

Syllabus: Physical Sciences at the Nanometer-Scale, and Quantum Sensing

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Meets 2:00 – 3:20 PM Tuesdays and Thursdays, in Science Room
204, and occasionally by On-line ZOOM Meeting at:

<https://texastech.zoom.us/j/98219672610?pwd=9lPltfTVCl6c8C5ph7mlGvoMKrjAsz.1>

Office Hours will be held on TR immediately following class, or by appointment.
In-person lab meetings will be held at the laboratories and locations listed by date in the
detailed class plan below.

We will not use a textbook in this class, but rather we will study journal articles and other
materials that are posted by date on the TTU Physics and Astronomy CEES web page under
the 'Instruction' tab page at: <https://www.depts.ttu.edu/phas/cees/>

There are no formal prerequisites for this course since we will cover all necessary background
material in class. A prior understanding of undergraduate upper-division-level
electromagnetism, quantum, and condensed matter physics will be helpful in this class.

This course will consist of both lectures and hands-on laboratory exercises and
demonstrations. In lecture, either in person or by hybrid online delivery, we will discuss the
principles of physics and chemistry as a function of size, down to the sub-nanometer scale,
which leads to a discussion of the nature of the onset of macroscopic quantum coherence
phenomena in materials (for example, mesoscopic devices, quantum Hall effects,
superconductors, superfluids, quantum-dot arrays, and Bose-Einstein Condensates (BEC), to
list only a few). Lectures will also provide an introduction to the laboratory exercises, and to
methods that are needed to interpret the data, and to understand the quantum phenomena that
are observed. This course also is designed to introduce graduate students and advanced
undergraduate students to state-of-the-art technology for measurement and fabrication in
condensed matter physics, and in quantum sensing. Students in this course will get hands-on
experience in operating these advanced systems that will be necessary throughout their career
in these experimental disciplines.

Laboratory safety is of paramount importance within this class, and in all subsequent
laboratory work that you do throughout your career. Students are required to obtain the
necessary online training from Texas Tech regarding laboratory safety before they are
admitted to the laboratories. Specific laboratory hazards, and how they are mitigated, will be
discussed in lecture before each laboratory module.

In the lab, students will learn the basics of operation of various electron microscopes, and the

Zeiss 540 Crossbeam system, which we will use to fabricate quantum dot arrays. Students will also learn the basics of how to fabricate laboratory apparatus, ranging from 3D printing to Focused Ion Beam (FIB) nanofabrication. Students will learn how to experimentally measure properties of quantum materials, and how these properties indicate the underlying emergent quantum phenomena at the sub-nanometer scale.

In addition to these ‘top - down’ approaches to engineering nanostructures, students will learn about ‘bottom – up’ self-assembly techniques to produce various nanoparticles and their associated nanostructures.

Finally, students will learn quantum sensing hands-on, by their operation of Superconducting Quantum Interference Devices (SQUIDs), other Josephson-junction devices, and their applications to low-frequency, ultra-precise magnetic flux measurements, and in other applications, including the use of ‘Shapiro steps’ in near-quantum-limited radiation detection. Finally, we will discuss the very new sub-field of quantum nucleonics and nano-nuclear physics, which are pioneering new vastly superior technologies in nuclear clocks and in new methods of nuclear energy conversion and nuclear rocketry.

Objectives

Students in this course will develop an understanding of, and basic competency in the associated laboratory practice, in the following areas:

- 1) Physics, quantum properties of materials, and in associated engineering principles, as a function of size
- 2) Multi-scale imaging, focused-ion beam fabrication, and quantum dot arrays
- 3) Magnetic properties of materials, and critical phenomena
- 4) Self-assembly and characterization of nanoparticles and their structures
- 5) Quantum coherence, superconductivity, Josephson effects, superfluidity and BEC
- 6) Quantum sensing using SQUIDs, Josephson devices, and quantum phase-coherent circuits

Grading

Attendance at, and participation in, all class and laboratory activities are mandatory, and this counts for 50% of your grade. Each student will be asked to plan, structure, conduct, and summarize in a presentation to the class, a laboratory-based project during the term, and the quality and effectiveness of this presentation, both oral and written, will count for 40% of your grade. Numerous informal quizzes will be given throughout the term, to assure that the essential concepts of each sub-topic are well understood. These quiz grades will count towards 10% of the overall course grade. There will be no final exam.

