UNIVERSITY OF CAMBRIDGE
Chemical Engineering and Biotechnology

CHEMICAL ENGINEERING TRIPOS

Part I

SYLLABUS 2017-18

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General Introduction

Students reading the Chemical Engineering Tripos normally progress as follows:

- 1st year: Part IA Natural Sciences Tripos or Part IA Engineering Tripos
- 2nd year: Part I Chemical Engineering Tripos (CET I)
- 3rd year: Part IIA Chemical Engineering Tripos (CET IIA)
- 4th year: Part IIB Chemical Engineering Tripos (CET IIB)

Progress is dependent on satisfactory performance in the previous year's course – honours standard in CET I is sufficient to do CET IIA. Students are normally required to achieve class II.2 or higher in CET IIA in order to progress to CET IIB.

The educational aims of the overall Chemical Engineering Tripos are to:

- give a sound education in the fundamentals of Chemical Engineering;
- develop the skills and confidence necessary for the solution of problems in the chemical, biochemical and allied industries;
- produce graduates of the highest calibre;
- provide an education accredited by the Institution of Chemical Engineers.

Outline of Part I Chemical Engineering Tripos (CET I)

In Part I students gain a broad exposure to the core Chemical Engineering topics.

There are lecture courses on:

- Fundamentals: process calculations; fluid mechanics; biotechnology fundamentals; heat and mass transfer fundamentals
- Process operations: separations; homogeneous reactors; biotechnology operations; heat and mass transfer operations
- Process systems: introductory chemical engineering
- Mathematics: engineering mathematics
- Enabling topics: stress analysis and pressure vessels; mechanical engineering for those who read Natural Sciences in the first year; introductory chemistry for those who read Engineering in the first year

In addition, students are required to undertake classes on:

- Exercises
- Chemical Engineering laboratory
- Computing skills
- Professional skills
- Engineering drawing: for those who read Natural Sciences in the first year
- Physical chemistry laboratory: for those who read Engineering in the first year

Full details of these courses are provided in the Part I Syllabus Document.

Students for Part I take four written examination papers. Papers 1-3 are taken by all students. Paper 4(1) is taken by students who read Natural Sciences in the first year, and Paper 4(2) is taken by students who read Engineering in the first year. The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Outline of Part IIA Chemical Engineering Tripos (CET IIA)

In Part IIA students continue their study of core chemical engineering topics, both by extending subjects that were introduced in Part I and by being exposed to new topics.

There are lecture courses on:

- Fundamentals: advanced fluid mechanics; equilibrium thermodynamics; radiative heat transfer; corrosion and materials
- Process operations: heterogeneous reactors; separations; bioprocessing; particle processing
- Process systems: process dynamics and control; process synthesis; safety, health and environment
- Mathematical methods: partial differential equations; statistics
- Enabling topics: process design

In addition, students are required to undertake:

- Exercises
- Design project
- Engineering ethics

Full details of these courses are provided in the Part IIA Syllabus Document.

Students for Part IIA take four written examination papers. These examinations are near the start of Easter term, after which the Design Project takes place. The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Rather than staying on for Part IIB, students may graduate with a B.A. degree after successfully completing Part IIA. Students leaving at this stage have not fully completed the academic requirements of the IChemE for becoming a Chartered Engineer.

Outline of Part IIB Chemical Engineering Tripos (CET IIB)

Part IIB is a masters-level course that gives students a deeper understanding of some fundamental subjects, introduces a range of specialist areas of knowledge, and provides an opportunity for broadening their education.

Topics in Groups A and D are compulsory. Students are required to take a total of six modules from Groups B and C, of which at least two must come from Group B and at least two must come from Group C. Further, at least two of the six modules chosen from Groups B and C should be assessed principally or entirely by written examination.

Group A consists of the following compulsory topics.

- Sustainability in chemical engineering
- Energy technology
- Chemical product design

Group B consists of advanced chemical engineering topics.

- Advanced transport processes
- Pharmaceutical engineering
- Rheology and processing
- Computational fluid dynamics
- Fluid mechanics and the environment
- Interface engineering

Group C consists of broadening material topics.

- Optical microscopy
- Optimisation
- Healthcare biotechnology
- Entrepreneurship
- Foreign language
- Biosensors
- Bionanotechnology
- Biophysics

The Group D topic is a compulsory project. Each student undertakes a research project, usually in collaboration with another student, supervised by a member of staff.

Full details of these courses are provided in the Part IIB Syllabus Document.

The format of examinations and weighting of written papers and project work is given in the Form and Conduct Notice published each year by the Chemical Engineering and Biotechnology Syndicate.

Students graduate with B.A. and M.Eng. degrees after successfully completing Part IIB. Provided they performed satisfactorily in the design component, they have satisfied the academic requirements of the IChemE for becoming a Chartered Engineer.

Student Workload Statement

It is expected that students will:

- attend and be attentive in all lectures and related classes;
- complete all assignments to a satisfactory standard by the imposed deadlines;
- prepare properly for all College supervisions;
- work in the vacations on consolidation, revision, exam preparation and any coursework.

The normal workload for a typical chemical engineering student is 45 hours each week during term. However, this is not a hard and fast figure. Some students work intensely and can achieve a great deal in an hour. Other students work less efficiently. In an ideal world, students would work on a particular task (problem sheet, lab write-up, exercise report) until the desired learning outcomes have been achieved. That said, students are advised not to spend significantly more time on work than the typical workload on a frequent basis. For supervision work, while it can be useful educationally for a student to battle through a problem to reach a solution (even if it takes a long time), it is perfectly acceptable for a student to “give up” after a decent effort and go on to the next question. One of the roles of supervisions is for students to ask for help on questions that they cannot answer. Question & Answer sessions and demonstrator assistance are also provided for much of the coursework to assist students.

Student Feedback

The Department of Chemical Engineering and Biotechnology has a strong tradition of good relations between staff and students, possibly facilitated by the tea room, and takes student feedback seriously.

You will be asked to complete a questionnaire on each lecture unit when it finishes. You will also be asked to complete an end-of-year questionnaire on the overall course. Please take time to fill these in. Staff very much value receiving constructive comments.

If there are any problems with teaching in the Department, please tell the lecturer or course organiser. It is a good idea to tell the organiser before the end of the course because it may be possible to rectify the problem. If the problem persists, then please tell the Director of Teaching, Dr Patrick Barrie. If you prefer to make comments anonymously, this can be done by e-mail to library@ceb.cam.ac.uk – the librarian will remove names before passing the comments on to relevant academic staff.

If there are any problems with College supervisions, then please tell your Director of Studies or Senior Tutor.

A further feedback mechanism within the Department is provided by the Staff-Student Consultative Committee (SSCC). This is the formal forum in which students comment on issues concerning life in the Department. Two student representatives will be elected from each undergraduate year group early in Michaelmas term to serve on this Committee. The SSCC also includes M.Phil. student representatives and Ph.D. student representatives. Meetings are held at least once a term.

There is also an undergraduate representative on the Chemical Engineering and Biotechnology Syndicate. This is the University body that is responsible for overseeing the running of the Department – it is the equivalent of a Faculty Board. The election of the undergraduate representative to the Syndicate takes place late in Michaelmas term.

Chemical Engineering Tripos: information on plagiarism

The University's website on plagiarism makes the following statement:

> "Plagiarism is defined as submitting as one's own work, irrespective of intent to deceive, that which derives in part or in its entirety from the work of others without due acknowledgement. It is both poor scholarship and a breach of academic integrity."

The open literature, including web-based literature, is available for you to consult. Discussions about continually assessed work with other students, or with demonstrators or supervisors, can be beneficial, and we wish to encourage such discussions. However, any work that you submit for assessment must represent your own knowledge and understanding and not that of someone else. When you draw on the work of others, e.g. words, facts, data, ideas, diagrams, and software, you must acknowledge the source with an appropriate citation.

Any attempt to pass off the work of others as your own is a serious offence. If plagiarism (which includes unauthorised collusion) is detected, the Examiners will award a mark which reflects the underlying academic merit and extent of a candidate's own work. Further, the case may be referred to the Senior Proctor, the University Advocate, or taken to the University's Court of Discipline, depending on the nature of the offence.

Moreover, as well as not copying the work of others, you should not allow another person to copy your work. If you allow another person to copy your work, you may be found guilty of assisting an attempt to use unfair means.

Some continually assessed work is designed to be carried out individually, and some in collaboration with other students. The specifications regarding the manner of working and reporting are shown in the Student Collaboration Table below.

Information about the University's policy and procedures on plagiarism can be found at http://www.admin.cam.ac.uk/univ/plagiarism/

Plagiarism Form

At the start of the academic year, you will be asked to sign a form confirming that you have read and understood the policies and procedures of the Department and the University on plagiarism.

