UNIVERSITY OF CAMBRIDGE
Chemical Engineering and Biotechnology

CHEMICAL ENGINEERING TRIPOS

Part IIB

SYLLABUS 2017-18

Contents ***Page***

This page is left blank intentionally.

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

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

Sustainability in Chemical Engineering

Level	*Term*	*Duration*
CET IIB	LT 2018	12 lectures

Background

Achieving the state of sustainability is seen as a critical societal challenge. It is a major factor in decision making in most industries employing chemical engineering graduates. This course will examine the foundation principles of sustainability, sustainability challenges in specific application areas and the role of chemical engineering in attaining the goals of sustainable development.

Aims

This course provides an overview of sustainability in a chemical engineering context. The aim is to establish the conceptual framework and apply quantitative methods to the analysis of chemical engineering technology with respect to its impact on sustainability.

Learning Outcomes

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

- Understand the concept of sustainability as a system's problem
- Understand basic concepts of general systems theory in application to technology systems
- Understand basic principles of environmental ecology; understand interaction of technological and environmental systems and their interconnections
- Describe principles of life cycle thinking; apply life cycle analysis to simple chemical processes
- Use thermodynamic analysis of simple chemical systems; be able to calculate exergy of technical systems
- Describe the water-energy-food nexus – an example of a system's problem.

Assumed Knowledge

Material	*Source*
Thermodynamics	CET I Process calculations
	CET IIA Equilibrium thermodynamics

Connections To Other Units

This course builds on material taught in CET I and CET IIB.

Self Assessment

Two problem sheets will be issued during lectures
This course was revised in 2014-15. Past examinations questions are:
CET IIB 2015-17 Paper A1 Section B.
The following examination questions on the previous form of the course may be useful:
CET IIB 2010-2014: Paper A1 Section B

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
AAL 1/9/2017	PJB	Group A: Compulsory Topics

Unit	*Staff*
Sustainability	Prof. A.A. Lapkin

Synopsis

1. Sustainability as a system' science
   Three pillars of sustainability
   Mathematical definitions of sustainability
   General systems theory and its application to sustainability

2. Life cycle thinking
   Principles of LCA
   LCA of chemical processes

3. Thermodynamics-based evaluation of environmental sustainability
   2nd Law efficiency
   Exergy

4. Water-food-energy nexus

Teaching Materials

References to original and review papers for background reading and discussion will be mentioned during lectures and deposited in Moodle.
The following general books may be useful:

- M. Robertson, "Sustainability Principles and Practice", Routledge, 2014.
- S.A. Moore (editor), "Pragmatic Sustainability. Theoretical and Practical Tools", Routledge, 2010.

Unit

Energy Technology

Level	*Term*	*Duration*
CET IIB	MT 2017 / LT 2018	20 lectures

Background

The future of society in the 21st century depends hugely on developments in Energy Technology. Most large-scale methods for converting energy from one form into another, including generation of electricity, depend on chemical engineering principles. It is good for students to revise chemical engineering principles by seeing how they can be applied in the field of energy technology.

Aims

The aim of the course is to use chemical engineering principles to perform calculations of relevance to the energy industries. The courses includes combustion science, the fundamentals of nuclear energy, renewable energy processes, and energy storage.

Learning Outcomes

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

- describe the principles of energy storage
- describe and perform calculations on gas-phase combustion reactions
- describe and perform calculations on liquid-phase combustion reactions
- describe and perform calculations on combustion of solids
- describe and perform calculations on wind turbines
- describe and perform calculations on hydroelectric turbines
- describe and perform calculations involving solar energy
- describe the physical principles behind radioactivity and nuclear reactions
- describe and perform calculations on radioactive decay
- describe and perform calculations on nuclear reactor design
- describe and perform calculations on poisoning of fission nuclear reactors
- describe the main features of nuclear power plants, including the safety aspects

Assumed Knowledge

Material	*Source*
Chemical Engineering principles	CET I and CET IIA

Connections To Other Units

This course is designed to revise and build upon key chemical engineering topics covered in previous years.

Self Assessment

Two examples sheets will be issued during lectures.
This course was given for the first time in 2014-15. The past exam questions are
CET IIB 2015-2017 / Paper A1 / questions 1 and 2

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
PJB/CdA 1/9/17	PJB	Group A: Compulsory Topics

Unit Energy	***Staff*** Drs P.J. Barrie and C. d’Agostino

Synopsis

The topics of the course will not necessarily be given in the order presented here.

1) Electricity and energy storage

2) Combustion processes
   - Introduction: combustion; heating values; types of flame
   - Combustion of gases: temperature in a flame; equilibrium; flame propagation; thermal explosions; radical explosions; chemical kinetics for $H_2 + O_2$
   - Combustion of liquids: heating time; mass transport, energy transport and combining equations
   - Combustion of solids: coal; biomass

3) Nuclear energy
   - Fundamentals of nuclear physics: atomic structure; binding mass energy; nuclear stability of isotopes; radioactive decay
   - Nuclear reactor physics: nuclear reactions; nuclear fusion; nuclear fission; nuclear fuel; nuclear power plants; handling of nuclear wastes
   - Safety aspects

4) Renewable energy processess
   - Wind energy: wind turbines; power coefficient; Betz limit; force on turbine; turbine blade design; power output for a steady wind; wind speed distribution; siting of wind turbines
   - Hydropower: introduction; impulse and reaction turbines; Euler’s turbine equation
   - Solar energy

Teaching Materials

One textbook with an appropriate approach (though not always sufficient detail) is:
- J. Andrews and N. Jelley: “Energy Science” (3rd ed., Oxford University Press, 2017).

A suitable textbook on the second half of the course is:
- R.L. Murray and K.E. Holbert: “Nuclear Energy” (7th ed., Butterworth-Heinemann, 2014)

Unit

Chemical Product Design

Level	***Term***	***Duration***
CET IIB	MT 2017	8 × 2 hour sessions + assessments

Background

Chemical and biochemical product design is an important activity for many industrial companies. Many practising chemical engineers need an understanding of product design in addition to process design.

Aims

To prepare students for the increasingly diverse range of challenges faced by chemical engineers in industry, in particular the increasing emphasis on design of the product in addition to the process.

Learning Outcomes

On completing this course, students should be able to:

- apply fundamental chemical engineering principles to design chemical and biochemical products at a level suitable to make an initial assessment of their viability/functionality/feasibility;
- demonstrate confidence in data/parameter estimation such that a pragmatic level of design can be carried out;
- make pragmatic assumptions about processes and products such that an initial level of design can be carried out;
- summarise succinctly and report both orally and in writing key information relating to their designs;
- demonstrate an understanding of the particularities of the design and manufacture of biochemical and nanotechnology inspired products.

Assumed Knowledge

Material	*Source*
Chemical engineering principles	CET I and CET IIA
Biotechnology and bioprocess engineering	CET I and CET IIA

Connections To Other Units

This course builds upon, and extends, design philosophies gained in CET IIA process design.

Self Assessment

Assessment

This course is assessed by coursework, including both written reports and oral presentations. Group and individual work will be included in the assessment. An element of peer assessment will be used in marking.

