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Inside This Issue

ON OUR COVER

RS1 Stage 1 tank inspection. The Cryogenic Demonstration Mission will launch in 2023 and demonstrate in-space transfer of cryogenic liquid hydrogen (LH_2). *Image: ABL Space Systems*

FEATURES

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From the Executive Director

As the days begin getting shorter and colder here in Chicagoland, the CSA team is hard at work bringing you the latest and greatest news in the world of cryogenics. In this issue of ***Cold Facts***, we bring you stories on medical applications, hydrogen technology, testing labs and research services, updates on the James Webb Telescope and advancements in fundamental understandings of physics.

For the better part of the last eight months, we have been focused on the planning and coordination of the 29th Space Cryogenics Workshop which is scheduled to take place virtually on November 15-16, 2021. By the time you receive this issue of ***Cold Facts***, there's a good chance the 29th SCW will have passed. So rather than encouraging you to register for the event, I'd like to take a moment to thank the team that helped make the first ever virtual Space Cryogenics Workshop a success.

First and foremost – the SCW co-chairs. Amir Jahromi and Mark Kimball of NASA's Goddard Space Flight Center were faced with the nearly impossible task of leading the SCW planning efforts as the COVID-19 pandemic raged on. On top of that, they navigated planning SCW through a management change at CSA. Amir and Mark, thank you for being patient with me as I learned the ropes, and for leading the planning of SCW so flawlessly! I'd also like to thank the former SCW co-chairs who answered the call when we needed advice and guidance – Michael Meyer, Franklin Miller, Adam Swanger and Ali Hedayat. Your time and effort do not go unnoticed.

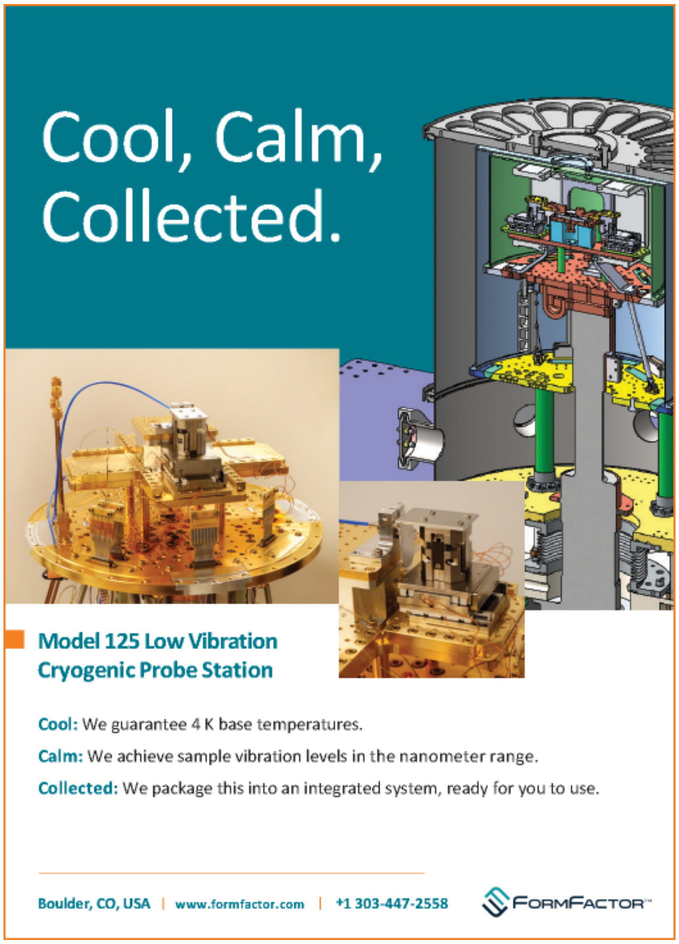
Next, I'd like to thank former CSA executive director Laurie Huget, and former CSA registered agent Werner Huget for providing important historical context and advice throughout the planning of SCW. I hope we didn't bring you too much stress during your much deserved retirement!

Last but not least, I'd like to thank the team here at CSA that is working diligently behind the scenes – graphic designer Israel Reza, online marketing manager Jo Snyder, advertising coordinator Lea Martinez, and ***Cold Facts*** editor Tate Paglia.

The Space Cryo Workshop isn't the only thing keeping us busy here at CSA. We are also happy to announce we'll be hosting the Foundations of Cryocoolers Workshop on June 27, 2022 in conjunction with ICC. The workshop will once again be taught by Dr. Ray Radebaugh. Keep your eyes peeled for more information and registration in the near future.

As 2021 comes to a close, we have begun the production process for the 2022 Cryogenic Buyer's Guide which is due to publish on December 17. We strive to provide a resource that is as accurate as possible as a service to the cryogenic community. Although we are past the point where substantive changes can be made to company listings, we will make every effort to incorporate changes in your basic information like address, phone and website, provided that we receive it by November 30.

As always, I hope you enjoy this issue of ***Cold Facts***! ■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DOE Announces Nearly $8 Million to Help Reach Hydrogen Shot Goals through National Laboratory H2@Scale Projects

On October 8, the US Department of Energy (DOE) announced nearly $8 million for nine cooperative projects that will complement existing H2@Scale efforts and support DOE's Hydrogen Shot goal to drive down the cost of clean hydrogen by 80% within the decade. The selected projects, or cooperative research and development agreements (CRADAs), will leverage the Advanced Research on Integrated Energy Systems (ARIES) platform to enable the integration of hydrogen technologies in future energy systems, including energy storage and a specific focus on safety and risk mitigation.

GKN's HY2MEGA is the largest metal hydride storage unit on the market and ideally suited for energy supply applications where safety and compactness are crucial. *Image: GKN Hydrogen*

The selected projects will support the Biden-Harris administration's goal of net zero carbon emissions by 2050 by testing key hydrogen systems, including safety components and providing real-world data to guide future clean hydrogen deployments in the United States. "Achieving our Hydrogen Shot goals will require all of us – the research community, industry, government and all stakeholders – working together and leveraging each other's strengths and expertise," said Acting Assistant Secretary for Energy Efficiency and Renewable Energy Kelly Speakes-Backman. "These projects announced today will help us do just that by fostering collaboration between the private sector and DOE National Laboratories to bring clean and cost-competitive hydrogen to scale."

The following projects were selected from the 2021 H2@Scale CRADA Call Supporting ARIES:

Topic 1: H 2@ARIES—Integrated Hydrogen Energy System Testing/Validation

The National Renewable Energy Laboratory (NREL) and GKN Metallurgy will validate and demonstrate the dynamic operation of a 520 kg hydrogen metal hydride storage subsystem integrated with the ARIES megawatt-scale hydrogen capabilities with an award amount of $1,722,089.

NREL and GE Renewable Energy will optimize wind turbine design specifically for hydrogen production from electrolysis, and validate designs using NREL's ARIES facilities with an award amount of $500,000.

NREL, Southern California Gas and University of California Irvine will evaluate the interconnection and interoperability requirements for grid-forming fuel cell inverters to enable hydrogen technologies to functionally replace traditional power generation equipment with an award amount of $1,189,000.

NREL and the Electric Power Research Institute (EPRI) will collaborate on a PEM electrolysis hydrogen production project focused on grid integration, variable operation with renewables, system size optimization and modeling to study the scaling of future hydrogen systems with an award amount of $1,157,219.

Topic 2: Applied Risk Assessment and Modeling for H2@Scale Applications

Sandia National Laboratories (SNL) and Wabtec will perform risk assessments on a hydrogen-powered locomotive and tender design including fueling, onboard storage and transfer of hydrogen from tender car to locomotive with an award amount of $525,000.

Pacific Northwest National Laboratory (PNNL), Seattle City Light, Port of Seattle and SNL will perform a large-scale hydrogen storage risk assessment to accelerate the Port of Seattle and Seattle City Lights' adoption of hydrogen for energy storage and port operations with an award amount of $770,000.

PNNL, Tri-County Metropolitan Transportation District of Oregon (TriMet), and SNL will conduct a detailed set of risk assessments of TriMet's entire hydrogen system to support the agency's planned deployment of hydrogen buses with an award amount of $525,000.

Topic 3: Next-Generation Sensor Technologies

NREL, National Energy Technology Laboratory, Gas Technology Institute, EPRI and Paulsson, Inc. will explore emerging hydrogen leak detection technologies for outdoor wide area monitoring applications in support of the Low Carbon Resources Initiative with an award amount of $1,000,000.

NREL, Renewable Innovations, Inc., Boyd Hydrogen LLC and Element One, Inc. will implement advanced sensor technologies for more reliable hydrogen leak detection in indoor hydrogen infrastructure applications to improve safety with an award amount of $525,000.

"I'm thrilled to see the National Energy Technology Laboratory's expertise being leveraged to advance new, innovative technologies that can support the wide-scale deployment of hydrogen technologies. This significant funding for research on emerging leak detection technologies will help drive down the cost of hydrogen and ensure it can be produced, transported and used safely and efficiently across many hard-to-decarbonize sectors of the economy. As Chairman of the Energy and Natural Resources Committee, I will continue to advocate for innovative energy solutions that are critical to charting a path to a cleaner energy future," said US Senator Joe Manchin (D-WV).

"It's important for the United States to support an all-of-the-above approach and make investments in a variety of energy technologies, including hydrogen," Senator Shelley Capito (R-WV) said. "Today's announcement is welcome news that will deliver funding to support and advance research efforts that explore innovative solutions in clean energy."

These investments are administered by DOE's Hydrogen and Fuel Cell Technologies Office to increase industrial and stakeholder engagement in H2@Scale and ARIES through investment and active participation in CRADA projects with DOE's national laboratories. This announcement was also part of a week-long celebration of Hydrogen and Fuel Cell Day, held annually on October 8 in recognition of hydrogen's atomic weight of 1.008. ■

Shell-Led Consortium Selected by DOE to Demonstrate Feasibility of Large-Scale Liquid Hydrogen Storage

A consortium of public, private and academic experts led by Shell International Exploration and Production, Inc. (Shell), a subsidiary of Royal Dutch Shell plc, is pioneering an ambitious path to enable large-scale liquid hydrogen (LH_2) storage for international trade applications.

This is a largely untapped field with potential for advancing the global commercialization of hydrogen as an accessible, affordable and low carbon energy commodity. The announcement was made on October 13.

Shell and the consortium partners – including McDermott's CB&I Storage Solutions, NASA's Kennedy Space Center (including Space Cryogenics Workshop 2019 co-chair Adam Swanger), GenH_2 (CSA CSM) and the University of Houston – have been selected by the US Department of Energy's (DOE) Hydrogen and Fuel Cell Technologies Office to demonstrate that a large-scale LH_2 tank, with a capacity ranging from 20,000 to 100,000 cubic meters, is both feasible and cost competitive at import and export terminals. The DOE has awarded $6 million to finance the project, and Shell and CB&I Storage Solutions will both provide an additional $3 million each, for a total project fund of $12 million.

"A cost-effective, long-range hydrogen supply chain can have a transformative impact in shaping a sustainable future for energy," said Yuri Sebregts, chief technology officer for Shell. "Our consortium recognizes that this project can become a cornerstone in making that future possible. It's a sizable engineering challenge – but we have the right people, partners and outlook to deliver this first-of-its-kind LH_2 storage technology. ■

JERA Starts Hydrogen Utilization Demonstration at LNG Thermal Power Plant

JERA, a Japanese leader in LNG and renewables aiming to "spark the transition to a clean energy economy," received notice August 28 of acceptance of its grant application to conduct a demonstration project related to hydrogen utilization at an LNG thermal power plant in Japan under the New Energy and Industrial Technology Development Organization's Green Innovation Fund program.

As JERA looks to achieve the practical use of hydrogen at existing LNG thermal power plants, the project will switch a portion of the LNG fuel used to generate electricity to hydrogen at its large-scale LNG thermal power plant in Japan and evaluate the resulting operational and environmental characteristics over a period of approximately the next five years, through March 2026. This is Japan's first initiative to use a large amount of hydrogen as fuel in a large-scale commercial LNG thermal power plant.

Because hydrogen does not emit CO_2 when burned, it is seen as a prospective next-generation fuel for use in thermal power stations instead of fossil fuels. JERA aims to reduce its use of fossil fuels and to develop "zero-emission thermal power" that emits no CO_2 during generation by using hydrogen and ammonia as fuel to reduce CO_2 emissions by gradually increasing the utilization rates for both.

Based on the results of a feasibility study to be conducted early in the project period, JERA aims to construct hydrogen supply and other related facilities at its LNG thermal power plant, to install combustors capable of co-firing hydrogen and LNG in its gas turbines, and to switch approximately 30% of the LNG used for electricity generation (by volume, equivalent to approximately 10% of heating value) to hydrogen by fiscal 2025.

Under its "JERA Zero CO_2 Emissions 2050" objective, JERA has been working to eliminate CO_2 emissions from its domestic and overseas businesses by 2050, promoting the adoption of greener fuels and pursuing thermal power that does not emit CO_2 during power generation. JERA officials state that the company will continue to contribute to energy industry decarbonization through its own proactive efforts to develop decarbonization technologies while ensuring economic rationality. ■

Pusan National University Researchers Introduce Improved Water Splitting Method

A hydrogen economy is one way in which a carbon neutral world can thrive. At present, the simplest way to produce hydrogen fuel is electrochemical water splitting: running electricity through water in the presence of catalysts (reaction-enhancing substances) to yield hydrogen and oxygen. This reaction, however, is very slow, requires specialized conditions and noble metal catalysts and is overall expensive. Thus, achieving a high hydrogen yield in an energy-efficient manner at low cost is challenging. To date, hydrogen production from water splitting has not been successfully commercialized.

On August 31, a team of researchers from Pusan National University, Korea, led by Professor Kandasamy Prabakar, announced the development of a method to design a novel electrocatalyst that can solve some of the problems associated with present electrochemical water splitting. Their work was made available online on April 6 and published in print in the September 2021 issue of Volume 292 of ***Applied Catalysis B: Environmental***.

Describing the study, Prabakar says, "Today, 90% of hydrogen is produced from steam reforming processes that emit greenhouse gases into the atmosphere. In our laboratory, we have developed a non-noble metal based stable electrocatalyst on a polymer support which can effectively produce hydrogen and oxygen from water at a low cost from transitional metal phosphates."

Prabakar's team fabricated this electrolyzer by depositing cobalt and manganese ions, in varying proportions, on a Polyaniline (PANI) nanowire array using a simple hydrothermal process. By tuning the Co/Mn ratio, they have achieved an overall high surface area for the reactions to occur and, when combined with the high electron conducting capacity of the PANI nanowire, faster charge and mass transfer was facilitated on this catalyst surface. The bimetallic phosphate also confers bifunctional electrocatalytic activity for the simultaneous production of oxygen and hydrogen.

In experiments to test the performance of this catalyst, the team found that its morphology substantially decreases the reaction overpotential, thereby improving the voltage efficiency of the system. As a testament to durability, even after 40 hours of continuous hydrogen production at 100 mA/cm^2, its performance remains consistent where water splitting was possible at a low input voltage of merely 1.54V.

In addition to these advantages, the low cost of transition metals improves the overall cost-effectiveness of the process. Indeed, the system can be scaled and adapted for application to a myriad of settings. Speaking of possible future applications, Prabakar explains, "Water-splitting devices that use this technology can be installed onsite where hydrogen fuel is required and can function using a low energy input or a completely renewable source of energy. For instance, we can produce hydrogen at home for cooking and heating using a solar panel. This way, we can achieve carbon neutrality well before 2050." ■


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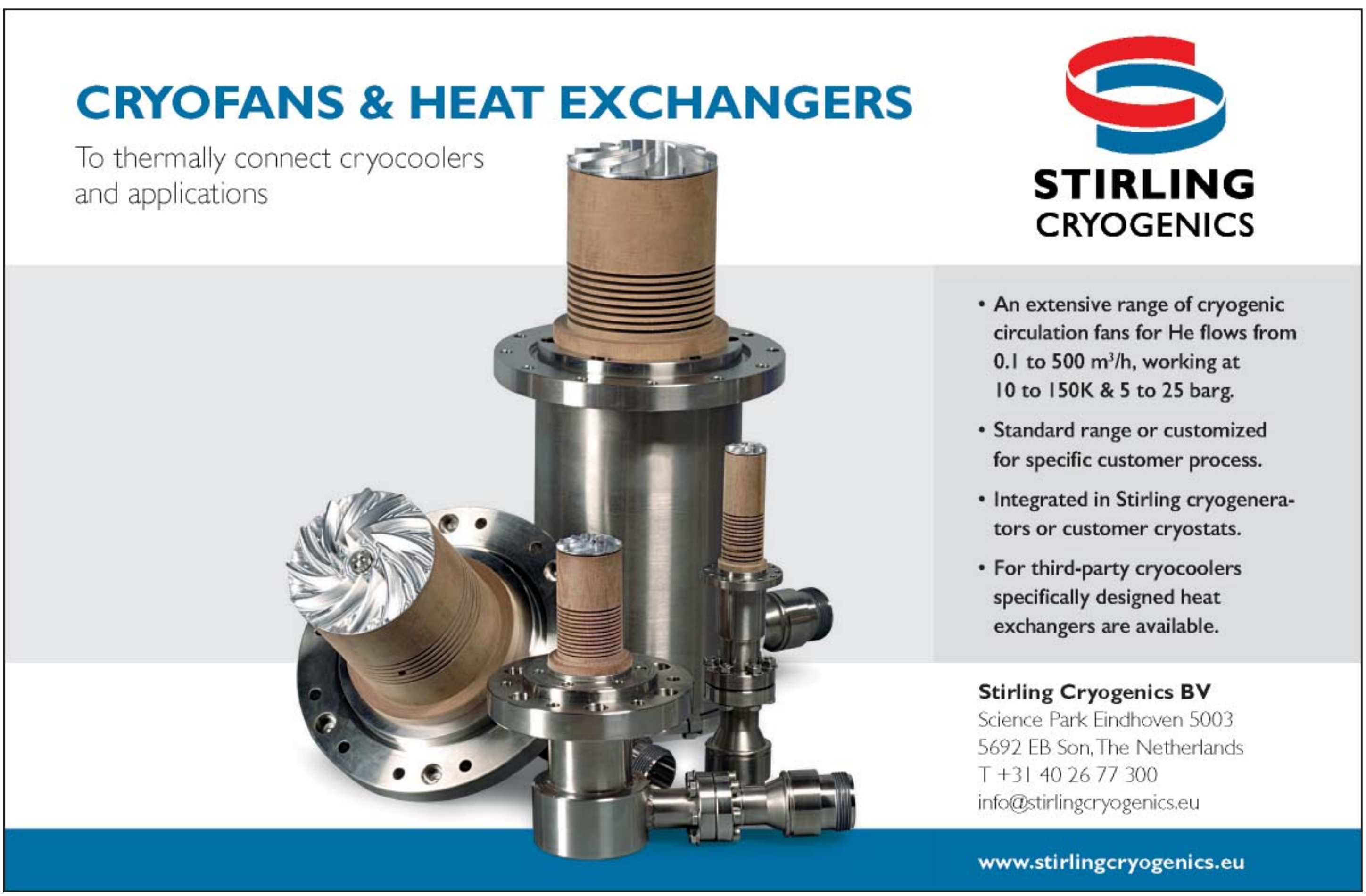
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Ballard Power Systems, Quantron AG Announce Partnership to Develop Hydrogen Fuel Cell Electric Trucks

Announced on September 7, the partnership of US-based Ballard, a developer of fuel cell technologies, and Quantron AG, a German electric vehicle producer, is expected to accelerate deployment and market adoption of fuel cell technologies in both regions. Initial collaboration will focus on the integration of Ballard's FCmove™ family of heavy-duty fuel cell power modules into Quantron's electric drivetrain and vehicles. Fuel cell electric truck platforms currently in development include a 7.5-ton delivery truck, a 44-ton heavy-duty work truck and a municipal waste collection truck. Initial deployment of fuel cell electric trucks is scheduled for the second half of 2022.