Student Collaboration Table 2017/2018

Level	Course	Instructions
CET I	Exercises	You must work as an individual.
CET I	Chemical Engineering Laboratory	You normally work in a group of two. You may collaborate with the other member or members of your group in conducting experiments and theoretical investigations, but your reports must be written independently.
CET I	Computing Skills	You must work as an individual.
CET I	Engineering Drawing	You must work as an individual.
CET I	Physical Chemistry Laboratory	You normally work in a group of two. You may collaborate with the other members of your group in conducting experiments and theoretical investigations, but your reports must be written independently.
CET IIA	Engineering Ethics	You must work as an individual.
CET IIA	Exercises	You must work as an individual.
CET IIA	Design Project	Because the projects are carried out in groups, cooperation between members of each group is essential. However, collaboration between different groups, and exchange of information, drawings, text, calculations and computer files, other than that which takes place at office hours and seminars, is prohibited. The report and associated calculations must represent the work only of the members of the group.
CET IIB	Chemical Product Design	Because some of the work is carried out in groups, cooperation between members of each group is essential. However, collaboration between different groups, and exchange of information, drawings, text, calculations and computer files, other than that which takes place during and following workshops and seminars, is prohibited. All individual reports must be written individually.
CET IIB	Research Project	You normally work in pairs, in which case you may collaborate with your partner in conducting experiments and theoretical investigations, but your reports must be written independently. If you work with a research group, you may collaborate with members of the group on experimental and theoretical investigations. However, your report must be written independently, and you should clearly state the assistance provided by other members of the research group.
CET IIB	Computational Fluid Dynamics	You must work as an individual.
CET IIB	Interface Engineering	You must work as an individual.
CET IIB	Healthcare Biotechnology	You must work as an individual when specified. You may work in a group when it is specified that you may do so, but all reports must be written independently.
CET IIB	Entrepreneurship	Because the projects are carried out in groups, cooperation between members of each group is essential. However, collaboration between different groups, and exchange of information, drawings, text, calculations and computer files, other than that which takes place at office hours and seminars, is prohibited. The group report must represent the work only of the members of the group. The individual reports must be written individually.
CET IIB	Foreign Language	You must work as an individual.
CET IIB	Biosensors	You must work as an individual when specified. When it is specified that you should work in a group, you may collaborate with the other members of your group in conducting experiments, theoretical investigations, and design exercises but your reports must be written independently.
CET IIB	Bionanotechnology	You must work as an individual when specified. You may work in a group when it is specified that you may do so, but all reports must be written independently.

Unit

Introductory Chemical Engineering

Level	***Term***	***Duration***
CET I	MT 2017	16 lectures

Background

This unit gives an overview of the chemical engineering industry to set the scene for other courses. It also contains sections on economic assessment of projects, and on safety, both of which are key topics in determining whether a process (or product) will be viable or not.

Aims

The aim is to introduce aspects of chemical engineering, including the industry, flowsheets, dimensional analysis, economics and safety.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- define chemical engineering and describe what the chemical industry does
- describe how chemical and biochemical processes can be analysed in terms of operations and flowsheets
- describe how chemical engineers design processes
- show an awareness of the importance of process innovation in the chemical industry
- use the method of dimensional analysis
- use methods for assessing the financial attractiveness of projects, including DCF techniques
- make costing estimates of plant items
- describe the concepts of risk and risk criteria
- give examples of English statute and civil law concerning safety and the influence of the EU on UK legislation

Assumed Knowledge

Material	*Source*
None	

Connections To Other Units

This unit sets the scene for other courses taught in Chemical Engineering. Some of the material will be used explicitly in the CET IIA Design Project. Safety, Health and the Environment (SHE) will be expanded and treated quantitatively in CET IIA.

Self Assessment

Three problem sheets will be issued.

The following exam questions indicate the level of achievement expected:
CET I: 2009-2017, Paper 4(1&2), q. 2, 3

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
BH/JAZ 5/9/2017	PJB	Process Systems

Unit	Staff
Intro Chem Eng	Dr B. Hallmark and Prof. J.A. Zeitler

Synopsis

An Introduction to Chemical Engineering (8 lectures, BH)

What is chemical engineering and what do chemical engineers do?

Overview of the (petro)chemical industry:

- Crude oil, minerals, coal and biomass as a raw materials
- Production of base chemicals and intermediates from raw materials
- Examples: Teesside process cluster; Merseyside chlor-alkali industry; Sasol coal to liquids and Choren biomass to liquids

Process design:

- Flowsheeting, block diagrams, process flow diagrams, piping and instrumentation diagrams
- Distillation - a key separation process in chemical processing
- Quantifying the flow sheet (process calculations)
- Control of processes
- Utilities; site and plant layout

The oil refinery:

- Refining in the UK context
- Refinery products
- Refinery processes: distillation, vacuum distillation, fluid catalytic cracking, hydrocracking, catalytic reforming, hydrodesulphurization
- Fawley virtual tour

Innovation in the process industry:

- Why innovation is important
- Raw material processing for acetyls production
- Routes for acetic acid synthesis – traditional *versus* modern, BP Cativa
- Case study: Saltend chemical park – BP LEAP, BP Avada
- An introduction to fine chemicals
- Innovation in ibuprofen production

Dimensional analysis – a powerful and versatile analytical tool in chemical engineering

Economics (4 lectures JAZ)

Economics – the allocation of scarce resources. Division of labour. Comparative advantage.
Project cash flow – components of cash flow, fixed and variable costs, overheads.
Depreciation – why it is not a cash flow. Its influence on cash flow via taxation and tax allowances.
Trade-offs between capital and operating costs.
Project evaluation, especially by discounted cash flow, net present value.
Costings of plant items.

Safety, Health and the Environment (4 lectures JAZ)

The concept of risk – safety and loss prevention. SHE and public attitudes to safety. Individual and societal risk, and accepted and imposed risk. Methods of quantifying risk.
Legislation – civil and statute law. Current UK and EU legislation. The responsibility of the individual.
Safety in design – basic principles and methods used to assure safety, including HAZOP.
Safety in operation – sources of hazard. Permit to work.
Safety culture – The importance of a sound safety culture will be stressed, and examples of UK and foreign process plant accidents will be referred to.

Teaching Materials

Suitable background reading will be discussed in lectures. Parts of the following books are relevant:

- J.A. Moulijn, M. Makkee, and A. van Diepen, "Chemical Process Technology", Wiley, 2nd ed. 2013.
- G. Towler and R. Sinnott, "Chemical Engineering Design", Butterworth-Heinemann, 2nd ed. 2012 (or its predecessor, volume 6 of Coulson and Richardson's "Chemical Engineering" series)
- M.S. Peters and K.D. Timmerhaus, "Plant Design and Economics for Chemical Engineers", McGraw-Hill, 3rd ed. 2003.
- R.L. Skelton, "Process Safety Analysis", IChemE, 1996.

Unit		
Fluid Mechanics		
Level CET I	***Term*** MT 2017	***Duration*** 16 lectures

Background

Fluid mechanics is central to many aspects of engineering, science and everyday life, e.g. the flow of process fluids along pipes, mixing, weather forecasting, wind resistance, and breathing. An understanding of the principles of fluid mechanics not only allows engineers and scientists to carry out useful calculations, but also gives the background for an understanding of phenomena as varied as flight and blood circulation.

Aims

This course aims to give an understanding of the principles of fluid mechanics to allow students to carry out useful calculations, and to give the background for an understanding of a variety of physical phenomena.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- Describe the relevant physical parameters and basic equations for the steady flow of ideal and Newtonian fluids
- Predict the behaviour of Newtonian fluids in simple geometries with practical applications to engineering
- Analyse laminar and turbulent flow in pipes and pipe networks to predict their operational characteristics
- Predict the performance characteristics of centrifugal pumps using dimensional analysis
- Analyse and predict the interaction between pumps and pipe networks
- Analyse the relationship between flow and pressure drop in a packed bed, and the requirements for fluidisation of the particles in the bed
- Predict the performance characteristics of packed beds and filters
- Use empirical data to size liquid mixing vessels and dimensional analysis to scale up mixing processes.

Assumed Knowledge

Material	*Source*
Newton’s laws of motion	School and Part IA
Integration and differentiation	School

Connections To Other Units

The material presented is used in other courses, notably CET I Heat and Mass Transfer and CET IIA Fluid Mechanics. Questions on dimensional analysis may assume knowledge of CET I Introductory Chemical Engineering. The theory taught is illustrated in some of the CET I Laboratory experiments.

Self Assessment

Problem sheets will be issued during lectures.

In recent years, the first three questions on CET I Paper 1 have been on fluid mechanics.