Prepared	***Approved***	***Subject Grouping***
LF/GC 10/8/2017	PJB	Group A: Compulsory Topics

Unit Product design	**_Staff_** Dr L. Fruk and Dr G. Christie

Synopsis

Chemical engineering shares with other engineering disciplines a tradition of courses in design. In these courses, students use what they have learned to synthesize new solutions to relevant problems. Normally, these problems have centred on chemical processes. For example, students can design an ammonia synthesis plant, or a cryogenic distillation unit for air separation.

This design experience has been a mainstay of the profession for over fifty years. It has successfully prepared students to work for large multi-national companies who make commodity chemicals. It has served the profession well.

However, over the last couple of decades, fewer students have gone to work for these commodity chemical companies. Increasing numbers take jobs in specialty chemicals, consumer products, and biomedical industries. Some of these jobs are in start-up companies. For students anticipating this type of career, process design may not be appropriate.

This course will centre on product design, not process design. In its lectures, it will review the business strategies, the idea generation, and the product architecture characteristic of product design. Students will solve open-ended problems based on particular products. For example, they could design a blood oxygenator, an energy-saving building ventilator, or a device for controlling drug release.

This course is based on a four stage template for product design:

- Needs
- Ideas
- Selection
- Manufacture

Three types of product are discussed:

- Molecular, e.g. drugs, pesticides, flavours, colours
- Microstructured, e.g. shoe polish, ice cream, paint
- Devices, e.g. artificial kidney, home oxygen enricher, house ventilator

Emphasis will be placed on the design and manufacture of biochemical products and sensors – these are gaining increasing importance in the modern chemical industry.

The two hour sessions will include periods of lecture and working on problems, either in groups or individually. These sessions will provide the basis for pieces of continually assessed work, either by a written report or an oral presentation.

Teaching Materials

The following books are recommended:

- K.T. Ulrich and S.D. Eppinger, “Product Design and Development”, McGraw-Hill, 5th ed. 2011.
- E.L. Cussler and G.D. Moggridge, “Chemical Product Design”, Cambridge University Press, 2nd ed. 2011.

Unit

Advanced Transport Processes

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

Background

Transport processes is one of the fundamental topics that helps define the chemical engineering discipline. The ability to model transport processes in different situations, such as in porous solids, in packed beds, in the presence of reaction and so on, is an important part of a chemical engineer's training.

Aims

The overall aim is to enable students to formulate solutions to unfamiliar transport problems occurring in chemical engineering. The course will emphasise the tackling of problems by applying fundamentals to produce a solution.

Learning Outcomes

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

- perform calculations on advective and diffusive fluxes in binary systems.
- describe diffusion in multicomponent systems, and understand the limitations of Fick's law.
- determine interphase heat and mass transfer coefficients in rich systems with significant fluxes of components.
- calculate the rate of transfer between gas and liquid phases when the gas reacts with the liquid at a finite rate.
- set up and use models for time-dependent transport problems.
- set up and use models for how fluid disperses as it travels through an open tube or a packed bed.
- tackle problems involving transport in porous solids.

Assumed Knowledge

Material	*Source*
Core chemical engineering topics	CET I and CET IIA

Connections To Other Units

This course builds on the knowledge gained in the CET I Transport Processes lectures, and the applications in CET I and CET IIA.

Self Assessment

There will be five problem sheets. Fully documented solutions will be available 10 days after each problem sheet is issued.
The following examination papers indicate the level of achievement expected:
CET IIB 2013-2017 Paper B1.

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
JSD 11/9/2017	PJB	Group B: Advanced Chemical Engineering Topics

Unit	*Staff*
Advanced Transport	Prof. J.S. Dennis

Synopsis

1. Mass and Energy Transport in a Binary System.
    - understanding advective and diffusive fluxes in binary systems.
2. Multicomponent Diffusion – Stefan-Maxwell Equations.
    - to understand what happens in a diffusing system when there are more than two components and there are significant changes in concentration, as in a practical catalyst. Limitations of Fick's Law.
3. Interphase Mass Transfer – Binary and Multicomponent Systems
    - how to determine heat and mass transfer coefficients in rich systems with significant fluxes of components.
4. Interphase Mass Transfer Continued: Gas-Liquid Mass Transfer
    - how to calculate the rate of transfer between a gas and liquid when the gas reacts with the liquid at a finite rate. Time-dependent aspects of gas absorption.
5. Time-Dependent PDEs – Revision and Extension
    - an extension of material covered in Part IIA PDEs to allow solution of time-dependent transport problems.
6. Reaction and Dispersion
    - how fluid disperses as it travels through a packed or open tube. Understanding tracer measurements on packed beds. How to formulate the correct boundary conditions for a packed bed reactor.
7. Transport in Porous Solids
    - how to tackle problems involving practical catalysts (gas-solid reactions).

Teaching Materials

Advice on suitable background reading will be given in lectures.

It is expected that one or two revision lectures will be given in the Easter Term, depending on demand.

Unit

Pharmaceutical Engineering

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

Background

The pharmaceutical industry contributes a key part to the UK economy and it stands out as one of the nation's largest manufacturing exporters. There are ample opportunities for chemical engineers to contribute their expertise in this sector. The industry is a major energy consumer and manufacturing practice sometimes lags behind other process industries (such as food) even though product quality is critical.

Aims

This course aims to give students an understanding of the fundamentals of pharmaceutical engineering. It introduces the subject and builds on established concepts from general chemical engineering to highlight specific applications and requirements of this industrial sector.

Learning Outcomes

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

- Understand the complex requirements set by pharmacological efficacy, formulation, primary and secondary manufacturing as well as the regulatory framework that govern this global industry
- Have an appreciation for the cultural differences between the R&D and manufacturing environments
- Understand the different type of dosage forms manufactured by the industry (solids, semi-solids and liquids)
- Know the major unit operations currently in place for batch production
- Understand the barriers that prevent further improvements to the quality of medicines using present manufacturing technologies
- Understand the state of the art in the drive towards continuous production, quality-by-design and process analytical technology

Assumed Knowledge

Material	*Source*
Chemical thermodynamics; reaction kinetics	CET I and CET IIA
Heat and mass transfer	CET I

Connections To Other Units

Pharmaceutical engineering is an extension to the general chemical engineering principles that the students have become familiarised with throughout CET I and IIA.

Self Assessment

Problem sheets will be issued during the lectures.
This course was taught for the first time in 2015-16. Past exam papesrs:
CET IIB 2016-17 Paper B3.

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
JAZ 1/9/2017	PJB	Group B: Advanced Chemical Engineering Topics

Unit	*Staff*
Pharmaceutical Engineering	Prof. J.A. Zeitler

Synopsis

1) The Pharmaceutical Industry
2) Design of Solid Dosage Forms
    a. Physicochemical properties
    b. Pharmacokinetics
3) Immediate Release Tablets
    a. Formulation
    b. Processing
4) Current Trends in Pharmaceutical Processing
    a. Quality by Design (QbD)
    b. Multivariate Analysis
    c. Process Analytical Technology (PAT)
    d. Microstructure Engineering
    e. Continuous Manufacturing
        - Real time release testing
        - Regulatory requirements
        - Example of continuous process
        - Advanced process control
5) Modified Release Technology
    a. Concepts
    b. Drug Release Behaviors
        - Diffusion barriers
        - Matrix technology
        - Osmotic drug delivery control
    c. Processing
        - Tablet film coating
        - Extrusion and spheronisation
        - Pellet film coating
6) Outlook
    a. Other Dosage Forms
    b. Personalised Medicine

Teaching Materials

The following textbooks are useful:

- D.J. am Ende (ed.), “Chemical Engineering in the Pharmaceutical Industry”, Wiley, 2011.
- M.E. Aulton and K.M.G. Taylor (eds.), “Aulton's Pharmaceutics”, Elsevier, 4th ed., 2013.
- P.J. Sinko (ed.), “Martin's Physical Pharmacy and Pharmaceutical Sciences”, Wolters Kluwer, 6th ed., 2011.
- Y. Qiu *et al.* (eds.), “Developing Solid Oral Dosage Forms”, Academic, 2009.