In Europe, various government subsidies and incentives will be available to vehicle fleet operators. Specifically, Germany has recently committed to covering up to 80% of conversion costs from internal combustion engines to alternative drives through its e-mobility support program.

Andreas Haller, founder and chairman of Quantron AG, said, "This is another important milestone for Quantron's global growth. The cooperation with Ballard enables us to bring customized hydrogen commercial vehicles with fuel cell electric drives to the market. Today we embark on a journey of joint development and production of fuel cell electric commercial vehicles."

Heavy-duty vehicles have a higher impact than any other type of vehicle on emissions and air pollution in cities. The critical role of hydrogen and fuel cell technologies in the decarbonization of this sector has now been recognized in many European countries' hydrogen strategies, and both have been deemed critical to the industry-wide decarbonization effort. The Quantron-Ballard collaboration will leverage the synergies between battery electric and fuel cell electric powertrains to enable a greener, faster and more cost effective decarbonization of transportation.

Robert Campbell, chief commercial officer of Ballard Power Systems, added, "Ballard is looking forward to collaborating with Quantron to accelerate the adoption of fuel cell technology for truck applications, bringing its 8th generation of heavy-duty fuel cell power module experience built upon 85 million kilometers of road service from over 3,500 buses and trucks powered by our leading PEM technology." ■

Five Things You Might Not Know About Hydrogen Shot

October 8 was Hydrogen and Fuel Cell Day, marking a perfect opportunity to learn more about the Department of Energy's (DOE) Hydrogen Energy Earthshot, or "Hydrogen Shot," to make clean and affordable hydrogen a reality.

Here are five facts you may not know about Hydrogen Shot:

1. It is the first of DOE's Energy Earthshots.

The Energy Earthshots initiative, launched by Energy Secretary Jennifer Granholm in June, is DOE's effort to set ambitious and achievable targets to make key clean energy technologies affordable in the next decade, as well as create new jobs and tackle the Biden administration's energy and climate goals. The first Earthshot – Hydrogen Shot – sets an ambitious yet achievable "1-1-1" goal to reduce the cost of hydrogen to $1 per 1 kilogram in 1 decade. The Hydrogen Shot is the first of a series of up to eight Energy Earthshots DOE will be launching over the next year.

2. It includes multiple ways to produce hydrogen from domestic energy resources.

Hydrogen Shot applies to all hydrogen production pathways under the DOE Hydrogen Program's portfolio. These pathways include hydrogen produced from renewable energy sources including solar and wind, as well as nuclear power, using processes such as electrolysis with water and electricity as inputs or advanced technologies that harness heat and light to produce clean hydrogen. Additional pathways convert natural gas or other feedstocks into hydrogen while ensuring emissions are mitigated through carbon capture and storage (CCS) technologies.

3. It also addresses carbon emissions for hydrogen production from non-renewables.

Hydrogen Shot will not only lower cost but will also require clean hydrogen. For the case of hydrogen from non-renewables, the Hydrogen Shot is pushing these pathways to lower life-cycle greenhouse gas emissions by at least 90% from current levels. Various processes such as reforming with waste or biomass (with CCS), pyrolysis and other innovations will contribute to helping drive down emissions.

4. It brings together perspectives from diverse people, communities and regions.

Achieving Hydrogen Shot is an all-hands-on-deck effort that will require engagement from multiple stakeholders with diverse perspectives, expertise

Bloom Energy Announces Commercial Availability of Hydrogen-Powered Fuel Cells

On September 29, California-based Bloom Energy announced the commercial availability of its Hydrogen Energy Servers — 100% hydrogen-powered fuel cells that deliver on-site, 24/7, zero carbon electricity — all in a simple, modular and flexible design. Orders are being accepted with commercial shipments expected to begin in 2022.

Dozens of countries across the globe have committed to net zero emissions goals by 2050, and more than 30 countries have hydrogen-specific strategies that are being activated. Hydrogen is well suited for an array of applications – including transportation – and unlocks a net zero emissions future for hard-to-decarbonize heavy industries.

Electricity production is the second largest contributor to greenhouse gas emissions in the US, with 62% of electricity produced through the combustion of fossil fuels. Hydrogen technologies, like hydrogen-powered fuel cells, significantly reduce the environmental impacts associated with electricity production and eliminate greenhouse gas emissions. As the hydrogen economy grows, the need for hydrogen for energy storage and power generation will accelerate. For power generation, as production of hydrogen becomes ubiquitous, Bloom Energy's Hydrogen Energy Servers will be another option in moving to net zero emissions.

"Bloom Energy has a complementary suite of solutions and strong partner ecosystem supporting both ends of the hydrogen economy — clean hydrogen production and efficient hydrogen utilization," said Deia Bayoumi, vice president of product management at Bloom. "With these offerings and collaborative solutions, our technology can be applied for today's needs and in the future as the hydrogen economy becomes more robust."

Renewable energy sources, such as solar and wind, are critical to clean power generation. However, these sources are also inherently intermittent, with periods of excess energy production that generate more electricity than transmission lines can carry. Curtailment is therefore needed to balance generation with consumption. By pairing renewables with the Bloom Electrolyzer, curtailment can be avoided; hydrogen can be produced at scale, compressed and stored for long duration during periods of excess renewable production.

The addition of hydrogen-powered fuel cells allows the stored hydrogen to be converted into 24/7, zero carbon electricity that can be used when energy is needed. This also enables islanded or remote communities with renewable resources to self-generate fuel for reliable electricity, without needing to import fuel to their local community.

"Our technology is distinctively suited to help hydrogen adopters thrive in the hydrogen economy," said Bloom executive vice president and chief technology officer Venkat Venkataraman. "Bloom Energy's hydrogen-powered fuel cells are built on the company's solid-oxide platform that has higher efficiencies compared to other fuel cell technologies, generating more electricity from less hydrogen, and providing reliable power helping organizations meet their zero carbon objectives."

Bloom Energy's solid-oxide platform is positioned to address both the realities of today's energy infrastructure and aspirations for the future energy ecosystem. Bloom microgrids demonstrate that needed modular and redundant power is possible today and they provide a cleaner replacement to backup diesel generators. Looking ahead, the fuel flexibility of Bloom servers enables an accelerated transition to the hydrogen economy with the use of natural gas, biogas, hydrogen or a blending of these fuels.

Bloom Energy's Hydrogen Energy Servers have undergone testing as part of a pilot project with SK ecoplant in Ulsan, South Korea, for the last five months with successful results. Throughout operation, the hydrogen-powered fuel cells provided 24/7, zero carbon electricity at efficiency levels exceeding expectations. ■

Hydrogen Shot... *Continued from page 12*

and experience to ensure clean hydrogen benefits are distributed equitably across communities and regions. Through formal Hydrogen Shot requests for information and annual summits and related workshops, the DOE Hydrogen Program is ensuring perspectives from a diverse range of stakeholders, including regional leaders, local groups, environmental justice community members, energy researchers, businesses among others, are brought to the table to inform decisions on future Hydrogen Shot research, development and demonstration activities.

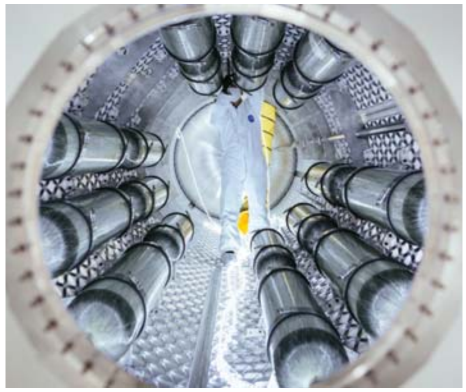
5. It fosters career development opportunities for graduates in multiple hydrogen-related disciplines.

With the broad range of hydrogen production pathways under Hydrogen Shot, building and fostering a bench of diverse, talented and dedicated clean energy students and early professionals will be critical as DOE and stakeholders work to bring Hydrogen Shot to reality. Through the DOE Hydrogen Shot Fellowship, announced by Secretary Granholm during the first Hydrogen Shot Summit, the DOE Hydrogen Program will bring in graduate students and early career professionals to work alongside DOE Hydrogen Program managers to help us achieve this bold goal and ensure its economic, environmental and societal benefits are distributed equitably across the communities that need them the most. Hydrogen Shot fellows will engage in Hydrogen Shot-related work from a wide range of research areas in hydrogen production, storage, delivery and end uses, as well as other crosscutting disciplines such as technology acceleration, analysis and communications. ■

TESTING LABS AND RESEARCH SERVICES

ABL Space Selected for NASA Cryogenic Demonstration Mission

On September 16, ABL Space Systems announced that it has been selected as the launch provider for the NASA Cryogenic Demonstration Mission. Developed under a NASA Tipping Point contract awarded in 2020, the Cryogenic Demonstration Mission will launch in 2023 and demonstrate in-space transfer of cryogenic liquid hydrogen (LH_2), the most challenging but highest-performing propellant for lunar and deep space exploration. The mission will help demonstrate numerous novel cryogenic propellant management technologies and help forge a path to sustainable Artemis operations on the moon and beyond. This selection marks ABL's first NASA science mission award and its 60th mission with the prime contractor, Lockheed Martin.



RS1 Stage 1 tank inspection. The Cryogenic Demonstration Mission will launch in 2023 and demonstrate in-space transfer of cryogenic liquid hydrogen (LH_2). *Image: ABL Space Systems*

In support of the mission, ABL will leverage the flexibility of the GS0 deployable launch system, which is built to rapidly activate new launch sites and support unique customer missions. The GS0 functionality will be extended to meet NASA's mission need for LH_2 operations. ABL will also advance RS1 with a hydrogen-compatible fairing and payload support systems.

"We do a lot of work at ABL focused on serving our customers' needs in the immediate future. Science missions like this let our team look further out onto the horizon and contribute to NASA's long-term roadmap of human exploration of the solar system," says Dan Piemont, president of ABL Space Systems. "This cryo demo is a great example of the unique science missions enabled by low-cost, dedicated launch, and we're happy that RS1 was chosen." ■

KEK to Launch a New World Premier International Research Center

The High Energy Accelerator Research Organization (KEK) has been selected to host a new world premier international research center for quantum-field measurement systems. It is the 14th World Premier International Research Center Initiative (WPI) promoted by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT). The announcement was made on October 18.

Dr. Masashi Hazumi (left) and Dr. Masanori Yamauchi (right). *Image: KEK*

The new center's name is the International Center for Quantum-field Measurement Systems for Studies of the Universe and Particles (QUP). It will be directed by Dr. Masashi Hazumi, a professor at the Institute of Particle and Nuclear Studies, KEK, and the PI of LiteBIRD, a space mission led by Japan Aerospace Exploration Agency (JAXA) for cosmic microwave background (CMB) measurements. He also worked in various international projects for cosmology and particle physics, including Belle at KEK. "I am thrilled about the launch of QUP. As the director, I want to support the Principal Investigators (PIs) and other researchers in taking on the challenge of making a giant leap forward. I am also delighted with new studies toward social implementation with the research cooperation of the Toyota Group," Hazumi says, "and as one of the PIs, I will also work on the LiteBIRD satellite that I initiated and is the flagship project of QUP."

QUP will integrate particle physics, astrophysics, condensed matter physics, measurement science and systems science in the works of invention and development of new systems for measuring quantum fields (space-time with particles and quasiparticles created and annihilated plus associated physical quantities). KEK is in the process of establishing QUP, aiming to start its activities by the end of this year.

The KEK Director General, Dr. Masanori Yamauchi, welcomes the new initiative: "KEK will support QUP's missions strongly. There are many research groups around KEK having great interest in the activities at QUP. Collaboration with those groups will also be beneficial. I hope that the outcome from QUP will significantly boost KEK's research as a whole."

QUP has a characteristic of the global and diverse nature of quantum field measurement. In addition to basic science, it will promote interdisciplinary research that transcends the boundaries of industry and academia. QUP will also promote corporations with world top institutes by opening three satellite offices in the Toyota Central R&D Labs in Aichi, Japan, JAXA's Institute of Space and Astronomical Science in Kanagawa, Japan, and the University of California, Berkeley in the US.

"I am exhilarated to launch a satellite of QUP at Berkeley. I believe it has great potential for making great discoveries in many fields, including my field of CMB observations," says Professor Adrian T. Lee of UC Berkeley.

Principal investigators will join from Japanese and foreign institutes, including AIST, Tohoku University and the University of Oxford (UK), in addition to investigators from KEK and the three satellite offices mentioned above.

"QUP will break national boundaries and accelerate the development of novel instruments for measuring quantum fields. I am excited to start the discovery voyage with this talented team," Professor Daniela Bortoletto at the University of Oxford says. ■

Center for Bright Beams Awarded $22.5 Million in Grant Renewal; Prepares Medical, Industrial Advances

by Rick Ryan, Cornell Laboratory for Accelerator-based Sciences and Education, cunews@cornell.com

A collaboration of researchers led by Cornell University has been awarded $22.5 million from the National Science Foundation (NSF) to continue gaining the fundamental understanding needed to transform the brightness of electron beams available to science, medicine and industry. The announcement was made on September 20.

Cornell doctoral student Ryan Porter prepares a superconducting radio-frequency cavity made from the element Nb3Sn in the clean room of Newman Lab. *Image: Cornell University*

The Center for Bright Beams (CBB), an NSF Science and Technology Center, was created in November 2016 with an initial $23 million award to Cornell and partner institutions. The center integrates accelerator science with condensed matter physics, materials science and surface science for the advancement of particle accelerator technologies.

These insights will help improve the performance and reduce the cost of accelerator technologies around the world and develop new research instruments that transform the frontiers of medicine, biology, materials science, condensed matter physics, particle physics and nuclear physics, as well as new manufacturing tools that enable chip makers to continue shrinking the features of integrated circuits.

"Currently, all of these scientific and industrial instruments are limited by the brightness of their beams," said Ritchie Patterson, director of the Center for Bright Beams, and the Helen T. Edwards Professor of Physics in the College of Arts and Sciences. "CBB is the only center in the world that brings together an interdisciplinary approach to address critical challenges limiting accelerator science. This renewed funding will help us build on our successes to date, which have benefited enormously from our collaborative approach."

The center is based at Cornell's Laboratory for Accelerator-based Sciences and Education (CLASSE), and includes scientists from Cornell's Departments of Physics, Applied and Engineering Physics, and Chemistry and Chemical Biology, as well as scientists from seven other universities and three national labs. CBB is organized into three interdependent research themes related to beam production, acceleration, dynamics and control. These themes combine to focus on the creation of smaller, brighter electron beams, making them more accessible in the near future for labs, hospitals and private industry.

Since 2016, CBB's research has resulted in an electron source with ten times smaller size and divergence than common sources in use today. This will open new pathways for drug design by allowing biologists who study the structure and dynamics of single molecules to reduce their data collection time by 90%.

The center has also created new methods for beam acceleration that match today's performance but are vastly simpler to operate. CBB's high field Superconducting Radio Frequency (SRF) cavities will cut the construction costs of the largest accelerators by up to billions of dollars by reducing the length of tunnels and the number of cavities. Relaxed cavity operating temperatures will simplify cryogenics, making beams more accessible to universities and industry, or "a beam in every basement."

There are roughly 30,000 industrial and medical accelerators in use today, with annual sales of $3.5 billion. David Muller, CBB's director of knowledge transfer in Phase I and the Samuel B. Eckert Professor of Engineering in the School of Applied and Engineering Physics, said the center's research aims to increase that number as brighter beams bring new capabilities. "With this new round of funding, CBB will pursue the most productive research to achieve even higher brightness," Muller said, "and we will ready these methods for accelerators being used by chip manufacturers and industrial leaders, as well as smaller research institutions."

For more than a century, major advances in physics, chemistry and biology have resulted from scattering, imaging, spectroscopy and colliding beam experiments.

But in order to see something new you must do something new, and these experiments are now becoming increasingly dependent on time-resolved information which allows for such things as true movies of molecular machines at work. Examples of other cutting-edge methods dependent on advances in particle beams include beams for tumor treatment, electron microscopes capable of imaging individual atoms, instruments for wafer metrology, and the Large Hadron Collider.

While CBB continues to make significant advances in the particle accelerator frontier, its greatest impact may be the result of educating future scientists in electron beam technology. "These large-scale colliders, intense X-ray sources and electron microscopes are essential tools for science and industry, but the US educates few students to understand the bright electron beams on which they depend for success," said Melissa Hines, associate director of CBB and professor of chemistry. "Our graduate students are helping to bridge this gap, and approximately half of CBB's students are in areas that the DOE has identified as areas of critical need. Our most important output is almost certainly going to be the large number of graduate students and postdocs, most of whom will go off to have a big impact in a variety of different fields."

