Study Abroad Curriculum Mapping
with Selected Partner Institutions

Department of Chemical and Biochemical Engineering
Rutgers University

September 2014
Studying abroad is an enriching experience. In the past years, many chemical engineering students have spent a year, a semester, or a summer studying at a partner institution abroad. Before leaving for study abroad, a student will need to select the courses that he or she will enroll in at the partner institution. This may be a tedious process since the student may not be familiar with the courses offered overseas.

In order to assist each student who are interested in studying abroad, the Department of Chemical and Biochemical Engineering has developed a “Curriculum Mapping Document” that identifies the courses at partner institutions that are equivalent to the required courses at Rutgers Chemical Engineering. This document is meant to be used as a guide. The information contained in this document was obtained from the course websites of the selected partners. To obtain the most up-to-date course offerings, please contact Rutgers Center for Global Education (Rutgers Study Abroad Office) at 102 College Avenue, New Brunswick, NJ 08901-8543.

**Important Notes:**
In this document, Rutgers Chemical Engineering courses are listed on the left, and the equivalent course at the partner institution is listed on the right. There are a couple important things to keep in mind when using the Curriculum Mapping:

1. This document includes courses offered by nine (9) partner institutions. You may study abroad at a partner institution not listed here. To receive the most up-to-date course syllabus and course offerings of a partner university, visit the website of the partner institution. You may contact Rutgers Center of Global Education.

2. The courses offered at partner institutions are subject to change. If an equivalent course is no longer being offered at the partner institute, it is the student’s responsibility to make sure that an equivalent course is taken. Students should consult with Director of Undergraduate Programs of Chemical Engineering and Dean of Undergraduate Education for advice. Final approval of course equivalency is made by both the undergraduate director or the dean.

3. Only required chemical engineering courses are mapped in this document. You may take non-chemical engineering or elective courses at the partner school. To determine the credits of courses not listed in this document, consult the Undergraduate Director and Associate Dean of Undergraduate Education.

4. The information contained in this document is subject to change. Use this document as a guide to identify the courses that you may take while studying abroad.
Understanding the Curriculum Mapping:

Below is a sample of the curriculum mapping for the University College Dublin:

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<tbody>
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<td>Course Name</td>
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<tr>
<td>01:640:251</td>
<td>Multivariable Calculus</td>
</tr>
<tr>
<td>01:750:229</td>
<td>Analytical Physics II Lab</td>
</tr>
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<td></td>
<td>No equivalent course for 01:750:229, Analytical Physics II Lab</td>
</tr>
<tr>
<td>01:160:307</td>
<td>Organic Chemistry I</td>
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<tr>
<td>01:160:308</td>
<td>Organic Chemistry II</td>
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In the first box, the two courses Advanced Calc. for Eng. (3 credits, offered in both the spring and fall) and Multivariable Calculus (4 credits, offered in both the spring and fall) have one equivalent course, Multivar. Calculus Eng. II (5 University of College Dublin Credits, offered only in the fall). This means taking ACM30030 (Multivar. Calculus Eng. II) would count for credit towards 01:640:421 and 01:640:251 (Advanced Calc. for Eng. and Multivariable Calculus). Organic Chemistry I (4 major credits, offered in both the spring and fall), Organic Chemistry II (4 major credits, offered in both the spring and fall), and Organic Chemistry Lab (2 major credits, offered in both the spring and fall) have two equivalent courses, Basis of Organic & Biological Chemistry and Structure and Reactivity in Organic Chemistry (5 University of College Dublin credits, offered in the fall). Analytical Physics does not have an equivalent course, and Physical Chemistry has one equivalent course, Quantum Mechanics & Molecular Spectroscopy. Information about the credit system, and particular courses are listed in the footnotes. Course calendar information is listed on page 5. Course description information is listed at the end of the document. You may double click on the endnote superscript towards the top right of the equivalent course to jump to the course description. Make sure to verify the term each course is offered in the University Calendar.
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University Calendar

University of Manchester
Semester 1- September until January, Christmas Break for one month
Semester 2- January until June, Easter Break for 3 weeks

University of Birmingham
Semester 1-September until December, 3 weeks for Christmas break
Semester 2-January until March
Exams May until June

University College London
Semester 1 September until December. Two week break for Christmas
Semester 2 January-March. One week for Easter.

University College Dublin
Semester 1-September until December (12 weeks), 1 month for Christmas
Semester 2-January until May, 2 weeks for Easter

HKUST
Fall-September until December. Two Weeks for Finals. One month and two weeks for Christmas.
Spring- February until May. Two weeks for finals. One week Spring break.

Pohang University
Semester 1- March until August (15 weeks)
Semester 2- September until February. (15 weeks)

University of Melbourne
Semester 1-March until June Finals in mid-June. 8 week winter break recess.
Semester 2- July until October. Finals in November.

University of Queensland
Semester 1- March until June
Semester 2- July until November

University of Auckland
Semester 1- March until June. Finals in Mid June. Two week break in July
Semester 2-July until November. Finals at end of October. Two week break in September
**Study Abroad Curriculum**  
**Mapping for The University Of Manchester**  
**B.S. Program, Chemical Engineering**

### Rutgers University Curriculum

<table>
<thead>
<tr>
<th>Course Number</th>
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<th>Credits</th>
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<tbody>
<tr>
<td>01:640:421</td>
<td>Advanced Calc. for Eng.</td>
<td>3.0</td>
<td>Fall &amp; Spring</td>
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<tr>
<td>14:155:201</td>
<td>Analysis I</td>
<td>M 3.0</td>
<td>Fall</td>
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<tr>
<td>14:155:307</td>
<td>Analysis II</td>
<td>M 3.0</td>
<td>Fall</td>
</tr>
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<td>Analytical Physics II</td>
<td>3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>01:750:229</td>
<td>Analytical Physics II Lab</td>
<td>1.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:324</td>
<td>Design Separ. Process</td>
<td>M 4.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:640:244</td>
<td>Differ. Equat. Eng. &amp; Physics</td>
<td>4.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:220:102</td>
<td>Microeconomics</td>
<td>3.0</td>
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<tr>
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<td>Multivariable Calculus</td>
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<td>14:155:303</td>
<td>Transport Phenomena I</td>
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<td>14:155:304</td>
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### The University of Manchester Equivalent Courses

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<tr>
<td>CHEN20041</td>
<td>Mathematical Methods 2</td>
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<td>CHEN10041</td>
<td>Chemical Eng. Design 1</td>
<td>10.0</td>
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</tr>
<tr>
<td>CHEN10011</td>
<td>Engineering Mathematics 1</td>
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<td>CHEN10072</td>
<td>Engineering Mathematics 2</td>
<td>10.0</td>
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<tr>
<td>PHYS10342</td>
<td>Electricity and Magnetism</td>
<td>10.0</td>
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<tr>
<td>MATH10232</td>
<td>Calculus and Applications B</td>
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<td>ECON10041</td>
<td>Microeconomic Principles</td>
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<td>MATH10121</td>
<td>Calculus and Vector A</td>
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<td>CHEM10101</td>
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<td>Basic Physical Chemistry</td>
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<td>CHEN10092</td>
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‡ A University of Manchester 10 credit course equates to around 100 total hours of work. For reference, a 10 credit Manchester course equals 3 credits at Rutgers. A 15 credit course equals 4 Rutgers credits, and 20 credit course equals 5 Rutgers credits. 45 University of Manchester credits per semester is the minimum credit load to achieve full-time status.
**Study Abroad Curriculum**  
Mapping for *The University Of Birmingham*  
B.S. Program, Chemical Engineering

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* Courses marked LI are linked and must be taken together  
* 06 22493 is a Full Term Course. It is advised that Students take Part A, offered in the Fall, equivalent to 01:640:421, Advanced Calc. for Eng  
** 04 23779 is a Full Term Course. It is advised that Students take Part A, offered in the Fall, equivalent to 14:155:307, Analysis II. Students may not supplement Part B for 06 25667, LI Multivariable & Vector Analysis, *The University of Birmingham* equivalent of 01:640:251, Multivariable Calculus  
*** 04 17126 is a Full Term Course. It is advised that students take Part B, offered in Semester 2, as Part B of the course equivalent to 14:155:324, Design Separation Process  
‡ A *University of Birmingham* 10 credit course equates to around 100 total hours of work per semester. For reference, a 10 credit Birmingham course is equivalent a 3.0 credit course at *Rutgers University*. A 15.00 credit course equates to 4.0 *Rutgers* credit course, and a 20 credit course equates to a 5.0 *Rutgers University* credit course
### Study Abroad Curriculum

**Mapping for University College London**

**B.S. Program, Chemical Engineering**

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*** The curriculum for MATH 1402, Mathematical Methods 2, only partially covers its equivalent course, 01:640:244, Differ. Equat. Eng. & Physics

**** MATH 1402, Mathematical Methods 2 contains material relevant to 01:640:421, Advanced Calc. for Eng


‡ A 4.0 credit course at University College London is equivalent to a 3.0 credit course at Rutgers University. Full-time status at University College London requires students to take 12 credits per semester.
### Study Abroad Curriculum

**Mapping for The University College Dublin**

**B.S. Program, Chemical Engineering**

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</table>

* CHEM20120, Physical Chemistry, is accepted in place of CHEM30060

†‡ A 5.0 credit *University College of Dublin* course is equivalent to a 3.0 credit *Rutgers University* course

The *University College of Dublin* semester is fifteen weeks long (twelve weeks learning, one week review for finals, two weeks for final examination.)
Study Abroad Curriculum  
Mapping for *Hong Kong University of Science & Technology (HKUST)*

**B.S. Program, Chemical Engineering**

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* In order to fulfill the requirement for 14:155:309, Thermodynamics II, both CENG 2210, Chem. Eng. Thermodynamics and CENG 3210, Separation Process must be taken, starting with CENG 2210

** MATH2021, Multivar. & Vector Calculus, is accepted in place of MATH2023. MATH2021 is a full-year course

† The credit system at *Hong Kong University of Science & Technology* is equivalent to that at *Rutgers University*
## Study Abroad Curriculum

**Mapping for Pohang University of Science & Technology**

**B.S. Program, Chemical Engineering**

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</table>

* Students may take MECH 250, Thermodynamics, a 3.0 credit course offered in Semester 1 as an equivalent to 14:155:208, Thermodynamics I

** MATH 200, Differential Equations, and PHYS 206, General Physics II contain a one-hour per week lab component.

*** MATH 110, Calculus, contains around six week of material that would be review to those who have taken 01:640: 152, Calculus II for the Mathematical and Physical Sciences

‡ The credit system at Pohang University of Science & Technology is equivalent to that at Rutgers University. The fall semester begins September 1st and ends February 28th, while the spring semester begins March 1st and ends August 31st.
### Study Abroad Curriculum

**Mapping for The University Of Melbourne**

**B.S. Program, Chemical Engineering**

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<thead>
<tr>
<th><strong>Rutgers University Curriculum</strong></th>
<th><strong>The University of Melbourne Equivalent Courses</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Course Number</strong></td>
<td><strong>Course Name</strong></td>
</tr>
<tr>
<td>01:640:244</td>
<td></td>
</tr>
<tr>
<td>14:155:201</td>
<td>Analysis I</td>
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<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>14:155:307</td>
<td>Analysis II</td>
</tr>
<tr>
<td>01:750:227</td>
<td>Analytical Physics II</td>
</tr>
<tr>
<td>01:750:229</td>
<td>Analytical Physics II Lab</td>
</tr>
<tr>
<td>14:155:324</td>
<td>Design Separ. Process</td>
</tr>
<tr>
<td>01:220:102</td>
<td>Microeconomics</td>
</tr>
<tr>
<td>01:640:251</td>
<td>Multivariable Calculus</td>
</tr>
<tr>
<td>01:160:307</td>
<td>Organic Chemistry I</td>
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<tr>
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<tr>
<td>01:160:311</td>
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</tr>
<tr>
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<tr>
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<td>Thermodynamics I</td>
</tr>
<tr>
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<td>Thermodynamics II</td>
</tr>
<tr>
<td>14:155:303</td>
<td>Transport Phenomena I</td>
</tr>
</tbody>
</table>

* PHYC 30018 covers subjects relevant to 14:155:303, 14:155:304, and 01:160:311, Transport Phenomena I and II, and Physical Chemistry, respectively. There is also a laboratory aspect of the course, consisting of 8, three hour laboratory sessions, including up to 30 minutes of pre-labor activity.