Unit

Rheology and Processing

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

Background

Rheology is the study of deformation and flow of all states of matter and the subject underpins our understanding of the way materials and liquids deform. Many of the materials and fluids handled by chemical engineers are not simple Newtonian liquids or elastic solids. Rheology is central to many chemical engineering applications, particular those involved in the 'sticky' end of processing such as polymers, paints, foodstuffs, pastes and bio-polymers.

Aims

The course aims to give students a grounding in rheology and its relationship to processes. It describes key concepts in rheology and rheological measurements, covers viscoelasticity and viscoplasticity, and includes some applications.

Learning Outcomes

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

- Describe the constitutive equations that are used in rheology.
- Develop quantitative models of, and analyse data from, the standard techniques used to make rheological measurements.
- Describe the physics of simple non-Newtonian fluids and employ this knowledge to construct quantitative models of flows of power law fluids in regular 1-D geometries.
- Derive relationships between flowrate, pressure drop (and derived quantities) for viscoelastic and viscoplastic fluids in standard geometries.
- Quantify the effect of time on the viscosity of structured and viscoelastic fluids.
- Describe and quantify the effects of formulation and processing parameters on the apparent viscosity of structured fluids.
- Understand the flow behaviour of suspensions and other multiphase fluids.

Assumed Knowledge

Material	*Source*
Mathematics	Part IA, CET I, CET IIA
Fluid mechanics	CET I, CET IIA
Concepts of stress and strain	CET I SAPV

Connections To Other Units

This module builds on previous courses in CET I and CET IIA that have been concerned with Newtonian and power law flow. It also uses concepts of stress and strain developed in the CET I SAPV lectures.

Self Assessment

Two problem sheets will be issued during the module, with solutions provided on Moodle. A complete list of past exam questions will be provided. The recommended supervision schedule is

(1) Examples paper A
(2) Examples paper B
(3) Tripos Qs and revision

Past exam papers: 2016-17 Paper B4 ; 2015 Paper B8 ; 2014 Paper B9 ; 2011-2013 Paper B8

Assessment

The material from this unit is assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
BH/CJN 5/9/2017	PJB	Group B: Advanced Chemical Engineering Topics

Unit	*Staff*
Rheology	Drs B. Hallmark & C.J. Ness

Synopsis

The module is organised in four sections of four lectures. The first 8 lectures will be given by Dr Hallmark, and the final 8 lectures will be given by Dr Ness.

A. Key concepts in rheology and rheometry
- Revision of stress, strain and strain rate
- The Newtonian constitutive equation
- The generalised Newtonian constitutive equation
- The power law fluid
- Carreau and Carreau-Yasuda fluids
- Measurement techniques and devices; capillary and rotational rheometry

B. Viscoelasticity
- Viscoelastic flow
- Modelling viscoelastic flow
- Building a phenomenological model of viscoelasticity
- The Maxwell model in differential form
- The Maxwell model in integral form with respect to strain rate and strain
- The general linear viscoelastic model
- The multimode Maxwell model and the Wagner damping factor
- Examination of the Cox-Merz rule
- Extension beyond small gradient flows
- Determining viscoelastic parameters from rheological measurements

C. Viscoplasticity
- The yield stress concept and constitutive equations
- Viscoplastic fluid flow patterns in simple shear
- Extensional flows of viscoplastic fluids: perfect plasticity and simulations
- Critique of the yield stress concept
- Wall slip

D. Applications and multiphase systems
- Rheology and microstructure: the Cross model as a quantitative constitutive model
- Suspensions
- Emulsions
- Foams and bubbly liquids

Teaching Materials

Lecture notes and examples papers are provided and are posted on Moodle. Annotated notes are **not** provided. There are a number of good books available.

- J.F. Steffe, “Rheological Methods in Food Process Engineering”, Freeman Press, 2nd ed. 1996: available free on-line at https://sites.google.com/site/jfsteffe/freeman-press
- J.M. Dealy and K.F. Wissbrun, “Melt Rheology and its Role in Plastics Processing”, Van Nostrand, 1990.
- C.W. Macosko, “Rheology: principles, measurements and applications”, Wiley-VCH, 1994.
- J.M. Dealy and R.G. Larson, “Structure and Rheology of Molten Polymers”, Hanser, 2006.
- F.A. Morrison, “Understanding Rheology”, Oxford University Press, 2001.

Unit

Computational Fluid Dynamics

Level	***Term***	***Duration***
CET IIB	MT 2017	8 lectures + 8 classes

Background

Computational fluid dynamics (CFD) is a branch of fluid mechanics which uses numerical methods and algorithms to solve and analyse problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces, as defined by suitable boundary conditions. CFD models are increasingly used in design optimisation – once a model is validated against experimental data, it can be used to optimise a physical system more effectively than modifying/re-testing a succession of prototypes.

Aims

This course aims to give students an understanding of the principles, capabilities and limitations of CFD, and enable them to model simple fluid systems involving mass, momentum and energy transfer.

Learning Outcomes

On completing this course and the associated assessed assignment, students should be able use ANSYS CFX, a leading commercial CFD software suite, to:

- Generate a 3D CAD representation of a simple fluid system involving solid boundaries
- Create a suitable 3D mesh, for use in the subsequent finite volume analysis
- Identify and define physical properties and boundary conditions that are required to model the system
- Configure an FEA solver to achieve efficient convergence of the predicted solution
- Assess the predictions of a model, with regard to mesh independence and accuracy
- Use a CFD model to investigate the optimum design of a physical system.

Assumed Knowledge

Material	*Source*
Basic principles of fluid mechanics	CET I - Fluid mechanics
Basic principles of heat and mass transfer	CET IIA - Heat & mass transfer fundamentals
Numerical methods	CET I - Engineering mathematics
	CET IIA - Partial differential equations

Connections To Other Units

The course builds on material learnt in previous years. It is possible that the techniques learned in this course may be of use in some IIB research projects.

Self Assessment

Structured problems will be issued throughout the first half the course; these can be attempted by students and then discussed in the weekly tutorial sessions. Additional tutorial material is available via the ANSYS student portal.

Assessment

An individual assignment will be issued at the end of the third week of the course. Students will be required to submit a report detailing their modelling work and the conclusions drawn from it.

Prepared	***Approved***	***Subject Grouping***
MEW 30/08/17	PJB	Group B: Advanced Chemical Engineering Topics

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

Synopsis

The course includes eight lectures and six 2-hour tutorial sessions, as detailed below. Tutorial sessions will be held in the computer suite where students can attempt the example problems using ANSYS CFX software.

