NATIONAL SCIENCE FOUNDATION
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NSF 18-035

Dear Colleague Letter: RAISE on Enabling Quantum Leap: Transformational Advances in Quantum Systems

December 14, 2017

Dear Colleagues:

In 2016, the National Science Foundation (NSF) identified 10 Big Ideas for Future Investment. The opportunity described in this Dear Colleague Letter (DCL) overlaps with two of those Big Ideas: Quantum Leap, which is a multi-pronged effort to advance fundamental understanding of quantum phenomena, materials, communications, and systems, and Convergent Research, which fosters the merging of ideas and approaches from widely diverse fields.

This DCL aims to encourage researchers to submit interdisciplinary research projects that must include at least three complementary components represented by researchers with expertise in the areas of physics, chemistry, mathematics, materials science, engineering, and computer/computational science, which are more broadly represented by the NSF Directorates for Mathematical and Physical Sciences (MPS), Engineering (ENG), and Computer and Information Science and Engineering (CISE). The innovative proposals must focus on quantum functionality by assessing aspects relevant to both fundamental and application concepts, and must result in experimental demonstrations of transformative advances towards quantum systems and/or proof-of-concept validations.

Quantum information science (QIS) is rapidly advancing as applications that use fundamental physical principles such as coherence, superposition, and entanglement are pioneered with ions, molecules, atoms, and atom-like systems such as vacancy centers in diamond. Superconducting qubits, quantum dots, and quantum optics are also advancing QIS. Longer coherence times, higher-fidelity methods for quantum state preparation and readout, and more controlled methods to manipulate single and multiple qubit systems are enabling achievements such as the implementation of mathematical concepts and quantum computing algorithms, new uses for quantum simulation, applications for quantum communication networks, and quantum-enhanced measurement technologies. Breakthroughs in these fields are expected to promote better understanding of quantum chemistry, high-temperature superconductivity, magnetism, topological matter, thermodynamics, quantum electrodynamical chemistry, entanglement generation and measurement, hybrid quantum systems, quantum annealing, quantum tomography, quantum control, quantum computation, and quantum simulation.

Materials science concepts and organizing principles are needed for assembling complex materials (including chemical systems), developing new materials, and validating theoretical predictions in order to gain advantage from such quantum phenomena. New quantum materials featuring unique quantum effects such as coherence, entanglement, superconductivity are emerging. These include atomic-layer materials, topological insulators, metastructures, endohedral fullerenes, multi-spin systems, metal-organic frameworks, radical conjugated polymers, quantum dots, and quasiparticles (skyrmions, magnons, and spinons). These materials not only possess extraordinary properties, but they also allow manipulation of their electronic or magnetic status through external stimuli with unprecedented efficiency and dramatically low energy loss, thus offering a pathway to ultra-fast, ultra-energy-efficient quantum sensing, quantum communication, quantum computing, and quantum simulation. Despite the remarkable advances in quantum materials recently demonstrated, there is much basic materials science research to be done in order to solve the challenges affecting the synthesis, characterization, and control of the desired functionalities.

Engineering scalable, stable, and robust platforms for a range of functions and applications is another critical step towards practical implementation of quantum technology systems. Design and testing of the quantum functionality at both the component and system level can provide important benchmarks for the practical viability of the proposed technology. There has been considerable progress on quantum technologies, for example, with integrated optics platforms that offer reliable heralded sources of single photons and photon pairs with high emission and coupling efficiency; with on-chip entanglement control; with on-chip quantum memories with low noise and long coherence times; with efficient ion-photon interfaces; with quantum frequency converters; with low-noise integrated photon detectors; and with quantum sensing. However, the engineering of integrated platforms for reliable and efficient systems is still in its infancy. Controls and error correction, through various hardware and software developments, are needed to mitigate the deleterious effects of decoherence, as are more robust, scalable platforms. Demonstrations of reproducible quantum functions for applications in quantum sensing, communication, or computing are of interest.

Computer and computational science and engineering will be needed when systems-level designs for networks including quantum components are made with higher levels of abstraction. In this context, this DCL encourages various aspects of quantum communication and quantum computing, such as the computational science of developing and designing quantum algorithms, studying quantum programming languages and approaches to compiling programs, developing an application of quantum computing using quantum programming languages, quantum architectures, quantum circuit synthesis and optimization, layout and scheduling, practical fault tolerance, as well as work on integrating devices into systems. Communication challenges include but are not limited to aspects of on-chip communication, networking, establishing secure and/or efficient communication protocols, quantum information theory, and topics in communication complexity. Development of mathematical concepts relating to quantum computing and communication as well as rigorous analyses are welcome. Work on integrating various aspects of quantum sensing, quantum communication, and quantum computation into systems is also of interest.

Proposals may also include aspects that align with the goals of the Directorate for Education and

Human Resources (EHR), particularly the goals of the NSF Research Traineeship (NRT) program to educate science, technology, engineering, and mathematics (STEM) graduate students in high-priority interdisciplinary research areas using innovative, evidence-based approaches that are aligned with changing workforce and research needs.

Through this DCL, issued by the MPS Divisions of Materials Research (DMR), Physics (PHY), Chemistry (CHE), and Mathematical Sciences (DMS); the ENG Division of Electrical, Communications, and Cyber Systems (ECCS); the CISE Division of Computing and Communication Foundations (CCF) and Office of Advanced Cyberinfrastructure (OAC); and the EHR Division of Graduate Education (DGE), NSF aims to specifically focus on interdisciplinary research aiming at advancing knowledge and demonstration of new quantum functionalities that can be reproducibly fabricated, scalable, and used in practical systems.

Principal investigators (PIs) are encouraged to respond to this DCL through the submission of a Research Advanced by Interdisciplinary Science and Engineering (RAISE) proposal. PIs must follow the guidance for RAISE proposals specified in the NSF Proposal and Award Policies and Procedures Guide (PAPPG; see Chapter II.E.3). Prior to submission of a RAISE proposal, a one-page white paper must be prepared and submitted, by February 16, 2018, to cognizant Program Directors from at least three of the following divisions/office: DMR, PHY, CHE, DMS, ECCS, CCF, and OAC. Upon receipt of an invitation from the cognizant Program Directors, a full proposal may be submitted. The proposal title must begin with "RAISE: TAQS:". Award size and duration are limited to no more than $1,000,000 over a maximum of five years.

Cognizant NSF Program Directors are:

- DMR: Tania Paskova, Tel: (703) 292-2264, Email: tpaskova@nsf.gov;
- ECCS: Dominique Dagenais, Tel: (703) 292-2980, Email: ddagenai@nsf.gov;
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- OAC: Vipin Chaudhary, Tel: (703) 292-2254, Email: vipchaud@nsf.gov;
- DGE: Tara Smith, Tel: (703) 292-7239, Email: tsmith@nsf.gov.

Sincerely,

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