Nanyang Technological University
Division of Chemistry and Biological Chemistry

Academic Year	AY20/21	**Semester**	2
Course Coordinator	Sumod Pullarkat & Lee Soo Ying		
Course Code	CM1041		
Course Title	Basic Physical Chemistry with Laboratory		
Pre-requisites	H2 Chemistry or equivalent		
No of AUs	4		
Contact Hours	Lectures: 39; Laboratory: 18; Tutorial: 6		
Proposal Date	09 January 2020		

Course Aims

The course covers fundamental concepts and organizing principles of physical chemistry that provide the basis for many aspects of chemistry and related fields, including analytical, inorganic, organic and bio-related chemistry. It will bring everyone to the same level of command of basic physical chemistry that is essential to progress to higher levels of core physical chemistry courses. Coupled with mathematical models, physical chemistry can provide quantitative results to compare with and understand experiments, and sometimes to stimulate new experiments. The concepts espoused in the course will be illustrated and connected with real world applications. Practical work is at the heart of chemistry. The laboratory component of the course therefore aims to expose you to chosen experiments which are meant to further consolidate the theoretical aspects learned during the course. The aim is to train you to apply the principles of thermodynamics, kinetics and spectroscopy presented in the lecture courses, in some illustrative experiments. This will help you gain familiarity with a variety of physico-chemical measurement techniques and instill in you the ability to work independently as well as part of a team.

Intended Learning Outcomes (ILO)

Upon successfully completing this course, you should be able to:

1. **<u>Gases and their Properties</u>**

(a) Associate and Administer the key underlying concepts defining the gaseous state of matter from both a physical and chemical perspective.

(b) Analyse the basis of key parameters such as pressure, volume, temperature and number of moles as applied to gases

(c) Examine the unit systems used to measure various properties of gases.

(d) Examine the gas laws and understand the underlying relationship between: the volume and the pressure of a gas; volume and the temperature of a gas and between volume and the number of moles of a gas at constant temperature and pressure

(e) Apply the ideal gas law to calculate values for pressure, volume, temperature, density, molar mass and amount of a gas. Solve basic problems involving variation in one parameter using the ideal gas equation.

(f) Discuss the circumstances under which deviations from the ideal gas law can occur in the case of real gases and apply the principles learned to generate a modified equation to illustrate the difference in calculated values between real and ideal gases.

(g) Assess the core principles of the kinetic-molecular theory of gases especially from the perspective of molecular speed and kinetic energy.

(h) Describe the phenomena of gas effusion and diffusion and use Graham`s law to explain the connection between rate of movement and molar mass.

2. **Intermolecular Forces and Liquids**

(a) Describe the molecular basis of classification of solutions as homogenous and heterogeneous.

(b) Describe the fundamental concepts which define the classification of a component as solvent and solute in a solution.

(c) Examine the physical basis by which a process is defined as endothermic and exothermic.

(d) Examine the key factors involved in the step wise process by which an ionic solid dissolve in a solution. Understand the energetics associated with each step.

(e) Identify the contribution of factors such as lattice enthalpy, enthalpy of hydration to the energetics of the solvation process.

(f) Analyze the concept of colligative properties associated with solutions.

(g) Examine the molecular basis of the key colligative properties such as depression in vapour pressure and melting point and elevation in boiling point that occurs upon adding a non-volatile solute to a solvent.

(h) Explain the key principles that dictate gas solubility and appreciate the origin of Henry`s Law.

(i) Explain the molecular basis of the osmosis process and osmotic pressure.

(j) Explain the role of semi-permeable membranes and their application in biological systems and in reverse osmosis.

3. **Solutions and their Behavior**

(a) Analyse the physical and molecular basis of the interactions between Ions and molecules with a permanent dipole

(b) Explain the interactions between molecules with permanent dipoles.

(c) Explain the concept dictating dipole dipole forces and its application to hydrogen bonding occurring in molecules.

(d) Analyse the unusual properties of water based on the concept of hydrogen bonding.

(e) Examine intermolecular forces involving non-polar molecules such as dipole-dipole forces and London dispersion forces.

(f) Consider the concept of vapor pressure, and the quantification of the same based on enthalpy of vaporization.

(g) Administer the Clausius-Clapeyron equation to scenarios involving change in temperature or vapour pressure of a solution. Solve problems using the equation.