CBB also includes Arizona State University; Brigham Young University; Northern Illinois University; University of California, Los Angeles; University of Chicago; University of Florida; University of New Mexico; Fermi National Accelerator Laboratory (CSA CSM); Lawrence Berkeley National Laboratory; and SLAC National Accelerator Laboratory (CSA CSM), and affiliates at other institutions.

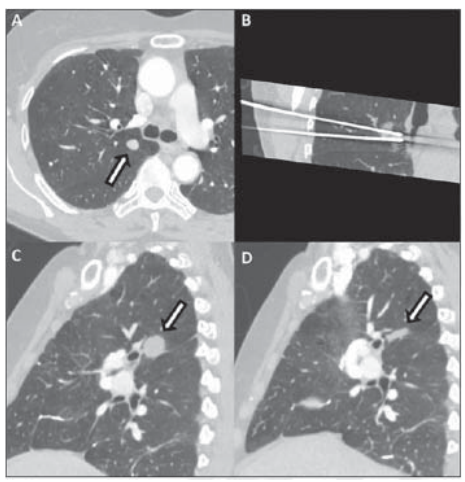
The NSF Science and Technology Centers: Integrative Partnerships program supports innovative, potentially transformative research and education projects that require large-scale, long-term awards. The centers foster cutting-edge research, education of the next generations of scientists and broad distribution of the knowledge and technology produced. ■

New Study Explores Percutaneous Image-Guided Microwave, Cryoablation for Lung Sarcoma

According to American Roentgen Ray Society's (ARRS) ***American Journal of Roentgenology (AJR)***, percutaneous image-guided microwave and cryoablation allow for repeat minimally invasive treatment of sarcoma lung metastases with manageable, predominantly mild complications. The study was published on October 7.

"High primary technical success, local control and overall survival support microwave and cryoablation for treating sarcoma lung metastases," concluded 2019 ARRS Scholar, Florian J. Fintelmann, of Massachusetts General Hospital and Harvard Medical School. Noting that ablation modality and tumor location did not affect local progression (p>.05), "treatment failure was low, especially for small tumors," he continued.

Fintelmann and colleagues' retrospective cohort study included 27 patients (16 women, 11 men; median age of 64 years; Eastern Cooperative Oncology Group performance score, 0–2) who underwent 39 percutaneous CT-guided ablation sessions (21 microwave, 18 cryoablation; 1–4 sessions per patient) to treat 65 sarcoma lung metastases (median 1 tumor per patient, range 1–12; median tumor diameter 11 mm, range 5–33 mm; 25% non-peripheral) from 2009 to 2021.



(A) Pre-procedure axial image from contrast-enhanced CT scan of chest demonstrates a 1 cm solid right upper lobe nodule adjacent to right mainstem bronchus (arrow). (B) Intra-procedural coronal reformatted image shows two cryoablation probes within nodule. (C) 1-month follow-up sagittal chest CT image shows expected post-ablation changes encompassing treated nodule (arrow). (D) 1-year follow-up sagittal chest CT image shows expected involution of treatment zone into flat bandlike scar without residual tumor (arrow). *Image: American Roentgen Ray Society (ARRS), American Journal of Roentgenology (AJR)*

Estimated two-year local control rate for microwave versus cryoablation was 95% and 98% for tumors ≤1 cm, and 62% and 79% for tumors >1 cm. Additionally, tumor size ≤1 cm was associated with decreased cumulative incidence of local progression (p=.048).

Reiterating the suitability of both percutaneous microwave and cryoablation for treating tumors ≤1 cm, whether peripheral or non-peripheral, "complications, if they occur, are not life-threatening," the authors of this AJR article added.

Founded in 1900, the ARRS is the first and oldest radiological society in North America, dedicated to the advancement of medicine through the profession of radiology and its allied sciences. An international forum for progress in medical imaging since the discovery of the X-ray, ARRS maintains its mission of improving health through a community committed to advancing knowledge and skills with an annual scientific meeting, monthly publication of the peer-reviewed ***American Journal of Roentgenology (AJR)***, quarterly issues of ***InPractice*** magazine, AJR Live Webinars and Podcasts, topical symposia, print and online educational materials, as well as awarding scholarships via The Roentgen Fund®. ■

The Most Powerful MRI Scanner in the World Delivers Its First Images

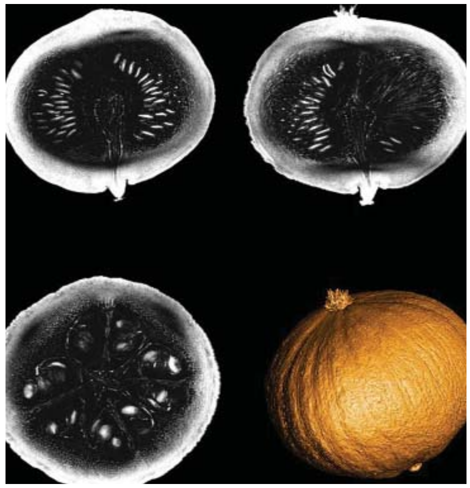
In September, the 11.7 Tesla MRI of the Iseult project, the most powerful in the world for human imaging, has just unveiled its first images. They validate the entire process that has enabled, thanks to multiple technological breakthroughs, the transformation of an "outstanding" magnet, delivered in 2017 to the French Alternative Energies and Atomic Energy Commission (CEA) Paris-Saclay site, into an "imager." This MRI, designed by CEA engineers and researchers together with Siemens Healthineers, will enable major advances in fundamental research, cognitive sciences and in understanding brain pathologies.

A pumpkin: this unusual object was chosen for its multiple textures by CEA engineers and researchers to make the first images with the world's most powerful 11.7 T human whole-body MRI of the Iseult project, installed at NeuroSpin at CEA-Paris-Saclay.

With a resolution of 400 microns in three dimensions, the images of the cucurbit prefigure the prowess that the scientific and technical teams of the CEA and their partners will be able to achieve in order to probe the human brain for the benefit of fundamental research, cognitive sciences and in understanding brain pathologies. These first acquisitions validate the entire process that has made it possible, thanks to multiple technological breakthroughs, to transform an "outstanding" magnet into an MRI machine.

"The development of the Iseult project magnet has been an exceptional human, technological and industrial adventure. To see it come to fruition with the achievement of the magnet nominal field strength – 11.7 T – followed by these first high-resolution images, which are so promising, is a real source of pride for all of us," adds Anne-Isabelle Etienvre, director of CEA-Irfu.

These images are the culmination of 20 years of research that have enabled us to apply innovative technological



The inside of a pumpkin as seen by Iseult. *Image: CEA*

developments made for CERN to medical research. This achievement is also the fruit of a Franco-German cooperation initiated in 2006, which involved academic partners, the University of Freiburg, and industrial partners Bruker Biospin, Alstom, now part of General Electric, Guerbet and Siemens Healthineers. Siemens Healthineers has installed the MAGNETOM 11.7 T imaging equipment that has enabled the acquisition of these first images.

"With our 7 Tesla scanner MAGNETOM Terra firmly established for clinical use and our recent introduction of 0.55 Tesla High-V MRI, it is exciting to me to keep pushing the envelope even further. I am very happy that our joint team effort pays off now. We can't wait to see what exciting new insights imaging at 11.7T will bring and to continue our long-standing innovation track at ultra-high field,", says Arthur Kaindl, Head of MRI at Siemens Healthineers.

Nevertheless, several optimizations still need to be carried out to obtain images of a quality approaching a resolution of 100 to 200 microns at 11.7 T. Before the Iseult MRI is fully commissioned and the first in vivo images are acquired on a human subject, the teams will be working in the coming months on the final verifications of the imaging equipment and the first tests of the radiofrequency coil developed specifically for the Iseult project. In 2022, the European Aroma project will be further deployed to develop a methodology for the optimal operation of this MRI. Finally, once the health authorities have given their approval, the new MRI will be used to conduct research with the help of volunteers.

Stanislas Dehaene, director of NeuroSpin, the neuroimaging platform at CEA-Paris-Saclay, said, "Thanks to this extraordinary MRI, our researchers are looking forward to studying the anatomical and structural organization of the brain in greater detail. This work will undoubtedly lead to major clinical applications."

132 tons, 5 meters in length, 5 meters in external diameter and 90 cm in internal diameter (to allow the passage of a whole human body): these are the extraordinary dimensions of the magnet of the Iseult project, which reaches a nominal magnetic field of 11.7 teslas, much more powerful than that of standard hospital MRIs (typically 1.5 or 3 T).

To achieve this field, the magnet is powered by a current of 1,500 amps. The conductor coils are permanently cooled by helium in a superfluid state at 1.8 Kelvin (-271.35 °C). The magnetic field of 11.7 T is a world record in the field of MRI for such a volume, and an absolute record with this type of superconductor material.

This magnet was designed by a CEA team that had already designed Tokamak magnets and the magnets for the CERN detectors that led to the discovery of the Higgs boson. Its manufacture began in 2010 in the Alstom – now GE – plant in Belfort and will take six years. Nearly four years of installation and fine-tuning work to achieve the required field homogeneity will then have been necessary before it is ready for operational use in 2021. ■

Improvements in Microscopy Home in on Biology's Elusive Details

The ASU research group (from left): Abhishek Singharoy, John Vant, Jonathan Nguyen, Petra Fromme, Chitrak Gupta and Wade Van Horn. *Image: ASU*

Researchers at Arizona State University's Biodesign Center for Applied Structural Discovery and School of Molecular Sciences, as part of a multi-institutional research collaboration, are carrying the field of microscopy a step further by refining a technique known as cryogenic electron microscopy, or cryo-EM.

The technology involves flash-freezing a biological sample of interest, then using a beam of electrons to image and record thousands of 2D images, assembled by means of computer into an atomic profile of the sample's structure. Such density maps, as they are known, can then be converted into a detailed 3D image.

The method is particularly useful for ferreting out subtleties of protein structure which are often missed through conventional modelling strategies. Such information is critical for the understanding of health and disease. Since proteins are the primary targets of most pharmaceutical drugs, a fuller picture of their structure and function is essential for designing more effective treatments, with fewer side effects.

The new research describes a method for producing more accurate structures through a sophisticated statistical method known as maximum entropy. This approach — which has been effectively applied in many domains ranging from protein research and neuroscience to ecology and the behavior of animal populations — is ideally suited to the refinement of cryo-EM data, producing the most unbiased structural model of a biological sample.

Molecules like proteins assume complex, three-dimensional forms and can also change shape during their functioning.

"Complex biomolecules actually exist in an ensemble of states, and you can take a kind of snapshot of these molecules in different conformations," said Abhishek Singharoy, corresponding author of the new study and an assistant professor at ASU.

Some of these conformations may persist in time, but others are extremely ephemeral, coming and going on time scales measured in billionths of a second.

The new technique described allows researchers to model these transitory structures, which can play a vital role in biological processes but are often missed using traditional cryo-EM techniques.

The ASU team is joined by researchers from the University of Illinois; Purdue University; Department of Mathematics and Computer Sciences, Grenoble, France; the University of Florida; and Stony Brook University.

"This work highlights how the integration and streamlining tools developed by labs with complementary expertise can be used in combination with experimental data to advance our understanding of structural biology," said Alberto Perez of the University of Florida.

The group's findings appear in the current Cell Press journal ***Matter***.

One of a triad of methods

A range of modern imaging techniques allows researchers to investigate crucial molecules of life, including proteins, nucleic acids and even single molecules. Cryo-EM, a variant of electron microscopy, was first developed in the 1970s. The technique was later recognized with the 2017 Nobel Prize in chemistry, awarded to Jacques Dubochet, Joachim Frank and Richard Henderson, pioneers in the field, for developing cryo-electron microscopy for the high resolution structure determination of biomolecules in solution.

Like other forms of electron microscopy, cryo-EM replaces photons of light used for illuminating samples in conventional light microscopy with a beam of electrons. Because resolution of an object by microscopy is limited to roughly one-half the wavelength of light used to illuminate the sample, the shorter wavelengths of electrons, which are dependent on their momentum, enable scientists to visualize tiny structures with astonishing clarity.

Cryo-EM is one of a triad of methods used for research in structural biology, joining X-ray crystallography and nuclear magnetic resonance spectroscopy (NMR). Each method has its own strengths. While X-ray crystallography can produce stunningly detailed structures in very high resolution, especially using X-ray free electron lasers or XFEL technology, the method struggles to image large or complex structures, including membrane proteins, as they are challenging to crystalize. The same is true of NMR.

Cryo-EM comes of age

Imaging large, complex biomolecules is where cryo-EM hits its stride, because samples do not require crystallization and can be studied in their native surrounding environment. In recent years, a new generation of high-speed cameras have been developed to help capture the dynamic activity of various biomolecules. The tricky part arises when researchers try to produce a 3D structural model from the raw data provided in the initial 2D density map of the molecule. Previously, this has involved making an educated guess about what the structure may look like and fitting the information provided in the density map into this model.

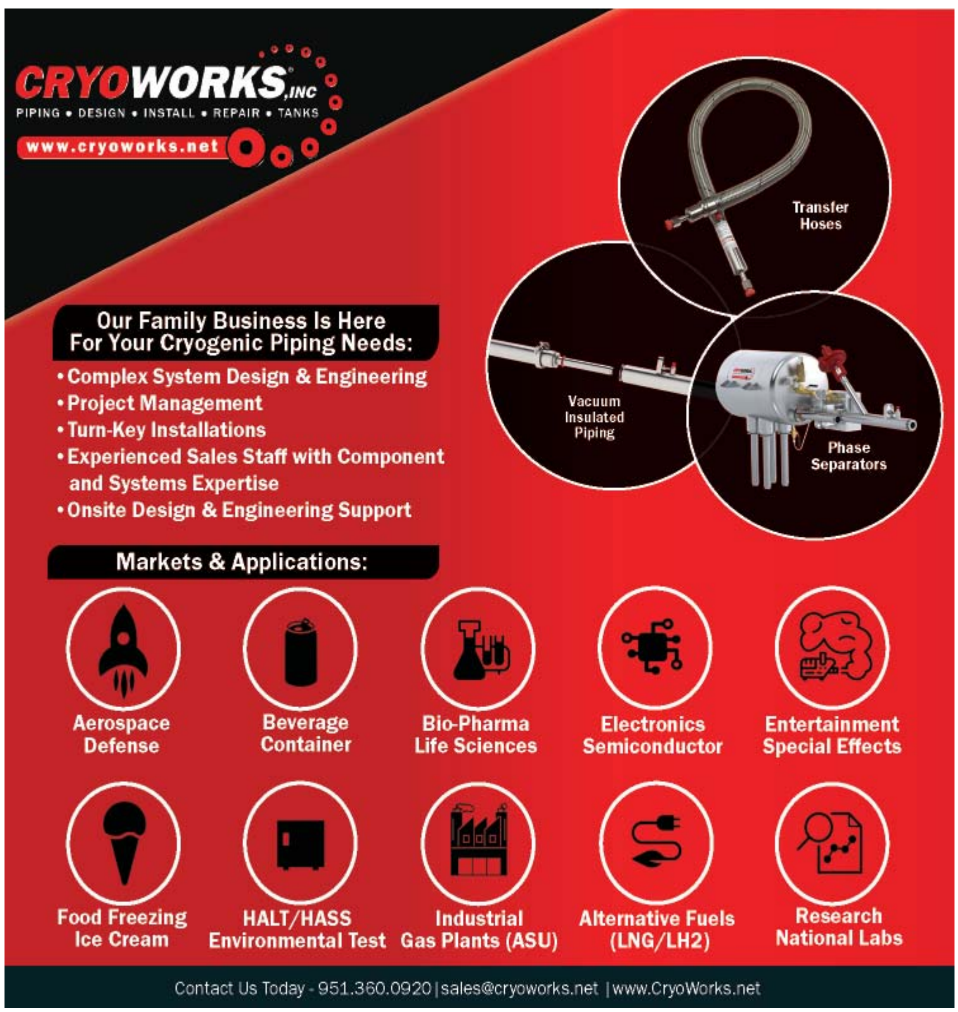
Inaccuracies can arise from the overfitting of raw data into the structural model. The new approach instead makes no assumptions about the final molecular structure apart from constraints that are known with certainty. By producing the most unbiased structure, this maximum entropy approach can help researchers fill in the blanks during structural determination, better accounting for the contribution of various conformations that may exist at very low frequency. A full understanding of biomolecules like proteins requires the simultaneous determination of the structures of all the relevant states that these molecules can assume.

To visualize this in simple terms, imagine trying to produce a model that illustrates the behavior of a boy who is standing still for an hour, except for occasional, fleeting movements of arms and legs. On average, nothing changes, and a resulting model of the boy would consist of a static, motionless image. A maximum entropy approach on the other hand would allow all various gestures, however brief, to contribute to the final image, yielding a much more accurate representation.

The new study presents six examples of elaborately folded proteins of various sizes, including large membrane and multi-domain systems. The results emphasize the ability of a maximum entropy statistical package known as CryoFold to discover molecular ensembles, including rare low-probability structures that have been experimentally validated and recognized as functionally relevant.

The maximum entropy technique can be used in conjunction with existing methods of data fitting in an iterative process capable of turning low resolution data into high resolution, 3D structures with a high degree of confidence. Such advances are helping cryo-EM reach its full potential by characterizing the entire conformational landscape of proteins and other important biomolecules.

"This work integrates multiple physics-based approaches to refine protein structures from cryo-EM data, providing not a single, static image of the protein, but rather a collection of structures, which is more representative of the true, dynamic nature of proteins," said Chitrak Gupta, co-author and a researcher in the Center for Applied Structural Discovery and School of Molecular Sciences. ■



Cryo Bios

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@esss.se

Georges Claude

Georges Claude led a career of constant innovation and improvement of technology. He was an engineer, inventor and businessman who developed the Claude cycle for liquefaction and refrigeration, helped to found Air Liquide (CSA CSM), invented and commercialized neon lighting and built the world's first ocean thermal energy conversion plant.

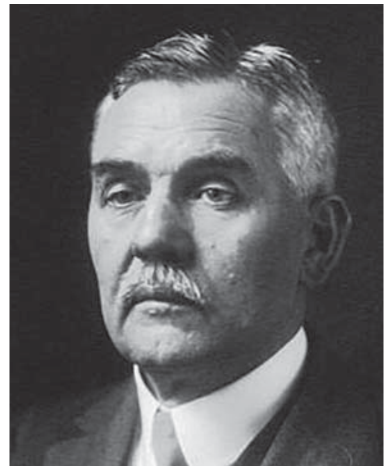
He was born in Paris and studied at the École de Physique et Chimie, graduating in 1886. After graduation, he held a number of positions including an inspector in an electrical cable factory, a manager of an electrical laboratory and the editor of a magazine covering topics in electricity. During this time, he suggested changes in the grounding of electrical equipment to reduce the possibility of electrocution.