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
MEW 13/9/2017	PJB	Fundamentals

Unit Fluids	***Staff*** Dr M.E. Williamson

Synopsis

1. *Introduction (~2 lectures)*
    - Fundamental properties of fluids, SI units in fluid flow
    - Surface tension
    - Archimedean upthrust, buoyancy
    - Shear stress, viscosity
    - Newtonian, non-Newtonian fluids
    - Laminar vs. turbulent flow

2. *Flow of ideal fluids (~4 lectures)*
    - Continuity equation (conservation of mass)
    - Bernoulli's equation (conservation of energy)
    - Momentum equation (conservation of momentum)

3. *Laminar flow (~3 lectures)*
    - Flow between flat plate and in pipes – parabolic velocity profile
    - Flow down a vertical plate – wetted wall column
    - Measurement of viscosity

4. *Turbulent flow (~3 lectures)*
    - Drag coefficient C_D, flow around a sphere
    - Fanning friction equation, flow through pipes
    - Piping networks, ring mains

5. *Centrifugal Pumps (~2 lectures)*
    - Introduction to pump types
    - Dimensional analysis
    - Pump and pipeline characteristics
    - Cavitation, Net Positive Suction Head (NPSH)

6. *Flow through packed and fluidized beds (~1 lecture)*
    - Darcy's Law; Carman Kozeny and Ergun correlations
    - Batch filtration
    - Fluidization regimes, bed expansion

7. *Liquid mixing (~1 lecture)*
    - Types of mixing, mixing mechanisms
    - Scale up of stirred vessels
    - Mixing power, mixing time
    - Mixing equipment

Teaching Materials

The recommended textbooks are:

- Y.A. Çengel and J.M. Cimbala, "Fluid Mechanics Fundamentals and Applications", McGraw Hill, 3rd ed. 2014 (or earlier edition).
- J.M. Kay and R.M. Nedderman, "Fluid Mechanics and Transfer Processes", CUP, 1985.
- J.M. Coulson and J.F. Richardson, "Chemical Engineering Vol. 1", Pergamon Press, 6th ed. 1999.

Unit

Process Calculations

Level	***Term***	***Duration***
CET I	MT 2017	24 lectures

Background

Chemical engineers are concerned with designing processes, operating processes and improving processes. To do calculations on processes, chemical engineers need to understand thermodynamics.

Aims

The aim is to cover the fundamental thermodynamic principles that enable the calculation of flowrates, compositions, temperatures and pressures around a process flowsheet. The course describes the application of conservation of mass and conservation of energy to batch and continuous systems, for non-reacting and reacting systems, for pure fluids and mixtures, together with prediction of equilibrium conditions.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- set up and solve mass balance equations
- set up and solve energy balance equations
- look up thermodynamic data in tables
- calculate the density, enthalpy and entropy of real fluids from an equation of state
- perform calculations on simple power and refrigeration cycles
- calculate thermodynamic properties of ideal mixtures
- calculate thermodynamic properties of real mixtures using partial molar properties and/or an appropriate equation of state
- use criteria for thermodynamic equilibrium to calculate equilibrium conditions, including phase equilibrium and chemical reaction equilibrium

Assumed Knowledge

Material	*Source*
Simple chemistry (moles etc.)	A-level
The notion of energy	GCSE and A-level

Connections To Other Units

Process calculations need to be performed when considering any process, whether it be a simple transformation or a complex series of transformations. This course is therefore essential knowledge for many of the other units in the Chemical Engineering Tripos.

Self Assessment

Seven problem sheets will be issued during lectures.

The following CET I examination questions indicate the level of achievement expected:
2009-2017, Paper 2, Questions 5-8.

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
AFR 9/8/2017	PJB	Fundamentals

Unit Process Calculations	***Staff*** Prof. A.F. Routh

Synopsis

1) Introduction
- Continuous and batch processes; process flowsheets
- Notation and conversion between units

2) Mass Balances
- Cases with and without chemical reaction
- Recycle and purge

3) State Functions and Equations of State
- Gibbs phase rule
- Compressibility; Virial equation; Van der Waals equation; Principle of Corresponding States; Peng-Robinson equation

4) Energy Balances
- Energy conservation in closed (batch) systems
- Energy conservation in open (continuous) systems
- Case study: design of evaporators
- Energy balances in systems involving a chemical reaction

5) Thermodynamic Relationships
- The second law of thermodynamics: entropy
- Manipulating relationships between state functions
- Calculation of enthalpies of real substances
- Calculation of entropies of real substances

6) Applied Thermodynamics
- Cycles that interconvert heat and work (1): Carnot, Otto, diesel cycles
- Changing the pressure of fluids: pumps, compressors, turbines, valves
- Cycles that interconvert heat and work (2): power cycles, refrigeration cycles

7) Thermodynamics of Mixtures
- Partial molar properties
- Ideal mixtures
- Equations of state for mixtures

8) Equilibrium
- Criteria for equilibrium
- Phase equilibrium for pure substances; Clapeyron and Clausius-Clapeyron equations
- Vapour-liquid equilibrium in the case of an ideal mixture (Raoult's law)
- Chemical reaction equilibrium and equilibrium constants based on activity

Teaching Materials

The recommended textbooks are:
- S.I. Sandler: "Chemical, Biochemical and Engineering Thermodynamics", Wiley, 4th ed. 2006.
- R.M. Felder and R.W. Rousseau: "Elementary Principles of Chemical Processes", Wiley, 3rd ed. 2000.
- D.M. Himmelblau and J.B. Riggs: "Basic Principles and Calculations in Chemical Engineering", Prentice Hall, 8th ed. 2012.

Unit		
Heat and Mass Transfer Fundamentals		
Level CET I	***Term*** LT 2018	***Duration*** 18 lectures

Background

Heat transfer and mass transfer are fundamental to many operations in chemical engineering as these transport mechanisms frequently limit (and thus control) the rate at which changes occur. The rate at which molecules or thermal energy, released (or consumed) by reactions, can be transported to or from manufacturing sites is very important. Understanding transport processes is a hallmark of chemical engineering expertise.

Aims

The purpose of these lectures is to provide an understanding of transport processes involving heat, mass and momentum in static and flowing fluids. Conduction, forced convection and free convection are discussed in detail; condensation and boiling are introduced.

Learning Outcomes

A key part of this course is the ability to develop quantitative models for processes and phenomena involving heat and mass transfer on the basis of identifying key physical phenomena. On completing this course and the associated problem sheets, students should be able to:

- describe and use the concepts required to analyse and explain phenomena involving heat and mass transfer
- describe and use the physics of steady and unsteady conductive and convective heat transfer to solve previously unseen problems by constructing quantitative models of the system based on the underlying transport processes
- describe and use relationships between heat, mass and momentum transfer
- calculate local rates of heat and mass transfer in single-phase systems, and heat transfer in vapour-liquid systems
- derive and understand the log-mean driving force
- describe the basic features of two-phase heat transfer in boiling and condensation

Assumed Knowledge

Material	*Source*
Fluid mechanics	• CET I Fluid Mechanics
Equation solving, first order ODEs	• First year mathematics
Single and double integrals. Use of Cartesian, polar and spherical polar co-ordinates.	

Connections To Other Units

The material covered in these lectures is used in many subsequent units in CET I, CET IIA and CET IIB.
The unit is integrated with that on Heat and Mass Transfer Operations. Some experiments in the CET I Laboratory relate to this unit. A CET I Exercise is often linked to this unit.

Self Assessment

A series of problem sheets will be provided with introductory problems as well as lists of questions at Tripos level. Further worked examples, with solutions, are provided on Moodle to assist students.
Suitable past examination questions are suggested on these problem sheets so that students can test their understanding and progress during the course and seek help when necessary. It is important that students test themselves using Tripos problems as well as the problem sheets.

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
DiW 25/7/2017	PJB	Fundamentals

Unit	***Staff***
H&MT Fundamentals	Prof. D.I. Wilson

Synopsis

18 lectures, which seek to deduce transport rates from fundamental considerations, and introduce correlations for cases where exact solutions are not available.

The coverage extends to steady state one-dimensional transport, film models, as well as an introduction to some unsteady state situations.

1. Conduction: Fourier's Law. Steady state heat conduction through a slab, cylindrical shell and sphere. Definition of the heat transfer coefficient; Nusselt number. Resistances in series.

2. Unsteady state heat conduction through solids; the Biot number; solutions in Heisler charts.

3. Principles of mass transfer – Diffusion. Fick's laws of diffusion. Stefan's method of measuring diffusivity. Definition of the mass transfer coefficient, and Sherwood number, *Sh*. Geometry effects. Diffusion from a sphere and total evaporation of a sphere. Counter diffusion, diffusion of species to a sphere followed by reaction at the surface. Diffusion and kinetic control. Effect of particle size and temperature on rate-determining step.

4. Forced convection heat and mass transfer – flowing systems. Dimensional analysis: $Nu = f(Re, Pr)$, $Sh = f(Re, Sc)$: the Prandtl and Schmidt numbers. Discussion of entry lengths and boundary layer effects. Results for developed turbulent flow: film model, *j*-factor, experimental results for flow in a pipe; Dittus-Boelter and other correlations. Combination of heat transfer modes: addition of heat transfer coefficients, fouling.

5. Natural convection: the physical significance of the Grashof number; heat and mass transfer from surfaces by natural convection. Discussion of the relative magnitudes of heat transfer by conduction, forced and natural convection, and radiation.

6. Two phase heat transfer: heat transfer in boiling liquids. Introductory aspects: pool and film boiling.

7. Two phase heat transfer: condensation of a vapour: Nusselt's analysis. Dropwise and filmwise condensation. Condensation in the presence of inerts.

Links to the questions on the problem sheets are provided.