** CHEM 10003 and CHEM 10004, Chemistry 1 & 2, contain irrelevant material. Please read course description.

*** CHEM 90007, Advanced Thermo & Reactor Engineering is a graduate level course.

‡ A 12.50 credit University of Queensland course is equivalent to a 4.0 credit Rutgers University course. Students would need to take 3.0 University of Melbourne courses (36.75 units) to achieve 12.00 Rutgers University credits.
# Study Abroad Curriculum

## Mapping for The University Of Queensland

**B.S. Program, Chemical Engineering**

### Rutgers University Curriculum

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Course Name</th>
<th>Credits</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>01:640:421</td>
<td>Advanced Calc. for Eng.</td>
<td>3.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>14:155:201</td>
<td>Analysis I</td>
<td>M 3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:307</td>
<td>Analysis II</td>
<td>M 3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>01:750:227</td>
<td>Analytical Physics II</td>
<td>3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>01:750:229</td>
<td>Analytical Physics II Lab</td>
<td>1.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:324</td>
<td>Design Separ. Process</td>
<td>M 4.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:640:244</td>
<td>Differ. Equat. Eng. &amp; Physics</td>
<td>4.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:640:251</td>
<td>Multivariable Calculus</td>
<td>4.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:220:102</td>
<td>Microeconomics</td>
<td>3.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:160:307</td>
<td>Organic Chemistry I</td>
<td>M 4.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:160:308</td>
<td>Organic Chemistry II</td>
<td>M 4.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:160:311</td>
<td>Organic Chemistry Lab</td>
<td>M 2.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:160:328</td>
<td>Physical Chemistry</td>
<td>M 4.0</td>
<td>Spring</td>
</tr>
<tr>
<td>14:155:208</td>
<td>Thermodynamics I</td>
<td>M 3.0</td>
<td>Spring</td>
</tr>
<tr>
<td>14:155:309</td>
<td>Thermodynamics II</td>
<td>M 3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:303</td>
<td>Transport Phenomena I</td>
<td>M 3.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:304</td>
<td>Transport Phenomena II</td>
<td>M 3.0</td>
<td>Spring</td>
</tr>
</tbody>
</table>

### The University of Queensland Equivalent Courses

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Course Name</th>
<th>Course Description</th>
<th>Credits</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>MATH 2100</td>
<td>Applied Mathematical Analysis</td>
<td>2.0</td>
<td>Fall</td>
<td></td>
</tr>
<tr>
<td>CHEE 2001</td>
<td>Process Principles</td>
<td>2.0</td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td>COSC 2500</td>
<td>Numerical Methods in Computational Science</td>
<td>2.0</td>
<td>Fall</td>
<td></td>
</tr>
<tr>
<td>PHYS1002*</td>
<td>Electromagnetism &amp; Modern Physics</td>
<td>2.0</td>
<td>Fall &amp; Spring</td>
<td></td>
</tr>
<tr>
<td>CHEE 3020</td>
<td>Process System Analysis</td>
<td>2.0</td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td>CHEE 3004</td>
<td>Unit Operations</td>
<td>2.0</td>
<td>Fall</td>
<td></td>
</tr>
<tr>
<td>MATH 1052</td>
<td>Multi. Calc. &amp; Ord. Diff. Equat.</td>
<td>2.0</td>
<td>Fall &amp; Spring</td>
<td></td>
</tr>
<tr>
<td>MATH 2000</td>
<td>Calculus &amp; Linear Algebra II</td>
<td>2.0</td>
<td>Fall &amp; Spring</td>
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<tr>
<td>ECON 1010</td>
<td>Introductory Microeconomics</td>
<td>2.0</td>
<td>Fall &amp; Spring</td>
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<tr>
<td>CHEM 1200</td>
<td>Chemistry 2</td>
<td>2.0</td>
<td>Fall</td>
<td></td>
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<tr>
<td>CHEM 2050**</td>
<td>Organic &amp; Inorganic Chem.</td>
<td>2.0</td>
<td>Spring</td>
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</tr>
<tr>
<td>CHEE 3000</td>
<td>Chem. Thermodynamics</td>
<td>2.0</td>
<td>Spring</td>
<td></td>
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<tr>
<td>CHEE 3003</td>
<td>Fluid &amp; Particle Mechanics</td>
<td>2.0</td>
<td>Fall</td>
<td></td>
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<tr>
<td>CHEE 3002</td>
<td>Heat &amp; Mass Transfer</td>
<td>2.0</td>
<td>Spring</td>
<td></td>
</tr>
</tbody>
</table>

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* PHYS 1002, Electromagnetism and Modern Physics contains a laboratory component. Additionally material relevant to 01:160:328, Physical Chemistry is taught.

** CHEM 2050 contains much material covering transition metals that is irrelevant to Chemical Engineering majors. This is the closest equivalent course, however.

*** Both PHYS 2041 and PHYS 3040, Quantum Physics contain a small laboratory component.

‡ A 2.0 credit University of Queensland course is equivalent to a 3.0 credit Rutgers University course. Students would need to take 4 University of Queensland courses (8 units) to achieve 12 Rutgers University credits.
# Study Abroad Curriculum

**Mapping for The University Of Auckland**

**Bachelor of Science Program**

**Chemical Engineering**

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Course Name</th>
<th>Credits</th>
<th>Term</th>
<th>Course Number</th>
<th>Course Name</th>
<th>Credits</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Rutgers University Curriculum</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>The University of Auckland</strong> Equivalent Courses</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01:640:421</td>
<td>Advanced Calc. for Eng.</td>
<td>3.0</td>
<td>Fall &amp; Spring</td>
<td>MATHS 361*</td>
<td>Partial Diff. Equat.</td>
<td>15.0</td>
<td>Spring</td>
</tr>
<tr>
<td>14:155:201</td>
<td>Analysis I</td>
<td>M 3.0</td>
<td>Fall</td>
<td>CHEMMAT 211*</td>
<td>Intro to Process Eng.</td>
<td>15.0</td>
<td>Spring</td>
</tr>
<tr>
<td>14:155:307</td>
<td>Analysis II</td>
<td>M 3.0</td>
<td>Fall</td>
<td>MATHS 270*</td>
<td>Numerical Computation</td>
<td>15.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:750:227</td>
<td>Analytical Physics II</td>
<td>3.0</td>
<td>Fall</td>
<td>PHYSICS 325</td>
<td>Electromagnetism</td>
<td>15.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:750:229</td>
<td>Analytical Physics II Lab</td>
<td>1.0</td>
<td>Fall</td>
<td>PHYSICS 390</td>
<td>Experimental Physics</td>
<td>15.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>14:155:324</td>
<td>Design Separ. Process</td>
<td>M 4.0</td>
<td>Spring</td>
<td>CHEMMAT 312*</td>
<td>Transfer Processes</td>
<td>15.0</td>
<td>Spring</td>
</tr>
<tr>
<td>01:640:244</td>
<td>Differ. Equat. Eng. &amp; Physics</td>
<td>4.0</td>
<td>Spring</td>
<td>MATHS 260*</td>
<td>Differential Equations</td>
<td>15.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:220:102</td>
<td>Microeconomics</td>
<td>3.0</td>
<td>Fall &amp; Spring</td>
<td>ECON 101</td>
<td>Microeconomics</td>
<td>15.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:640:251</td>
<td>Multivariable Calculus</td>
<td>4.0</td>
<td>Fall &amp; Spring</td>
<td>MATHS 253**</td>
<td>Advanced Math</td>
<td>15.0</td>
<td>Fall &amp; Spring</td>
</tr>
<tr>
<td>01:160:307</td>
<td>Organic Chemistry I</td>
<td>M 4.0</td>
<td>Fall &amp; Spring</td>
<td>CHEM 10101</td>
<td>Introductory Chemistry</td>
<td>30.0</td>
<td>Fall</td>
</tr>
<tr>
<td>01:160:311</td>
<td>Organic Chemistry Lab</td>
<td>M 2.0</td>
<td>Fall &amp; Spring</td>
<td>CHEM 92F*</td>
<td>Foundation Chem.</td>
<td>15.0</td>
<td>Fall</td>
</tr>
<tr>
<td>01:160:308</td>
<td>Organic Chemistry II</td>
<td>M 4.0</td>
<td>Fall &amp; Spring</td>
<td>No equivalent course for 01:160:311 Organic Chemistry Lab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01:160:328</td>
<td>Physical Chemistry</td>
<td>M 4.0</td>
<td>Spring</td>
<td>PHYSICS 350</td>
<td>Quantum Mechanics &amp; Atomic Physics</td>
<td>15.0</td>
<td>Spring</td>
</tr>
<tr>
<td>14:155:208</td>
<td>Thermodynamics I</td>
<td>M 3.0</td>
<td>Spring</td>
<td>CHEMMAT 212*</td>
<td>Energy &amp; Processing</td>
<td>15.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:309</td>
<td>Thermodynamics II</td>
<td>M 3.0</td>
<td>Fall</td>
<td>CHEMMAT 213*</td>
<td>Transfer Processes</td>
<td>15.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:303</td>
<td>Transport Phenomena I</td>
<td>M 3.0</td>
<td>Fall</td>
<td>CHEMMAT 212*</td>
<td>Energy &amp; Processing</td>
<td>15.0</td>
<td>Fall</td>
</tr>
<tr>
<td>14:155:304</td>
<td>Transport Phenomena II</td>
<td>M 3.0</td>
<td>Spring</td>
<td>CHEMMAT 213*</td>
<td>Transfer Processes</td>
<td>15.0</td>
<td>Fall</td>
</tr>
</tbody>
</table>

* These courses possess laboratory components.