Claude's first major innovation involved the storage of acetylene. Acetylene at the time was used as a source of lighting and was stored as liquid under high pressures. Unfortunately, acetylene stored in this manner was very explosive. Claude developed a way to more safely store acetylene by dissolving it in acetone. This technique greatly increased the use of acetylene as a lighting source and is essentially still used today for acetylene storage.

Claude next became interested in the liquefaction and separation of air into nitrogen and oxygen. Carl von Linde (***Cold Facts*** Vol 36, No. 2) had developed a way to continuously liquefy air in 1895 by precooling it and expanding it through a fixed orifice or value (Joule-Thomson expansion), and Claude knew that he could get more cooling for the same pressure difference if instead of expanding it through an orifice he made the air perform work by pushing on a piston. Linde was likely aware of this approach as well, but there were a number of problems with piston expanders, including heating due to friction between the piston and its surrounding casing, heat leak from the outside environment and freezing of the lubrication of the piston bearings. Claude addressed these issues and combining the piston expander with a precooling heat exchanger, developed what we know today as the Claude cycle. He first liquefied air using this technique in 1902. Today, cryogenic plants typically use a combination of the Claude and Linde approaches.

Ever the entrepreneur, Claude founded with Paul Delorme the Société L'Air Liquide in 1902. This was a company to exploit the liquefaction of air and its separation into component gases. Air Liquide today remains one of the largest industrial gas and cryogenics firms in the world.

At about the same time, a better understanding of the components of air was being developed. William Ramsey, an English chemist, had discovered a number of noble gases in air, including neon which constitutes 0.0018% of air by volume. While neon is quite rare, the large quantities of air that could now be liquefied and separated into their components meant that neon could be sold if a commercial application could be found. It is here that Claude's next contribution can be found.



Georges Claude

Born September 24, 1870

Died May 23, 1960

Saint-Cloud, France

The creation of light via a glow discharge caused by creating an electrical current in a sealed tube of gas was well known, and some commercialization had been done using nitrogen gas. Claude found that when neon was used in this way a very distinct bright red orange light was produced. He made improvements to existing tube designs, including altering the electrodes to prevent overheating, and first demonstrated neon light at the 1910 Paris Motor Show. Shortly afterwards, he patented neon lighting and founded the company Claude Neon. As part of Claude's commercialization efforts, he sold franchises of his company around the world, some of which exist today. The first neon signs in the United States are thought to be those installed in a Packard car dealership in Los Angeles in 1923, though there is some information that earlier signs existed in New York City.

Claude became quite wealthy via his neon lighting and air liquefaction work but unfortunately lost much of it funding his last major project. Ocean Thermal Energy Conversion (OTEC) uses the temperature difference between warm water on the surface of the ocean and cold water, deeper in the ocean, to produce electricity. Since the temperature difference between warm and cold ocean water is not very large, the efficiency of this process is low; but the temperature gradient is established by nature and thus cost free. This feature, coupled with the large amount of heat stored in the ocean, made OTEC worth investigating.

The concept of OTEC was first proposed by Jacques-Arsène d'Arsonval in 1881. There are two main approaches. One uses an intermediate fluid such as ammonia which is alternately evaporated and condensed by warm and cold ocean water in a closed Rankine cycle. During this cycle, the ammonia vapor drives a turbine producing electricity. The other approach injects warm ocean water into a near vacuum space, causing the water to evaporate. The resulting vapor then drives a turbo-generator producing electricity. The water vapor is then condensed by cold ocean water. It is this type of open cycle OTEC plant that Claude built.

He located the plant on the shore of Matanzas Bay, Cuba. Here there was warm surface water near a very deep drop-off that would provide cold water for the plant. He started building the plant in 1929 and while it did briefly produce electricity it suffered a number of problems, including being destroyed by a storm and the multiple loss of the long, deep cold water supply pipe. A subsequent attempt by Claude to build an OTEC plant on a ship also ultimately failed. Today, several small-scale OTEC pilot plants have been built.

During the Second World War, Claude was a strong supporter of the Vichy government in France and wrote a number of articles encouraging collaboration with Germany. After the war, Claude was convicted of collaboration and sentenced to life in prison. However, he was released in 1950 partly in recognition of his OTEC work. ■

850 Children Receive Stem Literacy Program at Edwards Vacuum Groundbreaking

by Lauren Nowicki, Chief Communications Officer, Dacon, lauren@laurennowicki.com

Edwards Vacuum, in collaboration with Marwick Associates, Equity Industrial Partners and Dacon, broke ground on the new 135,000 sf Manufacturing Center of Excellence on September 23. Specializing in technical products that utilize cryogenics for semiconductor manufacturing, chemical, life science, solar and R&D sectors, Edwards is currently hiring for 110 roles to staff the new facility spanning mechanical assemblers to engineers and scientists across various domains. The architectural design for this LEED facility is centered on four functional domains of manufacturing, labs, executive offices and warehousing. It is anticipated to open in the summer of 2022.

To mark the event, Edwards, Marwick, EIP and Dacon partnered with the literacy collaborative Haverhill Promise to fund the city's first STEM literacy program, earmarked at $20,000. Beginning next summer, the children ages 5-10 will have the opportunity to experience 30 lunch events in which they conduct a science experiment and are given a relevant book to take home. During the school year, children serviced by food pantries and after school programs will receive book bags with STEM-related experiments to build at home.

A total of 850 children will be touched by this program, with the end goal of every child having their own at-home library. "Research shows us that if children are not proficient readers by grade 3 it can have devastating effects not only in their ability to succeed in school, but also lifelong earning potential and overall health and well-being. Our goal is to change that trajectory," explains Jenny Arndt, Program Director… and it is working.

Just 3 years old, Haverhill Promise is one of only five literacy organizations in Massachusetts to win the coveted Bright Spot Community status from the Campaign for Grade-Level Reading. "Haverhill is an optimal choice for several reasons. Whereas most businesses tend to focus on ROI, Edwards focuses on cultural and human attributes. Haverhill offers diversity in both talent and culture with a strong sense of community. For this reason, we were attracted to building a STEM literacy program. We are excited that 850 children will be fed lunch while their minds are fed science and will be given books to take home. We believe this to be one of the few, if not only, STEM literacy programs in the state and hope that it will become the model for other communities. These are the future technologists who will be developing products at Edwards," explains Debbora Ahlgren, General Manager of Edwards Vacuum.

Lauren Nowicki, creator of the program and Chief Communications Officer for Dacon, adds: "We are not only creating the foundations of a building, but we are building foundations for life." ■

Cool Fuel

by Dr. Jacob Leachman, Associate Professor, Washington State University, jacob.leachman@wsu.edu

Hydrogen, Lenses and Lasers, Oh My!

The bar for getting the suffix of PhD after your name is high – you have to fundamentally change the philosophy in a field. As a faculty member responsible for training some of these individuals, I'm sometimes faced with the conundrum that advancing the philosophy implies that I have to change the way I was doing things. Thanks to newly minted Dr. Carl Bunge, I'm now trying to re-teach myself statistical thermodynamics while learning optics from scratch.

Carl's dissertation was the design and operation of a continuous, cryogenic, Raman spectroscopy system for measuring ortho-parahydrogen concentrations of a flow. In the August 2020 issue of ***Cold Facts*** Vol. 36, Issue 4, "Is It Parahydrogen or Para-Hydrogen," I gave you a preview of his room temperature measurements showing that the Raman system could resolve each of the J = 0, 1, 2, and 3 rotational modes of ortho- and parahydrogen. We had previously used the traditional method of using a hot-wire anemometer to back out the composition from the differences in thermal conductivity near 140 K. That system was a challenge, to say the least, as we were always having to replace all of the hot wires we busted.

Carl's spectrometer used a 532 nm green argon laser with horizontal polarization, 2-meter-long multimode fiber optics, and fused silica quartz lenses mounted in a ¼" Swagelok SS 316 cross. He found three of the lasers at my university's surplus in what may have been the find of the century. After tweaking the power levels and optical filter system Carl started generating spectrographs like the one in Figure 1 taken at 290 K and 16.7 bar pressure. You can see each of the four lower ro-vibrational energy transitions of hydrogen as the molecules are excited and then re-emit light read by the spectrometer. Compared to the old hot-wire anemometry method, this new method was like being able to see for the first time.

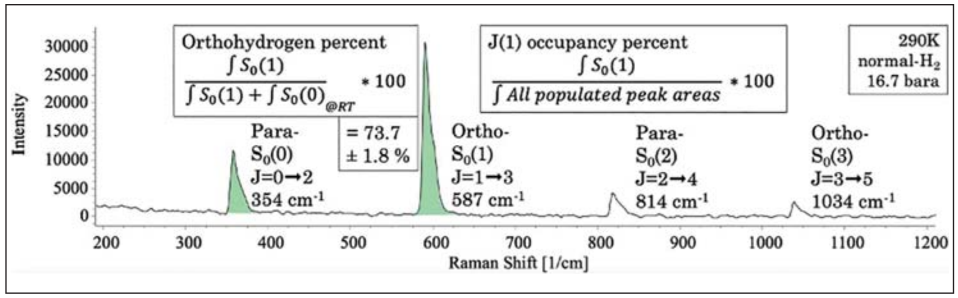


***Figure 1:** Rotational Raman spectrograph of hydrogen at 290 K and 16.7 bar.* *Image: Carl Bunge*

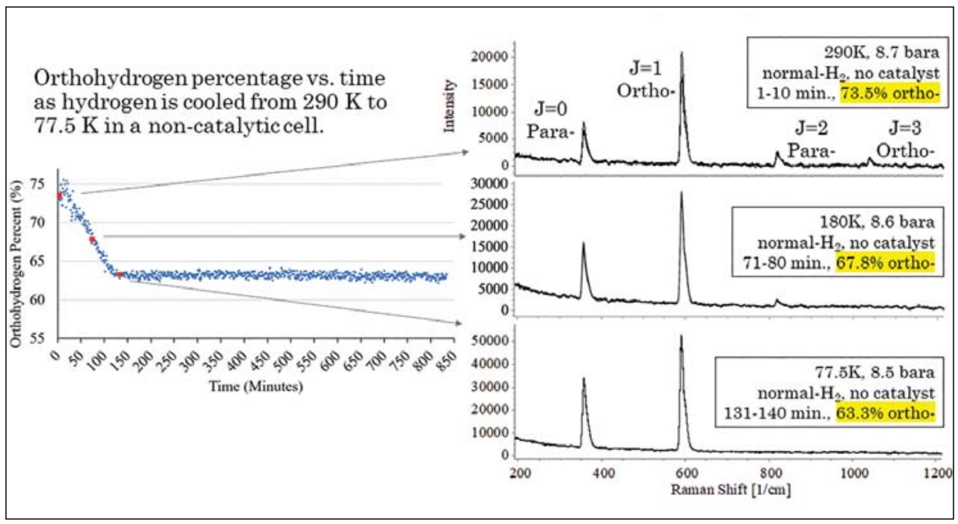


***Figure 2:** Spectrographs of hydrogen cooled in a non-catalytic cell at 290 K, 180 K, and 77.5 K.* *Image: Carl Bunge*

The room temperature values were acceptably near the anticipated 3:1 ratio of ortho-parahydrogen and the liquid hydrogen values were near 99.1% parahydrogen, also expected. We were excited. This is also when trouble began and how Carl learned why PhD's are hard. At any temperature in between ambient and 20 K his values were deviating significantly (<10%) and repeatedly from the expected ortho-parahydrogen equilibrium concentration predicted by statistical mechanics. Based on some recent publications in physics journals (that shall go unnamed), we were led to believe that the cause of deviations was due to only basing the equilibrium percentage of para-orthohydrogen on the J = 0 and J = 1 distribution, as those were the only peaks that could be resolved when the Raman technique was first developed. Now that we could resolve the higher peaks, were the statistical methods of old now wrong?

To resolve the source of discrepancies Carl decided to watch ortho-parahydrogen migration between energy levels during cooling from room temperature to 77.5 K in a non-catalytic measurement cell. This would tell us if hydrogen was moving uniformly between energy modes as sensed by the Raman probe, or if re-emission was mode specific. Figure 2 shows the migration of ortho- from 3→1 and para- from 2→0 as the temperature is reduced. Carl made the observation that the total ortho-parahydrogen concentration changed from 73.5% to 63.3% at 77.5 K when it should have remained constant. Natural ortho-parahydrogen conversion can only account for 0.02% of this conversion in 140 minutes at these low densities. NIST-calibrated sources showed the system was spot on. Raman spectroscopy would not be as easy as hoped.

Probing some old textbooks on the topic we found that even the simple differences in energy states of the hydrogen molecule have differing spectral intensities. More statistical thermodynamics. But once accounted for, Carl got his spectrometer agreeing with the ortho-parahydrogen percentages predicted by statistical thermodynamics. From what we can tell it's the first time anyone has done it with a continuous flow system and corrected for the differing spectral intensities between modes. With some post processing we hope to have a program to help others simply correct their Raman measurements to accurately agree with the statistical thermodynamic predictions.

Given the simplicity of Carl's setup, and the ability to measure composition at any temperature within the cryogenic regime, we don't plan to go back to the old thermal anemometry or other relative methods any time soon. And the statistical thermodynamic sages who developed the science of cryogenic hydrogen can rest at ease knowing that they still got it right. ■

NASA's James Webb Space Telescope Arrives in French Guiana After Sea Voyage

NASA's James Webb Space Telescope successfully arrived in French Guiana on October 12 after a 16-day journey at sea. The 5,800-mile voyage took Webb from California through the Panama Canal to Port de Pariacabo on the Kourou River in French Guiana, on the northeastern coast of South America. The world's largest and most complex space science observatory will now be driven to its launch site, Europe's Spaceport in Kourou, where it will begin two months of operational preparations before its launch on an Ariane 5 rocket, scheduled for December 18.

Once operational, Webb will reveal insights about all phases of cosmic history – back to just after the Big Bang – and will help search for signs of potential habitability among the thousands of exoplanets scientists have discovered in recent years. The mission is an international collaboration led by NASA, in partnership with the European and Canadian space agencies.

"The James Webb Space Telescope is a colossal achievement, built to transform our view of the universe and deliver amazing science," said NASA Administrator Bill Nelson. "Webb will look back over 13 billion years to the light created just after the big bang, with the power to show humanity the farthest reaches of space that we have ever seen. We are now very close to unlocking mysteries of the cosmos, thanks to the skills and expertise of our phenomenal team."

After completing testing in August at Northrop Grumman's Space Park in Redondo Beach, California, the Webb team spent nearly a month folding, stowing, and preparing the massive observatory for shipment to South America. Webb was shipped in a custom-built, environmentally controlled container.

After Webb is unloaded from the MN Colibri, it will be transported to its launch site, Europe's Spaceport in Kourou, French Guiana. *Image: NASA/Chris Gunn*

Late in the evening of September 24, Webb traveled with a police escort 26 miles through the streets of Los Angeles CA, from Northrop Grumman's facility in Redondo Beach to Naval Weapons Station Seal Beach. There, it was loaded onto the *MN Colibri*, a French-flagged cargo ship that has previously transported satellites and spaceflight hardware to Kourou. The *MN Colibri* departed Seal Beach Sunday, September 26, and entered the Panama Canal October 5 on its way to Kourou.

The ocean journey represented the final leg of Webb's long, earthbound travels over the years. The telescope was assembled at NASA's Goddard Space Flight Center in Greenbelt MD starting in 2013. In 2017, it was shipped to NASA's Johnson Space Center in Houston for cryogenic testing at the historic "Chamber A" test facility, famous for its use during the Apollo missions. In 2018, Webb shipped to Space Park in California, where it underwent three years of rigorous testing to ensure its readiness for operations in the environment of space.

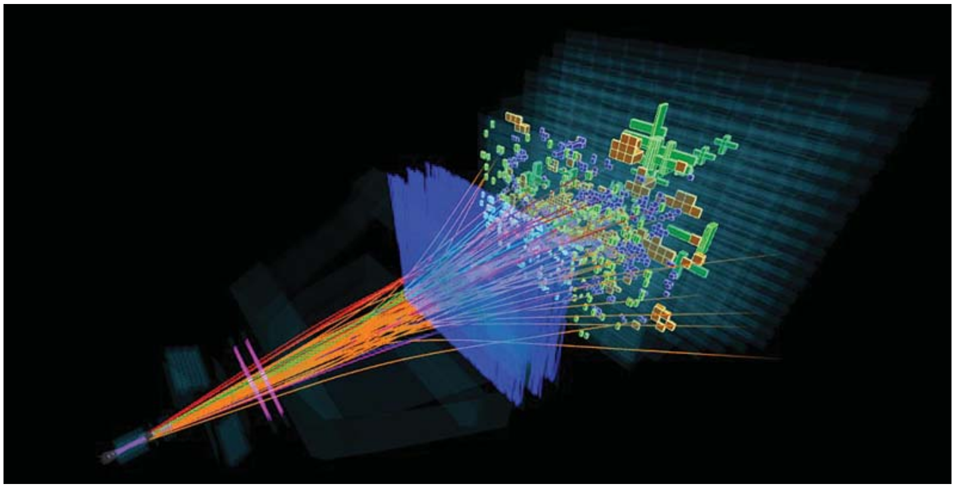
"A talented team across America, Canada, and Europe worked together to build this highly complex observatory. It's an incredible challenge – and very much worthwhile. We are going to see things in the universe beyond what we can even imagine today," said Thomas Zurbuchen, associate administrator for NASA's Science Mission Directorate in Washington. "Now that Webb has arrived in Kourou, we're getting it ready for launch in December – and then we will watch in suspense over the next few weeks and months as we launch and ready the largest space telescope ever built."

After Webb is removed from its shipping container, engineers will run final checks on the observatory's condition. Webb will then be configured for flight, which includes loading the spacecraft with propellants, before Webb is mounted on top of the rocket and enclosed in the fairing for launch.