Teaching Materials

Lecture notes are provided as a booklet with copies of sections on Moodle. Annotated notes and presentation materials are **not** provided: students need to come to the lectures. As well as conventional problem sheets being issued during the course, some further worked examples with solutions will be available on Moodle.
There are many books on heat and mass transfer. Two of the more accessible ones are:

- R.H.S. Winterton, "Heat Transfer", OUP Chemistry Primer, 1997 (**recommended**).
- F.P. Incropera, D.P. De Witt, T.L. Bergman and A.S. Lavine, "Fundamentals of Heat and Mass Transfer", Wiley, 8th ed 2017 (or an earlier edition).

More detailed books are:

- J.M. Kay and R.M. Nedderman, "Fluid Mechanics and Transfer Processes", CUP, 1985.
- E.L. Cussler, "Diffusion: mass transfer in fluid systems", CUP, 3rd ed. 2009.

Unit

Biotechnology

Level	***Term***	***Duration***
CET I	LT 2018	16 lectures

Background

Biotechnology relies on the application of engineering and bioscience to develop products from biological cells and systems. The scope of biotechnology ranges from newer technologies for the healthcare industries based on recombinant DNA technology and cellular engineering to traditional bioprocessing operations (brewing, food and waste treatment). Chemical engineering is a key discipline for the commercial exploitation of biotechnology, and chemical engineers are increasingly being employed in this sector.

Aims

To understand the role that chemical engineering plays in the pharmaceutical and biotechnological industries. The unit will describe the range of commercially valuable products that can be made in biological systems and will then focus on quantitative understanding and modelling of microbial and enzymatic reaction processes. The unit also provide a very basic introduction to molecular bioscience that is not provided elsewhere in the CET course.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- appreciate the difference between classical and modern biotechnology
- recognise fundamental cell types and describe their uses in biotechnology
- describe the biological processes operating in cells and how these may be exploited by biotechnology
- describe how genetic and protein engineering can be exploited by modern biotechnology
- understand terms such as systems biology and synthetic biology and recognise how they might influence future biotechnology
- use semi-empirical methods to describe the stoichiometry and rates of microbial growth
- use models for microbial growth to predict performance in various types of bioreactor
- understand the advantages and disadvantages of different types of bioreactors
- appreciate the potential use of enzymes in industrial processes
- derive kinetic models for enzyme-catalysed reactions and use them to analyse processes involving enzymes (including processes in which enzyme inhibition and inactivation occurs)
- understand why different types of reactor may be used for enzyme conversions, including the use of immobilised enzymes.

Assumed Knowledge

Material	*Source*
Mathematical methods	NST IA or ET IA
Reactors	CET I Homogeneous Reactors
Process Calculations	CET I Process Calculations

Connections To Other Units

The latter part of this unit will show how chemical engineering knowledge acquired in other parts of the course can be applied to biotechnology. The unit is particularly connected to Homogeneous Reactors and Process Calculations. There is no need for any previous biological knowledge.

Self Assessment

Problem sheets demonstrating the standard expected will be distributed during the lectures. Ability to solve these problems will guide student assessment of their own standard with respect to the material presented and examined. The following past examination questions are relevant:

CET I 2015-2017: Paper 3, questions 4,5,6
CET I 2011-2014 : Paper 3, questions 4,6
CET I 2009-2010 : Paper 3, questions 4,5,6

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
GSK/RMO 1/9/2017	PJB	Fundamentals / Process Operations

Unit	**Staff**
Biotechnology	Dr Gabriele Kaminski-Schierle and Dr Róisín Owens

Synopsis

Parts of the course are under review, and some aspects of the synopsis may change.

1. Introduction

2. A brief description of the biological cell and its functions, from DNA to RNA to proteins

3. Case study I: engineering insulin
   DNA, genes, proteins, amino acids, enzymes
   Principles of genetic and protein engineering
   Industrial exploitation

4. Case study II: antibody production
   Structure-function relationship
   Monoclonal antibodies
   Industrial exploitation

5. Case study III: bioethanol production
   Enzymatic functions
   Metabolism
   Glycolysis

6. Chemical equations describing the growth of cells
   Material balance equations for cell growth
   Generalized degree of reductance
   Yield coefficients
   Electron balances
   Microbial heat generation

7. Quantitative analysis of fermentation
   Batch fermentation
   Rates of product formation
   Continuous fermentation
   Two CSTFs in series
   Fed batch fermentation; Semi-batch fermentation

8. Enzymes and their use in industry
   Enzyme kinetics
   Molecular inhibition of enzyme activity
   Optimisation of enzyme activity
   Conversion achieved in reactors containing soluble enzymes (homogeneous phase)
   Immobilised enzymes

Teaching Materials

The following books are useful reference sources:

- B. Alberts *et al*., "Essential Cell Biology", Garland Science, 4th ed. 2014 (or earlier edition)
- B. Alberts *et al*., "Molecular Biology of the Cell", Garland Science, 6th ed. 2015 (or earlier edition)
- J.E. Smith, "Biotechnology", Cambridge University Press, 5th ed. 2009.
- C. Ratledge and B. Kristiansen, "Basic Biotechnology", Cambridge University Press, 3rd ed. 2006.
- D.P. Clark and N.J. Pazdernik, "Biotechnology", Academic Press, 2nd ed. 2016.

Unit

Homogeneous Reactors

Level	***Term***	***Duration***
CET I	MT 2017	8 lectures

Background

Many processes demand that chemical reactions be carried out in an economical and safe fashion. It is thus necessary to understand how to select and design reactors. Key factors include type of reactor, prediction of yield, selective manufacture of desired products and temperature control. The subject is relevant to operations taking place in the chemical, minerals, biochemical and food industries, and can play a vital part in environmental control. By using correct design and operation, the chemical engineer can control and manipulate the chemistry in order to ensure efficient and reliable processing.

Aims

The aims of this course are to introduce some types of homogeneous phase reactor (batch, continuous stirred tank, plug flow) and to perform mass and energy balances over them. These aspects, combined with a knowledge of reaction kinetics, will be used to predict reactor performance and enable sizing of reactors.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- identify the differences in operation and analysis of generic homogeneous phase reactor systems;
- demonstrate an understanding of equilibrium and kinetic expressions, order of reaction, reaction schemes, conversion, yield and selectivity;
- apply mass and energy balances to ideal reactor systems and solve reactor design problems using them;
- understand the influence of reaction characteristics on choice of reactor systems;
- quantify thermal effects in reactors and understand the practical implications thereof;
- appreciate the idea of non-ideality of flow in reactors.

Assumed Knowledge

Material	*Source*
Chemical reaction kinetics	School
Mass and energy balances	CET I Process Calculations
First order ODEs	ET or NST IA Maths

Connections To Other Units

The themes and material will be extended in CET IIA Heterogeneous Reactors.

Self Assessment

One problem sheet will be issued during the lectures.
The questions in the following Tripos papers indicate the level of achievement expected:
CET I Paper 3, 2010-2017, q.7

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
CdA 28/07/2017	PJB	Process Operations

Unit Reactors	***Staff*** Dr C. D'Agostino

Synopsis

1. *Homogeneous Phase Reactors*
    - Introduction to reactors
    - Types of homogeneous phase reactor: batch, continuous stirred tank, plug flow
    - Physical chemistry of reactions: rates of chemical reaction, rate laws and orders of reaction, equilibrium reactions

2. *Analysis of Isothermal "Ideal" Reactor Systems*
    - Fractional conversion
    - Batch reactors: constant volume and constant pressure systems
    - Continuous stirred tank reactors (CSTRs): space and residence times, liquid phase reactions, gas phase reactions
    - Plug flow reactors (PFRs): space and residence times, liquid phase reactions, gas phase reactions
    - Analysis of reactor systems containing more than one continuous reactor: graphical and analytical approaches
    - The influence of chemical factors on reactor choice: consecutive and parallel reactions
    - Equilibrium reactions: simple equilibrium system, pseudo/quasi steady state hypothesis

3. *Thermal Effects in Reactors*
    - Effect of temperature on equilibrium and reaction rates
    - Adiabatic reactors
    - Conversion as a function of temperature for a CSTR
    - Practical implications of thermal effects: optimal temperature progressions, multiple steady states
    - Temperature profiles along a PFR

4. *Non-Ideal Flow and Mixing in Continuous Reactors*
    - An introduction to residence time distributions (RTDs)

Teaching Materials

Recommended textbooks:
- H.S. Fogler, "Elements of Chemical Reaction Engineering", Pearson, 5th ed. 2016 (or earlier edition).
- O. Levenspiel, "Chemical Reaction Engineering", Wiley, 3rd ed. 1999.

Unit

Separations: Equilibrium Staged Processes

Level	***Term***	***Duration***
CET I	LT 2018	16 lectures

Background

Separation processes dominate most chemical engineering flowsheets. The business of this unit is separations organised as a cascade of stages, such that the streams leaving each stage are close to phase equilibrium. Simple thermodynamic principles limit the maximum separation that may be achieved in each stage.