** MATHS 253, Advanced Mathematics 3 contains material relevant to 01:640:421, Advanced Calc. for Engineers.

‡ A 15.00 credit University of Auckland course is equivalent to a 3.0 credit Rutgers University course. Students would need to take 4.0 University of Auckland courses (60 units) to achieve 12.00 Rutgers University credits. The University of Auckland semester is fifteen weeks.
Course Descriptions

University of Manchester

Link to Course Catalog


5. **Introduction**: Forces in nature; electric charge and its properties; vectors, fields, flux and circulation. **Electric Fields and Stationary Charges**: Coulomb's law and superposition; electric field and potential; capacitance; electric dipoles; energy in electric fields. **Magnetic Fields and Steady Currents**: Magnetic fields; Lorentz force; Biot-Savart and Ampère's laws; magnetic dipoles. **Electrodynamics**: Electromotive force; electromagnetic induction; Faraday and Lenz's laws; inductance; energy in magnetic fields. **Maxwell's Equations**: Maxwell's fix of Ampère's law; Maxwell's equations in integral form.

6. **Equilibrium stages**: Conceptual characterization of separations. **Batch distillation**: Rayleigh distillation and batch rectification for ideal mixtures. **Continuous distillation**: Revision of McCabe-Thiele construction, total and partial reboilers and condensers, plate efficiencies. **Non-ideal mixtures**: material and enthalpy balances, Ponchon-Savarit construction, operating characteristics, link with McCabe-Thiele construction. **Column hydraulics**: Characteristics of plates and packings, flooding, flooding correlations and sizing of columns, column control strategies.

The unit will cover first and second order ordinary differential equations including classification and standard solution methods. Applications will be drawn from the field of classical mechanics, but no prior experience in mechanics is expected or required. Matlab will be used to illustrate some of the ideas and methods.
Electrochemical Equilibria: The Nernst Equation

Chemical Potential

reaction coordinate, steric factor.

of reaction rates; Arrhenius equation, pre

life.

measuring reaction rates, rate laws, order of reaction.

12

Diazotization. N

give alkanes

Other oxidations of alkenes

alkenes bromonium ions, regioselectivity of opening, effect of nucleophilic solvents

different substrates

Some simple enol and enolate chem

istry

acetals and imines, protecting groups, reductive amination, the Wittig reaction, conjugate addition and substitution

carboxylic acid derivatives conjugation delocalization of amides

tetrahedral intermediates

hemiacetal formation

and phosphorescence

spectroscopy

reduction; carboxylic acid derivatives: esters and amides

carboxylic acids; interconversion between alcohols, aldehydes

electrophilic addition; stability of carbocations

H

Stokes' theorem and Gauss' theorem.

of calculus. The core conc

9

Pareto

run. Adjustment to changes in demand. (short

taxes.

equilibrium. Elasticity of demand and supply.

Derivation of the demand curve (single commodity case). Indifference Curve analysis: consumer

equilibrium, income consumption curves, price consumption curves. The costs of production. Perfect competition.

Profit maximization. The short run supply curve. Equilibrium of the competitive firm in the short run and the long

run. Adjustment to changes in demand. (short run and long run). Long run industry supply curve. Welfare and the

efficiency of markets: Consumer surplus and producer surplus. Maximizing the total (social surplus).

Pareto optimality and the problem of interpersonal comparison. Monopoly: Comparison with perfect competition.

Welfare costs of monopoly - the deadweight loss.

Introduces the basic ideas of complex numbers relating them to the standard rational and transcendental functions

calculus. The core concepts of limits, differentiation and integration are revised. Techniques for applying the

calculus are developed and strongly reinforced. Vectors in two and three dimensions are introduced and this leads on
to the calculus of functions of more than one variable, vector calculus, integration in the plane, Green's theorem,
Stokes' theorem and Gauss' theorem.

Three lectures illustrating the place of Chemistry in the Modern World. The invention of the Periodic Table

Lavoisier to Mendeleev. Sub-atomic structure Thompson to Schrodinger. The quantum mechanical description
of bonding and diatomic molecules. Common simplifications to describe bonding in polyatomic molecules.

Alkanes and cycloalkanes, conformation. Stereoisomerism. Mechanisms of reactions, electron movement and
distribution. Curly arrows. Polarization, inductive and resonance effects. Acidity, pKa; stability of anions.

Haloalkanes, synthesis and uses; substitution and elimination reactions. Ethers, alcohols and amines. Alkenes,
electrophilic addition; stability of carbocations. Alkynes; comparison with nitriles. Aldehydes and ketones,
carboxylic acids; interconversion between alcohols, aldehydes. Ketones and carboxylic acids by oxidation and

reduction; carboxylic acid derivatives: esters and amides. Spectroscopy, the basics. Beer-Lambert law. Rotational


Structure of the carbonyl group and review of nucleophilic additions to aldehydes and ketones. Hydration and

hemiacetal formation. Substitution at carbonyl groups leaving groups and use of pKa as a guide to the breakdown of
tetrahedral intermediates. Substitution reactions of acid chlorides. IR spectroscopy as a guide to the reactivity of
carboxylic acid derivatives conjugation delocalization of amides. Interconversion of carboxylic acids, esters, acid
chlorides and amides. Synthesis of alcohols and ketones from carboxylic acid derivatives - reactions with
organometallics. Acid and base catalysis. Substitution in which carbonyl oxygen is lost formation and hydrolysis of
acetals and imines, protecting groups, reductive amination, the Wittig reaction, conjugate addition and substitution.

Some simple enol and enolate chemistry. SN2 reactions nature of the transition state, relative reactivity of different
substrates and reagents. Hard and soft acids (electrophiles) and bases (nucleophiles). Reactivities of different leaving
groups halides and p-toluenesulfonates. SN1 reactions structure and stability of carbocations, relative reactivity of
different substrates. Stereochemical aspects of SN1 and SN2 reactions. E1 and E2 reactions kinetics, substrate
structure dependence, base and leaving group. Competing substitution and elimination. Addition of bromine to
alkenes bromonium ions, regioselectivity of opening, effect of nucleophilic solvents. Epoxides and epoxide opening.

Other oxidations of alkenes. Markovnikov and anti-Markovnikov hydration of alkenes. Hydrogenation of alkenes to
give alkanes. Reduction of alkenes. Structural features and reactivity of benzene (and other aromatics). Nitration,
sulfonation, halogenation and FriedelCrafts reactions of benzene. Direction and activation in substituted benzenes.
Diazotization. Nucleophilic aromatic substitution.

Rates of reaction; stoichiometry, mechanism and elementary reactions, molecularity. Experimental methods of
measuring reaction rates, rate laws, order of reaction. Determination of order. First, second and zeroth orders; half-
life. Parallel and consecutive reactions; rate determining step, steady state approximation. Temperature dependence
of reaction rates; Arrhenius equation, pre-exponential factor, activation energy, Arrhenius plot. Transition state,
reaction coordinate, steric factor. Fast reactions in solution; stopped flow, flash photolysis and relaxation methods.
Recapitulation of the 1st Law and of Thermochemistry. Exchange of Heat and Work in a Heat Engine; The Carnot
Chemical Potential. Phase Diagrams. Thermodynamic Description of Chemical Equilibria; with Examples.

Schrodinger Equation. Photoelectric Effect. Interaction of molecules with light. Particle in a box model. Particle on
a ring model. Particle on a sphere model. Rigid rotor model. Solutions for hydrogenic atoms.


Semester 1: This module uses real and complex analysis to develop the theory of Fourier transform up to the inversion formula for piecewise smooth functions. The properties of the Lebesgue integral that are needed are stated as facts at the beginning of the course and it is used throughout. The properties of the Laplace transform are deduced as a special case of the Fourier transform.

Semester 2: This module introduces students to the techniques and analysis of numerical methods in linear algebra, specifically to the numerical solution of linear equations and the numerical determination of eigenvalues and eigenvectors. The theory is further illustrated by applications using current software packages like eg., Maple or Matlab.

The aim of the module is to enhance the students' mathematical knowledge and confidence in preparation for the demanding applications of the final stage modules, and a possible research career involving engineering science. They will develop an understanding of the mathematical basis of many of the advanced systems of equations governing engineering problems.

Syllabus:
Number systems, errors and mathematical preliminaries, Taylor series
Non-linear equations - Newton's method
Interpolation and Approximation - Lagrange, cubic spline, least squares
Numerical Differentiation and Integration - Euler's method, Trapezoidal and Simpson's rule, Gauss Quadrature.
Systems of linear and non-linear equations
Ordinary Differential Equations - Euler's and Runge Kutta method
Vector differential calculus
Vector integral calculus
Stokes theorem and Gauss divergence theorems
Three-dimensional cylindrical and spherical co-ordinates Classification of partial differential equations
Solution of a range of differential equations of engineering importance

By the end of the module the student should be able to: Apply the laws of Gauss, Faraday and Ampère to problems involving charges and magnetic fields; Have a firm grounding of Maxwell's equations and their origins; Apply and solve Maxwell's equations to electromagnetic problems; Show that electric and magnetic fields can travel as waves in free space and media; Calculate the major laws of optics using electromagnetic theory; Apply Maxwell's equations in order to derive the conductivity of conductors and plasmas; Use Poynting's vector to calculate the power in an electromagnetic wave.

Students spend 6 hours per week in the Year 2 Laboratory during semester 1. One purpose of the lab is to allow students to investigate a variety of physical phenomena relevant to the second year module, and to understand their applications. In some cases, the lab experiments investigate material already presented in lectures; in other cases, the physics is introduced first in the lab. A second purpose of the lab is to introduce students to a range of techniques in experimental physics, and to develop experimental skills that will be helpful in future work, for example the Year 2 project.

This two semester module (part A in Semester 1, Part B in semester 2) introduces the methodologies for the synthesis of a new process and discusses the factors governing process selection. Process Integration and Unit Operations Part A first introduces problem-solving approaches reflecting current trends in process integration (efficient material and energy usage and emissions reduction). Pinch technology is introduced and used to develop heat exchanger networks, with software demonstrations. The following topics concern equilibrium stagewise process design, and starting with the unit operations of absorption, distillation and liquid-liquid extraction, students will be introduced to the concepts of stage to stage calculations and diagrammatic problem solving techniques. They are also introduced to novel processing routes, including a case study on supercritical fluids. Year 1 Chemical and Biochemical Processes is a prerequisite module, because that is where the concept that a process is an integrated whole and not just an assembly of unit operations has been introduced.
When mathematical modelling is used to describe physical, biological, chemical or other phenomena, one of the most common results is either a differential equation or a system of differential equations, which, together with appropriate boundary and/or initial conditions, describe the situation. These differential equations can be either ordinary (ODEs) or partial (PDEs) and finding and interpreting their solution lies at the heart of applied mathematics. This module develops the theory of differential equations with a particular focus on techniques of solving both linear and nonlinear ODEs. Fourier series, which arise in the representation of periodic functions, and special functions, which arise in the solution of PDEs such as Laplace’s equation that models the flow of potential, are also introduced. A number of the classical equations of mathematical physics are solved.

By the end of this module the student will be able to: define Opportunity Costs, demonstrate how they affect economic decisions, and identify these costs in a given economic decision, explain and apply the concepts of Marginal Benefits and Marginal Costs to determine optimal economic decisions for both consumers and firms, understand how producers and consumers interact in a competitive market.