4. **Basics of Chemical Reactivity: Equilibria**

(a) Associate the key concepts that define a system in equilibrium

(b) Appraise the molecular level factors involved in a system in equilibrium

(c) Define and differentiate the terms used in chemical equilibrium: Reaction Quotient (Q) and Equilibrium constant (K).

(d) Devise the setting up of equations to describe Equilibrium constant and the unit convention involved.

(e) Describe the principle involved in writing and manipulating expressions of K for various chemical including those involving pure liquids, pure solids and gases.

(f) Appraise the methods by which qualitative and quantitative information can be extracted from the value of K for a chemical system in equilibrium.

(g) Construct an ICE table to describe a system in equilibrium and understand the impact of external changes occurring during the course of the reaction to the equilibrium constant.

5. Kinetics: Simple Rates and Mechanisms of Chemical Reactions

(a) Determine and Discuss the key factors affecting reaction rates.

(b) Express rate through a rate law and determine its components; Calculate how concentrations change as a reaction proceeds.

(c) Associate the effect of concentration and temperature on rate, and how catalysts increase reaction rates.

6. Acid-Base Equilibria

(a) Analyse the developments in the ever broadening definitions of acid and base from Arrhenius to Bronsted-Lowry, and then to Lewis.

(b) Discuss the creation of the pH scale to measure the acidity of aqueous solutions.

(c) Analyse the molecular structures of acids to rationalize their relative strengths.

(d) Solve acid-base equilibria problems.

7. Ionic Equilibria in Aqueous Systems

(a) Explain how buffers work.

(b) Preparing a buffer of a particular pH.

(c) Describe how acid-base indicators work.

(d) Analyse various acid-base titration curves and how to calculate them.

8. Thermochemistry: Energy Flow and Chemical Change.

(a) Identify forms of energy and their interconversion.

(b) Discuss the First Law of Thermodynamics.

(c) Differentiate heat, *Q*, from work, *W*, and understand what a state function is.

(d) Analyse internal energy, *E*, versus enthalpy, *H*, and the major types of calorimetry.

(e) Apply Hess's Law to calculate an unknown change in enthalpy, ΔH.

9. <u>Basic Thermodynamics: Entropy, Free Energy, and Reaction Direction</u>

(a) Discuss the Second Law of Thermodynamics, and how to predict spontaneous change.

(b) Calculate the change in entropy of a reaction.

(c) Define entropy, free energy and work.

(d) Analyze the relation between free energy, equilibrium, and reaction direction.

10. <u>Basic Quantum Theory and the Hydrogen Atom</u>

(a) Discuss light as electromagnetic waves & photons; discuss how Einstein explained the photoelectric effect; and encountering discontinuous energy in quantized atomic spectra.

(b) Analyse the wave-particle duality for subatomic particles, the significance of the Schrödinger equation, and the interpretation of the wavefunction.

(c) Solve the Schrödinger equation for a particle in a one-dimensional box and use it to estimate quantized energy levels in various situations.

(d) Analyze the solutions of the Schrödinger equation for the hydrogen atom and construction of atomic orbitals.

Course Content

1. Gases and their Properties
2. Intermolecular Forces and Liquids
3. Solutions and their Behavior
4. Basics of Chemical Reactivity: Equilibria.
5. Kinetics: Simple Rates and Mechanisms of Chemical Reactions.
6. Acid-Base Equilibria.
7. Ionic Equilibria in Aqueous Systems.
8. Thermochemistry: Energy Flow and Chemical Change.
9. Basic Thermodynamics: Entropy, Free Energy, and Reaction Direction.
10. Basic Quantum Theory and the Hydrogen Atom.

Assessment (includes both continuous and summative assessment)

Component	Course ILO Tested	Related Programme LO or Graduate Attributes	Weighting	Team/Individual	Assessment rubrics
1. Midterm Test 1	1,2,3	Competence, Creativity	10%	Individual	Appendix 1
2. Midterm Test 2	5, 6, 7	Competence, Creativity	10%	Individual	Appendix 1
3. Final Examination	1, 2, 3, 4, 5, 6, 7, 8, 9, 10.	Competence, Creativity	50%	Individual	Appendix 1
4. Laboratory (Team work)	1,2,3,5,6,8	Competence, Creativity, Communication and Character	30%	Individual	Appendix 2
Total			*100%*		

Formative feedback

Formative feedback: Lecturers and TAs will be closely working with you to monitor your learning progress. They will provide you with timely feedback to improve your understanding of concepts. Furthermore, you will be given opportunities to express your ideas and discuss them with lecturers and TAs.