Aims

The aim of this course is to describe the fundamental principles behind equilibrium staged processes. The subject is initially treated in a general way, with examples of different separations processes then being introduced.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- explain why stages must often be cascaded together to form effective separation processes
- write component and overall material balances around single stages and cascades
- understand graphical thermodynamic relationships describing equilibrium between phases
- carry out design and rating calculations on gas absorption and desorption units
- carry out calculations on a flash separator
- carry out design and rating calculations on a binary distillation column
- carry out elementary design and rating calculations on a batch distillation process
- carry out elementary design and rating calculations on a solvent extraction unit

Assumed Knowledge

Material	*Source*
Steady-state material balances, mole fraction, partial pressure, mole ratio, fractional recovery	CET I Process Calculations
Gibbs phase rule, saturated vapour pressure	CET I Process Calculations
Process economics	CET I Introductory Chemical Engineering

Connections To Other Units

This unit assumes some knowledge of equilibrium thermodynamics (taught in CET I Process Calculations); further relevant thermodynamics is taught in CET IIA. Some separations processes that are limited by transfer rates (rather than equilibrium) are taught in CET I Heat and Mass Transfer Operations.
Further separations techniques are described in the CET IIA course on Separations.

Self Assessment

Problem sheets will be issued during lectures.

The following CET I examination questions indicate the level of achievement expected:
2009-2017: Paper 3, all questions in Section A.

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
JSD 11/09/2017	PJB	Process Operations

Unit	*Staff*
Separations: ESP	Prof. J.S. Dennis

Synopsis

1. Introduction
   - 1.1 Background and Aims
   - 1.2 Separation Philosophy
   - 1.3 Analysis of a Single Equilibrium Stage
   - 1.4 Cascade of Equilibrium Stages
   - 1.5 Non-linear Equilibrium

2. Counter-Current Cascades
   - 2.1 The McCabe-Thiele Construction
   - 2.2 Pinches
   - 2.3 Case of High Rates of Transfer of Solute
   - 2.4 Worked Example
   - 2.5 Stage Efficiencies
   - 2.6 Desorption/Stripping

3. Group Methods
   - 3.1 Kremser-Souders-Brown Equation (KSB)
   - 3.2 Particular Forms of the KSB Equation
   - 3.3 General Plot of Eq. 3.6
   - 3.4 Worked Example

4. Vapour-Liquid Equilibrium for Binary Distillation
   - 4.1 Pure Components
   - 4.2 Pure Components in Presence of Non-Condensible Gas
   - 4.3 Binary Mixtures of Volatile Components
   - 4.4 Mixtures of Water + Single Hydrocarbon
   - 4.5 Raoult's Law
   - 4.6 Relative Volatility

5. Binary Distillation
   - 5.1 Single Equilibrium Stage
   - 5.2 Distillation Column
   - 5.3 Design Calculations
   - 5.4 Practical Arrangements
   - 5.5 Azeotropic Mixtures
   - 5.6 Economics
   - 5.7 Worked Example

6. Batch Distillation
   - 6.1 Simple Batch Distillation
   - 6.2 Evaluation of Rayleigh's Equation
   - 6.3 Rectification
   - 6.4 Limiting Cases

7. Solvent Extraction
   - 7.1 Liquid-Liquid Extraction (LLE)
   - 7.2 Presentation of Equilibrium Compositions
   - 7.3 Cascades of Countercurrent Stages

Teaching Materials

Suitable textbooks are:
- E.J. Henley, J.D. Seader and D.K. Roper "Separation Process Principles", Wiley, 3rd ed. 2011.
- P.C. Wankat, "Separation Process Engineering", Pearson, 4th ed. 2016 (or earlier edition).

These cover material in more detail than does this lecture unit, and also include material taught in CET IIA.

Unit

Heat and Mass Transfer Operations

Level	***Term***	***Duration***
CET I	LT 2018	8 lectures

Background

Heat transfer (heating, cooling, phase change) and separation processes (mass transfer) involve the transport of energy or mass across a boundary from one stream to another. If the transport is rapid, the streams might reach equilibrium and thermodynamics will control the performance of devices. However, many forms of separation process, and nearly all heat transfer processes, feature slow transport. In these cases, the performance of equipment is controlled by the heat and mass transfer rates.

Aims

The aim of this course is to give students an understanding of the interaction between transfer rate and equipment size in the performance of continuous contacting processes. The course will cover two types of process in detail, namely (*i*) simple heat transfer in heat exchangers and (*ii*) gas absorption or desorption in packed columns.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- show how to calculate the local, steady-state rates of transfer of (*i*) heat in heat exchangers, and (*ii*) mass in gas absorption or desorption;
- understand how local rates can be integrated to model the performance of continuous contacting units, and to appreciate the differences between design and rating calculations;
- understand how transport resistances, approach to equilibrium and effect of configuration (co- or counter-current) affect unit performance;
- appreciate the analogy between heat and mass transfer;
- undertake the initial thermal design of a heat exchanger with one or more passes on each side;
- undertake the initial process design of a packed column gas absorber or desorber.

Assumed Knowledge

Material	*Source*
Mass and energy balances	CET I Process Calculations
Heat and mass transfer	CET I Heat and Mass Transfer Fundamentals

Connections To Other Units

This course builds on the material presented in Heat and Mass Transfer Fundamentals, but now scales up the results to predict the performance of unit operations. The material covered in these lectures is used in several other courses throughout the Chemical Engineering Tripos. In particular, the course is likely to be used in a CET I Exercise and the CET IIA Design Project.

Self Assessment

Two problem sheets will be issued, one on heat transfer and one on mass transfer.
The following examination questions indicate the level of achievement expected:
CET I Paper 1, 2010-2017, all Q.8

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
SLR 25/07/2017	PJB	Process Operations

Unit H&MT Operations	***Staff*** Dr S.L. Rough

Synopsis

This course considers transfer of energy or mass (but not both simultaneously) between two, single-phase streams in plug flow. The design and operation of devices will be addressed, which will affect heat transfer and mass transfer. The treatment of both processes is similar owing to the heat/mass transfer analogy and will be developed first for heat transfer and then applied to a subset of mass transfer devices, namely simple gas absorbers.

1. *Principles of Heat Transfer between Fluid Streams*
    - Concentric tube heat exchanger: integration of heat transfer equations; effect of pressure drop
    - Co- and counter-current flow
    - Rating calculations
    - Analogy between heat and mass transfer
    - Heat transfer correlations

2. *Heat Transfer Devices*
    - Heat exchangers: design; multi-pass; temperature crosses; selection; fouling

3. *Mass Transfer - Gas Absorption*
    - Separation equipment: wetted wall, packed and plate columns
    - Column sizing (dilute case): gas-liquid interfaces; equilibrium relationships; mass transfer coefficients; operating lines; pinch; transfer units (HTU, NTU)
    - Use of HETPs
    - Operating features: selection of packed column diameter

Teaching Materials

The following textbooks cover far more material than included in this course, but are useful for reference:

- W.L. McCabe, J.C. Smith and P. Harriott, "Unit Operations of Chemical Engineering", McGraw-Hill, 7th ed. 2005.
- J.M. Coulson and J.F. Richardson, "Chemical Engineering Volume 2", Butterworth-Heinemann, 5th ed. 2002.
- J.M. Kay and R.M. Nedderman, "Fluid Mechanics and Transfer Processes", Cambridge University Press, 1985.
- F.P. Incropera, D.P. De Witt, T.L. Bergman and A.S. Lavine, "Fundamentals of Heat and Mass Transfer", Wiley, 8th ed. 2017 (or an earlier edition)

Unit

Engineering Mathematics

Level	***Term***	***Duration***
CET I	LT and ET 2018	24 lectures

Background

Virtually every aspect of an engineer's education and professional life involves the use of mathematical techniques. Many engineering problems result in linear or non-linear algebraic or differential equations. Techniques for solving these equations, whether numerically or analytically, play a key role in predicting process outputs and so are needed in the design, control and optimisation of industrial applications.

Aims

The course aims to develop an understanding of the mathematical techniques presented and to cover the formulation and solution of chemical engineering problems by using appropriate analytical or numerical techniques.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- perform integration numerically
- use numerical methods for solving ODEs
- use numerical methods for solving non-linear equations
- set up and solve optimisation problems (both unconstrained and constrained)
- set up matrices and manipulate them to solve systems of linear equations
- solve certain types of ODE analytically
- understand the Laplace transform conceptually as a transformation between solution variable spaces
- use the Laplace transform to solve ODEs
- make mathematical models of linear systems of algebraic equations
- formulate and solve dynamic material and energy balances

Assumed Knowledge

Material	*Source*
Linear algebra and calculus	NST IA and ET IA
Material and energy balances	CET I Process Calculations

Connections To Other Units

The skills acquired in this unit are needed to solve problems in other courses in the Chemical Engineering Tripos.