"Webb's arrival at the launch site is a momentous occasion," said Gregory Robinson, Webb's program director at NASA headquarters. "We are very excited to finally send the world's next great observatory into deep space. Webb has crossed the country and traveled by sea. Now it will take its ultimate journey by rocket one million miles from Earth, to capture stunning images of the first galaxies in the early universe that are certain to transform our understanding of our place in the cosmos." ■

New Fundamental Physics? Currently Unexplainable Phenomena Reported from Large Hadron Collider Experiment

Results announced by the LHCb experiment at CERN have revealed further hints for phenomena that cannot be explained by our current theory of fundamental physics. In March 2020, the same experiment released evidence of particles breaking one of the core principles of the Standard Model – our best theory of particles and forces – suggesting the possible existence of new fundamental particles and forces. Now, further measurements by physicists at Cambridge's Cavendish Laboratory have found similar effects, boosting the case for new physics.



A typical LHCb event fully reconstructed. Particles identified as pions, kaon, etc. are shown in different colors.
Image: CERN, LHCb Collaboration

The Standard Model describes all the known particles that make up the universe and the forces that they interact through. It has passed every experimental test to date, and yet physicists know it must be incomplete. It does not include the force of gravity, nor can it account for how matter was produced during the Big Bang, and it contains no particle that could explain the mysterious dark matter that astronomy tells us is five times more abundant than the stuff that makes up the visible world around us.

As a result, physicists have long been hunting for signs of physics beyond the Standard Model that might help us to address some of these mysteries. One of the best ways to search for new particles and forces is to study particles known as beauty quarks. These are exotic cousins of the up and down quarks that make up the nucleus of every atom.

Beauty quarks don't exist in large numbers in the world as they are incredibly short-lived – surviving on average for just a trillionth of a second before transforming or decaying into other particles. However, billions of beauty quarks are produced every year by CERN's giant particle accelerator, the Large Hadron Collider, which are recorded by a purpose-built detector called LHCb.

The way beauty quarks decay can be influenced by the existence of undiscovered forces or particles. In March, a team of physicists at LHCb released results showing evidence that beauty quarks were decaying into particles called muons less often than to their lighter cousins, electrons. This is impossible to explain in the Standard Model, which treats electrons and muons identically, apart from the fact that electrons are around 200 times lighter than muons. As a result, beauty quarks ought to decay into muons and electrons at equal rates. Instead, the physicists at LHCb found that the muon decay was only happening around 85% as often as the electron decay.

The difference between the LHCb result and the Standard Model was about three units of experimental error, or "3 sigma" as it is known in particle physics. This means there is only around a one in a thousand chance of the result being caused by a statistical fluke.

Assuming the result is correct, the most likely explanation is that a new force that pulls on electrons and muons with different strengths is interfering with how these beauty quarks decay. However, to be sure if the effect is real, more data is needed to reduce the experimental error. Only when a result reaches the "5 sigma" threshold, when there is less than a one in a million chance of it being due to random chance, will particle physicists start to consider it a genuine discovery.

"The fact that we've seen the same effect as our colleagues did in March certainly boosts the chances that we might genuinely be on the brink of discovering something new," said Dr. Harry Cliff from the Cavendish Laboratory. "It's great to shed a little more light on the puzzle."

Today's result examined two new beauty quark decays from the same family of decays that were used in the March result. The team found the same effect – the muon decays were only happening around 70% as often as the electron decays. This time the error is larger, meaning that the deviation is around "2 sigma", meaning there is just over a 2% chance of it being due to a statistical quirk of the data. While the result isn't conclusive on its own, it does add further support to a growing pile of evidence that there are new fundamental forces waiting to be discovered.

"The excitement at the Large Hadron Collider is growing just as the upgraded LHCb detector is about to be switched on and further data collected that will provide the necessary statistics to either claim or refute a major discovery," said Professor Val Gibson, also from the Cavendish Laboratory. ■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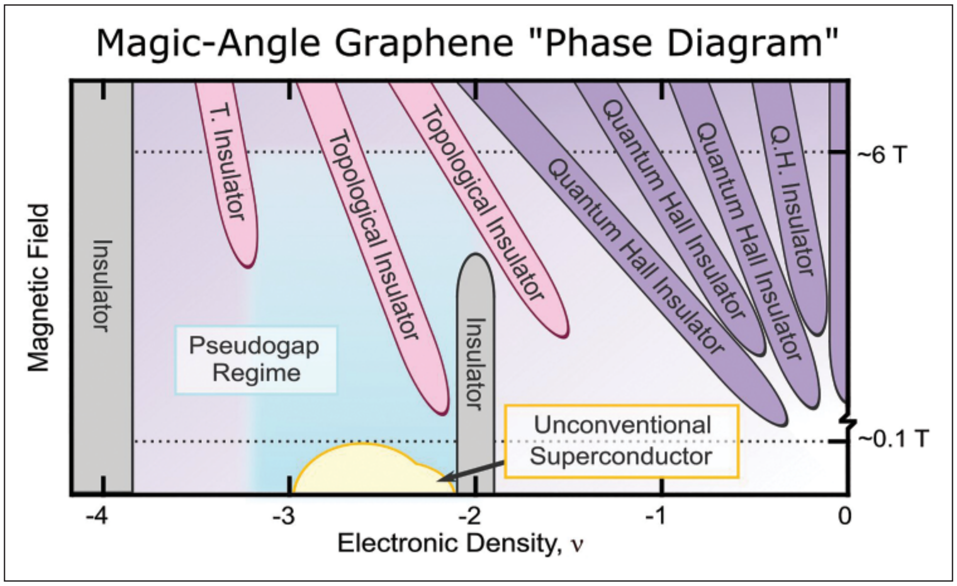
Unmasking the Magic of Superconductivity in Twisted Graphene

The discovery in 2018 of superconductivity in two single-atom-thick layers of graphene stacked at a precise angle of 1.1 degrees (called 'magic'-angle twisted bilayer graphene) came as a big surprise to the scientific community. Since the discovery, physicists have asked whether magic graphene's superconductivity can be understood using existing theory, or whether fundamentally new approaches are required — such as those being marshalled to understand the mysterious ceramic compound that superconducts at high temperatures. Now, as reported in the journal ***Nature*** on October 20, Princeton researchers have settled this debate by showing an uncanny resemblance between the superconductivity of magic graphene and that of high temperature superconductors. Magic graphene may hold the key to unlocking new mechanisms of superconductivity, including high temperature superconductivity.



Magic-angle graphene is an incredible multifunctional material, easily tuned amongst a diverse set of quantum phases by changing its temperature, magnetic field, and electronic density. Here, researchers have uncovered essential signatures of its unconventional superconducting phase (yellow), which conducts electricity with zero resistance and zero energy loss, and its previously unknown pseudogap regime (blue), a seemingly necessary precursor to superconductivity.
Image: Yazdani Lab, Princeton University

Ali Yazdani, the Class of 1909 Professor of Physics and Director of the Center for Complex Materials at Princeton University, led the research. He and his team have studied many different types of superconductors over the years and have recently turned their attention to magic bilayer graphene. "Some have argued that magic bilayer graphene is actually an ordinary superconductor disguised in an extraordinary material," said Yazdani, "but when we examined it microscopically it has many of the characteristics of high temperature cuprate superconductors. It is a déjà vu moment."

Superconductivity is one of nature's most intriguing phenomena. It is a state in which electrons flow freely without any resistance. Electrons are subatomic particles that carry negative electric charges; they are vital to our way of life because they power our everyday electronics. In normal circumstances, electrons behave erratically, jumping and jostling against each other in a manner that is ultimately inefficient and wastes energy.

But under superconductivity, electrons suddenly pair up and start to flow in unison, like a wave. In this state the electrons not only do not lose energy, but they also display many novel quantum properties. These properties have allowed for a number of practical applications, including magnets for MRIs and particle accelerators as well as in the making of quantum bits that are being used to build quantum computers. Superconductivity was first discovered at extremely low temperatures in elements such as aluminum and niobium. In recent years, it has been found close to room temperature under extraordinarily high pressure, and also at temperatures just above the boiling point of liquid nitrogen (77 K) in ceramic compounds.

But not all superconductors are created equal.

Superconductors made of pure elements like aluminum are what researchers call conventional. The superconductive state – where the electrons pair together – is explained by what is called the Bardeen-Cooper-Schrieffer (BCS) theory. This has been the standard description of superconductivity that has been around since the late 1950s. But starting in the late 1980s new superconductors were discovered that did not fit the BCS theory. Most notable among these "unconventional" superconductors are the ceramic copper oxides, called cuprates, that have remained an enigma for the past 30 years.

The original discovery of superconductivity in magic bilayer graphene by Pablo Jarillo-Herrero and his team at the Massachusetts Institute of Technology showed that the material starts out first as an insulator but, with the small addition of charge carriers, it becomes superconducting. The emergence of superconductivity from an insulator, rather than a metal, is one of the hallmarks of many unconventional superconductors, including most famously the cuprates. "They suspected that superconductivity could be unconventional, like the cuprates, but they unfortunately did not have any specific experimental measurements of the superconducting state to support this conclusion," said Myungchul Oh, a postdoctoral research associate and one of the lead co-authors of the paper.

To investigate the superconductive properties of magic bilayer graphene, Oh and his colleagues used a scanning tunneling microscope (STM) to view the infinitesimally small and complex world of electrons. This device relies on a novel phenomenon called "quantum tunneling," where electrons are funneled between the sharp metallic tip of the microscope and the sample. The microscope uses this tunneling current rather than light to view the world of electrons on the atomic scale.

"STM is a perfect tool for doing these types of experiments," said Kevin Nuckolls, a graduate student in physics and one of the paper's lead co-authors. "There are many different measurements that STM can do. It can access physical variables that are typically inaccessible to other [experimental techniques]."

When the team analyzed the data, they noticed two major characteristics, or "signatures," that stood out, tipping them off that the magic bilayer graphene sample was exhibiting unconventional superconductivity. The first signature was that the paired electrons that superconduct have a finite angular momentum, a behavior analogous to that found in the high temperature cuprates twenty years ago. When pairs form in a conventional superconductor, they do not have a net angular momentum, in a manner analogous to an electron bound to the hydrogen atom in the hydrogen's s-orbital.

STM operates by tunneling electrons in and out of the sample. In a superconductor, where all the electrons are paired, the current between the sample and the STM tip is only possible when the superconductor's pairs are broken apart. "It takes energy to break the pair apart, and the energy dependence of this current depends on the nature of the pairing. In magic graphene we found the energy dependence that is expected for finite momentum pairing," Yazdani said. "This finding strongly constrains the microscopic mechanism of pairing in magic graphene."

The Princeton team also discovered how magic bilayer graphene behaves when the superconducting state is quenched by increasing the temperature or applying a magnetic field. In conventional superconductors, the material behavior is the same as that of a normal metal when superconductivity is killed – the electrons unpair. However, in unconventional superconductors, the electrons appear to retain some correlation even when not superconducting, a situation that manifests when there is roughly a threshold energy for removing electrons from the sample. Physicists refer to this threshold energy as a "pseudogap," a behavior found in the non-superconducting state of many unconventional superconductors. Its origin has been a mystery for more than 20 years. "One possibility is that electrons are still somewhat paired together even though the sample is not superconducting," said Nuckolls. "Such a pseudogap state is like a failed superconductor."

The other possibility, noted in the ***Nature*** paper, is that some other form of collective electronic state, which is responsible for the pseudogap, must first form before superconductivity can occur. "Either way, the resemblance of an experimental signature of a pseudogap with the cuprates as well as finite momentum pairing can't be all a coincidence," Yazdani said. "These problems look very much related."

Future research, Oh said, will involve trying to understand what causes electrons to pair in unconventional superconductivity – a phenomenon that continues to vex physicists. BCS theory relies on weak interaction among electrons, with their pairing made possible because of their mutual interaction with the underlying vibration of the ions. The pairing of electrons in unconventional superconductors, however, is often much stronger than in simple metals, but its cause – the "glue" that bonds them together – is currently not known.

"I hope our research will help the physics community to better understand the mechanics of unconventional superconductivity," Oh said. "We further hope that our research will motivate experimental physicists to work together to uncover the nature of this phenomenon." ■

World's Largest Helium Hub Comes Onstream

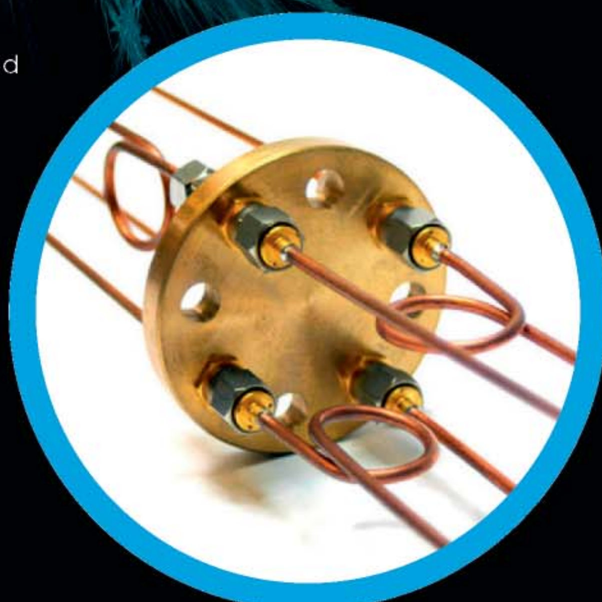
The commissioning ceremony for the world's largest Logistics Center for the servicing of helium containers (helium hub), which will be used to deliver liquid helium to the global market, took place virtually September 8. The helium hub – which is located in the Nadezhdinskaya in the district of Primorsky Krai, Russia, near seaports in the Primorye Territory – is the key link in the logistics chain of commercial helium supplies from the Amur Gas Processing Plant (GPP).

The Amur GPP is being built near the town of Svobodny in the Amur Region. The plant receives multicomponent gas via the Power of Siberia gas pipeline from the Chayandinskoye field in Yakutia; later on, it will also receive gas from the Kovyktinskoye field in the Irkutsk Region.

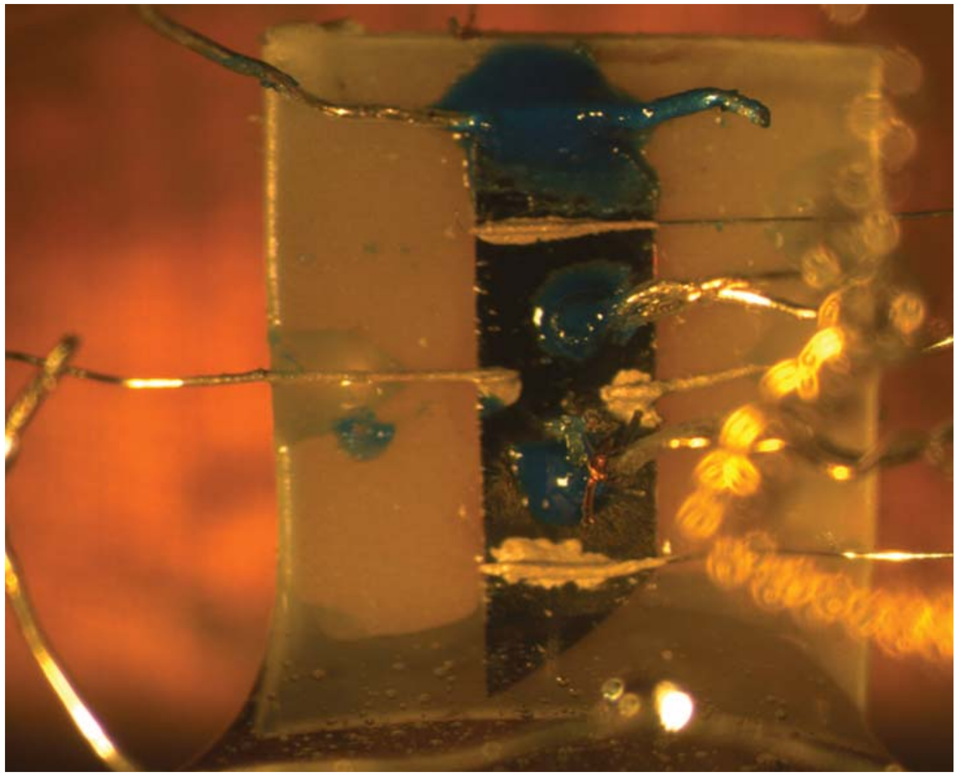
The commissioning ceremony for the first production train of the Amur GPP was held June 9. The plant will have a starting design capacity of 42 billion cubic meters of gas per year. When the plant reaches its full design capacity in 2025, it will produce 60 million cubic meters of helium per year, becoming the global leader in helium production.

The opening of the Logistics Center is synchronized with the gradual increase in the Amur GPP's capacities. The GPP's second production train (of six in total) was put in operation the day before the ceremony. The first of three helium separation, liquefaction and packaging units is now online with an annual capacity of 20 million cubic meters. The helium production process uses spiral heat exchangers and was launched for the first time in Russia at a mechanical engineering plant in St. Petersburg.

The new hub will provide servicing for containers that are sent to the GPP to be filled, arrange logistics operations and carry out acceptance, perform weight checks, and prepare thermally insulated containers arriving from the Amur GPP for further loading onto sea vessels. The containers are designed to maintain the temperature of -269 °C in order to keep the helium in a liquid state. The hub will have the capacity to perform more than 4,000 operations with thermally insulated containers per year. This is an unprecedented figure, as there are currently only 2,000 thermally insulated cryogenic containers in the world, which collectively carry all of the helium produced worldwide. ■



Experiments Reveal Formation of a New State of Matter: Electron Quadruplets



The iron-based superconductor material, Ba1–xKxFe2As2, is mounted for experimental measurements.
Image: Vadim Grinenko, Federico Caglieris

The central principle of superconductivity is that electrons form pairs. But can they also condense into foursomes? Recent findings have suggested they can, and a physicist at KTH Royal Institute of Technology in Stockholm published the first experimental evidence of this quadrupling effect and the mechanism by which this state of matter occurs. The results were published on October 19 in ***Nature Physics***.

Professor Egor Babaev and collaborators presented evidence of fermion quadrupling in a series of experimental measurements on the iron-based material, Ba1–xKxFe2As2. The results follow nearly 20 years after Babaev first predicted this kind of phenomenon, and eight years after he published a paper predicting that it could occur in this material.