Summative Feedback: Summative feedback on laboratory reports and mid-term tests will be given. For laboratory reports, you will be provided with comments on mistakes, areas of improvement and examples of good practice in scientific writing etc.

This will help you to achieve the intended learning outcomes 1 to 13 above.

Learning and Teaching approach

Lectures (39 hours)	The lectures will convey key concepts in basic physical chemistry, providing critical information and background on how the concepts come about, with relevant theories and equations. The concepts will be illustrated with worked examples and with real world applications to show the relevance and importance of learning chemistry and its links to other disciplines.
Tutorials (6 hours)	TAs will provide materials containing concepts taught in classes and cover related applications derived from corresponding lectures. You will be assigned to a small group for interactive discussions, which will help you to develop your own critical thinking capability and problem solving skills in a team-based learning environment.

Laboratory (18 hours)	Laboratory session will consist of three main parts. Pre-laboratory exercises will involve online pre-lab quiz to be attempted prior to a lab session and consists of risk assessment and questions based on the lab manual to ensure that students have read and understood the respective experimental description before starting the actual lab session. During the actual lab session students will typically work in pairs and conduct the assigned experiment under the supervision of laboratory TAs following the instructions provided in the lab manual. This will train students in applying concepts learned to real life situations. Subsequent to the lab session you are to submit a individual post-lab report in the prescribed format which will help to develop your critical thinking ability, ability to assimilate, evaluate and present the data gathered during a lab experiment.

Reading and References

Recommended textbooks:

Chemistry & Chemical Reactivity, 10th Ed (2019), Kotz/Treichel (KT), Cengage Learning Asia Pte. Ltd., ISBN 978-1-337-39907-4.

Chemistry: The Molecular Nature of Matter and Change, 8th Ed (2018), Silberberg/Amateis (SA); McGraw-Hill Education; ISBN 978-I-259-92175-9

Recommended reference textbook: Elements of Physical Chemistry, 7th Ed (2016), Atkins / de Paula (AdP); Oxford University Press; ISBN: 9780198727873

Course Policies and Student Responsibilities

You are expected to read the lecture/tutorial/laboratory materials prior to the respective lecture/tutorial/laboratory session. This will help you to learn much more efficiently as you will already have an impression on the topics to be covered. For laboratory sessions, besides reading the laboratory manual and understanding the experimental procedure, you should also complete the risk assessment component of the lab report in which you should list possible hazards and their prevention steps. You should also read through the recommended textbooks as outlined in the Weekly Schedule.

Academic Integrity

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values.

As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Course Instructors

Instructor	Office Location	Phone	Email
Sumod Pullarkat	CBC-06-02	63168906	sumod@ntu.edu.sg
Soo-Ying Lee	CBC 04-01	65138465	sooying@ntu.edu.sg

Planned Weekly Schedule

Week	Topic	Course ILO	Readings/Activities
1	Gases and their Properties	1	KT Ch 10
2	Intermolecular forces and Liquids	2	KT Ch 11
3	Solutions and their Behavior	3	KT Ch 13
4	Principles of Chemical Reactivity: Equilibria	4	KT Ch 15
8	Kinetics: Simple Rates and Mechanisms of Chemical Reactions.	5	SA Ch 16
9	Acid-Base Equilibria.	6	SA Ch 18
10	Ionic Equilibria in Aqueous Systems.	7	SA Ch 19
11	Thermochemistry: Energy Flow and Chemical Change.	8	SA Ch 6
12	Basic Thermodynamics: Entropy, Free Energy, and Reaction Direction.	9	SA Ch 20
13	Basic Quantum Theory and the Hydrogen Atom.	10	AdP Ch 12 & 13

CBC Programme Learning Outcome

The Division of Chemistry and Biological Chemistry (CBC) offers an undergraduate degree major in Chemistry that satisfies the American Chemical Society (ACS) curricular guidelines and equips students with knowledge relevant to the industry. Graduates of the Division of Chemistry and Biological Chemistry should have the following key attributes:

1. Competence
Graduates should be well-versed in the foundational and advanced concepts of chemical science, be able to evaluate chemistry-related information critically and independently, and be able to use complex reasoning to solve emergent chemical problems.