Self Assessment

Problem sheets will be issued during lectures.
The questions in the following Tripos papers indicate the level of achievement expected:
CET I 2010-2017, paper 2, questions 1, 2, 3, 4

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
EJR/VSV 2017	PJB	Mathematical Methods

Unit	***Staff***
Engineering Mathematics	Dr E.J. Rees and Dr V.S. Vassiliadis

Synopsis

Numerical Methods (9 lectures, EJR)

- Integration: Trapezium rule and its errors
- Ordinary differential equations: Euler's method and modified Euler; Second and fourth order Runge Kutta; Simultaneous first order ODEs; Second and higher order ODEs; Difficulties encountered
- Optimisation: Single variable; Several variables (unconstrained, constrained, Lagrange multipliers, linear programming)
- Non-linear systems of equations: Single non-linear equation (dominant terms and bounding functions, Newton-Raphson, successive substitution, interval halving, problems with iteration); Simultaneous non-linear equations (successive substitution, Newton-Raphson using Jacobian)

Linear Algebra (3 lectures, VSV)

- Linear algebraic equations
- Matrices, vectors
- Solution of linear equation systems: Gaussian elimination and LU factorisation
- Partitioned equation systems and partitioned matrices and vectors

ODEs (4 lectures, VSV)

- Classification of ODEs
- First order equations: Standard methods of solution (review)
- Second order non-linear equations: Derivative substitution method; Homogeneous function method
- Linear equations of higher order: Homogeneous equations; Non-homogeneous equations; Method of undetermined coefficients; Method of variation of parameters; Picard iteration

Mathematics of Process Dynamics (8 lectures, VSV)

- Laplace transforms: introduction; basic properties; using transforms to solve differential equations; initial and final value theorems
- Linear systems: transfer functions; modelling; frequency response
- Dynamic mass and energy balances: formulation of conservation statements; solution of dynamic equations (mixed/unmixed, variable volume, chemical reaction)

Teaching Materials

The recommended textbook is:
E. Kreyszig, "Advanced Engineering Mathematics", Wiley, 10th ed. 2011.

Other reference books will be recommended at appropriate points in lectures.

Unit		
Stress Analysis and Pressure Vessels		
Level CET I	***Term*** LT 2018	***Duration*** 8 lectures

Background

The analysis of stress and strain is central to many engineering practices, including the design of pressure and reactor vessels. In a number of cases the mechanical design of process vessels is the key component to safe and efficient operation. It is therefore essential that a chemical engineer has a sound grounding in terms of understanding the basics and design aspects of stress and strain analysis. Engineers are using these methods of analysis to study structures such as nanostructures, bio-cells and even molecular structures.

Aims

The purpose of these lectures is to give an introduction to stress analysis sufficient for simple pressure vessel design and to provide a foundation in later units. This unit is concerned with the distribution of stress and strain in solid bodies. It will be used to describe failure criteria for engineering materials, to introduce the notion of a tensor and to prepare students for the study of stresses in three dimensions (e.g. in granular materials).

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- identify the most likely mode of failure in a pressure vessel
- quantify the stresses and strains in 2-D thin-walled pressure vessels holding a fluid at elevated pressure and/or temperature
- calculate the stresses and strains generated by imposing torsion on a rod or tube
- predict the change in dimension and volume of a simple piece resulting from a change in temperature
- relate the stresses and strains in a pressure vessel to brittle and ductile failure criteria
- calculate the stress state in a slab given a set of strain gauge data

Assumed Knowledge

Material	*Source*
Basic applied maths; mechanics	School

Connections To Other Units

The material may be used in the CET I design exercise and the CET IIA design project.
The course links closely with the units on structures and materials. The stress analysis component of the unit is used later in lecture units on rheology and fluid mechanics.

Self Assessment

One problem sheet will accompany the material in the unit. Students should be able to complete the introductory problems after reading through the relevant lecture material.

There are a large number of old exam questions in existence which are of the appropriate standard. Chapters 7 and 8 in Gere and Goodno's book contain a large number of example problems and questions.
Recent exam questions: 2010-2017 Paper 4(1&2) Q1

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
DiW 25/7/2017	PJB	Enabling Topic

Unit SAPV	***Staff*** Prof. D.I. Wilson

Synopsis

Introduction.

1 Pressure Vessels.
Vacuum vessels - Euler buckling.

2 Fracture.
Stress concentrators. Fracture.

3 Three-Dimensional Stress and Strain.
Tensor Notation
Biaxial Stresses - Hoop and Longitudinal Stresses.
Elasticity and Strains - Young's Modulus and Poisson's Ratio.
Hoop, Longitudinal and Volumetric Strains.
Bulk and Shear Moduli.
Strain Energy. Overfilling of Pressure Vessels.

4 Thermal Effects.
Coefficient of Thermal Expansion. Thermal Effect in Pressure Vessels.
Two-Material Structures. The Bimetallic Strip.

5 Torsion.
Shear Stresses in Shafts - $\tau/r = T/J = G\theta/L$. Thin-walled shafts.

6 Two-Dimensional Stress Analysis.
Nomenclature and Sign Convention for Stresses.
Mohr's Circle for Stresses.
Application of Mohr's Circle to Three-Dimensional Systems.

7 Failure Criteria.
Tresca's Criterion. The Stress Hexagon. Von Mises' Criterion. The Stress Ellipse.

8 Two-Dimensional Strain Analysis.
Direct and Shear Strains. Mohr's Circle for Strains. Measurement of Strain - Strain Gauges.
St. Venant's Principle.

9 Round up.

Teaching Materials

The lecture notes include worked examples and provide ample coverage of the taught material. These will be available on Moodle after being issued in lectures.

The recommended textbook for further explanation, worked examples and exercises is:
J.M. Gere and B.J. Goodno “Mechanics of Materials”, CL Engineering, 9th ed., 2017 (or earlier edition).
This book is equally useful for CET I Structures.

Unit		
Convergence Material: §1 – Mechanical Engineering		
Level CET I	***Term*** MT 2017 / ET 2018	***Duration*** 26 lectures

Background

An insight into mechanical engineering is useful for chemical engineers, particularly those concerned with design. This course contains a mixture of mechanical engineering topics: mechanics of materials, structural engineering, and dynamics.

Aims

This course aims to give §1 (ex-NST) students a basic knowledge of general mechanical engineering principles and topics. The specific topics are mechanical properties of materials, structures, dynamics.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- discuss the mechanical properties of materials
- predict the conditions at which materials failure will occur by various mechanisms (plastic instability; fast fracture; fatigue; creep).
- draw shear force and bending moment diagrams for beams in equilibrium
- identify statical indeterminacy
- calculate deflections of initially straight beams
- calculate beam curvature
- use Macauley's method and superposition methods
- calculate bending and shearing stresses within beams
- calculate bending stresses in composite beams
- calculate buckling using Euler's strut analysis
- solve mechanics problems which involve acceleration and/or impact
- solve dynamics problems involving translational and rotational motion

Assumed Knowledge

Material	*Source*
Calculus	School; NST IA Mathematics
Newton's laws of motion	School
Force and moments	School

Connections To Other Units

Some of the material may be used in the Design Projects. The Structures part of the course is closely related to CET I Stress Analysis and Pressure Vessels.

Self Assessment

Problem sheets will be issued during lectures.
The following examination questions indicate the level of achievement expected:
CET I 2010-2017: Paper 4(1) questions 4-9 but <u>not</u> those involving Laplace transforms (which are no longer taught within this module)

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
ACF *et al*. 12/8/2017	PJB	Enabling Topics

Unit Mech Eng	**_Staff_** Dr A.C. Fisher, Dr A.J. Sederman, Dr S.L. Rough

Synopsis

1. Mechanical Properties of Materials (6 lectures, ACF)

- Types of material
- Properties of materials
- The tensile test: stress and strain; stress-strain curves
- Elastic behaviour: elastic parameters (Young's modulus; Poisson's ratio; shear modulus; bulk modulus); measurement and physical origin of the Young's modulus
- Plastic deformation: tension and compression; hardness (and measurement of yield strength σ_y); physical basis for plastic flow; plastic instability (onset of necking)
- Fast fracture and toughness: condition for fast fracture; mechanisms
- Fatigue: high and low cycle fatigue; fatigue of cracked components; proof testing
- Creep: steady state model; mechanisms; tertiary creep
- Materials selection: pressure vessel example; introduction to the CES Selector database

2. Structures (12 lectures, AJS)

- General equilibrium of beams
- Sign conventions; shear force and bending moment diagrams; statical indeterminacy
- Deflection of straight elastic beams
- Curvature and bending stiffness; slope-deflections methods and superposition; Macauley's method
- Bending and shearing stresses within beams
- Second moments of area, $\sigma / y = M / I = E\kappa$; C compound beams; combined bending moment and axial load, central one third rule; shearing force per unit length $q = SA_e\bar{y} / I$, shearing stress
- Bending stresses in composite beams
- The transformed section; reinforced concrete; pre-stressed concrete
- Buckling: Euler's strut analysis

3. Introductory Dynamics (8 lectures, SLR)

Translational (linear, curvilinear) and rotational motion of point masses, rigid bodies and ensembles

- Definitions, concepts and laws
- Kinematics
- Frictional forces
- Elastic forces (simple harmonic motion)
- Curvilinear motion
- Work and energy; Power and efficiency
- Momentum and impulses
- Rotational motion

Teaching Materials

The following books are useful reference sources:

- M.F. Ashby and D.R.H. Jones, "Engineering Materials 1: an introduction to properties, applications and design", Butterworth-Heinemann, 4th ed. 2012 (or earlier edition).
- J.M. Gere and B.J. Goodno "Mechanics of Materials", CL Engineering, 9th ed., 2017 (or earlier edition).
- S.H. Crandall, N.C. Dahl and T.J. Lardner, "An Introduction to the Mechanics of Solids", McGraw-Hill, 3rd ed. 2013 (or earlier edition).
- J.L. Meriam and L.G. Kraige, "Engineering Mechanics: Dynamics", Wiley, 8th ed. 2016 (or earlier edition).