The materials that will be covered are: (i) an introduction to General Equilibrium; (ii) externalities and Public Goods; (iii) monopoly; (iv) oligopoly; (v) markets with asymmetric information (vi) an introduction to game theory.

Most models of real world situations depend on more than one variable and the techniques of calculus can be extended to solve problems arising in such situations. Typically these are problems whose solutions are functions of position, describing, for example, heat distribution or velocity potential, and involve the partial differentiation or multiple integration of functions of more than one variable. The theory and classification of stationary points of functions of two or more variables is developed allowing maxima and minima, including those subject to constraints, to be identified. The differential operators divergence, gradient, curl and the Laplacian are introduced. These are used in particular in the integral theorems (the Divergence theorem and the theorems of Green and Stokes) that relate line, surface and volume integrals and are used in the mathematical formulation of physical conservation laws. This module develops fundamental ideas that are used both in applied mathematics and in the development of analysis.

This module introduces some of the most conceptually and practically important reactions in Organic chemistry. A mechanistic approach is adopted; that is, the behavior of organic molecules is explained by referring to simple molecular orbital descriptions of bonding and concepts such as electronegativity and polarization. A relatively narrow range of principles can then be used to rationalize a diverse array of transformations. In practical terms, the module shows how organic molecules can be constructed from simple starting materials or building blocks and how functional groups can be added or manipulated accurately and with control.

By the end of the module the student should be able to: Understand the basic concepts of structure and reactivity in carbon-based systems; Understand the basic mechanisms of reaction at sp3, sp2 and sp carbon centres; Use the knowledge of reactions and mechanisms to devise simple synthetic reaction sequences; Use the knowledge of reactions and mechanisms to rationalize observations given; To undertake simple synthetic organic reactions in the laboratory, in order to develop basic manipulations and techniques.

This module provides an introduction to Aromatic Chemistry (the concept of aromaticity, electrophilic aromatic substitution, substituent effects and, briefly, heteroaromatic compounds) and an introduction to Reactive Intermediates (carbocations, carbanions, arynes, radicals, carbenes and nitrenes). The associated Laboratory component allows techniques and manipulations associated with synthetic organic chemistry to be further developed and, in some instances, reinforces the lecture material.

By the end of the module students should be able to: Demonstrate an understanding of aromaticity and to identify whether a compound can be considered as aromatic Demonstrate an understanding of electrophilic aromatic substitution and be able to draw arrow-pushing mechanisms for the reaction of aromatic compounds with a range of electrophiles. Students should also be able to predict and account for substituent effects in electrophilic aromatic substitution reactions. Demonstrate an understanding of the structure, bonding and reactivity of carbocations, carbanions, arynes, radicals, carbenes and nitrenes. Demonstrate the ability to perform synthesis in organic chemistry, characterise products obtained and present the results obtained in a coherent manner.

This module develops further the chemistry of carbon-based compounds, and builds upon the principles and concepts introduced in the co-requisite module (Synthesis and Mechanism I). Two distinct areas are covered in the
module: The Chemistry of Carbonyl Compounds (enolate chemistry; enamines; aldol reactions; Claisen condensation) and Physical Organic Chemistry which looks at how physical methods are used to probe the reactivity of organic molecules. The associated Laboratory component allows techniques and manipulations associated with synthetic organic chemistry to be further developed and, in some instances, reinforces the lecture material.

By the end of the module students should be able to:
Demonstrate an understanding of enolate chemistry, including enamines, the aldol reaction and the Claisen condensation. Demonstrate an understanding of how physical methods can be used to probe the reactivity of organic molecules and be able to interpret the results of physical experiments in terms of organic reaction mechanisms.
Demonstrate the ability to perform synthesis in organic chemistry, characterise products obtained and present the results obtained in a coherent manner.

Quantum Mechanics:
Experimental observations of atoms and their interactions with radiation provided the driving force for the invention of Quantum Theory. Quantum Mechanics offers the only model we have that explains the properties for atomic systems. Evidence will be reviewed that leads us to the need and use of Quantum Mechanics. We will see how Schrodinger's wave mechanics and Heisenberg's uncertainty principle can help us to understand atoms. This module concentrates on the concepts and avoids a full mathematical treatment.

Optics and Waves:
The study of wave motion underpins our understanding of basic physics. We discuss the properties of waves, often taking as an example transverse waves in strings but also illustrating how the results are applicable not only to sound and light but also to quantum mechanics. The study of optics builds directly on our wave concepts. Applications and links to other branches of physics are emphasized.

By the end of the module the student should be able to:

Quantum Mechanics:
Appreciate the limitations of classical mechanics and the need for a theory at the microscopic level; Understand the implications of the wave-like behavior of matter and electromagnetic radiation; Understand various atomic models and the experimental evidence provided by optical and X-ray spectra, and methods for their production and study; Apply the wave-like behavior of matter to electrons and the consequences for bound states.

Optics and Waves: Describe the basic concepts of wave motion and describe both travelling and standing waves; Describe the interference and diffraction of waves and the importance of spatial and temporal coherence; Use phasors in order to calculate interference patterns produced by sets of regular very narrow slits and also the diffraction pattern produced by a slit of finite width; Describe the laws of reflection and refraction and apply them to mirrors and lenses; Describe how modern light sources and detectors operate; Link the concepts developed in the module and use them to solve a wide range of problems.

Quantum Mechanics describes the behavior of matter on sub-microscopic scales and, together with relativity, is one of the two foundations of modern physics. Quantum systems are often described as having both wave-like and particle-like aspects to their behavior, and are famous for producing results that defy common-sense intuition based on observations at everyday scales. In this module we will introduce Schrödinger's wave equation and use it to investigate the behavior of simple quantum systems, from a free particle through to single-electron atoms. We will discuss the wavefunction, which describes the state of a system, how to interpret it, and how making a measurement changes the wavefunction. We will illustrate some of the non-intuitive behavior of quantum systems, show how it arises, and how, in the limit of large energies, it tends towards classical behavior. We will discuss how mathematical operators are used to represent physical quantities, and see where the Uncertainty Principle comes from. We will introduce the quantum treatment of angular momentum and show how an additional property of the electron (spin) is required to describe atomic states. We will consider the special properties of quantum states consisting of more than one electron, and show how the existence of complex chemistry depends on these.

By the end of the module the student should be able to:
Perform approximate calculations using the de Broglie relation and the Heisenberg Uncertainty Principle; Normalize a wavefunction; Use wavefunctions to calculate expectation values and the probabilities of different outcomes of measurements; Show how measurement changes the wavefunction; Be familiar with the use of Hermitian operators to represent physical quantities in quantum mechanics and the properties of their eigenvalues and eigenfunctions; Explain the physical significance of each element of an eigenvalue equation; Be familiar with the time-dependent
and time-independent Schrödinger equations; Solve the time-independent Schrödinger equation for simple 1-D and 3-D potential problems; Describe the main features of the solutions for a range of problems; Evaluate the commutator of two operators and explain its physical significance; Be aware of how the Pauli exclusion principle arises and be able to apply it to multi-electron systems; Describe the properties of angular momentum in quantum mechanics; Relate the quantum numbers of atomic electrons to physical variables and know how their different values are related; Explain why the concept of electron spin is required to explain experimental observations.

The aim of this module is to give a thorough grounding in the principles of quantum mechanics. It builds on the wave mechanics studied in Years one and two where the wave nature of matter was introduced as described by the Schrodinger equation. In this module we begin with the fundamental postulates underlying quantum mechanics.

We will introduce Dirac's notation for doing quantum mechanics which will allow us to study quantum properties like "spin" which have no counterparts in classical physics. This is vital for applications of quantum mechanics such as quantum computing. We will also see how the Schrodinger equation originates. The module will cover fundamental aspects - such as the connection between symmetry and conservation laws - as well as applications and approximate, yet powerful, tools like perturbation theory for handling situations where exact results are not possible.

By the end of the module the student should be able to:
Describe the main postulates of quantum mechanics; Compute the probabilities of observables and expectation values given a sequence of measurements of a quantum system; Use Dirac notation; Use operator commutation relations to compute the time-dependence of expectation values and uncertainty relations; Separate the Schrodinger equation to address issues like the degeneracy of states in quantum systems in two or three dimensions and the time-dependence of a wavefunction from stationary states; Use angular momentum and spin operators; for example, to discuss the Stern-Gerlach experiment; identify and construct non-interacting wavefunctions suitable for indistinguishable fermions and bosons; (Advanced students) Use time-independent perturbation to first order and the variational method to approximate solutions to quantum problems.

Fluid Flow:
Introduction to fluid flow phenomena in engineering. Hydrostatics: Pressure variation with position in a static fluid, manometers, hydrostatic forces on submerged surfaces, forces on unconstrained bodies, surface tension and capillarity, methods of surface tension measurement. Hydrodynamics: classification of flows in terms of variation of flow parameters in time and space, the concepts of streamline and stream tube, the principles of continuity, energy and momentum, turbulent flow. Applications of principles to engineering problems, including flow measurement by orifice, Venturi, Pitot tube, rotameter & weirs. Forces on pipe bends, nozzles and plates. Steady flow problems concerning head loss and pressure drop due to friction in pipe flows (Bernoulli), non-circular ducts, friction factors, Moody diagram and friction losses in fittings. Physical fluid properties, their dimensions and units, SI System, dimensional analysis.

Thermodynamics:

Heat Transfer:

This module looks to develop the required skills for any graduate chemical engineering in the area of chemical thermodynamics, with particular emphasis on how this information is used in practice.
The type of material covered will be:
(i) Introduction; refresh of fundamentals (zeroth, 1st, 2nd, 3rd laws, free energies)
(ii) Equations of state
(iii) Vapor-liquid equilibria and other phase equilibria
(iv) Chemical Potential and use in single and multicomponent systems
(v) Concept of fugacity and it links to Chemical Potential
(vi) Activity Coefficients
(vii) Phase Separation
(viii) Chemical Reaction Equilibria
This course is a continuation of Mathematical Methods 3 (MATH2401) and aims to introduce further tools required to solve the partial differential equations which arise in applied mathematics. It first looks at the application of the separation of variables method in cylindrical and spherical coordinates. This necessitates a study of Bessel's and Legendre's equations and their solutions. This is done via a combination of the Frobenius method of series solution of ODE's together with generating functions.

The course then moves on to study transform methods of solving PDEs, complementing the method of separation of variables and concentrating on the Fourier and Laplace transforms. The necessary techniques of integration in the complex plane will be reviewed.

Topics covered include:

This course offers an introduction to numerical analysis, the theory underlying the numerical methods that are frequently used to solve a wide range of practical problems. Methods covered in this course should include: estimating solutions of ordinary differential equations (including systems with initial or boundary conditions); finding real roots of equations; interpolation and fitting of functions to prescribed data points; fast Fourier transforms; advection schemes.

Basic programming skills are required for the project component, and students taking this course should have some experience with e.g. FORTRAN or Mathematica or C/C++, or be willing to learn such skills themselves.

Syllabus:

Milestones in electromagnetism [1 Week]

Electrostatics [6 Weeks]
Coulomb's law; electric field; Gauss' law; superposition principle; electric field for a continuous charge distribution and electrostatics in simple geometries (spherical, cylindrical and planar distribution of charges). Gauss' law in differential form. Electric potential; electric field as gradient of the potential; electric potential for a point charge; electric potential for a discrete charge distribution; electric dipole; potential of a continuous charge distribution. Electrostatic energy; energy for a collection of discrete charges, and for a continuous charge distribution.