Wk	Lecture topic	Tutorials	Assessed assignment
1	#1 Introduction to computational fluid dynamics	File management using ANSYS Workbench.	
	#2 The equations of fluid flow – a review	Creating a 3D CAD model using ANSYS Design modeler (based on example of a fluid mixing system)	
2	#3 Numerical solution to the equations of fluid flow	3D modeling (cont.) Meshing	
	#4 Meshing techniques		
3	#5 Definition of boundary conditions	Meshing.	
	# 6 Definition of physical properties	Overview of the assessed assignment.	Generate 3D geometry
4	#7 Solver control	Solver Configuration	
	#8 Post-processing and data analysis		Meshing, physics definition, solver configuration
5	-	Post-processing	Simulations, evaluation of accuracy and mesh independence
6	-	General assistance	Design optimisation
7	-		Report preparation
8	-		Report preparation

Students are expected to allocate approximately 20 hours to the assessed assignment.

Teaching materials

The recommended textbook is:
J.D. Anderson, “Computational Fluid Dynamics – The Basics with Applications”, McGraw-Hill 1995.
ANSYS Inc, CFX 15.0 User guides, ANSYS 2013 (available on Moodle).

Unit		
Fluid Mechanics and the Environment		
Level CET IIB	***Term*** MT 2017	***Duration*** 16 lectures

Background

Fluid mechanics is central to chemical engineering. Chemical engineers are concerned with flows in industrial processes and also in the natural environment. Examples of the latter include the discharge of gaseous effluents from chimneys, the accidental release of chemicals into the ocean or atmosphere, the motion of pollutants in soil and the flow of stored carbon dioxide in porous rocks. As fluids flow in the environment, their physical properties are altered, they are mixed or separated, and they take part in chemical reactions. Both natural and human-induced flows have a large impact on the Earth. In this course, we introduce the fundamentals needed to describe and quantify such flows.

Aims

The aim is to cover the fundamental fluid mechanics principles to enable the solution of laminar and turbulent environmental flows.

Learning Outcomes

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

- analyse and solve problems concerning inert and reactive flows arising from localized, instantaneous discharges in the ocean and atmosphere
- analyse and solve problems concerning the inert and reactive transport of chemicals in porous media

Assumed Knowledge

Material	*Source*
Basic fluid mechanics	CET I Fluid Mechanics
Navier-Stokes equation	CET IIA Fluid Mechanics
ODEs and PDEs	CET I Mathematics, CET IIA Mathematics

Connections To Other Units

This unit builds on previous fluid mechanics options. It may complement other CET IIB options.

Self Assessment

Two examples sheets will be issued during lectures.
The following examination papers indicate the level of achievement expected:
CET IIB: 2017 Paper B6; 2015 Paper B4 ; 2014 Paper B5; 2013 Paper B5; 2012 Paper B4; 2011 Paper B4

Assessment

The material from this unit is assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
SSSC 10/9/2017	PJB	Group B: Advanced Chemical Engineering Topics

Unit	***Staff***
Fluid Mechanics and the Environment	Prof. S.S.S. Cardoso

Synopsis

This course is divided into two parts, on turbulent flows in the atmosphere and oceans, and laminar flows in porous rocks.

1 Turbulent flows in the atmosphere and oceans

2.1 Inert and reactive plumes

Turbulent plumes; dimensional analysis.
Equations of motion; entrainment; Gaussian profiles. Density stratification.
Multiphase plumes. Effects of chemical reaction and dissolution. BP oil plume in the Gulf of Mexico 2010.

2.2 Jets

Forced plumes and buoyant jets.
Characteristic length-scales.
Entrainment and rate of spreading.

2.3 Plumes and jets in nature and industry

Various examples of real flows. Solved example problems.

2.4 Inert and reactive thermals

Turbulent thermals; dimensional analysis.
Equations of motion; entrainment.
Effects of chemical reaction.
Fukushima nuclear cloud 2010.

2 Laminar flows in porous rocks

2.1 Inert and reactive flows in porous media

Darcy’s equation.
Conservation of mass, chemical species and energy.
Examples of inert flows in the Earth’s sub-surface in 1-D, 2-D and 3-D geometries; Bessel functions.

2.2 Buoyant convection in a layer of fluid

Linear Stability Analysis. Base state. Perturbations. The Rayleigh number.
Minimum critical Rayleigh number for the onset of convection.
Climate change. Carbon dioxide sequestration in saline aquifers. Effects of geochemical reactions.

2.3 Buoyant plumes in fluid-saturated porous media

Boundary-layer approximations of the governing equations.
Velocity and temperature distributions in 2-D and 3-D plumes. Radius of the plume.
Flow under the seafloor: continental margin- and seep-plumes driven by thermal and solutal density differences.

2.4 Osmotic and buoyant flow

Osmosis in a porous medium. Solute size-restriction and other mechanisms. Kedem-Katchalsky equations. Derivation from kinetic theory, fluid mechanics and thermodynamics.
Flow near submarine mud-volcanoes: implications for methane-hydrate melting and climate change.

Teaching Materials

Recommended books

- D.J. Tritton “Physical Fluid Dynamics”, Oxford University Press, 2nd Edition 1988.
- J.S. Turner, “Buoyancy Effects in Fluids”, Cambridge University Press, 1973.
- P.F. Linden, “Convection in the environment”. In *Perspectives in Fluid Dynamics* (ed. G.K. Batchelor, H.K. Moffat & M.G. Worster), Cambridge University Press, 2000.
- D.L. Turcotte and G. Schubert “Geodynamics”, Cambridge University Press, 2nd Edition 2002.

Unit		
Interface Engineering		
Level CET IIB	***Term*** MT 2017	***Duration*** 16 lectures

Background

Interfaces exist everywhere in nature. Interfaces between solid, liquid and vapour phases have always been important in chemical engineering as chemical engineers have always worked with multi-phase systems. Interfaces are becoming increasingly important as more materials are manufactured with smaller scale features and in smaller devices. An understanding of interfacial phenomena means that surfaces can be designed to promote desired behaviour.

Aims

The aim of this module is to explain the principles involved with interfaces between two fluids, and between two fluids and a solid. The approach will be quantitative, in 1-D where possible, so that students can construct simple models of surface-tension driven phenomena. The focus will be on continuum phenomena. The relationship to nanoscience will be flagged.

Learning Outcomes

This course was introduced in 2016-17 so the specific learning outcomes may change slightly.

On completing this course and the associated problem sheets, students should be able to tackle problems involving

- surface tension, surface energy, contact angle and spreading
- fluid statics, including the shape of interfaces and buoyancy/surface tension effects
- simple fluid flows with surface tension boundary conditions
- disturbances leading to instabilities (though not perturbation analysis)
- the effect of surface structure and composition
- surfactants

Assumed Knowledge

Material	*Source*
Fluid mechanics	CET I and CET IIA
Thermodynamics	CET I and CET IIA
Equation solving, ODEs, integral calculus, 1 and 2D coordinates	Part IA

Connections To Other Units

Surface tension is mentioned in CET I Heat and Mass Transfer and CET IIA Reactors. The material covered in these lectures may complement other CET IIB modules.