Unit

Convergence Material: §2 – Introductory Chemistry

Level	***Term***	***Duration***
CET I	MT 2017 / ET 2018	26 lectures

Background

A knowledge of Chemistry is useful for Chemical Engineers because they often need to interact with chemists in developing a particular process or product. Further, many advances in product development now take place because of an understanding at the molecular level. This unit contains short courses on a number of chemistry topics: chemical bonding, inorganic chemistry, organic chemistry, analytical chemistry and physical chemistry.

Aims

This unit aims to give §2 (ex-ET) students a working knowledge of chemistry principles, with the emphasis on understanding properties at the molecular level.

Learning Outcomes

On completing this course and the associated problem sheets, students should be able to:

- apply valence bond theory to predict some properties of molecules
- understand how an electronic wavefunction contains information on the energy and location of an electron
- describe the basis of molecular orbital theory
- apply molecular orbital theory to predict some properties of molecules
- describe the basis of band theory for metals, insulators and semi-conductors
- explain the properties of some transition-metal complexes
- understand isomerism and stereochemistry in organic chemistry, and give examples
- understand reaction mechanisms in organic chemistry, and give examples
- understand the general features of molecular spectroscopy
- predict and interpret UV/visible spectra, infrared spectra, microwave spectra and NMR spectra of simple molecules
- understand other analytical chemistry methods (elemental analysis, mass spectrometry, chromatography)
- understand the molecular basis behind thermodynamic parameters such as internal energy, heat capacity, enthalpy and entropy
- understand when chemical reactions occur spontaneously
- perform thermodynamic calculations on chemical reactions, including prediction of equilibrium compositions at different temperatures and pressures

Assumed Knowledge

Material	*Source*
▪ School level chemistry	School

Connections To Other Units

The subject material is useful background knowledge for a number of other courses in CET I and CET IIA (thermodynamics, reactors, separations). An understanding of chemistry may be required in the CET IIA Design Project.

Self Assessment

Problem sheets will be issued during lectures.

The following examination questions indicate the level of achievement expected:
CET I 2010-2017: Paper 4(2) questions 4-9.
(though students should be aware that the course topics have changed slightly over this time).

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
ACF *et al*. 12/8/17	PJB	Enabling Topics

Unit Chemistry	***Staff*** Dr M.D. Mantle, Dr A.C. Fisher and Prof. C.F. Kaminski

Synopsis

1. *Chemical Bonding (6 lectures; MDM)*
   - The periodic table; valence bond theory; Lewis structures
   - Introduction to quantum mechanics:
     - general principles
     - the Schrödinger equation and wavefunctions for one-electron atoms
     - energy levels
   - Molecular orbital (MO) theory:
     - linear combination of atomic orbitals (LCAO)
     - homonuclear and heteronuclear diatomic molecules;
     - hybridization; three-centre two-electron bonds; limitations
     - MO theory for metals; insulators and semiconductors
   - Introduction to transition-metal chemistry
     - oxidation number and the eighteen electron rule
     - metal-metal bonds
     - use of HOMOs and LUMOs in transition metal complexes

2. *Organic Chemistry (4 lectures; MDM)*
   - Nomenclature and resonance structures
   - Isomerism and stereochemistry
   - Introduction to reaction mechanisms: curly arrows, nucleophiles and electrophiles

3. *Analytical Chemistry (8 lectures; ACF)*
   - Introduction
   - General features of molecular spectroscopy
   - Ultraviolet/visible spectroscopy
   - Infrared spectroscopy
   - Microwave spectroscopy
   - Nuclear magnetic resonance spectroscopy
   - Methods of elemental analysis
   - Mass spectrometry
   - Chromatography

4. *Physical Chemistry (8 lectures; CFK)*

(a) Chemical Thermodynamics: discusses the molecular basis of the following
   - Internal energy
   - Heat capacity
   - Enthalpy and enthalpy changes
   - Entropy and entropy changes
   - Gibbs energy changes
   - Equilibrium constants

(b) Reaction Kinetics
   - Rate of reaction; finding rate laws and rate constants
   - Reaction mechanisms: elementary reactions; steady-state hypothesis; chain reactions
   - Temperature dependence of rate constants: collision theory for gases; transition state theory
   - Catalysis

Teaching Materials

Suitable textbooks covering much of the course are:
- J. Keeler and P. Wothers, “Chemical Structure and Reactivity: an integrated approach”, OUP, 2nd ed. 2013.
- P. Atkins and J. de Paula, “Atkins’ Physical Chemistry”, OUP, 10th ed. 2014 (or any earlier edition).

Useful short books for topics 1 and 2 are:
- M.J. Winter, “Chemical Bonding”, OUP Chemistry Primers, 1994.
- G.M. Hornby and J.M. Peach, “Foundations of Organic Chemistry”, OUP Chemistry Primers, 1993.

Unit

Exercises

Level	***Term***	***Duration***
CET I	MT 2017 / LT 2018	5 exercises

Background

The exercises are mini-projects or extended open-ended problems. The exercises take far longer to solve than a single supervision problem or exam question, and are often similar to tasks that chemical engineers undertake in industry. The final exercise will involve the process and mechanical design of an item of equipment, a key part of the chemical engineering discipline.

Aims

The aim of the exercises is to give students some experience of solving extended problems. Students should improve their time management and report-writing skills by doing them, as well as deepening their knowledge of the topics. The final exercise gives students experience of chemical engineering design.

Learning Outcomes

On completing the exercises, students should be able to:

- solve open-ended non-idealised chemical engineering problems
- perform the process design and mechanical design of an item of process equipment such as a heat exchanger
- manage their time so that they can meet a deadline for a "long" task
- write reports

Assumed Knowledge

Material	*Source*
Related CET I courses	CET I

Connections To Other Units

These exercises will deepen students' understanding of the related CET topics.

Self Assessment

Assistance will be available during the exercises in the form of Question & Answer sessions. Demonstrators can advise on method, but they will not tell you whether your answer is "right" or not.
There will be feedback on each Exercise after marking.

Assessment

The reports submitted are marked and contribute to the overall final mark for the year. The deadlines for submission will be adhered to strictly: material submitted after the deadline will be given zero marks unless a Tutor's note is received giving a satisfactory reason.
The final exercise on design will be worth three times as many marks as each one of the earlier exercises.

Prepared	***Approved***	***Subject Grouping***
PJB 1/9/2017	PJB	Classes

Unit	***Staff***
Exercises	Dr P.J. Barrie + others

Synopsis

The theme of each exercise is subject to change.

Michaelmas term 2017
Exercise 1 : Process Calculations
Exercise 2 : Fluid Mechanics

Lent term 2018
Exercise 3 : Reaction Engineering
Exercise 4 : Heat and Mass Transfer
Exercise 5: Process and Mechanical Design (continues into Easter term 2017)

Teaching Materials

A handout will be issued at the start of each exercise giving full instructions.

Unit				
Chemical Engineering Laboratory				
Level CET I		***Term*** MT 2017/LT 2018		***Duration*** 8 laboratory sessions

Background

The ability to perform experiments is an important skill for chemical engineers. This laboratory class contains experiments on fluid mechanics and transport processes. The experiments will normally be performed in pairs.

Aims

This unit should improve practical skills, knowledge of underlying theory, ability to analyse results, and ability to write reports. Two experiments are designed to give Section 1 students (ex-NST) experience of equipment construction and testing.

Learning Outcomes

On completing this unit, students should be able to:

- perform experiments on fluid mechanics and transport processes
- construct and test equipment (Section 1 students)
- analyse experimental results
- perform appropriate error analysis
- write reports well

Assumed knowledge

No prior knowledge is assumed – the laboratory manual contains the necessary information.
A workshop will be given on report writing and on error analysis, both of which are important components to this unit.

Connections To Other Units

The experiments are designed to complement the lecture courses in CET I Fluid Mechanics and CET I Heat and Mass Transfer Fundamentals. In some cases, students will do the experiment first, and so have a "head start" when the theory is covered in lectures. In other cases, students will cover the theory first in lectures, and then improve their understanding by doing the experiment.

Report writing skills are useful throughout the Chemical Engineering Tripos, and the ability to analyse results (including error analysis) is important in experimental CET IIB Research Projects.

Self Assessment

Reports are marked by staff and senior demonstrators and feedback will be provided.

Assessment

The marks from the set of 8 reports are submitted to the Examiners.
Any piece of work submitted after the published deadline will receive zero marks, unless Dr Butler receives a Tutor's note within one week of the deadline that gives an acceptable reason for late submission.

