences in temperature measurement and control. We picked 'transdiodes' for temperature measurement in our system, because they are so simple to use, inexpensive to replicate, and easy to read out. There's even some good semiconductor physics in explaining why a diode's forward voltage drop, under 10-μA constant-current excitation, ought to depend nearly linearly on the absolute temperature. So in our supporting electronics we include a 'small instrument module' or SIM from SRS, Inc. which excites, and reads out, up to four of these thermometers.

That SIM, in turn, takes one slot of a 'SIM crate', which will hold up to 8 single-width SIMs. So we built the rest of our supporting electronics to fit into single- and double-width SIMs also depending on the power supply that's part of the crate.

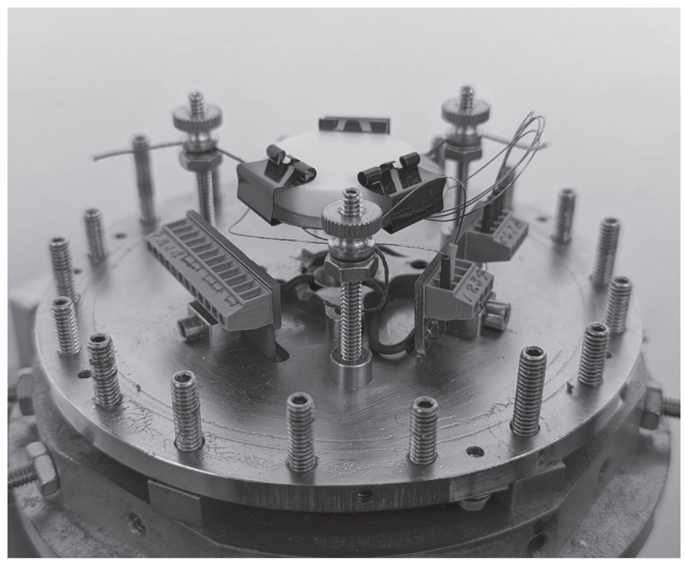
One of the first of the SIMs we designed to support the dewar is our special 'PI temperature controller', which reads out the (transdiode-derived) temperature of the experimental baseplate in our dewar, and then applies the right amounts of heat (resistively) to maintain it at a chosen or 'target' temperature. This servomechanism is another learning opportunity for students, perhaps the first one they've encountered which allows the student full control of the 'proportional' and 'integral' terms built into its algorithm. We routinely achieve temperature resolution, and stability, of better than 0.1 K over the full 80-350 K temperature range.

So already at this point, students will have learned something about cryogenics, vacuum, and temperature measurement and servo-control. From a narrowly-physics point of view, that's all just infrastructure for what comes next – namely, the physics experiments. But from an education-and-training point of view, think how applicable all this experience is to future careers in research, development, academia, and industry!

What the infrastructure supports

A working TeachSpin CMP dewar thus offers, in its interior, a temperature-controlled baseplate onto which our experiments, or *your students'* special-project or student-research experiments, can be mounted. That whole plate can be temperature-stabilized, or temperature-ramped, over a wide range. Experiments on this baseplate can live inside the main vacuum space of the dewar, or they can be sealed inside one of our two 'inner cans' to give a space that can be evacuated as well, or can be backfilled with the gas, and to the pressure, desired. So for example, some of our experiments have this interior sample space filled to one-atmosphere pressure with dry nitrogen gas, which serves as a 'transfer gas' for cooling a sample suspended in it.

Students also have full electrical access to experiments in this space, via 12 uncommitted wires available for inputs and outputs. We've dealt with the issue of vacuum feedthroughs on these wires, and have also arranged convenient and reliable solderless connection techniques for both ends of each of these wires.



The specific-heat experiment: an alumina sample atop the instrumented 'addendum', itself suspended by three Kevlar lines.

Students also have mechanical access to this space, even under operation, as we've arranged for a centerline access port down the axis of the dewar, from a quick-connect seal at the top to the interior of the sample space. In some experiments, this offers the chance for real-time sample exchange to the interior of even a cold dewar; in other experiments, this offers the possibility of mechanical translation or rotation of objects inside the sample space.

We know that in our CMP offerings, all this infrastructure accounts for the majority of the costs to users. But with our developments, such a financial investment in cryogenic, vacuum, and electronic capabilities will continue to be useful for many years to come. A TeachSpin CMP system will provide an arena for a host of experiments, including ones that you (and we) haven't yet thought of.

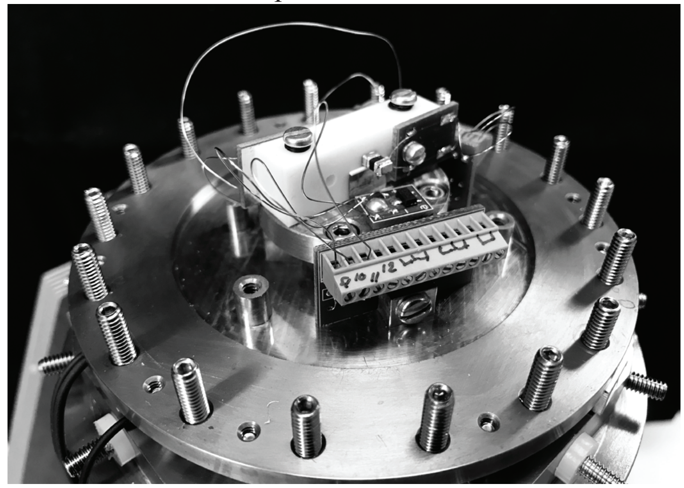
What experiments are already available

Now moving from foundational capabilities to physics pay-offs, let us remind you of experiments that are already available from TeachSpin. Each of these experiments is designed to fit inside our CMP system; each arrives complete with experimental samples, and with all the support electronics it requires.