Conductors [3 Weeks]
Electric field and electric potential in the cavity of a conductor; fields outside charged conductors; method of images. Vacuum capacitors: definition of capacitance; parallel plates, spherical and cylindrical capacitors; capacitors in series and parallel; energy stored in a capacitor.

Dielectrics [1 Weeks]
Dielectrics: definition and examples. Energy of a dipole in an electric field. Dielectrics in capacitors: induced charge, forces on dielectrics in non-uniform fields.

DC circuits [3 Weeks]
Current and resistance; Ohm's law; electrical energy and power. DC circuits: emf, Kirchoff's rules. Examples.

**Magnetostatics [5 Weeks]**
Magnetic field, motion of a charged particle in a magnetic field and Lorentz force. Velocity selector, mass spectrometer, Hall effect. Ampere's law and Biot-Savart law. Magnetic field due to a straight wire, a solenoid, a toroid and a current sheet. Magnetic force between current carrying wires. Energy of a magnetic dipole in a uniform field.

**Electromagnetic induction [4 Weeks]**

**AC circuits [3 Weeks]**
AC generators and transformers; circuit elements (R,C,L); impedance, complex exponential method for LCR circuits: the RC circuit, the RL circuit and the RLC circuit. Resonances, energy and power in the RLC circuit.

**Maxwell's equations [1 Weeks]**
Maxwell's equations in vacuo and plane wave solution

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5 Syllabus:
Linear ordinary differential equations
Non-linear ordinary differential equations
Asymptotic behaviour of integrals

7 Intended as an introductory course for students who have no background in Economics and are interested in pursuing studies mainly in other subjects, this course introduces students to the central principles of microeconomics. By the end of the course, students should be entirely familiar with the most commonly used concepts from theoretical models of supply and demand; be aware of the applicability and limitations of theory; combine concepts with data, and give explanations to current phenomena based on solid analytical models; understand debates over consumer, firm behaviour, and prices; current policies and their effect on consumers and firms.

8 This course introduces all the techniques necessary for an understanding of the theorems of Green and Stokes. These theorems are important in the theory of electrostatic potential and Laplace's Equation. This equation is often solved by the 'separation of variables' technique and for this reason Fourier series are also studied.

**Syllabus:**
Partial differentiation. Chain rule. (Taylor series).
Integration over volumes. Flux, Gauss' theorem, Green's theorem, Stokes' theorem, divergence, curl, standard identities and manipulations, summation convention.
Fourier series: periodic functions, approximating series, formulae for coefficients.
Series solution of ordinary differential equations about regular points.
An introduction to organic chemistry. The course involves lectures, tutorials and laboratory work. A flavour of the material covered in this course is presented below:


The course involves lectures, tutorials and laboratory work. Content includes synthesis, reactivity, structure determination and mechanism in organic chemistry and biologically important molecules. CHEM1201 (or equivalent) is a prerequisite.

**Section A:** Organic Synthesis I Reactivity And Synthetic Methods: Basic carbonyl chemistry, enolate chemistry. Retrosynthetic Analysis I: Concepts. Retrosynthetic Analysis II: 1, 3-Functionalised Compounds and Their Disconnections. Retrosynthetic Analysis III: 1,5-Functionalised compounds and their disconnections.

**Section B:** Spectroscopy: 1H, 13C, 19F, 31P NMR Spectroscopy, Mass Spectrometry, Structure elucidation using IR, NMR, MS.

**Section C:** Organic Synthesis II: Nitrogen, sulfur, Boron, Silicon and Oxygen. Difunctionalised Compounds 1,2 Difunctionalised compounds and their disconnections, Umpolung methods, advanced disconnections Diels-Alder Reactions.

**Section D:** Aromatic and Heteroaromatic Compounds: Substitution and Addition reactions.

This course aims to develop an understanding of the principles of quantum mechanics and their implications to the solution of physical problems. Topics include:


**Syllabus:**

**Review of one electron atoms. [2 Lecture]**

**Many electron atoms [10 Lecture]**

**Molecular Structure and spectra [9 Lecture]**
Atoms and Electromagnetic Fields [4 Lecture]

Brief introduction to scattering [2 Lecture]
Total cross section. Differential cross section. Examples of electron-, positron- and positronium- total cross-sections: dominant interactions. Quantum scattering

13 Topics include:

14 Topics include:

15 Modes of heat transfer: conduction, convection, radiation; Fourier's law; conduction in cylindrical and spherical shells (critical thickness of insulation for tubes); derivation of heat conduction equations for transient and multidimensional cases; boundary and initial conditions; methods for solving 1-D transient heat conduction equation (slab, sphere and cylindrical geometries); thermally thin bodies, lumped heat transfer coefficient. Convective heat transfer. Dimensional analysis; forced convection; natural convection; correlations for heat transfer coefficient. Thermal radiation; electromagnetic spectrum; the black surface; real surfaces; shape factors; radiation transfer through gases. Solar energy. Two phase flows; flow regimes; homogeneous flow; separated flow; drift-flux model; bubbly flow; slug flow; annular flow. Condensation, evaporation and boiling; film condensation; film evaporation; pool boiling; forced convection boiling and condensation; heat pipes. Heat exchangers; logarithmic mean temperature difference; pressure drop; pressure drop in a tube for a compressible gas; counterflow double-pipe heat exchangers; shell and tube exchangers; condensers; kettle reboilers; thermosyphon reboilers; multiple effect evaporators. Direct contact gas-solid exchangers; cyclic batch operation - fixed beds.

16 Prediction of transport properties.
1 This module introduces students to advanced techniques in multivariable calculus with an emphasis on applications in Engineering and the Physical Sciences. Topics covered will include: Vector fields and potentials, Gradient, Divergence and Curl; Transformations between rectilinear, cylindrical and spherical co-ordinates; Line integral, work integrals; Double integrals and Green's Theorem; Stokes' Theorem and the Divergence Theorem; Laplace's/Poisson's equation; The heat equation, the wave/string equation; Fourier Transform and Fourier Series.

2 This module will introduce students to principles and techniques that are used in the analysis of chemical and biochemical engineering processes. Steady state and un-steady state mass and energy balances are fundamental tools for the assessment of such process. The use of balances in, for example, the development sustainable process will be introduced. Students’ analytical abilities and problem solving skills will be developed through regular homework assignments. Their technical reporting and communication skills are developed in the preparation and delivery of a presentation on a technical topic making use of internet and library resources. The module will include a number of site visits.

3 Students will learn to apply selected numerical methods in the solution of chemical engineering based problems using Matlab and Excel. The module content will cover selected topics from the following,
1. Algorithms, Precision & Errors
2. Solutions of Non-Linear Equations
3. Solution of Systems of Non-Linear Algebraic Equations
4. Iterative Solutions of Systems of Linear Equations
5. Polynomial Interpolation
6. Cubic Spline Interpolation
7. Linear Regression
8. Data Smoothing & Differentiating
9. Non-Linear Regression
10. Numerical Integration
11. Numerical Solution of Ordinary Differential Equations
12. Partial Differential Equations

4 This module presents the field theory of electromagnetism. Gauss's Law, Ampere's Law, Biot-Savart's Law and Faraday's Law are examined from the perspective of Maxwell's Equations. The physical significance of these equations is emphasized. Solutions to Maxwell's Equations in the form of electromagnetic waves are presented. Their behavior in vacuum, dielectrics, conductors, wave-guides, and at the interface between media is described. Electromagnetism as a relativistic phenomenon is discussed and the nature of light is investigated. The source of electromagnetic radiation is identified.

5 On completion of this module, students should be able to:
1. Demonstrate an understanding of the analysis of a range of separation processes in terms of equilibrium stages as applied to chemical, oil & gas & bioprocessing systems.
2. Design and analyze batch and continuous distillation systems for binary systems, to achieve a specified degree of separation.
3. Apply the Fenske-Underwood Gilliland method to the preliminary design of multi-component distillation systems.
4. Specify appropriate system configurations for drying and multiple-effect evaporation processes.
5. Design absorption/scrubbing systems, based on the height and number of transfer units and on the generalised pressure drop correlation.
6. Develop and apply the fundamental equations required for the design of cascades, with particular reference to liquid-liquid extraction systems.
7. Specify the configuration and operating conditions of a selected range of solid-liquid and solid-gas separation systems.
8. Use selected simulation tools for the preliminary analysis of a range of unit operations.
This course introduces students to the theory of differential equations and dynamical systems and to their many applications as mathematical models. The topics covered prepare the student for more advanced subjects in ordinary differential equations, dynamical systems theory, numerical methods and partial differential equations.

**Course Outline:**
A) Review of the theory of 1st-order ODEs
B) 2nd-order ODEs: Definitions, linear vs. nonlinear, dimensional analysis, examples
Examples: forced and damped systems, Riccati equation, mechanical oscillations, resonances, etc.
D) Systems of 2 coupled ODEs: Linear and nonlinear, phase plane analysis, critical points and classifications in terms of eigendirections and eigenvalues, Jacobi last multiplier method (integrating factor), non-autonomous systems and chaos.
Examples: population models, the tragedy of the commons, epidemic models, etc.
Examples: Solving transcendental equations in classical and quantum mechanics, finding the critical points of highly non-linear ODE systems, integrating numerically ODE systems such as the chaotic Lorentz model or the integrable prey-predator system

This module provides a basic analytical framework for understanding the functioning of markets. The module begins by examining gains from trade and exchange, demand, supply and price determination in individual markets and the effect of taxes in those markets. The module also examines market failure and regulation and the justification and nature of government intervention in markets. The module also examines the economics of firms in different types of market structures (competition, monopoly, and oligopoly), strategic interaction between economic agents (elementary game theory) and basic issues in the economics of labor markets.

The module is an introduction to organic chemistry, the chemistry of carbon. It covers the common organic molecules (alkenes, alcohols, amines, carbonyls etc.) and emphasises their recognition, naming, reactions and relevance to everyday life and health. Specific topics include 3D aspects of chemistry, what exactly happens in a chemical reaction and how it is done in practice. A significant proportion of the module is devoted to the larger molecules of life (proteins, carbohydrates, fats) and shows how these can be understood in terms of the simpler molecules.

This module advances the concepts of the chemical reactivity of carbonyl and aromatic compounds with a specific emphasis placed on gaining an understanding of their different modes of reaction. It includes numerous examples of the application of the described chemistry to the making of complex chemical entities. The laboratory sessions complement the material covered in lectures.

This module has two parts. The first part presents the key principles and techniques of quantum theory along with applications of the theory to relevant model systems. This knowledge is then employed to make a comprehensive description of (i) the internal structures of hydrogen-like and many-electron atoms, (ii) how atoms interact with light, and (iii) why atomic properties exhibit periodic trends. The second part of this module deals with the rotational, vibrational and electronic spectroscopy of molecules examining how changes in the energy, structure and motion of molecules affect their spectroscopic properties. Conversely, careful analysis of molecular spectra is demonstrated to be an important way by which one may obtain critical information about the nature of molecules such as their electronic structure, the strengths, lengths and angles of their bonds, and their dipole moments.

