
First-Year Seminar

Phases of Matter: Remarkable changes of properties by varying temperature and pressure.

Isaac Silvera

(Thursday 3:45-5:45, Lyman 224)

There are readings every week including websites, articles, and chapters in books. I may invite an occasional guest to attend the first-year seminar, people with experience or expertise in certain areas such as the many phases of water. The class is designed so that the students generate curiosity and questions on the behavior of matter. We discuss the many phases of matter, gas/liquid/solid, as well as materials that do not have all of these phases. We also discuss remarkable phases and phenomena that have been studied and understood in the past century, such as superfluidity, superconductivity, and magnetism, all still active fields of research. I recommend this seminar to students with a strong interest in physics or chemistry and a desire to learn about the remarkable phases that matter can enter.

I plan two outings for the class, both at Harvard. One to a laboratory to view high pressure and low temperature apparatus and another to the Harvard Helium Liquefier.

Course Syllabus

The readings are either from websites, downloadable articles, or books-- hopefully these readings stimulate class discussion. At the end of the semester I ask the students to write a short article on the level of a science news article on one of the subjects covered.

Academic Integrity

Science is a social effort so collaboration on the understanding of assignments and discussions is allowed.

Disability Access

Harvard University values inclusive excellence and providing equal educational opportunities for all students. Our goal is to remove barriers for disabled students related to inaccessible elements of instruction or design in this course. If reasonable accommodations are necessary to provide access, please contact the Disability Access Office (DAO). Accommodations do not alter fundamental requirements of the course and are not retroactive.

Students should request accommodations as early as possible, since they may take time to implement. Students should notify DAO at any time during the semester if adjustments to their communicated accommodation plan are needed.

Weekly Seminars

Week 1- States of Matter, Phase transitions, Phase Diagrams, Order, and the Order Parameter

Students should read the articles on the following web sites

<https://www.inspiritvr.com/general-chemistry/states-of-matter/states-of-matter-study-guide>

<https://www.inspiritvr.com/general-chemistry/states-of-matter/reading-a-phase-diagram#introduction>

Phases of matter can be changed by varying temperature or pressure, discussed in the next meetings.

Week 2- Temperature and Heat

Read the following articles including the sub-articles on the website

<https://www.britannica.com/science/temperature--simple>

<https://byjus.com/physics/temperature/> --more extensive

Read Chapter IV, **Temperature Measurement** in G.K. White, **Experimental techniques in low temperature physics**, 2nd edition, Clarendon press 1968.

Week 3- Pressure and Density

Read the following general article on pressure.

<https://www.khanacademy.org/science/physics/fluids/density-and-pressure/a/pressure-article>

Then for static pressure in Diamond Anvil Cells (DACs) read the article

Jayaraman, Reviews of Modern Physics, **Diamond Anvil Cell and High-**

Pressure Physical Investigations 55, 65 (1983).

Also

Chapter 8 on **Shock waves** in the book **High Pressure Experimental**

Methods, Oxford University press, 1996 by M. Eremets

The class will visit a laboratory to view diamond anvil cells , cryostats, and optical measuring systems.

Week 4- Phases of Water

Solid water only had one phase in equilibrium with its vapor pressure as temperature was lowered below the freezing point of water. When we introduce pressure along with temperature we find that a remarkable almost 20 structural phases of water have been discovered. Read the articles

A.N.Dunaeva et al, **Phase Diagram of H₂O: Thermodynamic Functions of the Phase Transitions of High Pressure Ices**, Solar System Research 1010, Vol 44 202-222, 2010
Pleiades Publishing Inc.

T.C. Hansen, **The everlasting hunt for new ice phases** Nature Comm 12:3161, 2021; this article reports the phase XIX (19).

Week 5- Helium and superfluidity

There are two isotopes of helium with masses 3 and 4. Read the short article on the web

<http://hyperphysics.phy-astr.gsu.edu/hbase/lhel.html>

Then read the first two chapters in the book by J. Wilks, Clarendon Press, 1967

The class will visit the Helium liquefier and recovery and distribution center at Harvard.

Week 6- Electrical charge and spin in materials. The charge and spin have a remarkable effect on properties of materials.

Read Chapter 10 (**Electric Fields in Matter**) in the book **Electricity and Magnetism**, 2nd edition by Ed Purcell, McGraw Hill Book Company, 1985.

Week 7- Metals and Semiconductors

In the book **Introduction to Solid State Physics** by Charles Kittel 7th edition John Wiley and Sons

Read pages 141 to 197.

Week 8- Insulator Metal Transitions

Read the article E. Wigner and H. B. Huntington, **On the Possibility of a Metallic Modification of Hydrogen**, J. Chem. Phys. 3, 764 (1935).

Week 9- Insulators and Semiconductors

In the book **Introduction to Solid State Physics** by Charles Kittel 7th edition John Wiley and Sons

Read chapter 8 **Semiconductor Crystals** (pgs. 197-233)

Week 10- Superconductivity

In the book **Introduction to Superconductivity**

2nd edition, 1996, McGraw-Hill by M. Tinkham read pages 1-16 and 43-70.

Week 11- Magnetism

In the book **Introduction to Solid State Physics** by Charles Kittel 7th edition John Wiley and Sons

Read chapters 14 and 15, **Diamagnetism, and Paramagnetism; Ferromagnetism and Antiferromagnetism**