The pairing of electrons enables the quantum state of superconductivity, a zero-resistance state which is used in MRI scanners and quantum computing. It occurs within a material as a result of two electrons bonding rather than repelling each other, as they would in a vacuum. The phenomenon was first described in a theory by Leon Cooper, John Bardeen and John Schrieffer, whose work was awarded the Nobel Prize in 1972.

So-called Cooper pairs are basically "opposites that attract." Normally two electrons, which are negatively charged subatomic particles, would strongly repel each other. But at low temperatures in a crystal, they become loosely bound in pairs, giving rise to a robust long-range order. Currents of electron pairs no longer scatter from defects and obstacles and a conductor can lose all electrical resistance, becoming a new state of matter: a superconductor.

Only in recent years has the theoretical idea of four-fermion condensates become broadly accepted. For a fermion quadrupling state to occur there has to be something that prevents condensation of pairs and prevents their flow without resistance, while allowing condensation of four-electron composites, Babaev says.

The Bardeen-Cooper-Schrieffer theory didn't allow for such behavior, so when Babaev's experimental collaborator at Technische Universität Dresden, Vadim Grinenko, found in 2018 the first signs of a fermion quadrupling condensate, it challenged years of prevalent scientific agreement. What followed was three years of experimentation and investigation at labs at multiple institutions in order to validate the finding.

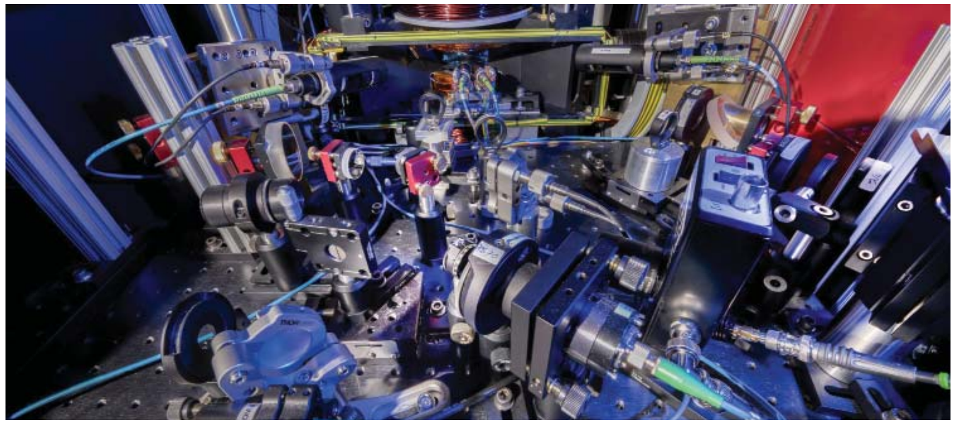
Babaev says that key among the observations made is that fermionic quadruple condensates spontaneously break time-reversal symmetry. In physics time-reversal symmetry is a mathematical operation of replacing the expression for time with its negative in formulas or equations so that they describe an event in which time runs backward or all the motions are reversed.

If one inverts time direction, the fundamental laws of physics still hold. That also holds for typical superconductors: if the arrow of time is reversed, a typical superconductor would still be in the same superconducting state. "However, in the case of a four-fermion condensate that we report, the time reversal puts it in a different state," he says. "It will probably take many years of research to fully understand this state," Babaev says. "The experiments open up a number of new questions, revealing a number of other unusual properties associated with its reaction to thermal gradients, magnetic fields and ultrasound that still have to be better understood."

Contributing to the research were scientists from Institute for Solid State and Materials Physics, TU Dresden, Germany; Leibniz Institute for Solid State and Materials Research, Dresden; Stockholm University; Bergische Universität at Wuppertal, Germany; Dresden High Magnetic Field Laboratory (HLD-EMFL); Wurzburg-Dresden Cluster of Excellence ct.qmat, Germany; Helmholtz-Zentrum, Germany; National Institute of Advanced Industrial Science and Technology (AIST), Japan; Institut Denis Poisson, France. ■

Switching on a Superfluid

There is a lot to be learned by studying microscopic and macroscopic changes in a material as it crosses from one phase to another, for example from ice to water to steam. But while these phase transitions are well understood in the case of water, much less is known about the dynamics when a system goes from being a normal fluid to a superfluid, which can flow with zero friction without losing any energy. A new study at Swinburne University of Technology in Melbourne, Australia, observing transition of an atomic gas from normal fluid to superfluid, provides new insights into the formation of these remarkable states, with a view to future, superfluid-based, quantum technologies, such as ultralow energy electronics.



The ultracold atomic lab at Swinburne University of Technology. *Image: Swinburne*

Superfluid formation was seen to involve a number of different timescales, each associated with different dynamical processes that take place upon crossing the phase boundary.

Understanding dynamic transitions, towards future technologies

As a nonequilibrium, dynamic process, phase transitions are challenging to understand from a theoretical perspective, inside these fascinating and potentially useful states of matter. Such non-equilibrium phenomena in many-body quantum systems involves a complex interplay of correlations spanning vastly different spatio-temporal scales. Access to the full dynamics in most materials can be prohibited by the ultrashort timescales.

Future technologies based on quantum states such as superfluids or superconductors will need to be "switched" (on/off), so understanding how systems evolve after switching answers important basic questions, such as how fast such devices can operate.

Forming a superfluid involves the correlated motion of the many microscopic constituents within a large collection of quantum-mechanical particles. "Dilute gases of ultracold atoms however, allow measurements of real-time dynamics on accessible timescales," explains lead author Dr. Paul Dyke of Swinburne. "Here we use an ultracold gas of strongly interacting fermionic atoms (i.e., a Fermi gas), to study how the correlations required to form a superfluid build up after a sudden quench of the interactions. This takes the system out of equilibrium. By measuring the subsequent dynamics as the system returns to equilibrium, we can resolve the different timescales involved for the various correlations to build up. These timescales depend on the corresponding length scales, with short-range correlations and pair formation developing quickly, while the overall momentum distribution can take several orders of magnitude longer to reach equilibrium."

The new experiment showed that formation and condensation of fermion pairs can take place on very different timescales depending on the speed of the quench, and the contact parameter is seen to respond very quickly to changes in the interaction strength, indicating that short-range correlations evolve far more rapidly than the long-range correlations necessary to form a Bose-Einstein condensate of atom pairs. The contact parameter quantifies the likelihood of finding two atoms in very close proximity to each other, and it is strongly enhanced when atoms form pairs.

Ultracold gas studies at FLEET

Researchers often use ultracold atoms to study quantum systems, because of the ability to perfectly "tune" atomic interactions. Quantum gases of ultracold, neutral atoms are now helping unlock the fundamental physics of Fermi systems, often uncovering phenomena not readily accessible in other systems.

By increasing the interaction strength between fermionic atoms, experiments can explore the "unitary" limit, where the atomic behavior is expected to reveal universal features of interacting fermions that could connect our understanding of superconductivity and Bose-Einstein condensation. "Fundamental discoveries made from experiments such as these can help guide FLEET's quest to develop dynamically switchable materials in which particles can move without dissipating energy," explains corresponding author Professor Chris Vale.

Vale leads FLEET's studies of quantum gases at Swinburne, where his lab routinely cools atomic gases to temperatures approaching absolute zero. In this temperature range, quantum behaviors that are usually only found at a microscopic level become prominent at a macroscopic level.

Vale is one of over 100 FLEET (the ARC Centre of Excellence in Future Low-Energy Electronics Technologies) researchers, all motivated by one grand challenge: to reduce the energy used in information and communication technology (ICT), which already accounts for at least 8% of global electricity use and is doubling every decade.

FLEET will develop systems in which electricity flows with minimal resistance and therefore minimal wasted dissipation of energy, and devices in which this "dissipationless" electric current can be switched on and off at will. These devices will enable revolutionary new electronics and communications technologies with ultralow energy consumption. ■

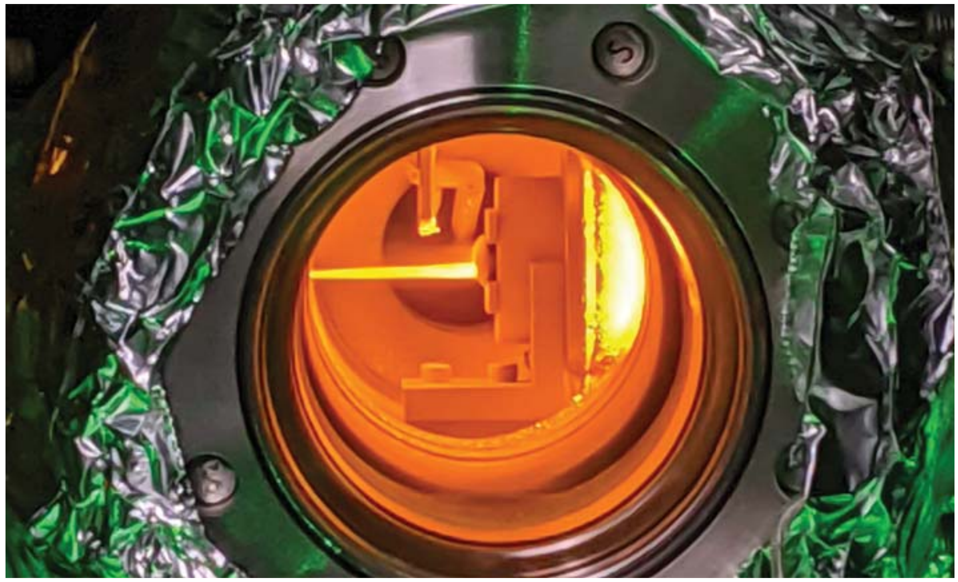
Heating Up Quantum Science Education with Laser Cooling

Courtesy of Columbia University

A series of interactive workshops developed by Columbia University physicist Sebastian Will and STEMteachersNYC will give educators tips and tools to cover quantum science in their classrooms.

If you imagine a laser, you might think of beams of light popping balloons or slicing through a metal slab like butter. Lasers can indeed heat things up, but they can also cool things down.

These days, physicists use laser cooling to understand the fundamentals of quantum physics, with implications for building things like super-precise atomic clocks and super-fast quantum computers. To study the quantum properties of atoms – how they behave when classical, temperature-based influences are stripped away – you need to chill them to as close to absolute zero as you can. This is where the lasers come in.



Cooling in progress. A beam of sodium atoms glows orange as they re-emit photons after being struck by a laser beam.
Image: Claire Warner/Courtesy of Columbia University

As Claire Warner, a graduate student in Sebastian Will's lab at Columbia, recently explained to a group of teachers from across the United States, photons, the energy packets that make up light, have momentum when fired from a laser. When those photons hit an atom, that atom gets a "momentum kick" that slows it down. In just three milliseconds, atoms can be super-cooled to just above absolute zero, -459.67 °F. Quantum physics then takes over, and it's off to the experimental races.

"Laser Cooling: Quantum Physics Applications for High School Students" is the most recent workshop in a series that Will's lab is developing with the nonprofit STEMteachersNYC. Funded by Will's National Science Foundation CAREER award, the Quantum Physics Outreach Program (QPOP) is giving high school teachers the tools to share quantum physics with their students.

"It's providing teachers with simple concepts that allow them to make a connection to modern quantum technology," Will said. In collaboration with Fernand Brunschwig at STEMteachersNYC, Will and his graduate students distill their work in experimental physics to a few simple ideas that the teachers attending the workshops can understand. The training has a multiplier effect for reaching new audiences: if 50 teachers who attend a workshop go on to teach these concepts to 30 students at a time, that's now 1,500 students with new quantum knowledge, Will added.

Often, high school students have already covered the basics – atomic energy levels, force and momentum, waves and the Doppler effect and so on – just not necessarily in the context of quantum physics. Once equipped, teachers can take their students from performing calculations with hypothetical cannonballs to calculations about laser cooling, a real-world physics application. "The conceptual leaps that need to be made aren't that big," Warner said.

Warner is now an expert on laser cooling, but wasn't always. Popular science tends to focus on outer space or black holes, and although the basics of quantum physics have been around for nearly a century, most high school classrooms still focus on classical Newtonian physics. "There aren't PBS specials on quantum physics and its modern applications," she said. She learned about ultracold atoms in a physics lab as an undergraduate; she hopes the workshops might introduce students to quantum science even earlier in their academic careers.

Developing the workshops has been challenging, said Warner. In speaking to other researchers, a few technical words can convey what you mean. That's not the case when translating to a room of high school teachers. "You can't use jargon or acronyms," she said. "You really have to go back to basics." Will said that he and his students, with STEMteachersNYC, are continuously improving the workshops as they move forward.

"The public image of quantum is, 'Oh my, I can't possibly understand this. It's too weird,'" Brunschwig said. But the quantum world is all around us, he noted, one that he hopes the workshop series will help to demystify. ■

Chart Industries' SES Cryogenic Carbon Capture™ Technology Selected for Funding by Department of Energy

Chart Industries, Inc., a leading diversified global manufacturer of highly engineered equipment for the industrial gas and clean energy industries, has been notified of its US Department of Energy (DOE) funding award for its Sustainable Energy Solutions Cryogenic Carbon Capture™ (CCC) technology.

With this DOE funding, Chart's team intends to design, build, commission and operate an engineering-scale CCC process at Central Plains Cement Company LLC's cement plant in Sugar Creek MO. Central Plains Cement Company LLC is a wholly owned subsidiary of Eagle Materials. The project will scale the CCC system to a capacity of nominally 30 tonnes of CO_2 per day with the intention of demonstrating that the system captures more than 95% of the CO_2 from the flue gas slipstream and produces a CO_2 stream that is more than 95% pure.

The DOE funding for this project is $4,999,875, which was one of the four largest funding amounts out of the 12 projects funded. The DOE awards totaled $45 million to advance point-source carbon capture and storage technologies that can capture at least 95% of CO_2 emissions generated from natural gas power and industrial facilities that produce commodities like cement and steel.

This project deepens Chart's relationship with the DOE by working together on an ongoing project that looks at combining carbon capture with energy storage to enable better adoption of renewables on the grid and also participating in the H2@SCALE Texas hydrogen project. In addition to this DOE award notification, in September 2021 Chart booked an engineering order for their carbon capture offering from a publicly traded industrial manufacturing company producing materials for the heavy construction industry for a potential US location carbon capture facility.

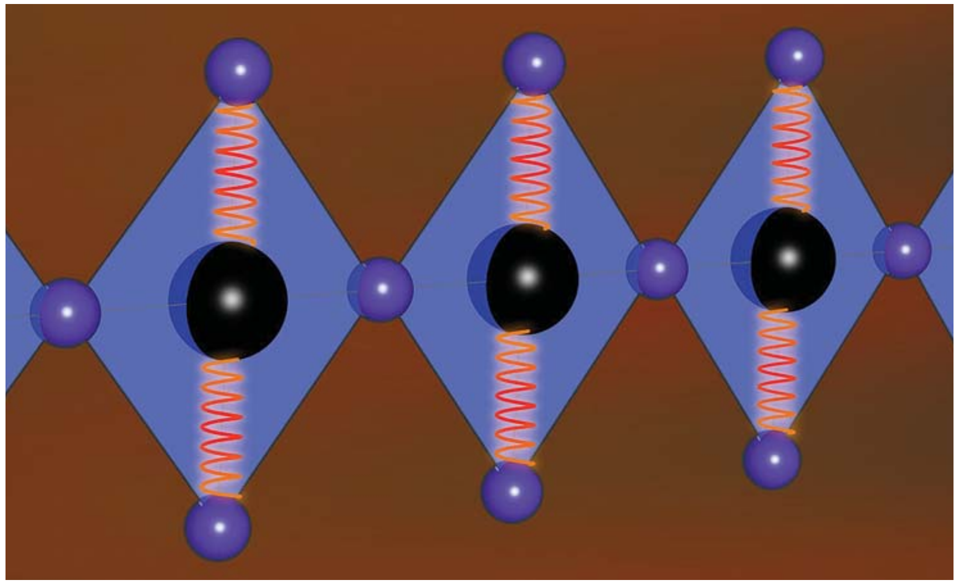
Chart's third quarter 2021 carbon capture activity has been "robust," with the signing of a Memorandum of Understanding with FLSmidth as well as TECO 2030 to cooperate on further carbon capture, utilization and storage (CCUS) development and application in a broad set of industries, including industrial, cement and marine. Additionally, the SES (CCC) technology was recognized by researchers at Massachusetts Institute of Technology and Exxon as the most competitive CCUS solution, with the determination that the cost to produce cement and capture CO_2 using Chart's CCC technology is 24% higher than producing cement with no CO_2 capture (not accounting for any value for the CO_2 being captured), while other capture technologies range from a 38% increase to a 134% increase in the cost of producing cement and capturing CO_2 vs producing cement with no CO_2 capture, contributing to greenhouse gas emission.

"We are delighted that public and private entities recognize Chart as a leader in carbon capture technologies and products," stated Jill Evanko, Chart's CEO and President. "We view this award as well as our third quarter 2021 commercial activity as meaningful steps and accelerators toward capturing (pun intended) significant share of our anticipated $6 billion total addressable market for carbon and direct air capture in 2030." **www.chartindustries.com** ■

SLAC Scientists Succeed in Doping a 1D Chain of Cuprates

by Glennda Chui, SLAC National Accelerator Laboratory, glennda@slac.stanford.edu

A study led by scientists at the Department of Energy's SLAC National Accelerator Laboratory along with Stanford and Clemson universities has synthesized the first 1D cuprate material that can be doped. Their analysis of the doped material suggests that the most prominent proposed model of how cuprates achieve superconductivity is missing a key ingredient: an unexpectedly strong attraction between neighboring electrons in the material's atomic structure, or lattice. That attraction, they said, may be the result of interactions with natural lattice vibrations. The team reported their findings on September 9 in ***Science***.



An illustration of 1D copper oxide, or cuprate, chains that have been "doped" to free up some of their electrons in a study led by researchers at SLAC National Accelerator Laboratory and Stanford and Clemson universities. Copper atoms are black and oxygen atoms purple. The red springs represent natural vibrations that jiggle the atomic lattice, which may help produce an unexpectedly strong attraction (not shown) between neighboring electrons in the lattice. This "nearest-neighbor" attraction may play a role in unconventional superconductivity – the ability to conduct electric current with no loss at relatively high temperatures. *Image: Greg Stewart/SLAC National Accelerator Laboratory*

When scientists study unconventional superconductors – complex materials that conduct electricity with zero loss at relatively high temperatures – they often rely on simplified models to get an understanding of what's going on. Researchers know these quantum materials get their abilities from electrons that join forces to form a sort of electron soup. But modeling this process in all its complexity would take far more time and computing power than anyone can imagine having today.