Self Assessment

Three problem sheets will be provided with introductory problems as well as problems approaching Tripos level. Solutions to the problem sheets are provided on Moodle.
Past examination paper:
CET IIB: 2017 Paper B7

Assessment
The material from this unit is assessed by written examination (75%) and a coursework task (25%). The submission date for the latter will be the first day of Lent Full Term.

Prepared	***Approved***	***Subject Grouping***
DiW 25/7/2017	PJB	Group B: Advanced Chemical Engineering Topics

Unit	***Staff***
Interface Engineering	Prof. D.I. Wilson

Synopsis

1 Introduction and basic concepts
- 1.1 Surface tension, surface energy and simple fluids
- 1.2 Wetting, contact lines and contact angles
- 1.3 Spreading

2 Surface tension in fluid mechanics
- 2.1 Governing equations for flow
- 2.2 Stress balance equations
- 2.3 Governing equations in dimensionless form
- 2.4 Curvature, κ

3 Static or quasi-static fluid applications
- 3.1 Simple menisci
- 3.1.1 Capillaries
- 3.1.2 Kelvin equation
- 3.2 Wetting of walls
  - 3.2.1 The long wall
  - 3.2.2 The Wilhelmy plate
  - 3.2.3 Partially immersed bodies
  - 3.2.4 Froth flotation
  - 3.2.5 Pilkington float glass process
- 3.3 Liquid bridges and cohesion
  - 3.3.1 Simple analysis of liquid bridges between particles
  - 3.3.2 Real liquid bridges
  - 3.3.3 Viscous forces in liquid bridges
  - 3.3.4 The science of sandcastles

4. Surface tension in flow
- 4.1 Rise in a capillary – the Washburn equation
- 4.2 The water bell
- 4.3 Droplet spreading
- 4.4 Jet breakup
  - 4.4.1 Cylindrical jet behaviour
  - 4.4.2 Region II: the Plateau-Rayleigh instability
  - 4.4.3 Rayleigh instability: formal treatment

5. Surfaces, surfactants and surface energies
- 5.1Thermodynamic origin of ELV
- 5.2 Surface energies of solids
- 5.3 Surface morphology
  - 5.3.1 Rough surfaces – the Wenzl model
  - 5.3.3 Contact line hysteresis and pinning
- 5.4. Surfactants
  - 5.4.1 Soluble surfactants: the Gibbs adsorption isotherm
  - 5.4.2 Insoluble surfactants
- 5.5 Marangoni forces and flows

Links to the questions on the examples papers will be provided in lectures.

Teaching Materials

Lecture notes are provided as a series of booklets and will be available on Moodle. Annotated notes and presentation materials are **not** provided: students need to come to the lectures.

There is no set text for this module: books with relevant sections will be mentioned. Papers from journals will be referred to and copies will be put on Moodle if copyright allows.

Unit

Optical Microscopy

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

Background

The observation of microscopic processes is key to a huge number of scientific and industrial applications. Optical microscopy is one of the most widely used analytical techniques, used for material characterisation, quality control, chemical composition analysis, process analytics, DNA sequencing, observation of biomedical processes, etc.

Aims

The aim of this unit is to develop an understanding of the principles underlying state-of-the-art optical measurement techniques used for microscopy and to describe several key technologies and applications that are used in industry and research.

Learning Outcomes

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

- understand fundamental principles of image formation in different modes of light microscopy.
- understand the physical concepts that affect image resolution and contrast.
- design conceptually advanced microscopy instrumentation that achieves the required sensitivity and resolution for a given application.
- analyse image data correctly and quantitatively in the presence of noise.
- understand the underlying technology of advanced microscope instrumentation.
- provide real world examples of modern microscopy technologies used in research and industry.

Assumed Knowledge

Material	*Source*
Basic mathematics	Part IA, CET I
Basic spectroscopy	Part IA Chemistry or CET I Analytical Chemistry

Connections To Other Units

Self Assessment

Two problem sheets will be issued during the course.
This course was first introduced in 2014-15.
Past examination papers: CET IIB 2016-17 Paper C1 ; 2015 Paper B5.
Some examination questions on a related former course are useful: CET IIB: 2013 Paper B6 Q2(a) and (b); 2008 Paper B7 Q1(a); 2006 Paper B6 Q3

Assessment

The material from this module will be assessed by written examination.

Prepared	***Approved***	***Subject Grouping***
CFK 1/9/2017	PJB	Group C: Broadening Topics

Unit	**Staff**
Optical Microscopy	Prof. C.F. Kaminski

Synopsis

Fundamental Background

- A brief history of the microscope
- Concepts of image formation
- Mathematical background: the Fourier transform (and its importance for image formation and resolution)
- The problem of optical diffraction and its effect on image resolution: Point spread and optical transfer functions
- Microscope resolution, contrast and sensitivity
- Interrogating molecules: light absorption, emission, and scattering
- The technology: lasers, lenses, cameras, and all that

Basic Microscopy techniques

- Brightfield microscopy
- Fluorescence microscopy: Obtaining chemical specificity
- Coherent and incoherent imaging
- Improving image contrast: Confocal microscopy

Sample preparation techniques

- Synthetic fluorophores
- Fluorescent proteins, antibodies, and labelling of biological samples.

Advanced Techniques

- Imaging the molecular environment: Fluorescence lifetime microscopy and polarisation resolved imaging.
- Detecting single molecules
- Optical super-resolution techniques: resolving objects smaller than the wavelength of light

Image processing techniques

- Deconvolution of image noise
- Contrast enhancement techniques
- Object identification and tracking

Applications

- Microscopy for chemical detection and process control
- Gene sequencing
- Imaging in living systems and uncovering molecular mechanisms of disease
- Imaging whole organisms

Teaching Materials

No book covers the course material exactly; most books are either too basic or too advanced for the purpose of this course. However the following are outstanding web resources that illustrate aspects of the course. They contain interactive Java tutorials which allow you to see different modes of imaging and to explore physical concepts:

- The *optical microscopy primer* website: http://micro.magnet.fsu.edu/primer/index.html
- The *microscopyu* website: http://www.microscopyu.com/

Unit

Optimisation

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

Background

Optimisation is an important mathematical tool in chemical engineering. Developing efficient methods for finding the optimum of an objective function that may be linear or non-linear in nature remains an active research area. Applications in industrial practice are numerous as well as in a number of scientific, financial and interdisciplinary important domains.

Aims

This course gives students an advanced view of optimisation and its applications. In the first half of the course, the emphasis is on the establishment of the theoretical concepts underpinning optimisation models and their connection to numerical solution techniques. The second half of the course presents the application of the theory in specific areas of practical interest, such as optimal control in chemical process models, parameter estimation and model fitting, and other applications.

Learning Outcomes

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

- formulate and solve linear and non-linear optimisation models, specifically:
  1. solve linear programming problems by the Simplex method
  2. solve equality-constrained non-linear programming problems by the Lagrange multiplier method
  3. solve inequality-constrained optimisation problems via modification of the Lagrange multiplier method
- learn the basic operation of modern non-linear numerical solution algorithms, such as interior point methods
- understand how the issue of model non-convexity limits obtaining globally optimal solutions for non-linear models, and how this impacts optimisation-based decision-making
- transcribe the description of engineering problems, e.g. in the form of process briefs and numerical data, into mathematical programming models and optimise them, with particular emphasis on linear programming models
- formulate and solve linear parameter estimation problems as optimisation models which is important in fitting models to experimental and measurement data
- formulate and solve allocation type problems and material flow problems through connectivity networks (e.g. flow through a pipeline network)
- formulate problems involving ODEs as model constraints (optimal control problems) into standard optimisation models
- use sensitivity analysis as a post-optimality tool to assess which operating conditions and parameters have most impact on the solutions obtained for any type of optimisation problem.