On completion of this module students should be able:
1. to provide a molecular-level interpretation of key thermodynamic variables such as internal energy (U), Entropy (S) and Gibbs Free Energy (G)
2. to solve chemical engineering problems amenable to analysis by chemical thermodynamics, in particular those relating to first and second law principles (U, S, G)
3. to synthesize and solve rate-law expressions for both homogenous and non-homogenous chemical reacting and equilibrium systems
4. to analyze heat cycles in terms of achievable efficiencies and propose techniques to maximize heat-cycle efficiency
On completion of this module students should be able to:

- Estimate solubility of gases and solids in liquids;
- Construct binary phase equilibrium diagrams for a range of solvents using non-ideal thermodynamics;
- Analyze liquid-liquid equilibrium systems;
- Analyze reaction schemes to determine equilibrium constants and reaction conversions;
- Use thermodynamic software tools and conduct simulations of flash operations available in commercial software packages. Demonstrate an understanding of the role of thermodynamics in safe and effective process design.

On completion of this module students should have acquired:

1. A familiarity with the modes of heat transfer and their relevance in practical engineering systems.
2. The ability to calculate rates of heat transfer for steady-state, mixed-mode exchange in chemical engineering configurations.
3. An understanding of the basic elements of heat exchanger operation and design.
4. An understanding of the fundamental principles of molecular diffusion and the physical basis of the underlying phenomena.
5. The ability to determine steady-state concentration profiles and diffusional fluxes in simple geometries.
6. The ability to determine overall mass transfer coefficients for inter-phase mass transfer and to determine the rate-limiting step.
7. An ability to estimate losses in pipe flows.
8. An ability to apply the Engineering Bernoulli equation to practical flow configurations.

On completion of this module students should be able to:

1. Model steady and unsteady heat exchange systems involving conduction and/or convection.
2. Explain the origin and significance of selected dimensionless groups and apply dimensionless correlations to a variety of heat exchange configurations.
3. Specify and design simple heat exchangers having due regard for the safety and environmental implications of design decisions.
4. Apply the macrobalances of mass, momentum and energy to typical process flows including piping networks, packed-bed and fluidized-bed reactors, pumped circuits, agitated reactors etc.
5. Analyze and quantify the effects of non-Newtonian behavior upon fluid flow in piping and reactor configurations.
6. Select and specify such items as pumps, valves and agitator impellers for a variety of process applications.
Derivatives of the Laplace equations, the wave equations and diffusion equation; Methods to solve equations: separation of variables, Fourier series and integrals and characteristics; maximum principles, Green's functions.

Processes and process variables, engineering data. The conservation principle. Material and energy balances on non-reactive and reactive process units and systems, recycle and purge. Unsteady state processes.

Computer arithmetric, matrix computation, interpolation and approximation, numerical integration, solution of nonlinear equations.

This course employs a calculus-based approach. Key topics include Coulomb’s law, electric field and potential, Gauss’ law, capacitance, circuits, magnetic force and field, Ampere’s law, electromagnetic induction, AC circuit, Maxwell’s equations, electromagnetic waves, geometric optics, interference and diffraction.

Laboratory accompanying PHYS 1413.


First order equation, linear second order equations, Laplace transform, Euler and Runge-Kutta methods, introduction to partial differential equations, matrix, systems of linear equations, eigenvalue and eigenvector, systems of differential equations, orthogonal projection.

Theory of firm in a free enterprise system; theory of consumer demand; market structures and resource allocation; efficiency of competitive markets; selected topics on government regulation. Students with non-local qualifications should seek department’s or school’s approval for enrollment in the course.


Structure and bonding; regio-, geometric, and stereoisomerism; polar and radical reactions of alkenes and alkynes; substitution and elimination reactions; and an introduction to NMR, IR, and mass spectrometry.

Dienes, resonance and aromaticity; electrophilic aromatic substitution and nucleophilic aromatic substitution; benzylic and allylic reactivity; the chemistry of carbonyl compounds and carboxylic acid derivatives; the chemistry of amines; pericyclic reactions.

Experimental techniques of organic chemistry; preparation, separation and characterization of organic compounds and natural products

Basic quantum theory, atomic and molecular structure, equilibrium statistical thermodynamics.

Applications of fluid mechanics in chemical engineering. Fluid properties; energy equations and applications in process systems; flow in pipes and channels, around submerged objects. Laminar and turbulent flow, flow measurements.

The study of differential equations, which are the equations containing derivatives of functions, is one of the most beautiful and important applications of calculus to our everyday lives. It is remarkable and inspiring that the fundamental principles that govern many phenomena (in the fields of not only Sciences and Engineering, but also Economics and Social sciences) could be expressed in the language of differential equations.

In this course we aim to learn the following:
1. The 1st- and 2nd order ODEs
2. System of ODEs
3. Series solutions of ODEs
4. Laplace transforms
5. Fourier series
6. PDEs (Wave equation, Heat equation, Laplace equation), etc.

Lecture Plan:
1. Thermodynamic system, heat and work
2. Mass and energy balance
3. Entropy balance
4. Heart engines, power cycles, machieries
5. Evaluation of thermodynamic properties with partial derivatives, equations of states and engineering concepts

Lecture Plan:
1. Roundoff Errors and Computer Arithmetic
2. Algorithms and Convergence
3. The Bisection Method
4. Fixed-Point Iteration
5. Newton's Method
6. Error Analysis
7. Zeros of Polynomials
8. The Lagrange Polynomials
9. Divided Differences
10. Hermite Interpolation
11. Cubic Spline
12. Parametric Curves
13. Numerical Differentiation
14. Richardson's Extrapolation
15. Numerical Integration
16. Composite Numerical Integration
17. Romberg Integration
18. Adaptive Quadrature
19. Gaussian Quadrature
20. Multiple Integrals
21. Linear System of Equations
22. Pivoting Strategies
23. Linear Algebra and Matrix inversion
24. The Determinant of a Matrix
25. Matrix Factorization
26. Special Types of Matrices
27. Norms of Vectors and Matrices
28. Eigenvalues and Eigenvectors
29. Iterative Technique for Solving Linear Systems
30. Iterative Technique for Solving Linear Systems
31. Error Bounds
4 General Physics II covers electromagnetism and optics, including electric field and potential concepts, electric current and magnetic field, induction law, dielectrics and magnets, electromagnetic wave, and optics. Fundamental concepts of quantum physics are also introduced briefly.

Course Plan:
Chapter 20 Electric charge, Force, and Field
Chapter 21 Gauss’s Law
Chapter 22 Electric Potential
Chapter 23 Electrostatic Energy and Capacitors
Chapter 24 Electric Current
Chapter 25 Electric Circuits
Chapter 26 Magnetism: Force and Field
Chapter 27 Electromagnetic Induction
Chapter 28 Alternating-Current Circuits
Chapter 29 Maxwell’s Equations and Electromagnetic Waves
Chapter 30 Reflection and Refraction
Chapter 32 Interference and Diffraction
Chapter 33 Relativity

5 Experimental laboratory course to supplement PHY 102, through which students confirm and understand the fundamental principles of physics.

6 Course Plan:
1. Economic principles
2. Economic thinking
3. Comparative Advantages
4. Supply and Demand
5. Elasticity
6. Supply, Demand, and Policy
7. Consumer/Producer Surplus
8, 12.* Taxes, Tax Systems
9. International Trade
10, 11. Externalities, Public Goods
21. The Theory of Consumer Choice
13. Cost of Production
14. Competitive markets
15. Monopoly
16. Monopolistic competition
17. Oligopoly
23, 24. Measuring National Income
25. Long-term growth: Productivity
27. Financial system, Finance
29, 30. Monetary System, Money growth, and Inflation
31. Open economy

7 Calculus is a one-semester course of fourteen weeks, each consisting of two 75-minute Lectures, one 50-minute lecture and two 50-minute exercise sessions (not including one week each for the midterm and final exams), which covers concepts and techniques from both single-variables and multi-variable calculus.

Course Outline:
Week 1-2: Basic Terminologies, Limits and Continuity
Week 2-3: Differentiation and Integration
Week 3: Infinite Sequences and Series
Week 4: Tests of Series Convergence
Week 5: Power Series and Taylor Series
Week 6: Vectors
Week 6-7: Vector-Valued Functions and Partial Derivatives
Week 8: Midterm Exam
Week 9: Gradients, Directional Derivatives, and Level Sets
Week 10: Taylor Series for Two Variables
Week 11: Multiple Integrals in Rectangular Coordinates
Week 12-13: Multiple Integrals in Other Coordinates
Week 13-14: Line Integrals of Vector Fields
Week 14-15: Stokes’ Theorem
Week 15: The Divergence Theorem
Week 16: Final Exam

8 Lecture Plan:
1. Structure and Bonding
2. Polar Covalent Bonds; Acids, and Bases
3. Organic compounds: Alkanes and Their Stereochemistry
4. Organic compounds: Cycloalkanes and Their Stereochemistry
5. An overview of Organic Reactions
6. Alkenes: Structure and Reactivity
7. Alkenes: Reactions and Synthesis
8. Alkynes: An Introduction to Organic Synthesis
9. Stereochemistry
10. Organohalides
11. Reactions of Alkyl halides: Nucleophilic Substitutions and Eliminations
12. Structure Determination: Mass Spectrometry and IR Spectroscopy
13. Structure Determination: Nuclear Magnetic Resonance Spectroscopy

9 Lecture Plan (Continued from Organic Chemistry I CHEB 206)
14. Conjugated Dienes and Ultraviolet Spectroscopy
15. Benzene and Aromaticity
16. Chemistry of Benzene
17. Alcohols and Phenols.
18. Ethers and Epoxides
19. Aldehydes and Ketones.
20. Carboxylic Acids and Nitriles
22. Carbonyl Alpha- Substitution Reactions.
23. Carbonyl Condensation Reactions
24. Amines
25. Special Topics in Biomolecules
26. Special Topics in Macromolecules

10 Lecture Plan:
1. Introduction & Orientation - Extraction, Crystallization, and m.p.(Tech. 3,5)
2. TLC & Column Chromatography.(Exp.4, Tech.4,10,11)
3. Distilation & Gas Chromatography.(Tech.7,12)
4. Grignard Reaction & IR Analysis(Exp. 31)
5. Reduction ofd, 1 Camphor(Exp. 21)
6. Adol Condensation(Exp. 47)
7. Witting Reaction(Hand - out)
8. Final Exam & Check out

11 Lecture Plan:
1. Classical vs. quantum mechanics, Schrödinger equation
2. Quantum mechanical postulates
3. Particle in a box, tunneling through a square potential barrier
4. Operators and commutation
5. Particle in a sphere and others
6. Vibration and rotation of molecules
7. Hydrogen atom
8. Many-electron atoms, Spin & orbital angular momentum
9. Chemical bonding in diatomic molecules
10. Molecular structure and energy levels for polyatomic molecules
11. Electronic spectroscopy, Lasers
12. Molecular symmetry, Group theory, and Nuclear magnetic resonance spectroscopy

Course Objective:
We learn the basic principles of momentum transfer related to fluid motion. Important concepts are taught along with the derivation of fundamental equations that govern fluid flows. Such concepts include material volume, linear momentum principle, kinematics, stress tensor, dimensional analysis, etc. Several application problems are also covered for better understanding of governing principles.