2. Creativity
Graduates should be able to synthesize and integrate multiple ideas across the curriculum, and propose innovative solutions to emergent chemistry-related problems based on their training in chemistry.

3. Communication
Graduates should be able to demonstrate clarity of thought, independent thinking, and sound scientific analysis and reasoning through written and oral reports to audiences with varying technical backgrounds. They should also be able to effectively engage other professional chemists in collaborative endeavours.

4. Character
Graduates should be able to act in responsible ways and uphold the high ethical standards that the society expects of professional chemists.

5. Civic-mindedness
Graduates should be aware of the impact of chemistry on society, and how chemistry can be applied to benefit mankind. They should also be aware of and uphold the best chemical safety practices.

Appendix 1: Assessment Criteria for mid-term and final exam

mid-terms 1 and 2- MCQ questions

Standards		
Fail standard (0-4 marks)	**Pass standard (5-7 marks)**	**High standard (8-10 marks)**
Answers to the questions are mostly incorrect.	Answers to the questions are mostly correct.	Answers to the questions are almost always correct.

final exam – MCQ questions

Standards		
Fail standard (0-4 marks)	**Pass standard (5-7 marks)**	**High standard (8-10 marks)**
Answers to the questions are mostly incorrect.	Answers to the questions are mostly correct.	Answers to the questions are almost always correct.

final exam – short answer questions

Standards		
Fail standard (0-4 marks)	**Pass standard (5-7 marks)**	**High standard (8-10 marks)**
Answers demonstrate the ability to repeat factual knowledge but not to apply it outside of the lecture context. Answers do not have a strong logical underpinning or maybe attempts to answer both ways at the same time.	Answers to the standard level question are correct and show the ability to apply concepts from the course, but a high level of critical thinking is absent. Answers are reasonably logical, but with gaps.	Answers to all questions show a high and consistent level of critical analysis of the information presented and creative solutions to the problems. Answers are highly logical and demonstrate strong reasoning. Answers are concise and to the point.

Appendix II – Assessment criterion for lab proforma

	Exceptional (10-8)	Admirable (6-7)	Acceptable (4-5)	Poor (1-3)
Overall presentation	Appropriate as a piece of scientific writing. Words were chosen carefully and appropriately. Sentence structure was clear and easy to follow. The report is free of spelling, punctuation, calculation and grammatical errors.	Minimal awkward phrasing or word choices. Minimal mistakes in calculations and explanations	Many passages are phrased poorly, contained awkward word choices, or many long sentences. Narrative is disorganized in many places. Multiple grammatical and/or spelling errors.	Poorly organized report with frequent awkward phrases, poor word choices and wrong inferences/calculations. Lacks cohesion, style and fluidity.
Answers to Proforma questions	Relevant experimental data/calculation steps are presented which are used for answering proforma questions. Demonstrates a logical, coherent working knowledge and understanding of important experimental concepts, forms appropriate conclusions based on interpretations of results, includes applications of and improvements in the experiment, collected data and analysis and demonstrates accountability by providing justification for any errors. Address all specific questions posed in the proforma.	All data and associated figures, calculations etc. are presented. Demonstrates an understanding of most important experimental concepts, forms conclusions based on results and/or analysis but either lacks proper interpretation, suggests inappropriate improvements in the experiment or lacks overall justification of error. Address most of the specific points for questions posed in the proforma.	Most figures, graphs, and tables are included, but some important or required features are missing. Certain data reported are not mentioned in the text or are missing. Captions are not descriptive or incomplete. While some of the results have been correctly interpreted and discussed, partial but incomplete understanding of results is still evident. Student fails to make one or two connections to underlying theory. Address some of the specific points or questions posed in the proforma.	Figures, graphs, and tables are poorly constructed; have missing titles, captions or numbers. Certain data reported are not mentioned in the text. Important data missing. Does not demonstrate an understanding of the important experimental concepts, forms inaccurate conclusions, suggests inappropriate improvements in the experiment and lacks overall justification of error. Address none of the specific points or questions posed in the proforma.