Assumed Knowledge

Material	*Source*
Numerical methods	CET I Engineering Maths
Material balances	CET I Process Calculations
Process economics	CET I Introductory Chemical Engineering

Connections To Other Units

This unit uses many of the basic chemical engineering building blocks from earlier years. It is independent of other CET IIB units.

Self Assessment

Problem sheets will be issued during lectures. Students should feel not only that they have learnt new material in the course but that they have gained by looking at familiar material from a different perspective.
The following are past examination papers:
CET IIB 2016-17 Paper C2 ; 2015 Paper B6 ; 2013 Paper B7 ; 2011-2012 Paper B6 ; 2010 Paper B7

Assessment

The material from this module will be assessed by written examination.

Prepared	*Approved*	*Subject Grouping*
VSV 27/07/2017	PJB	Group C: Broadening Topics

Unit	*Staff*
Optimisation	Dr V.S. Vassiliadis

Synopsis

1. General background on advanced optimisation theory
2. Linear and non-linear models
3. The Simplex method for Linear Programming
4. Interior point methods for the solution of constrained optimisation problems
5. Global optimisation aspects
6. Applications:
    a. Multiperiod models
    b. Optimal control
    c. Routing problems and formulations
    d. Parameter estimation problems
    e. Network optimisation problems (minimum path, network flow problems)
    f. Resource allocation problems

Teaching Materials

- H.A. Taha, "Operations Research: an introduction", Pearson, 9th ed. 2010.
- T.F. Edgar and D.M. Himmelblau, "Optimization of Chemical Processes", McGraw-Hill, 2nd ed. 2001.
- D.G. Luenberger and Y. Ye, "Linear and Nonlinear Programming", Springer, 3rd ed. 2008.
- C.A. Floudas, "Nonlinear and Mixed-Integer Optimization: fundamentals and applications", Oxford University Press, 1995.

Unit		
Healthcare Biotechnology		
Level CET IIB	***Term*** LT 2018	***Duration*** 14 lectures + 2 workshops

Background

Healthcare is the diagnosis, treatment, and prevention of disease, illness, injury, and other physical and mental impairments in humans. It is regarded as an important determinant in promoting the general health and well-being of the world's population and can form a significant part of a country's economy, with costs in the range 10-16% of GDP in OECD countries. Healthcare accounts for ~65% of current R&D spending in biotechnology.

Aims

This course aims to lay a foundation in the prevalence, pathologies, diagnosis and treatment of the major diseases afflicting humans in the 21st century. The course will cover the challenges encountered in drug discovery and development, drug delivery, regulation and the newer approaches involving gene, protein, cell-based and bionic therapies. Key developments for the future, including stratified and personalised medicine and E- and m-medicine will also be discussed.

Learning Outcomes

On completion of this course and associated problem sheets, students should be able to:

- Demonstrate an understanding of the major healthcare challenges in the 21st century and their impact on society.
- Understand the threat of newly emerging and re-emerging infectious diseases on established and emerging economies.
- Show an ability to evaluate healthcare drivers, threads and applications. Students should be able to calculate disease incidence and prevalence and acquire knowledge on fundamental health economics.
- Appreciate the value of biomarker discovery in diagnostic, prognostic and personalized medicine. Students should be able to suggest appropriate biomarker strategies for healthcare applications such as diagnosis and drug discovery; students should be able to calculate sensitivity and specificity of a test or intervention.
- Demonstrate an understanding of the drug discovery stages and clinical trial phases within the pharmaceutical industry; students should be able to evaluate clinical trial designs and comment on the advantages and limitations of a given design.
- Define the potential and current limitations in regenerative and bionic medicines
- Appreciate E- and m-healthcare applications and their potential impact on society in terms of Big Data applications for healthcare provision.

Assumed Knowledge

This course will assume some basic biology gained in CET I Biotechnology and CET IIA Bioprocessing.

Connections To Other Units

This course is independent of other units.

Self Assessment

Students will be able to assess their progress through interaction with staff giving the course and through feedback gained from presenting their analyses to the class and through workshops.

Assessment

This course is assessed entirely by coursework (group oral presentations and individual written reports). The report will be an extended piece of work on some relevant aspect of healthcare biotechnology. Students will be expected to synthesise knowledge from across the course.

Prepared	***Approved***	***Subject Grouping***
SB 26/8/2017	PJB	Group C: Broadening Topics

Unit Healthcare Biotech	*Staff* Prof. S. Bahn

Synopsis

1. Healthcare challenges in the 21st century
2. Introduction to healthcare biotechnology
3. Newly emerging and re-emerging infectious diseases
4. Neurodegenerative and neuropsychiatric diseases
5. Biomarker technologies for increasing our understanding of major diseases and their clinical application
6. Drug discovery and pharma industry
7. Proteomics application for biomarker research
8. Epidemiology and biostatistics
9. Clinical trial design and evaluation
10. The relevance of healthcare biotechnology for chemical engineering
11. Workshop 1: Group work; Biomarker applications for personalized medicine approaches; ~3 hours presentations
12. Biopharmaceuticals and cytotherapies
13. Sensors, diagnostics and devices: E- and m-Medicine
14. Bionic and augmentative devices
15. Workshop 2: Group work; sensors, diagnostics and clinical devices; ~2 hours presentation

Teaching Materials

Lecture notes and reference lists will be provided and posted on Moodle.

Unit

Entrepreneurship

Level	*Term*	*Duration*
CET IIB	LT 2018	12 lectures + assessments

Background

Entrepreneurship is an approach to management that emphasises the pursuit of opportunity regardless of resources currently controlled. Whether you plan to start a new venture at some point in the future or to pursue a scientific career, the ability to display entrepreneurial behaviour has never been more important.

Aims

The aim of this course is to provide students with an introduction to the theory and practice of entrepreneurship and new venture creation. The course assumes no prior knowledge of the subject and will equip students with much of the knowledge required to launch and manage a high potential new venture.

Learning Outcomes

On completing this course students should be able to:

- understand the role of entrepreneurs in taking new scientific and technological developments to market
- assess the viability and feasibility a new business idea
- understand how to raise financial capital
- write a business plan and present it to a potential investor

Assumed Knowledge

Material	*Source*

No prior knowledge is assumed.

Connections To Other Units

Self Assessment

Feedback on the continually assessed modules will be provided as the course proceeds.

Assessment

The material from this unit is assessed by coursework consisting of individual memos, a group presentation, and a group report.

Prepared	*Approved*	*Subject Grouping*
PJB 8/9/2017	PJB	Group C: Broadening Topics

Unit Entrepreneurship	***Staff*** Centre for Entrepreneurial Learning (Judge Business School)

Synopsis

This information is subject to change.

Lectures are expected to be given on Monday and Thursday afternoons at 4 pm.