Lecture Plan:
1. Introduction to transport phenomena & fluid mechanics
2. Vector tensor analysis
3. Basic concepts (material volume, linear momentum principle)
4. Kinematics (description of motion)
5. Stress in a fluid (cause of motion)
6. The Navier-Stokes equation
7. Dimensional analysis & Reynolds number
8. 1D laminar flow
9. Low Reynolds number flow & Stokes flow
10. Electrokinetic flow (electrical double layer, electroosmotic flow, electrophoresis)
11. Turbulence

Course Objective:
The principles of heat and mass transfer are studied along with application problems. In heat transfer, the three fundamental mechanisms, conduction, convection, and radiation are studied in detail. Then we will go on to the mass transfer part to study molecular diffusion and convection problems. During the last part of the course, we will touch the transport problems related to the electrolyte solutions to meet the cutting edge technologies such as biomedical engineering, micro/nanofluidics, and lithium battery problems. During the last week, students' perspectives will be extended by touching the analogies between the physical transport phenomena and financial transport phenomena in economics.

Lecture Plan:
1. Heat conduction (Fourier's law)
2. Heat Convection (Forced convection, Natural convection)
3. Radiation (Black body radiation, non-Black body, Shape factor)
4. Molecular diffusion (Fick's law) - Stokes-Einstein diffusivity
5. Convection
6. Electrokinetics (Planck-Nernst-Poisson Equation)
   - Electroosmosis in micro/nano channels (nano pores)
   - Transport phenomena in a lithium battery
7. Analogy to financial transport phenomena
   - Convective transport equation and Black-Scholes model in financial engineering
Differential equations arise as common models in the physical, mathematical, biological and engineering sciences. This subject covers linear differential equations, both ordinary and partial, using concepts from linear algebra to provide the general structure of solutions for ordinary differential equations and linear systems. The differences between initial value problems and boundary value problems are discussed and eigenvalue problems arising from common classes of partial differential equations are introduced. Laplace transform methods are used to solve dynamical models with discontinuous inputs and the separation of variables method is applied to simple second order partial differential equations. Fourier series are derived and used to represent the solutions of the heat and wave equation and Fourier transforms are introduced. The subject balances basic theory with concrete applications.

This subject is an introduction to chemical engineering flowsheet calculations, including materials balances, unit systems, and the prediction of real gas behavior. The concept of conversion of mass is developed as the basis for determining mass flows in chemical processing systems. Students will be introduced to flowsheeting packages and chemical engineering simulation software. The subject will include exercises in process optimization and the solution of ill-defined process problems. The teaching of process safety is critical to any undergraduate chemical engineering program. Students need to understand their responsibilities to themselves, their work colleagues and the wider community. They need to be aware of safe practices and also the consequences that may arise when those safe practices are not followed. This subject introduces students to concepts of process safety and the consequences when safety management systems fail.

Energy balances: The concepts of energy, work and heat, the units of energy, internal energy, enthalpy, heat capacity, latent heat, evaluation of enthalpy changes. The general energy balance equation, enthalpy balances, system boundaries. Enthalpies of pure components and selection of enthalpy data conditions.


HYSIS: Training in the use of the process simulations package HYSIS. Performing simple material and energy balances using the package.

Computer packages, such as MATLAB, Maple and Mathematica, are indispensable tools for many scientists and engineers in simulating complex systems or studying analytically intractable or computationally intensive problems. This subject introduces such numerical and symbolic techniques with an emphasis on the development and implementation of mathematical algorithms including aspects of their efficiency, accuracy and stability. The different strategies and style of programming methodologies required when tackling problems either numerically or symbolically are highlighted. Examples used to illustrate numerical mathematics include the direct solution of linear systems and time-stepping methods for initial value problems. Symbolic methods will be demonstrated with a wide range of examples, such as applications to chaos theory and perturbative solutions to differential equations.

Learning Outcomes:
On completion of this subject, students should:

Understand the significance and role of both roundoff error and truncation error in some standard problems in scientific computing;
Be able to write simple numerical programs that utilize a numerical Problem-Solving Environment such as Matlab;
Learn how to use a symbolic software system such as Mathematica to tackle certain mathematical problems exactly;
Be able to use both numerical and symbolic techniques, with the appropriate programming idioms, as required when undertaking a mathematical or modeling investigation.
This subject is designed for students with a strong interest and background in physics, and aims to provide a deep understanding of a broad range of physics principles and applications. Topics include:

**Fluids:** water and air pressure, breathing, hydraulics, flight (pressure in fluids, buoyancy, fluid flow, viscosity, surface tension).

**Thermal physics:** heating and cooling, energy balance in environments, engines, refrigerators (temperature and thermal energy, kinetic theory, phase changes, heat transfer mechanisms, first law of thermodynamics, diffusion).

**Electricity and magnetism:** electrical devices, lightning, household electricity and electrical safety, electric motors, power generation and transmission, Earth’s magnetic field, particle accelerators, communications (electric charge and field, conductors and insulators, electric potential, capacitance, resistance, electric circuits, magnetic field, Faraday’s law of induction, Maxwell’s equations, electromagnetic waves).

**Quantum and atomic physics:** spectroscopy, lasers (photon, blackbody radiation, matter waves, quantisation in atoms, interaction of light with matter, x-rays).

**Nuclear physics and radiation:** nuclear energy, radiation safety, formation of atoms in stars, carbon dating (the atomic nucleus, radioactive decay, half-life, ionising radiation, nuclear fission and fusion).

This subject covers fundamental concepts of diffusion and conservation within momentum, heat and mass transport. Use of these concepts is integral to the profession of Chemical Engineering. For example, heat exchangers are used throughout Chemical Engineering processes to transfer thermal energy from one stream to another. Knowledge of heat transport and momentum transport (ie fluid flow) is required to design a heat exchanger, other key pieces of Chemical Engineering process equipment, including distillation columns. Similarly, knowledge of mass transport is required to design other key Chemical Engineering processes, such as distillation.

This subject aims to extend the fundamental concepts of heat transfer from that covered in CHEN20009 Transport Processes to include natural and forced convection and two phase systems. Mass transfer concepts are extended to unsteady state mass transfer and Fick's Second Law, prediction of diffusivity and of mass transfer coefficients. These fundamental concepts are then applied to the design of processes and equipment including shell and tube, air-cooled and plate heat exchangers, evaporator systems, membrane devices, binary distillation systems, gas absorbers and cooling towers. Experience in the use of appropriate simulation packages such as HYSYS for exchanger and distillation column design are included. This simulation work builds on the skills developed in CHEN20009 Chemical Process Analysis 2.

Indicative Content:

**Forced Convection:** Use of heat transfer correlations to predict coefficients;

**Heat Exchange:** concept of an overall heat transfer coefficient, fouling factors; determination of the area required for a given heat duty, Heat exchanger design. Use of simulation packages such as HYSYS and ASPEN.

**Free convection:** discussion and application of Grashof Number and other dimensionless groups.

**Condensation and Boiling:** Fundamentals. Evaporation: various evaporator types and their advantages and disadvantages (forced circulation, film types); multiple and single effects; backward and forward feed; boiling point elevation; mechanical recompression; evaporator energy balances.

**Mass Transfer:** Unsteady state mass transfer and Fick's Second Law; prediction of diffusivity; dimensional analysis and equations of change for mass transfer.

**Distillation:** single-stage separations, equilibrium flash, differential distillation; multistage separations, operating lines, reflux; binary distillation, varying reflux ratio, minimum reflux, total reflux, optimum reflux, feed plate location, side streams, open steam; tray efficiency via overall and Murphree efficiencies. Use of simulation packages such as HYSYS.

**Gas absorption:** basic mass transfer mechanism; material balances, co-current and countercurrent flow, limiting L/G ratio; multistage absorption and the absorption factor method; continuous contact, transfer units, height of a transfer unit, calculation of number of transfer units. Humidification and cooling tower height calculation.

**Membrane Systems:** Microfiltration, ultrafiltration, nanofiltration and reverse osmosis. Gas separation systems. Robeson’s bound. Electrodialysis and pervaporation. Membrane selection.

This subject studies the fundamental concepts of functions of several variables and vector calculus. It develops the manipulation of partial derivatives and vector differential operators. The gradient vector is used to obtain constrained extrema of functions of several variables. Line, surface and volume integrals are evaluated and related by various integral theorems. Vector differential operators are also studied using curvilinear coordinates. Functions of several variables topics include limits, continuity, differentiability, the chain rule, Jacobian, Taylor polynomials and Lagrange multipliers. Vector calculus topics include vector fields, flow lines, curvature, torsion, gradient, divergence, curl and Laplacian. Integrals over paths and surfaces topics include line, surface and volume.
The subject provides an introduction to stoichiometry; gases; energy and thermochemistry; chemical equilibrium; acid-base chemistry; properties of solutions, aspects of main group chemistry; structure and bonding in elements and compounds of groups 14-18; solutions and pH equilibria; physical properties of solution, intermolecular forces and extended solid state structures; structure and bonding of alkanes, alkenes and alkynes; benzene and its derivatives; functional groups; and spectroscopy and determination of structure.

Quantum mechanics plays a central role in our understanding of fundamental phenomena, primarily in the microscopic domain. It lays the foundation for an understanding of atomic, molecular, condensed matter, nuclear and particle physics.

Topics covered include: The basic principles of quantum mechanics (probability interpretation; Schrödinger equation; Hermitian operators, eigenstates and observables; symmetrization, antisymmetrization and the Pauli exclusion principle; entanglement), wave packets, Fourier transforms and momentum space, eigenvalue spectra and delta-function normalization, Heisenberg uncertainty principle, matrix theory of spin, the Hilbert space or state, vector formation using Dirac bra-ket notation, the harmonic oscillator, the quantization of angular momentum and the central force problem including the hydrogen atom, approximation techniques including perturbation theory and, the variational method, applications to atomic and other systems.

This subject is divided into advanced thermodynamics (approximately 9 weeks) and advanced reactor engineering (approximately 3 weeks).

The laws of thermodynamics, which govern energy and the direction of energy flow, are amongst the most important fundamentals of chemical engineering that students learn during their course. This subject revises and expands the students’ understanding of the conservation of energy, learnt through subjects such as Chemical Process Analysis and Fluid Mechanics. In addition the students learn about the concepts of entropy and equilibrium, which form the basis for the topics of phase equilibrium, mixture properties, mixture equilibrium, reaction equilibrium and interfacial equilibrium – topics that stretch across the entire chemical engineering curriculum.

The reactor engineering component of the course focuses on heterogeneous reactions and the influence of mass transfer on chemical reactions and reaction design. The topics are solid-catalysed reactions, fluid-fluid reactions and fluid-solid reactions. During the subject, students learn about the effect of mass transfer on the overall rate of reaction and how to account for heterogeneous systems in reactor design.