We'll start with the newest first: We offer the best **superconductivity** experiment yet, in making visible three phenomena associated with (high-temperature) superconductivity. We include a well-crafted 4-wire sample-bar of BSCCO, so that the resistivity of the sample can be followed from starting temperatures down to, and through, the superconducting transition near 108 K. Students will enjoy establishing an upper bound for its resistivity in the 'super' state. For the benefit of users with the Magnetic Susceptibility apparatus, we provide another 'chip' sample of BSSCO, so they can monitor the prodigious change in its magnetic susceptibility at the transition – the cold-enough sample goes into a markedly diamagnetic state. And we also provide an annular 'ring' sample of BSCCO, with a magnet in place to provide initial flux, and a magnetic-field probe to monitor (via the field it creates) the persistent current that develops when the magnet is withdrawn. Students will discover the phenomenon of 'critical current density', and will learn its dependence on temperature. They can also follow the flow of persistent currents for *days on end* – how small an upper bound can your students put on the resistivity of a superconductor from this sort of observation?

Adiabatic Demagnetization: Also known as 'magnetic cooling', this thermodynamic phenomenon is sure to fascinate students, the more so as one of the samples provided (metallic gadolinium) offers its magnetic cooling in the neighborhood of 300 K. We include a compact permanent-magnet field source, capable of >0.9 T, as a method for ordering the magnetic moments in a sample, and we monitor the effects on the sample's temperature by the artful use of thermocouples. Students can see the few-Kelvin cooling that occurs when, in the right starting-temperature range, the sample is pulled out of the high-field region, and its moments become disordered to serve as an 'entropy sponge', hence providing actual refrigeration.

Specific Heat: when you add a metered pulse of heat to a sample, its temperature rises – but by how much? The specific heat tells you, and experiments like this are foundational thermodynamics. We've used electrical heating, and supply a pulsed-heating SIM that permits precise measurements of the heat delivered; we've used transdiode transducers (and our 'high-gain utility-amplifier' SIM) to detect the modest (< 1 K) temperature rises that follow. Our sample-set includes samples showing marked deviations from the classical (Dulong-Petit) behavior of specific heat as a function of temperature. It also includes samples showing solid-to-solid *phase transitions* – how should that show up in this sort of data?



Peeking from its white mount, one end of a BSCCO bar sample for 4-wire resistivity measurement.

Magnetic Susceptibility: if you build an 'air-core transformer' with primary and secondary coils, then you know that filling its interior with a magnetic material can increase the emf you get from the secondary (for fixed ac-excitation of the primary). An optimized version of such a transformer is our 'Hartshorn coil', a differential transformer easily capable of seeing enhancements (or decreases) of even a few parts per million in that secondary emf. Alternating-current excitation of the primary current, and lock-in detection of the secondary emf, allows the measurement of the magnetic susceptibility of the sample inside the transformer. This measurement can be done as a function of temperature. Curie paramagnetism can easily be distinguished from other sorts of para- and dia-magnetism.

Electrical Transport: The easiest electrical measurements that can be performed on a sample are of its resistance, and of the Hall potential that develops given a sample current and a (perpendicular) static magnetic field. We supply with this experiment some well-crafted SIMs providing constant currents (from 1 μA to 100 mA) to a sample. We suggest the remarkably useful 'high gain utility amplifier' that permits detection of (differential) voltage drops across a sample in the 0.1 μV - 10 V range. So the resistivity of metal, and of semiconductor, samples can be measured over a huge range. We also include a dismountable coil capable of generating a modest magnetic field at the sample's location, making it possible to measure the Hall coefficient in semiconductor samples.

That's five experiments already, and we're thinking of even more. Do you have a favorite experiment that you'd like added to the list? Or, do you have a favorite sample that ought to be showcased using one (or more!) of these experiments? Let us know – we're happy to have an 'open architecture' in our CMP program.

TEACH SPIN
Tri-Main Center, Suite 409
2495 Main Street
Buffalo, NY 14214-2153

PRSRT STD
US POSTAGE
PAID
Buffalo, NY
Permit No. 2

Inside:

Condensed-Matter Physics:
Infrastructure & Experiments

Hoping to see you at the TeachSpin exhibition trailer
'Food Truck for the Physics Mind'
at the APS March meeting, 14-18 March 2022 in Chicago

We also welcome you to **ALPhA Immersions**
on the TeachSpin experiment of your choice
at our site in Buffalo, NY, 20-24 June 2022
see **https://advlab.org/Immersions2022**