So, for understanding one key class of unconventional superconductors – copper oxides, or cuprates – researchers created, for simplicity, a theoretical model in which the material exists in just one dimension, as a string of atoms. They made these one-dimensional cuprates in the lab and found that their behavior agreed with the theory pretty well.

Unfortunately, these 1D atomic chains lacked one thing: they could not be doped, a process where some atoms are replaced by others to change the number of electrons that are free to move around. Doping is one of several factors scientists can adjust to tweak the behavior of materials like these, and it's a critical part of getting them to superconduct.

"The inability to controllably dope one-dimensional cuprate systems has been a significant barrier to understanding these materials for more than two decades," said Zhi-Xun Shen, a Stanford professor and investigator with the Stanford Institute for Materials and Energy Sciences (SIMES) at SLAC. "Now that we've done it," he said, "our experiments show that our current model misses a very important phenomenon that's present in the real material."

Zhuoyu Chen, a postdoctoral researcher in Shen's lab who led the experimental part of the study, said the research was made possible by a system the team developed for making 1D chains embedded in a 3D material and moving them directly into a chamber at SLAC's Stanford Synchrotron Radiation Lightsource (SSRL) for analysis with a powerful X-ray beam. "It's a unique setup," he said, "and indispensable for achieving the high-quality data we needed to see these very subtle effects."

From grids to chains, in theory

The predominant model used to simulate these complex materials is known as the Hubbard model. In its 2D version, it is based on a flat, evenly spaced grid of the simplest possible atoms.

But this basic 2D grid is already too complicated for today's computers and algorithms to handle, said Thomas Devereaux, a SLAC and Stanford professor and SIMES investigator who supervised the theoretical part of this work. There's no well-accepted way to make sure the model's calculations for the material's physical properties are correct, so if they don't match experimental results it's impossible to tell whether the calculations or the theoretical model went wrong.

To solve that problem, scientists have applied the Hubbard model to 1D chains of the simplest possible cuprate lattice – a string of copper and oxygen atoms. This 1D version of the model can accurately calculate and capture the collective behavior of electrons in materials made of undoped 1D chains. But until now, there hasn't been a way to test the accuracy of its predictions for the doped versions of the chains because no one was able to make them in the lab, despite more than two decades of trying. "Our major achievement was in synthesizing these doped chains," Chen said. "We were able to dope them over a very wide range and get systematic data to pin down what we were observing."

One atomic layer at a time

To make the doped 1D chains, Chen and his colleagues sprayed a film of a cuprate material known as barium strontium copper oxide (BSCO), just a few atomic layers thick, onto a supportive surface inside a sealed chamber at the specially designed SSRL beamline. The shape of the lattices in the film and on the surface lined up in a way that created 1D chains of copper and oxygen embedded in the 3D BSCO material.

They doped the chains by exposing them to ozone and heat, which added oxygen atoms to their atomic lattices, Chen said. Each oxygen atom pulled an electron out of the chain, and those freed-up electrons become more mobile. When millions of these free-flowing electrons come together, they can create the collective state that is the basis of superconductivity.

Next the researchers shuttled their chains into another part of the beamline for analysis with angle-resolved photoemission spectroscopy, or ARPES. This technique ejected electrons from the chains and measured their direction and energy, giving scientists a detailed and sensitive picture of how the electrons in the material behave.

Surprisingly strong attractions

Their analysis showed that in the doped 1D material, the electrons' attraction to their counterparts in neighboring lattice sites is 10 times stronger than the Hubbard model predicts, said Yao Wang, an assistant professor at Clemson University who worked on the theoretical side of the study.

The research team suggested that this high level of "nearest-neighbor" attraction may stem from interactions with phonons – natural vibrations that jiggle the atomic latticework. Phonons are known to play a role in conventional superconductivity, and there are indications that they could also be involved in a different way in unconventional superconductivity that occurs at much warmer temperatures in materials like the cuprates, although that has not been definitively proven.

The scientists said it's likely that this strong nearest-neighbor attraction between electrons exists in all the cuprates and could help in understanding superconductivity in the 2D versions of the Hubbard model and its kin, giving scientists a more complete picture of these puzzling materials.

Researchers from DOE's Oak Ridge National Laboratory (CSA CSM) contributed to this work. **www6.slac.stanford.edu** ■

SPOTLIGHT ON A CORPORATE SUSTAINING MEMBER (CSA CSM)

Quantum Technology Corp. Releases Paper on Liquid Hydrogen – System Design and Safety

by Y. Xiao; C. Winter; O. Marin and Y. Zhang, Quantum Technology Corporation

Quantum Technology Corp. (QTC) manufactures hydrogen liquefiers, from several liters per day to several tons per day capacity. Safety and local regulations are key to a successful project. The safety aspects of a hydrogen liquefaction plant are discussed in this article. Liquid hydrogen expands 790 times from its boiling point at 20 K to 273 K at 1 atm; therefore, the design and reliability of relief systems and regulated maximum filling levels are critical in liquid hydrogen filling and storage.

According to 49 CFR Ch1 (10-1-11 Ed), it can be concluded that a maximum level of 94% can be applied normally. To prevent overfilling, pneumatic, non-electronic instrumentations such as level gauge, differential pressure indicators are recommended, and should be interlocked with scale readings from plant PLC through various transmission protocols. Vent location, sizing, and fire detection systems should also be considered holistically to ensure safe venting during operation and emergencies.

Impurities, which can freeze and concentrate inside the liquefier, are another safety concern. Gas impurities must be monitored frequently, while oxygen level must be maintained below 2ppmv. To prevent re-gasification of solid oxygen residue inside the system due to repeated filling and pressurization of LH_2 storage vessels, adequate purging and periodic cleaning to remove trace oxygen is required.

Other than passive methods such as LEL sensors, interlocks, building design and ventilation, the addition of administrative procedures and PPE are essential to detect hydrogen leakage. Best practices include breathing air respirator location and signage, portable working hydrogen sensor and oxygen concentration detector be always carried in rated hazardous zones.

All the above should be examined during design reviews and HAZOP activities to assess the likelihood and severity of accidents. Measures should be taken to reduce or eliminate the identified risks and ensure a safe environment for all. **www.quantum-technology.com** ■

NSF Grant Funds New 40T SC Magnet Design at National MagLab

A new $15.8 million grant from the National Science Foundation (NSF) will produce a detailed design for the world's most powerful superconducting magnet at the Florida State University-headquartered National High Magnetic Field Laboratory (CSA CSM). While the National MagLab is already home to more than a dozen world-record magnets used by researchers from around the world, the future 40-tesla magnet will advance the study of quantum matter with its low noise environment that surpasses present-day resistive and hybrid magnets.

The MagLab team. *Image: MagLab*

The design for a new 40T magnet will call for the use of cutting-edge materials known as high temperature superconductors, which allow a near perfect flow of electrons at higher temperatures than their earlier low temperature counterparts. To put this magnet design in perspective, a typical refrigerator magnet has a field of about .01T and low temperature superconductors have a maximum field of 25T.

"This project is a fantastic example of how science works on the edge of our understanding: engineers will design a new instrument that has never been built before that holds the promise to become a state-of-the-art tool for physicists to answer outstanding research questions about the mysteries of quantum materials," explained Greg Boebinger, MagLab director and co-primary investigator on the grant. "Our user community is excited about the virtually limitless time at peak field and low noise environment this future magnet, once constructed, would provide to advance their research goals."

Dozens of researchers within the lab's Magnet Science and Technology department and Applied Superconductivity Center will bring their unique expertise in materials research, magnet design and technology development to this new project. The MagLab's demonstrated successes in magnet research and development include two recent breakthroughs in HTS technology: a 32T all-superconducting magnet that was designed, built and reached full field at the MagLab in December 2017 (***Cold Facts*** Vol. 34, No. 1) and a 14.5T test coil that reached a world record 45.5T field strength inside a 31T resistive magnet.

"Magnets are only as good as the materials and technologies in which they are built," said Mark Bird, director of the Magnet Science and Technology Division at the National MagLab. "A magnet like this can only be achieved at the National MagLab where we are leading a revolution in understanding and leveraging high temperature superconductors."

For the final design, MagLab scientists and engineers are considering two different magnet technologies using the high temperature superconductor known as "rare earth barium copper oxide" or REBCO. The two design strategies take different approaches to address inconsistency in the performance of the REBCO tape. One design uses multiple REBCO tapes in parallel, while the other involves applying a resistive insulation to the tape. The team will develop test coils to advance our understanding of screening currents, stress and quench protection – each one a component of the myriad technical arcana that must be mastered for the future magnet to be successful.After additional testing and characterization work, MagLab engineers will complete a final design that will describe in complete detail how a 40T superconducting magnet should be constructed, including the cost and schedule.

"The National High Magnetic Field Laboratory's extraordinary work over the past few decades is evidenced by the fact that they continue to attract support from the National Science Foundation and others to take us even further in magnet development," said Interim Vice President for Research Laurel Fulkerson. "We are proud of the work they have already done and will continue to do as they develop a design for the 40T magnet."

The grant funds design work through 2026 and is part of the NSF's Mid-scale Research Infrastructure 1 Program (Mid-scale RI-1), special funding that supports the design efforts for compelling projects that meet a scientific need and enable US researchers to remain competitive in a global research environment.

"US researchers need cutting-edge tools to stay at the forefront of science and technology," said NSF Director Sethuraman Panchanathan. "NSF is committed to filling this mid-scale space in the American scientific research infrastructure by investing in research facilities and instrumentation that advance next-generation discoveries." Success at this stage will lay the groundwork for a future proposal that, if successful, would fund the construction of the 40T magnet and is an important stepping stone on the route to a future 60T hybrid magnet, one of the most challenging future magnets yet proposed. **https://nationalmaglab.org** ■

AFCryo Develops Solution for Bio Preservation in Inhospitable Environments

New Zealand-based AFCryo, a division of Fabrum Solutions, has developed a unique solution to a problem not often considered, yet vital to the safe preservation and development of our natural world. The company designed and produced a novel liquid nitrogen production solution to secure and protect biosamples – specifically for livestock breeding – at the ultralow temperatures required to ensure their safety in remote, underserved and naturally hot environments – the AFCryo CryoCube.

Utilizing this technology, AFCryo was able to meet the needs of a first-time customer: Ethiopia's Ministry of Agriculture's Livestock and Fisheries division.

Governments, private organizations and nonprofits have been working to identify reliable systems to maintain precious samples from endangered, valuable and crucial species like essential livestock samples to support breeding programs. "For the last 15 years, many projects in these challenging environments have failed," said Nigel Bartlett, sales manager at AFCryo & Fabrum Solutions.

"It's usually just too dusty, too dirty and too hot for these systems to operate properly. In some cases, the areas that need these systems are underserved with things like reliable electricity or proper infrastructure. We recognized the need for a simple, low maintenance system that can circumnavigate those challenges."

That solution came in the form of a self contained complete liquid nitrogen unit based off AFCryo's existing technology. "We had to address the concerns that have existed since this issue came to light, but we had the added challenge of making the project work under the conditions set by COVID," Bartlett said. "Thankfully, they kind of went hand-in-hand: making the system deployable with the minimum amount of human input would help not only minimize interactions in accordance with COVID guidelines but mean easy commissioning for any environment in the future."

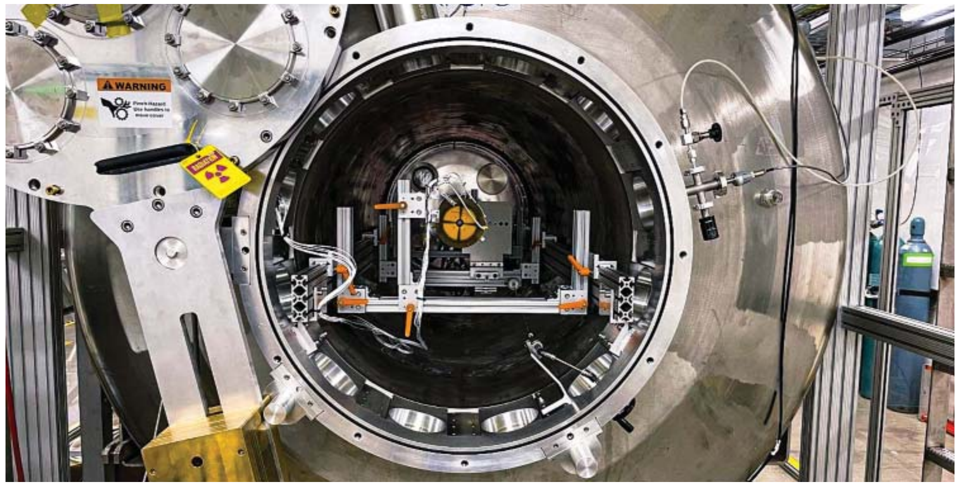
The container-based system is thermally insulated and maintains a positive air flow pressure which uses filters to keep dust, temperature and contaminants at the lowest possible levels. "All a customer needs is an electricity source and they're set," Bartlett adds

"After commissioning, we can remotely monitor the system from our facilities. The system is all automatic, so a steady stream of electricity and a diligent monitor ensure a continuous, reliable system for liquid nitrogen production, biopreservation and herd development."

With the help of AFCryo's self-contained unit, preservation and herd development efforts around the world stand to benefit from reliable systems to ensure the security of their valuable samples and protection of Earth's biodiversity. **af-cryo.com** ■

Scientists Recreate Cosmic Reactions to Unlock Astronomical Mysteries

How do the chemical elements, the building blocks of our universe, get built? This question has been at the core of nuclear physics for the better part of a century. At the beginning of the 20th century, scientists discovered that elements have a central core or nucleus. These nuclei consist of various numbers of protons and neutrons. Now, scientists at Michigan State University's Facility for Rare Isotope Beams (FRIB) have built and tested a device that will allow pivotal insights into heavy elements, or elements with very large numbers of protons and neutrons. Ben Kay, physicist at the US Department of Energy's (DOE) Argonne National Laboratory, led this effort. FRIB is a DOE Office of Science User Facility.



An interior view of SOLARIS and the accelerator and detectors at the rear. *Image: Argonne National Laboratory*

Kay and his team have completed their first experiment using the device, called SOLARIS, which stands for Solenoid Spectrometer Apparatus for Reaction Studies. Planned experiments will reveal information about nuclear reactions that create some of the heaviest elements in our world, ranging from iron to uranium.

Also planned are experiments with exotic isotopes. Isotopes are elements that share the same number of protons but have different numbers of neutrons. Scientists refer to certain isotopes as exotic because their ratios of protons to neutrons differ from those of typically stable or long-lived isotopes that occur naturally on Earth. Some of these unstable isotopes play an essential role in astronomical events. "Exploding stars, the merger of giant collapsed stars, we are now learning details about the nuclear reactions at the heart of these events," said Kay. "With SOLARIS, we are able to recreate those reactions here, on Earth, to see them for ourselves."

The new device follows in the footsteps of HELIOS, the Helical Orbit Spectrometer, at Argonne. Both use similarly repurposed superconducting magnets from a magnetic resonance imaging (MRI) machine like that found in hospitals. In both, a beam of particles is shot at a target material inside of a vacuum chamber. When the particles collide with the target, transfer reactions occur. In such reactions, neutrons or protons are either removed or added from nuclei, depending on the particles, and their energies, used in the collision. "By recording the energy and angle of the various particles that are released or deflected from the collisions, we are able to gather information about the structure of the nuclei in these isotopes," said Kay. "The innovative SOLARIS design provides the necessary resolution to enhance our understanding of these exotic nuclei."

What makes SOLARIS truly unique is it can function as a dual-mode spectrometer, meaning it can make measurements with either high or very low intensity beams. "SOLARIS can operate in these two modes," explained Kay. "One uses a traditional silicon detector array in a vacuum. The other uses the novel gas-filled target of the Active-Target Time-Projection Chamber at Michigan State, led by SOLARIS team member and FRIB senior physicist Daniel Bazin. This first experiment tested the AT-TPC." The AT-TPC enables scientists to use weaker beams and still collect results with the needed high accuracy.

The AT-TPC is essentially a large chamber filled with a gas that serves as both the target for the beam and the detector medium. This differs from the traditional vacuum chamber that uses a silicon detector array and a separate, thin, solid target. "By filling the chamber with gas, you are ensuring that the fewer, larger particles from the low intensity beam will make contact with the target material," said Kay. In that way, the scientists can then study the products from those collisions.

The team's first experiment, led by research associate Clementine Santamaria of FRIB, examined the decay of oxygen-16 (the most common isotope of oxygen on our planet) into much smaller alpha particles. In particular, the eight protons and eight neutrons in oxygen-16 nuclei break up into a total of four alpha particles, each consisting of two protons and two neutrons. "By determining how oxygen-16 decays like this, comparisons can be made to that of the 'Hoyle state,' an excited state of a carbon isotope that we believe plays a key role in the production of carbon in stars," explained Kay.

Kay and his team recorded over two million reaction events during this experiment and observed several instances of the decay of oxygen-16 into alpha particles.

The dual functionality of SOLARIS will allow for an even broader range of nuclear reaction experiments than before and give scientists new insights into some of the greatest mysteries of the cosmos. **https://nationalmaglab.org** and **https://frib.msu.edu** ■

Groundbreaking Held for National Quantum Computing Center in Oxfordshire

Quantum optics expert Professor Sir Peter Knight with a shovel at the groundbreaking ceremony. *Image: STFC*

A groundbreaking ceremony was held on September 20 at the UK's National Quantum Computing Center (NQCC) in Oxfordshire, ahead of the commencement of construction works. Professor Sir Peter Knight, Chair of the National Quantum Technology Programs Strategy Advisory Board, led the formal ceremony at the building site, based within the Rutherford Appleton Laboratory (RAL) at the Harwell Campus. Set to open in mid-2023, the 4,035 square meter building will ultimately provide space for more than 120 residents and researchers from academia, industry, government, quantum partner organizations and quantum start-ups.

The NQCC is a new research institution, representing a £93 million investment through UK Research and Innovation (UKRI). The center is being delivered jointly by the UK's Engineering and Physical Sciences Research Council (EPSRC) and Science and Technology Facilities Council (STFC). The NQCC is dedicated to accelerating the development of quantum computing by addressing the challenges of scaling the emerging technologies, enabling the UK to remain at the forefront of this transformative new field. The national center is part of the UK's National Quantum Technologies Program (NQTP) – a 10-year, £1 billion program that aims to ensure the successful transition of quantum technologies from laboratory to industry.