Prepared	***Approved***	***Subject Grouping***
SAB 1/9/2017	PJB	Classes

Unit	*Staff*
Chem Eng Lab	Dr S.A. Butler

Synopsis

The laboratory features the following experiments:

1. Measurement of convective heat transfer coefficients
2.1 Construction and characterisation of an orifice plate (§1 students only)
2.2 Measurement of liquid flow rate (§2 students only)
3.1 Test apparatus for a centrifugal pump (§1 students only)
3.2 Dimensional analysis of a centrifugal pump (§2 students only)
4 Friction factors in a smooth tube
5 Determination of liquid viscosity
6 Rise velocities of air bubbles in water
7 Drag force on a cylinder
8 Fluidised beds
9 Mass transfer in a wetted wall column
10 Impact of a jet

Students perform experiments in pairs on a fortnightly basis according to a set schedule. Each pair performs 8 experiments (4 MT, 4 LT). Not every student performs every experiment.

There are alternative versions of Experiments 2 and 3 for §1 students (ex-NST) and §2 students (ex-ET).

Demonstrators are available during each class to offer help and practical advice concerning the conduct of the experiments.

Students submit write-ups of their results according to the schedule in the Laboratory Manual. There are two types of write-up:

- Standard reports
- Standard reports with error analysis

Teaching Materials

A Laboratory Manual containing full information on the course will be handed out at the beginning of the course.

Unit

Computing Skills

Level	***Term***	***Duration***
CET I	MT 2017, LT 2018	6 exercises

Background

A chemical engineer's professional life is rarely free from interaction with computers. While new programs may be written using a computer language such as FORTRAN or C++, the great power of modern PCs lies in the commercial packages that have been written for them. These range from applications for solving general mathematical problems to highly specialized chemical engineering design programs. In this unit we will explore a few programs that are widely used to solve some problems.

Aims

This unit aims to ensure confidence with a spreadsheet package (*Excel*) and a mathematical package (*MatLab*). It also familiarises students with a process simulation package (*UniSim*).

Learning Outcomes

On completing this course students should be able to:

- Use spreadsheets proficiently (*Microsoft Excel*)
  - Input data, manipulate data, solve non-linear problems numerically, and produce graphs
- Use a numerical computing package (*MathWorks MatLab*)
  - Define new functions, solve non-linear problems, perform numerical optimisation, solve ODEs and produce graphs
- Use a process simulation package (*Honeywell UniSim*)
  - Implement and simulate process flowsheets
  - Optimise flowsheets within the simulator package

Assumed Knowledge

Material	*Source*
Linear algebra and calculus	NST IA and ET IA
Process calculations	CET I Process Calculations

Connections To Other Units

Students will use the computing applications to solve problems throughout the Chemical Engineering course.

Self Assessment

There are six supervised tasks. The first four tasks will be in the Michaelmas Term; the other two tasks will be in the Lent Term.

Assessment

Candidates need to demonstrate to the examiners that they are proficient in computing skills. Those who fail to demonstrate such proficiency may be required to take a practical examination.

Prepared	***Approved***	***Subject Grouping***
VSV 27/07/2017	PJB	Classes

Unit Computing	***Staff*** Dr V.S. Vassiliadis and Dr B. Hallmark

Synopsis

Task 1
Data manipulation and problem solving using *Excel*

Task 2
Performing numerical optimisation of a function using *MatLab*

Task 3
Finding and selecting appropriate roots of a function using *MatLab*

Task 4
Numerical solution of an ODE using *MatLab*

Task 5
Simple set-up of a process flowsheet using *UniSim*

Task 6
Set-up and optimisation of a process flowsheet using *UniSim*

The theme of each task is subject to change.

Teaching Materials

Primers giving advice on how to use the software will be available on Moodle.

Unit

Engineering Drawing (§1)

Level	*Term*	*Duration*
CET I	MT 2017	1 lecture; 5 × 3 hour sessions

Background

This unit is for Section 1 students, i.e. those who did Part IA Natural Sciences.
Engineering drawings are an important method of communication used in industry. All engineers must be able to communicate their designs and to understand drawings produced by others.

Aims

To train students to read and understand engineering drawings, and to develop basic skills in 2D and 3D technical drawing.

Learning Outcomes

On completing this unit students should be able to:

- Understand basic concepts of projection theory
- understand the basic principles of orthographic projection
- produce drawings of simple objects and basic engineering components
- demonstrate that they can read drawings by producing a sketch of an object represented on a drawing
- use a CAD package for producing 2D and 3D engineering drawings as well as detailed first and third angle projections.

Assumed Knowledge

Material	*Source*
None	

Connections To Other Units

The skills acquired will be used in the CET I exercise on mechanical design and in the CET IIA Design Project.

Self Assessment

The progress of students will be continuously assessed by a series of graded tasks that will be completed during the unit under the supervision of demonstrators.

Assessment

Candidates are required to satisfy the examiners that they can make and interpret drawings. Those failing to complete the drawing class satisfactorily may be required to take a drawing examination.

Prepared	*Approved*	*Subject Grouping*
KY 12/9/2016	PJB	Classes

Unit Drawing	***Staff*** Dr K. Yunus

Synopsis

Projection Theory
The students will be introduced to simple orthographic projection, which illustrates how a three dimensional object can be represented on a flat sheet of paper. The unit will start with very simple shapes, and will progress to include engineering components. The various conventions used will be demonstrated, including first and third angle projection, the use of dotted and chain-dotted lines, *etc.*

Engineering Drawing
The basic theory will be expanded to cover more complex engineering components, including the theory of sectioning, and the detailed conventions required for such components will be explained. Sketching skills will be developed by giving the students a simple engineering component both to sketch and to draw orthographically.

Reading Drawings
The ability to read drawings will be tested by giving the students a drawing of an engineering component and asking them to produce an isometric sketch of that component.

CAD Skills
Students will be introduced to a working with a CAD package and given exercises to produce engineering 2D and 3D drawings as well as drawings with projected surfaces and sections.

Teaching Materials

Use will be made of handouts produced for Part IA Engineering students, backed up by some specialist CET material.

Unit

Physical Chemistry Laboratory (§2)

Level	*Term*	*Duration*
CET I	MT 2017	5 × 2 hour labs

Background

This laboratory class is for Section 2 students, i.e. those who did Part IA Engineering. Students perform the five experiments in pairs.

Aims

The aims of this laboratory class are:

1. to give students some exposure to experimental techniques in physical chemistry;
2. to expose students to some of the difficulties and uncertainties involved in chemistry laboratory work;
3. to reinforce some concepts from CET lectures.

Learning Outcomes

On completing this unit, students should be able to:

- perform experiments in physical chemistry
- analyse experimental results
- write reports

Assumed Knowledge

Material	*Source*
Nothing advanced	A-level chemistry (or equivalent)

Connections To Other Units

Each of the experiments is relevant to the CET I lecture unit on Introductory Chemistry, but there are also links to CET I Homogeneous Reactors and CET I Biotechnology.

Self Assessment

Students will write up each experiment, and these will be marked and returned to them. Students will be able to discuss their reports with a demonstrator.

Assessment

Candidates are required to satisfy the examiners that they can perform simple laboratory tests and experiments. Anyone failing to complete this laboratory class satisfactorily will be required to take a practical examination.

Prepared	*Approved*	*Subject Grouping*
ACF 12/8/2017	PJB	Classes

Unit Phys Chem Lab	***Staff*** Dr A.C. Fisher

Synopsis

There are five experiments:

1. Reaction kinetics in a stirred tank reactor

2. Reaction kinetics in a flow system

3. Measurement of ideal and non-ideal gases and solutions

4. UV-visible spectroscopy

5. Michaelis-Menten analysis for enzyme reaction kinetics

[These experiments are subject to change]

Teaching Materials

A laboratory manual will be issued to Section 2 students at the start of term.

Unit

Professional Skills

Level	*Term*	*Duration*
CET I	ET 2017	5 × 2 hour workshops

Background

Employers sometimes wish that graduates learnt more “transferable skills” whilst at university. These are skills that include the ability to communicate effectively, work well in teams, use modern IT tools, and so on. Many transferable skills are embedded throughout the CET course.

Aims

These workshops provide an opportunity for students to improve some of their transferable skills. It also enables students to hear an industrial perspective on some issues.

Learning Outcomes

On completing this unit, students should have a better understanding of transferable skills and a better perspective of some aspects of the process industries.

Assumed Knowledge

Material	*Source*
None	

Connections To Other Units

Presentations are compulsory in the CET IIA Design Project and CET IIB Research Project. Team working is an essential part of the CET IIA Design Project. All modules feature extensive connection to relevant industrial practice.

Self Assessment

Students should be able to follow the content of the modules and use the information presented to critique and improve their own abilities.

Assessment

This course is not formally assessed. However, the workshops are compulsory – a record will be taken of attendance and forwarded to the CET I Examiners.

Prepared	*Approved*	*Subject Grouping*
BH 1/9/2017	PJB	Classes

Unit	***Staff***
Prof Skills	Dr B. Hallmark

Synopsis

There are a number of topics presented in self-contained modules. The workshops will be presented by visiting speakers from the Teaching Consortium group of companies. A typical list is:

- Presentation skills
- Team working
- Application forms
- Risk analysis and management
- Project management

A final list will be issued before the start of the Easter Term.

Teaching Materials

Companies in the Teaching Consortium
supporting undergraduate teaching in Chemical Engineering in 2017-18