Required and Recommended Syllabus Statements are provided by the TTU Provost’s Office, and they are linked below. They will be updated by the Provost’s Office if needed during this semester:

The Office of the Provost will update the language when required and has committed to using the same web-page for all future updates:

Required Statements: <https://www.depts.ttu.edu/tlpdc/RequiredSyllabusStatements.php>

Recommended (optional)

Statements: <https://www.depts.ttu.edu/tlpdc/RecommendedSyllabusStatements.php>

There is also an optional statement on the use of AI – there are three statements that could be used, depending on how students may (or may not) use AI in their studies. In this class, students are encouraged to use any AI tool that they like, but all students are encouraged to independently verify the accuracy of the results from using such tools:

<https://www.depts.ttu.edu/tlpdc/AI-Syllabus-Statements.php>

Daily Course Plan

Due to advanced laboratory equipment availability, maintenance, and outages, this detailed plan is subject to change with advanced notice to the class by email. The default location of the class is in Science 204, but laboratory meetings will be announced ahead of each class meeting. All class meetings are held from 2:00 – 3:20 PM on Tuesdays and Thursdays. Attendance is mandatory.

Date	Location	Topic
8/26	Science 204	Introduction to the class, grading, laboratory safety Introduction to nanoscience and quantum sensing How are things different at the sub-nanometer scale? Bottom-up and top-down nanofabrication technology Discuss Richard Feynman, “Plenty of room at the bottom” (1959)
8/28	Science 204	Discuss the Physics Today article on Josephson and Bardeen Machining, 3D printing, resin printing, laser cutting and printing
9/02	Science 204	Introduction to self-assembly of nanoparticles Nanomaterials safety
9/04	Reese B61 (carpool)	Nanoparticle synthesis and experimentation Demo of advanced instrumentation design
9/09	Science 204	Quantum nucleonics Nano-nuclear energy technology Fission fragment rocket (FFR)
9/11	Science 204	Nuclear measurements and nuclear laboratory safety
9/16	ESB 153	Radiation detection CR-39 for alpha particle and neutron track analysis Gamma and neutron spectroscopy Tritium assays
9/18	ESB 153	Continuation of the above
9/23	Science 204	Introduction to how and why physical size matters
9/25	Science 204	Applications in Quantum Sensing
9/30		Guest Lecture: Prof. Yun Suk Eo: degenerate 2D electron gasses
10/02		Guest Lecture / Lab: Prof. Yun Suk Eo: Quantum Hall Effect
10/07	(Imaging Center, IC)	Introduction to the Zeiss Crossbeam 540 SEM and FIB Introduction to Hitachi 3400

10/09	IC	Advanced techniques in SEM: Radiation detection
10/14	IC	Design and fabrication of nanodot arrays in platinum using FIB
10/16	IC	Completion of electronic imaging and FIB nanofabrication
10/21	IC	Introduction to electron microscopy, TEM, SEM TEM nanoparticle imaging and characterization SEM nuclear track imaging in CR-39 and wide-area mapping / AI
10/23	Science 204	Bell's Inequality, EPR Paradox, Interpretation of Quantum Mechanics
10/28	Science 204	Survey of quantum computing and quantum sensing efforts
10/30	Science 204	Superconductivity, magnetic flux quantization, and Josephson effects
11/04	Science 118	Guest Lecture: Prof. Yun Suk Eo, Transport theory / measurements
11/06	Science 118	Guest Lecture and Lab : Prof. Yun Suk Eo, Transport measurements
11/11	Science 204	Theory and operation of SQUIDs and SQUID circuits
11/13	ESB 153	Operations of SQUIDs
11/18	ESB 153	Shapiro steps, flux-locking SQUIDs, other applications
11/20	Science 204	Other quantum sensors – Rydberg Sensors, Diamond NV Sensors, etc.
11/25	Science 204	Student lab projects
11/27	No Class	Thanksgiving holiday
12/2	Science 204	Students lab projects and last day of class