UKRI Chief Executive Professor Dame Ottoline Leyser said, "This is an important step forward in the journey towards creating a flagship facility for the UK quantum community to harness the exciting potential of this technology. Breaking ground on this site brings us closer to realizing our ambition of addressing the challenges in this burgeoning field by bringing experts from the public, private and third sectors into one hub."

The Center will work with businesses, government and the research community to deliver quantum computing capabilities for the UK and support the growth of the emerging industry. Working closely with industry and research organizations, the NQCC will provide access to quantum computers as they come on stream, leading to new jobs, skills and knowledge creation. This will help UK businesses and researchers to tap into the potential of this technology to develop a range of applications for quantum computing, fully unlocking its capabilities.

Harwell Science and Innovation Campus was chosen as the ideal site for the hub as it also houses other complementary research capabilities at STFC's Rutherford Appleton Laboratory and Diamond Light Source. Hosting the facility on the RAL site means the center will be independent of any business or university ties, creating an ideal position to attract new industrial partners who will be able to take advantage of the co-location of these national research facilities to collaborate and make progress in their own scientific research. ■

Look who's NEW in the Cold Facts Buyer's Guide

Cold Facts Buyer's Guide is the place to find suppliers in every area of cryogenics and superconductivity. These are the new suppliers added to the Buyer's Guide since the last issue of ***Cold Facts***. Find it online at **csabg.org**.

Dixon

Dixon®, founded in 1916, provides viable solutions for both typical and uncommon fluid handling applications: from LNG marine bunkering to rocket fueling, petrochemical exploration and production, as well as chemical, and pharmaceutical processing.

GenH2 Corp.*

GenH2 has engineered the first end-to-end filling station solution to make pure hydrogen on site with zero CO_2 emissions. All products are flexible, designed to be stackable/scalable and controlled by an integral central processing capability.

IC Biomedical*

IC Biomedical manufactures premium-quality cryogenic storage and transport equipment. In 2020, International Cryogenics was merged with Worthington's Life Sciences Cryogenic Equipment division (formerly Taylor-Wharton Cryoscience) to form IC Biomedical.

Prestige Technology (S) Pte Ltd.

Prestige Technology provides end-to-end turnkey cryogenic pipe system solutions and applications. The company's systems are built with a focus on quality and performance, providing extensive services covering maintenance, repairs and project follow-up. ■

***CSA CSM**

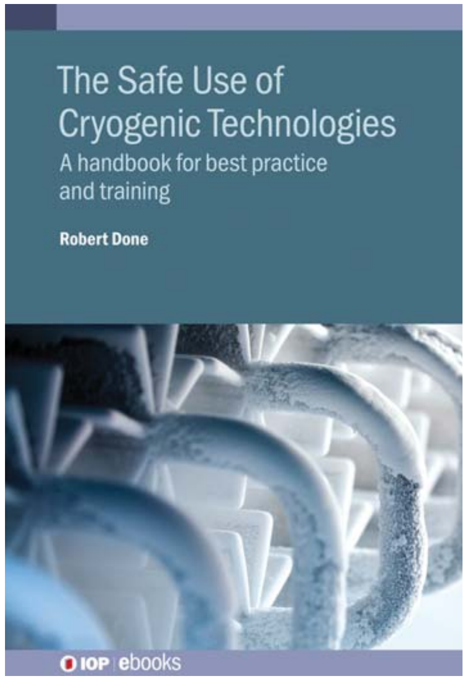
Book Review: *The Safe Use of Cryogenic Technologies by Robert Done*

by Dr. John Weisend II, European Spallation Source ERIC, CSA Chairman, john.weisend@esss.se

It is becoming common for large-scale scientific projects to include cryogenic systems provided by other countries. Examples of this include CERN, the European Spallation Source, ITER and the PIP II project at Fermilab (CSA CSM). While these contributions are quite valuable, one of the big challenges in such projects is understanding which safety regulations are relevant and how to apply them. This is true even in situations where common standards, for example within the European Union, should apply.

One of the virtues of Robert Done's recent book (IOP Publishing, 2021) on cryogenic safety is that it addresses this problem in great detail. The author provides an extensive listing of the important safety regulations that may affect cryogenic systems. Specifically, he examines the safety regulations from the United Kingdom (UK), United States of America (US) and the European Union (EU). The role of international and nongovernmental organizations is also described. As these regulations may change over time, the author wisely does not attempt to paraphrase the regulations but rather describes what they cover and then provides references to the regulations themselves. These references include clickable links that can be directly accessed via the ebook itself.

The book begins with a brief introduction to cryogenics and cryogenic temperatures followed by a description of the overarching safety regulations in the UK, US and EU. The next four chapters provide the bulk of the added value of this book. Each chapter, in turn, covers applicable cryogenic safety regulations from the UK, US, EU and international and nongovernmental organizations. The next two chapters qualitatively describe hazards found in cryogenic systems and how to mitigate them. Oxygen deficiency or asphyxiation hazards are rightfully given their own chapter describing risks and mitigations. Two detailed case studies involving the quantitative calculations of oxygen concentrations during accident scenarios and the mitigations taken to reduce the risk illustrate the lessons of the asphyxiation hazards chapter.



Overall, the book is well organized and well written. The main points of each chapter are nicely summarized, and extensive references provide links to additional information. While a more quantitative approach to some of the cryogenic hazards might have been preferred, such information exists in other texts and this book nicely complements the existing literature on cryogenic safety. The book is suitable for both students and professionals and contains useful information for the general public.

The Safe Use of Cryogenic Technologies is a valuable addition to the cryogenic safety literature. Its description of relevant cryogenic safety regulations from multiple authorities is quite noteworthy. This book is recommended for all personal and institutional libraries, particularly those in institutions with international collaborators. More and more, this applies to everyone. ■

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$159.00 suggested retail price in USD
ISBN 978-0-750-33123-4
http://2csa.us/kq

FROSTY'S FAVORITE FOTOS

Here it is! Frosty's Favorite Foto! We'll be including the most popular photo from Frosty in each issue. Visit the CSA site to see all the photos!

Photo caption: Photographing the ongoing civil engineering for new passages, caverns and shafts that will enlarge CERN's subterranean accelerator complex. When completed, they will house the powering, protection and cryogenic systems for the High-Luminosity LHC.
Image: Samuel Hertzog and Jules Ordan

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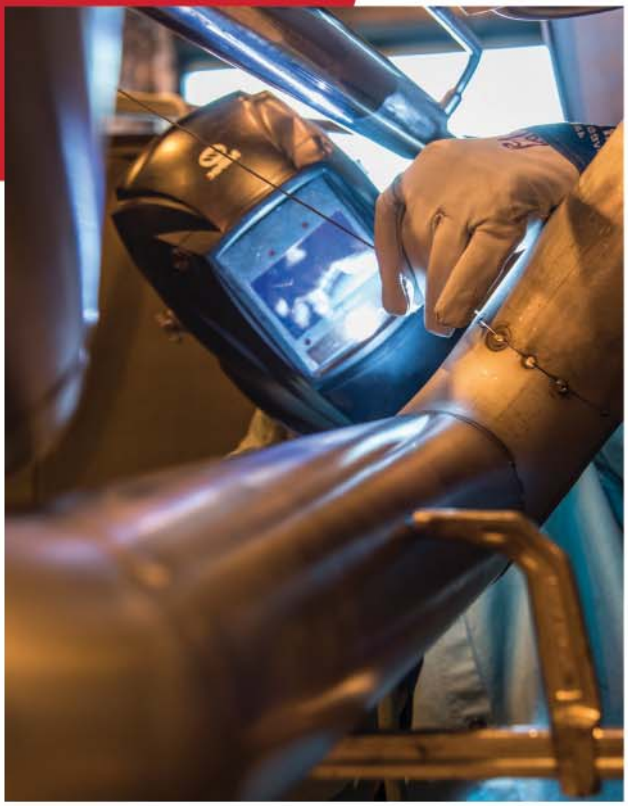
Moving you ahead.

Gardner Cryogenics is a world leader in the storage and transport of liquid hydrogen and helium. We help you move and store molecules with near-zero loss.



UNIQUE TECHNOLOGIES

Gardner's leading-edge technologies provide the lowest heat-leak for the longest hold times and highest yields. Our liquid helium and liquid hydrogen distribution systems are the most reliable, safest, and most efficient in operation.

WORLD-CLASS MANUFACTURING

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Product Showcase

This Product Showcase is open to all companies and related manufacturers offering new or improved products for cryogenic applications. We invite companies to send us short releases (75 words or fewer) with high resolution JPEGs of their products to editor@cryogenicsociety.org.

Dixon

Eagle Valves

Dixon Eagle brand bellows-sealed cryogenic valves are used in LNG and liquid industrial gas applications including cryogenic piping systems, high purity industrial gas tanks, ISO containers and transportation trailers.

These robust valves are field repairable and Dixon offers a host of options to tailor them to your needs. They are constructed of stainless steel, have a temperature rating from -452 °F to 300 °F, and are bubble tight to 600 PSIG nitrogen. **dixonvalve.com** ■

Habonim

Bidirectional Cryogenic Floating Ball Valve

Bidirectional cryogenic ball valves are operable in cryogenic flow systems, including the growing Small-Scale LNG (SSLNG) market. Ball valves offer a higher flow (Cv) as compared to globe valves of the same size, meaning smaller sizes are possible without compromising on flow rate. Habonim developed and offers the unique, patented bidirectional cryogenic floating ball valve featuring all the benefits of the high flow quarter turn ball valve, plus bidirectional full Δp sealing.

The valve is especially beneficial in systems used to transport, store and handle SSLNG where systems need to be smaller, lightweight and more cost-effective, while still maintaining maximal flow for shorter load and offload operations. **habonim.com** ■

Leybold

TURBOLAB Core High Vacuum Pump Systems

With the TURBOLAB Core, vacuum specialist Leybold is launching a small plug-and-play high vacuum pumping system for research, laboratory and industrial applications. Within the TURBOLAB series, the compact tabletop unit fills the gap for entry-level vacuum needs that require a clean, dry, stable high and ultrahigh vacuum. The TURBOLAB series is now available in a total of five variants featuring TURBOVAC 90 i and 250 i backed by DIVAC 1.4 and now covers the complete application spectrum for R&D and analytical applications. The systems includes the oil- and maintenance-free TURBOVAC i turbomolecular pump, the DIVAC 1.4 dry diaphragm backing pump and a simple controller providing users with the benefit of easy serviceability. **leybold.com** ■

People, Companies in Cryogenics

On September 1, the **US Department of Energy** announced $17.5 million in funding for advanced research projects in particle accelerator science and technology as well as university-based traineeships that will build a diverse, skilled pipeline of American scientists and engineers in the fields of high energy physics accelerators and instrumentation.

....

Venture Global LNG and **PGNiG** (Polish Oil and Gas Company) finalized an agreement under which PGNiG will purchase an additional two million tonnes per annum of liquefied natural gas (LNG) from Venture Global for 20 years. Cargoes will be supplied from Venture Global's Calcasieu Pass LNG and Plaquemines LNG export facilities. The documents were signed during a ceremony at the Warsaw Stock Exchange.

....

Caterpillar Inc. and **Chevron USA Inc.** announced that they will collaborate "to confirm the feasibility and performance of hydrogen for use as a commercially viable alternative to traditional fuels" for transportation modes such as line-haul rail, marine vessels and prime power, beginning with the demonstration of a hydrogen-powered locomotive.

....

The **Fermi Research Alliance**, a partnership of the **University of Chicago** and **Universities Research Association** that manages the **Fermi National Accelerator Laboratory** (CSA CSM) on behalf of the US Department of Energy, announced September 10 that **Nigel Lockyer** will step down after eight years as director of the national laboratory that leads US research in particle physics.

....

Höegh LNG Partners LP announced on September 24 that it has entered into an agreement with a subsidiary of **New Fortress Energy Inc.** to charter the *Höegh Gallant* for floating storage and regasification unit operations for a period of ten years, with a planned commencement during the fourth quarter of 2021.

....

A collaboration between scientist and CSA Board Chairman **John Weisend** of the European Spallation Source and **Mike Edgerton** of Lund University which resulted in a new musical composition was reported in ***Cold Facts*** Volume 27, Number 1. Due to COVID restrictions the premiere

Image: Weisend

of *Der Rufer* was delayed for a year. Now that restrictions are being relaxed, *Der Rufer* received its World Premiere in Oldenburg, Germany, on Oct. 30 and its Swedish premiere during the Inter Feral Arts New Music Festival on Oct. 8 in Malmö, Sweden, by the Bremer Schlagzeugensemble. Directly preceding this event, Weisend presented an overview of work done at ESS, including topics such as He II and Second Sound, then both Weisend and Edgerton contributed to a panel discussion on Art and Science. Listen to the composition at **http://2csa.us/kp**

....

The **American Physical Society** (APS) has elected two scientists from the US Department of Energy's **Brookhaven National Laboratory** as 2021 APS fellows. Brookhaven Lab particle physics experimentalist **Kétévi Adiklè Assamagan** is being honored "for significant contributions to experimental studies of the Standard Model Higgs boson and the search for new phenomena beyond the Standard Model using the Higgs boson as a tool, and for leading physics outreach in Africa including founding the African School of Fundamental Physics and Applications." Brookhaven Lab nuclear physics theorist **Swagato Mukherjee** is being recognized "for seminal work employing ab initio lattice quantum chromodynamics (QCD) to uncover fundamental information on the QCD phase diagram at finite temperatures and baryon density, and for the creative use of these methods to provide limits on the location of the critical point in heavy-ion collisions."

....

The C5 (Low Temperature Physics) commission of **The International Union of Pure and Applied Physics** announced its "Call for nominations of Young Scientist Prizes for 2022." Each winner will give an invited presentation at the 29th International Conference on Low Temperature Physics (LT29), Sapporo, Japan, August 18-24, 2022. (**http://2csa.us/ha**) Candidates for the prize should have received their PhD within eight years from the deadline for submission of nominations. The deadline is December 15, 2021 at 11:59 pm CST. ■

Meetings & Events

Space Cryogenics Workshop
November 15-16, 2021
Virtual online conference
spacecryogenicsworkshop.org

Foundations of Cryocoolers Short Course
June 27, 2022
Bethlehem, PA
http://2csa.us/kn

ICC 22
June 27- 30, 2022
Bethlehem, PA
http://2csa.us/kn

29th International Conference on Low Temperature Physics
August 18- 24, 2022
Sapporo, Japan
http://2csa.us/ha

ASC 2022
October 23-28, 2022
Honolulu, HI
http://2csa.us/ko

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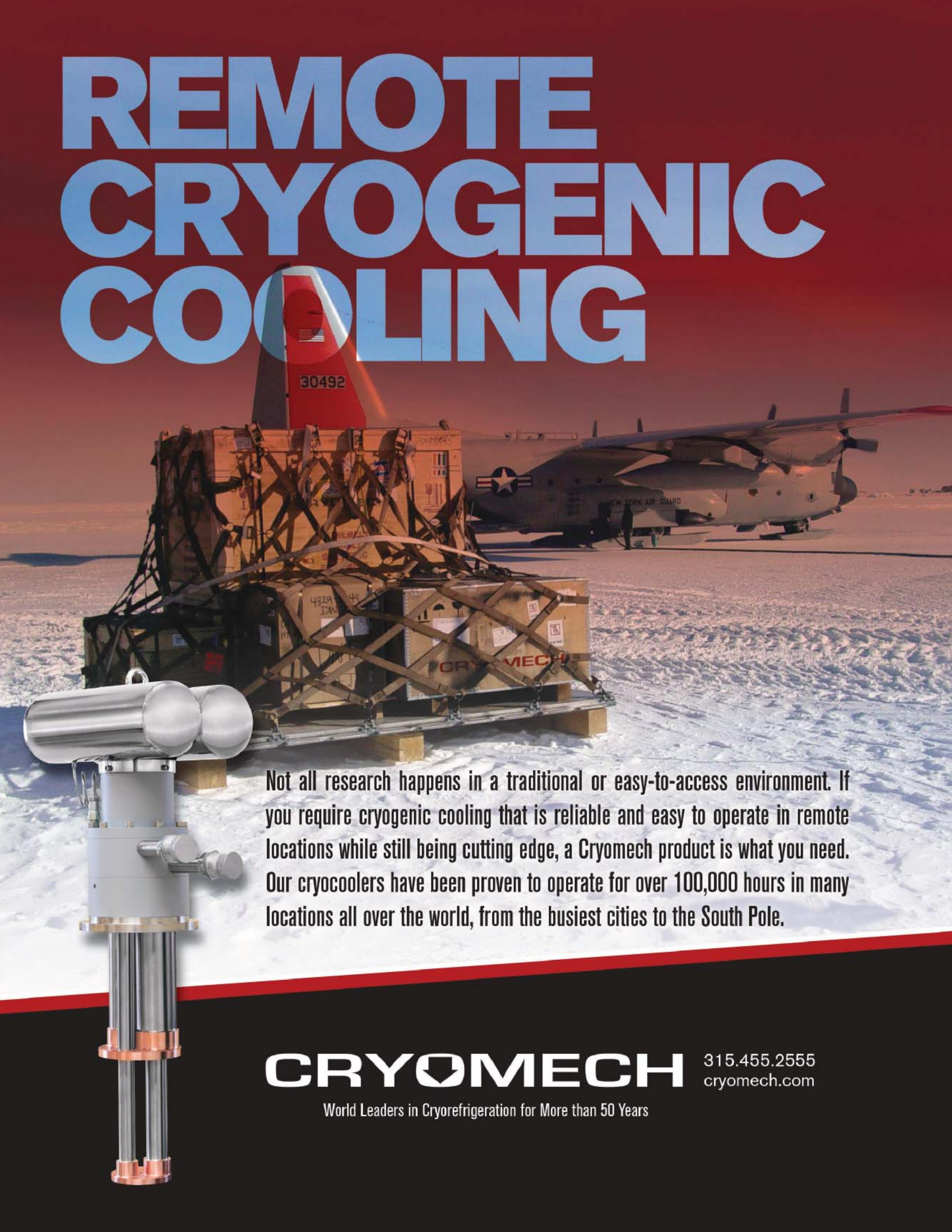
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