1. Introduction

2. Applying creativity in commercialisation - 1

3. Due diligence in technology

4. Stepping stones for commercialisation

5. Intellectual property

6. Applying creativity in commercialisation – 2

7. Market and industry assessment

8. Routes to market

9. Start-up process

10. Raising money

11. Forming and working as a team

12. How to make an effective presentation

Teaching Materials

Students are provided with a comprehensive course manual which provides much of the background material required for the assessment. Students wishing to gain further insights into the field should read the following texts, both of which are excellent:

- J.A. Timmons and S. Spinelli Jr., "New Venture Creation: entrepreneurship for the 21st century", McGraw-Hill, 8th ed. 2008.
- Jack Lang and the Cambridge University Entrepreneurship Centre, "The High-Tech Entrepreneur's Handbook", Pearson Education, 2001.

Unit		
Foreign Language		
Level CET IIB	***Term*** MT 2017 / LT 2018	***Duration*** 15 × 2 hour sessions

Background

Knowledge of a foreign language can be very useful for chemical engineers. The Language Unit within the Engineering Department offers courses in French, German, Spanish, Chinese and Japanese at beginner level, intermediate level and advanced level.

Aims

The programme prepares students to be able to operate in the foreign language chosen at home and abroad, and to be aware of the cultural aspects of the language. The programme encourages students to take responsibility for their own learning.

The courses are aimed specifically at engineering students and may include some technical content.

Learning Outcomes

The specific outcomes vary according to the level.

Assumed Knowledge

- Beginner level: none.
- Intermediate level: roughly the equivalent of GCSE. There are three stages within this level according to proficiency.
- Advanced level: roughly the equivalent of AS and A level. There are two stages within this level according to proficiency.

Connections To Other Units

None.

Self Assessment

Students will be able to assess their progress by accessing old exam papers on the Language Unit's website and attempting the questions. They will also be able to practise and improve their language skills by using the Language Unit's teaching resources (CDs, DVDs, satellite TV, magazines etc.).

Assessment

Six elements are assessed, either continuously or in tests at the end of MT and/or LT. The elements are listening, oral, reading, writing, presentation, and coursework. Further details are on the Language Unit's website.

Prepared	***Approved***	***Subject Grouping***
PJB 8/9/2017	PJB	Group C: Broadening Topics

Unit Languages	***Staff*** D. Tual (Dept of Engineering Language Unit)

Synopsis

The following languages are available at Beginner, Intermediate and Advanced levels of study:

- French
- German
- Spanish
- Chinese
- Japanese

Further information can be found on the Language Unit website at:
http://www.eng.cam.ac.uk/teaching/language/content/

Chemical engineers are only permitted to choose one language (at one level).

Teaching Materials

A list of useful books and other resources will be provided.

Unit

Biosensors

Level	***Term***	***Duration***
CET IIB	LT 2018	14 lectures + lab

Background

The teaching of this unit is shared between the Department of Chemical Engineering and Biotechnology (CEB) and the Department of Engineering (CUED. The course covers the principles, technologies, methods and applications of biosensors and bioinstrumentation.

Aims

The objective of this course is to link engineering principles to understand biosystems in sensors and bioelectronics. It will provide details of methods and procedures used in the design, fabrication and application of biosensors and bioelectronic devices.

Learning Outcomes

On completing this course students should be able to:

- extend principles of engineering to the development of bioanalytical devices and the design of biosensors
- understand the principles of linking cell components and biological pathways with energy transduction, sensing and detection
- appreciate the basic configuration and distinction among biosensor systems
- demonstrate appreciation for the technical limits of performance
- make design and selection decisions in response to measurement problems amenable to the use of biosensors

Assumed Knowledge

Material	*Source*

No previous knowledge of biosensors is required.

Connections To Other Units

Self Assessment

Assessment

The material from this unit is assessed by coursework.

There will be two marked assignments. The first will involve a laboratory session illustrating the functional demonstration of glucose sensor technology. The second assignment will involve a team-based design exercise. This design exercise will involve teams of students engaged in designing a real-world biosensor.

Prepared	***Approved***	***Subject Grouping***
EAHH 5/9/2017	PJB	Group C: Broadening Topics

Unit Biosensors	***Staff*** Profs A.A. Seshia (Engineering) and E.A.H. Hall (CEB)

Synopsis

1. Introduction

- Overview of biosensors
- Fundamental elements of biosensor devices
- Engineering sensor proteins

2. Electrochemical Biosensors

- Electrochemical principles
- Amperometric biosensors and charge transfer pathways in enzymes
- Glucose biosensors
- Engineering electrochemical biosensors

3. Optical biosensors

- Optics for biosensors
- Attenuated total reflection systems

4. Mass and acoustic biosensors

- Saubrey formulation
- Acoustic sensor formats
- Quartz crystal microbalance

5. Lab-on-chip technologies

- Microfluidic interfaces for biosensors
- DNA and protein microarrays
- Microfabricated PCR technology

6. Diagnostics for the real world

- Communication and tracking in health monitoring
- Detection in resource limited settings

Teaching Materials

References will be supplied in lectures.

Unit		
Bionanotechnology		
Level CET IIB	***Term*** LT 2018	***Duration*** 16 lectures

Background

Bionanotechnology combines the principles of nano-engineering and bioscience to develop novel methodologies for design of functional materials and devices. These might include water repellent materials for the automotive industry, materials for energy harvesting or tissue engineering, a variety of diagnostic and electronic devices, all aimed at addressing key environmental and medicinal challenges. One of the key roles of a chemical engineer is to bring creative, sustainable and economically viable concepts from theory to practice and this can often be done only by thinking out of box and taking inspiration from various disciplines. Bionanotechnology is a real exercise in interdisciplinarity.

Aims

This course aims to cover fundamental principles of nano-engineering such as nanomaterials preparation, structuring and characterization methodologies and show how these can be used in synergy with fundamental biotechnological/biochemical concepts to join biointerfaces with engineered components.

Learning Outcomes

This course was introduced in 2016-17 so the specific learning outcomes may still change slightly.

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

- Understand the chemical basis of nanomaterial preparation
- Identify the right method of nanomaterial characterization
- Describe the key differences between the macro- and the nano- world
- Describe chemical strategies to conjugate biomolecules with various surfaces
- Identify key challenges in hybrid materials design
- Understand how biomolecules can be used for material design
- Understand the role of DNA beyond its application in genetics
- Describe the engineering principles behind biological motors
- Think of new classes of bio-inspired catalyst to be used in industrial processes
- Understand the definition and principles of nanomedicine
- Understand the basic principles of biosensor design
- Identify key issues in potential scale up of biotechnological concepts
- Think along interdisciplinary lines connecting apparently different concepts together

Assumed Knowledge

Material	*Source*
▪ Synthetic and physical chemistry	IA Chemistry or CET I Chemistry
▪ Basic biology/biochemistry	CET I Biotechnology
▪ Basics of material science	IA Engineering or CET I Materials

Connections To Other Units

The material in this course builds on fundamental science learnt in earlier years. It may complement other CET IIB options.

Self Assessment

Two problem sheets will be issued during lectures.
Past examination paper: CET IIB 2017, Paper C7

Assessment

The material from this unit is assessed by a combination of written examination (75%) and coursework (25%).

Prepared	***Approved***	***Subject Grouping***
LF 10/8/2017	PJB	Group C: Broadening Topics

Unit Bionanotechnology	**_Staff_** Dr L. Fruk

Synopsis

1) Introduction to Bionanotechnology
- Definition, examples and main concepts
- Introduction to different classes of nanomaterials and their properties
- Key challenges in bionanotechnology: self assembly, bioconjugations
- Application examples

2) Nanoparticles
- Synthetic methods, surface stabiilsation, ligand exchange
- Strategies for surface modification, ligand exchange
- Bioconjugation strategies, bio-nano hybrid design
- Self assembly

3) DNA Nanotechnology
- Structural properties of DNA, principles of assembly
- DNA origami
- Applications in molecular sensing and drug delivery
- DNA templated opto-electronics

4) Protein Based (Nano)structures
- Fusion proteins, protein tags, protein modification strategies
- Artificial ion channels, nanopores
- Protein templates for nanomaterial preparation
- Proteins in material science
- Bioinspired motors and controlled molecular transport

5) Analytical and Structuring Methods in Bionanotechnology
- Microscopy (TEM, AFM, overview of fluorescence microscopy)
- Spectroscopy (fluorescence, surface enhanced Raman, IR)
- Quartz balance, electrochemistry, mass spectroscopy
- Lithography, direct laser writing

6) Biosensors, Therapeutics, Nanomedicine
- Drug delivery principles and challenges
- Contrast agents
- Bioelectronics

Teaching Materials

The recommended textbooks are:
- C. M. Niemeyer and C. A. Mirkin: "Nanobiotechnology: Concepts, Applications and Perspectives, Vols I and II", Wiley 2004-2007.
- Y. Xie, "The Nanobiotechnology Handbook", CRC Press, 2013
- G. Cao and Y. Wang, "Nanostructures and Nanomaterials", World Scientific, 2nd ed. 2011.

Unit		
Biophysics		
Level CET IIB	***Term*** LT 2018	***Duration*** 16 lectures

Background

Modelling biological systems is essential for applications of engineering and bioscience to develop products from biological cells and systems. The future Healthcare, Food and Energy sectors will rely heavily on these skills, and thus the course will be invaluable for future Chemical Engineers.

Aims

To understand how to model biological systems and make them amenable for quantitative exploitation.

Learning Outcomes

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

- appreciate various biological processes at a molecular, cellular and tissue level
- have an overview of quantitative biology
- apply various modelling approaches, including the basics of numerical methods in biological physics
- apply basic concepts involving thermal and statistical physics in living systems
- understand the basic concepts of biomolecules as two state systems, e.g. on/off states
- understand the principle behind various biophysical techniques such as atomic force microscopy, NMR, optical tweezers etc.
- understand the basic principles behind various optical techniques, such as super-resolution, Foerster resonance transfer, etc. certain microscopy techniques
- understand the principles behind DNA origami and nanofabrication

Assumed Knowledge

Material	*Source*
Biological concepts	CET I Biotechnology

Connections To Other Units

The material in this unit may complement other CET IIB options.

Self Assessment

Two examples sheets will be issued during lectures.
Past examination paper:
CET IIB 2017 Paper B8.

Assessment

The material from this unit is assessed by written examination ;

Prepared	***Approved***	***Subject Grouping***
GSK 1/9/2017	PJB	Group C: Broadening Topics

Unit	*Staff*
Biophysics	Dr G.S. Kaminski-Schierle

Synopsis

1. Introduction
2. Quantitative Biology
    - Demonstration on how diverse aspects of living systems are underpinned by the physics of complex systems.
    - Modelling based on physical principles to complement experimental investigations.
    - Overview of quantitative cell biology including primer lectures on cell biology for chemical engineers.
3. Energy balance of Living Systems
    - Examination of life from a biophysicist's perspective and application of some thermal and statistical models for living systems with examples ranging from motor proteins to cooperative binding.
    - Impact of energy balance on protein folding/misfolding, on determining the structure function relationship of proteins, on molecular motors, etc.
4. Biophysical Techniques
    - Introduction to various biophysical techniques such as atomic force microscopy, NMR, transmission electron microscopy, mass spectroscopy, etc.
    - Specific applications of the various techniques in living systems will be discussed.
5. Optical Techniques
    - A brief introduction to various optical techniques (super-resolution microscopy, optical tweezer, Foerster resonance energy transfer etc.) will be given and their application in living systems will be discussed
6. DNA origami and nanofabrication
    - How biological systems can be exploited to produce nanostructures, such as DNA origami and how nanofabrication, such as lab-on-chips can be exploited to study living organisms in a fully controlled environment.

Teaching Materials

The recommended textbook is:
- R. Phillips, J. Kondev, J. Theriot and H.G. Garcia, "Physical Biology of the Cell", Garland Science, 2nd ed. 2013.

A suitable reference textbook on cell biology is
- B. Alberts *et al.*, "Molecular Biology of the Cell", Garland Science, 6th ed. 2014.

Unit

Research Project

Level	*Term*	*Duration*
CET IIB	MT ; LT; start of ET	MT to week 3 of ET

Background

Chemical engineers are often involved with research. Fundamental research includes understanding scientific principles, developing new experimental methods, and developing new computational methods. Applied research includes developing an innovative process, measuring parameters or modelling an existing process with a view to improving it, and developing a new product.

Aims

The aim is for students to develop research skills and experience the trials, tribulations and satisfactions of original research. This helps qualify students, in part, to undertake, commission or supervise such work.

Learning Outcomes

The learning outcomes will vary from project to project.

For most projects, students should be able to:

- assess the risks associated with the research
- perform work safely and complete relevant safety documentation
- extract relevant information from the scientific literature
- design experiments and/or write computer programs
- perform experimental work and/or perform computational simulations
- analyse experimental data and/or modelling results
- work as part of a team
- present work by oral presentation and poster
- write a dissertation on the project

Assumed Knowledge

Material *Source*

This will vary from project to project.

Connections To Other Units

Students are recommended to attend any CET IIB modules that are directly related to their research project. Some research projects will have no direct connection to units within the Chemical Engineering Tripos.

Self Assessment

Students have weekly meetings with their supervisor to discuss progress.

Assessment

The material from this unit is assessed principally by written dissertation, with a small mark contribution from oral presentation and poster.

Prepared	*Approved*	*Subject Grouping*
AJS 1/9/2017	PJB	Group D: Research Project

Unit	***Staff***
Research Project	Dr A.J. Sederman (coordinator)

Synopsis

Each student undertakes a major project, usually in collaboration with another student, supervised by a member of academic staff. Students should meet with their academic supervisor weekly to discuss progress and future work. The supervisor may allocate one or more mentors, such as PhD students or post-doctoral workers, to assist with the day-to-day running of the project.

All students undertake a safety training course at the start of Michaelmas Term.

Students are expected to spend 10 hours per week in Michaelmas Term and Lent Term on the research project. Students may choose to work more hours on the project than this minimum, but should be aware that they need to strike a balance between work on the research project and on other elements of the course. Members of academic staff have been informed of this fact.

Students are expected to perform additional work over the vacations (e.g. data analysis, report writing), but are not normally expected to perform laboratory work during the vacation.

Students give a 6-minute oral presentation and a poster presentation on their project towards the end of Lent term.

Students submit a dissertation (maximum length of 40 pages) on their project in Easter term. The dissertations are marked independently by two Examiners.

Teaching Materials

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