The concepts covered by this subject provide the fundamental basis for chemical and process engineering and are utilised throughout all sectors of industry by engineers. This subject provides students with the ability to perform detailed calculations of complex systems to predict the performance and thus design process unit operations.

Indicative Content:

The advanced thermodynamics component focuses on the definitions and applications of the laws of thermodynamics, especially the implications of entropy and equilibrium on phases, mixtures, chemical reactions and interfaces:

1st Law of Thermodynamics: Closed and open systems, Unit operations, Thermodynamic cycles
2nd Law of Thermodynamics: Entropy, Reversibility and Spontaneity, Gibb’s Equations, Thermodynamic Identities and Maxwell Relations
Phase Equilibria of Pure Substances: Equilibrium Criteria, Fugacity
The advanced reactor engineering component focuses on mass-transfer limitations in multi-phase chemical reactions and reactor design:

Non-ideal flow in reactors
Rate controlling mechanisms (film resistance control, chemical reaction control, surface and pore diffusion control, ash layer diffusion, shrinking core mechanisms, effectiveness factors and Thiele modulus)
Kinetic regimes for fluid-fluid and gas-fluid reactions
Fluid-particle reaction design
Catalytic reactor systems

Topics covered include - Fluid statics, manometry, derivation of the continuity equation, mechanical energy balance, friction losses in a straight pipe, Newton’s law of viscosity, Fanning friction factor, treatment of roughness, valves and fittings; simple network problems; principles of open channel flow; compressible flow, propagation of pressure wave, isothermal and adiabatic flow equations in a pipe, choked flow. Pumps – pump characteristics, centrifugal pumps, derivation of theoretical head, head losses leading to the actual pump head curve, calculating system head, determining the operating point of a pumping system, throttling for flow control, cavitation and NPSH, affinity laws and pump scale-up, introduction to positive displacement pumps; stirred tanks- radial, axial and tangential flow, type of agitators, vortex elimination, the standard tank configuration, power number and power curve, dynamic and geometric similarity in scale-up; Newtonian and non-Newtonian fluids, Multi-dimensional fluid flow-momentum flux, development of multi-dimensional equations of continuity and for momentum transfer, Navier-Stokes equations, application to tube flow, Couette flow, Stokes flow.
MATH2100 will cover the following 4 topics. (Also for a general outline of the course, read About MATH2100.)


**Topic 2. Laplace Transforms (Kreyszig Chapter 6).** The Laplace Transform and its Inverse Transform. Linearity, Shifting, Convolution and the use of Partial Fractions. Transforms of Derivatives and Integrals. Use of Laplace Transforms to solve Linear Differential Equations including those involving discontinuous functions such as the Step Function and the Dirac Delta function.


On completing this course students will be able to: Analyze any process as a system including defining sensible system boundaries and identifying all input and output streams, formulate and solve mass and energy balances for process systems with and without reaction, produce a clearly written engineering communication and effectively sell a case through oral presentation, have improved their ability to manage their own study and their ability to work effectively in an engineering team.

**Module 1:** (Weeks 2 & 3)
Finite precision and discretisation
Finite precision arithmetic and error, arithmetic on computers, evaluating functions and sums
Fundamentals of numerical analysis, numerical differentiation and integration

**Module 2:** (Weeks 4 & 5)
Solving equations
Solving equations (root-finding)
Interpolation and curve-fitting.

**Module 3:** (Weeks 6 & 7)
Systems of equations
Systems of linear equations.
Iterative methods, nonlinear equations.

**Module 4:** (Weeks 8 & 9)
Differential equations I
Ordinary differential equations (ODEs)
Initial value problems

**Module 5:** (Weeks 10 & 11)
Differential equations 2
Boundary value problems
Finite element and finite difference methods

**Module 6:** (Weeks 12 & 13)
High-dimensional problems
Partial differential equations (PDEs) - DEs with more than 1 independent variable
Monte Carlo methods for high-dimensional integration and other problems

**Module 1:**
Electricity
Coulomb's Law, superposition.
Electric field, electric field due to continuous charge distributions.
Electric flux, Gauss's Law.
Electrostatic potential.
Potential and Fields.

**Module 2:**
Magnetism and Waves
Current.
Magnetic field, magnetic force on current.
Electromagnetic induction.

**Module 3:**
Waves - superposition, standing waves, interference.
Wave optics - concept of light as a wave, interference and diffraction.

**Module 4:**
Modern Physics
Special Relativity
Reference frames.
Time Dilation.
Length Contraction.
Lorentz transformations.
Quantum Physics
The end of classical physics.
Quantization.
Wavefunctions and uncertainty.
One dimensional Quantum Mechanics.

5 The course introduces a systems approach to understanding and analysing the structure and behaviour of industrial processes. The context and needs that give rise to process systems are examined along with the concepts of unit operations & unit processes. Understanding the nature of individual units and complex flowsheets is done through analysis of degrees of freedom & solvability issues. Techniques for the decomposition of large, complex systems to smaller problems are developed. Application of computer-aided flowsheeting tools facilitate process analysis, which includes economic & environmental impacts.

6 The aim of this course is to integrate concepts from fluid and particle mechanics, thermodynamics and heat and mass transfer such that students are able to use these concepts to make holistic decisions about selection and specification of equipment suited to specific objectives, as well as to analyse and troubleshoot problems. With an understanding of these concepts as well as new modelling techniques to be introduced in the course, students will be able to critically and professionally approach authentic cases. In this way the course looks back at the principles learnt and their application but also looks forward towards capstone courses which foreground a broader design approach.
On completing this course students will:
Be able to apply theory to real world situations and problems.
Gain an understanding of the fundamental concepts in each of the technologies to be studied, including thermodynamics, equipment design, operation and simulation issues.
Have learned how to specify and select process hardware best suited to various problems and objectives.
Have used case histories to analyse the most effective problem solving and trouble-shooting methods.
Have learned how to tailor his or her approach to specific design, analysis and troubleshooting problems.

After successfully completing this course you should be able to:

1. Sketch, interpret and manipulate functions of two or more variables.
2. Calculate tangent planes and use them as approximations to functions.
3. Find the maxima and minima of functions of two variables.
4. Apply the method of Lagrange multipliers to optimisation problems.
5. Solve and analyse certain families of first and second order ODEs.
6. Model a problem with ODEs and either analytically or numerically solve the differential equation and interpret the output.
7. Work fluently with parametric forms of curves, and derive parametric forms.
8. Understand fields and determine conservative fields and path integrals.
9. Model and solve problems with some real-world complexity using analytical methods and/or numerical methods via Matlab programs.

Lecture Plan:
1. Solve a variety of first order ODEs
2. Use the methods of undetermined coefficients and variation of parameters to solve non-homogenous 2nd order ordinary differential equations
3. Derive properties of the hyperbolic functions and apply them in various mathematical contexts.
4. Evaluate multiple integrals, and change the order of integration
5. Apply your knowledge of multiple integrals to solve problems of volume, area, centre of mass and moments of inertia.
6. Evaluate integrals in cylindrical and spherical polar coordinates
7. Know when to effectively use polar, cylindrical and spherical coordinate systems in problems involving multiple integrals.
8. Understand the notion of a vector field, use the operators "grad", "div" and "curl" effectively and understand their significance.
9. Understand and apply Green's theorem
10. Parameterize surfaces and be able to evaluate and apply surface and flux integrals, and be able to use the theorems of Gauss and Stokes appropriately.
11. Find the LU or PLU decomposition of a given matrix and use it to solve a corresponding system of linear equations.
12. Use eigenvalues and eigenvectors to (orthogonally) diagonalize certain matrices and use these techniques in a variety of applications.
13. Understand and apply the power method.
15. Model and solve problems with real-world application using mathematical techniques covered in this course.
16. Present clear and concise mathematical arguments in assignments and exams.

Provides students with a practical understanding of the core economic principles that explain why individuals, companies and governments make the decisions they do, and how their decision-making might be improved to make best use of available resources.

This course builds on concepts that have been introduced in CHEM1100 (Chemistry 1) thereby developing the knowledge and understanding across inorganic, physical and organic chemistry necessary for advancement to the higher levels of study in chemistry, biochemistry and engineering courses. Core topics include: reaction profiles and kinetics, structure, reactivity and mechanisms, organic functional group chemistry, structural determination, acid and base chemistry and transition metal chemistry.
This course contains all of the theory for both inorganic & organic chemistry that a student will need to advance to third level chemistry. Topics covered will include: Synthesis & mechanism in organic chemistry; Transition Metal Chemistry; Bonding and Molecular Orbital Theory; Molecular Modelling; Stereochemistry; Modern spectroscopic techniques for Structural Analysis; Strategies for complex syntheses.

The aim of this course is to introduce students to the theory and concepts of quantum physics. Important experiments in the development of quantum physics will also be discussed. We will introduce students to the main ideas of quantum physics and teach the basic mathematical methods and techniques used in the fields of advanced quantum physics, atomic physics, laser physics, nanotechnology, quantum chemistry, and theoretical mathematics. Some of the key problems of quantum physics are also described, concentrating on the background derivation, techniques, results, and interpretations. We will not finish a complete exploration of all the predictions of quantum physics, but it is hoped that the predictions and problems explored here will provide a useful starting point for those interested in learning more. The intention is to explore problems which have been the most influential on the development of quantum physics and formulation of what we now call modern quantum physics.

Through studying PHYS3040 students will:
Develop an understanding of the basic features and laws of quantum physics
Develop an understanding of the key concepts in quantum physics such as quantum probabilities, superposition states, quantization, wave-particle duality, simultaneous measurement, symmetry and conservation laws, density operator, Heisenberg and Schrodinger pictures, particle identity.
Develop an understanding of and ability to apply the Dirac mathematical formalism of quantum mechanics.
Develop an understanding of and an ability to apply techniques such as matrix mechanics, wave mechanics, perturbation theory to quantum physics situations.
Develop an understanding of the quantum behaviour of important physical systems in fields such as atomic physics, molecular physics, solid state physics, quantum optics via the application of quantum physics methods.
Develop an ability to apply the methods of quantum physics to new physical systems and obtain analytical and numerical results describing the behaviour.

Basic concepts in thermodynamics, forms of energy; properties of pure substances, phase diagrams & phase transitions; first law of thermodynamics & applications - mass & energy balances in open & closed systems; entropy & second law of thermodynamics, exergy; topical engineering case studies.


This is an introductory course in Partial Differential Equations (PDE’s). We cover Fourier series, Fourier integrals, boundary value problems and separation of variables, with application to the solution of second order PDE’s in one, two and three dimensions.

1. **Introduction [3 lectures]**
   PDE’s and boundary conditions. Modeling the diffusion (heat) equation. Introduction to separation of variables.

2. **Fourier Series [5 lectures]**

3. **Sturm-Liouville Problems [4 lectures]**
   Eigenvalues and eigenfunctions. Strum-Louville eigenvalue problems, existence and orthogonality of solutions, eigenfunction expansions.

4. **Fourier Transforms [4 lectures]**
   Fourier representation of delta function. Convolution theorem. Application to PDEs.

5. **Wave Equation [7 lectures]**

6. **Laplace Equation [6 lectures]**

7. **Laplace Transforms [3 lectures]**
   Introduction to transform methods. Calculation and properties of the transform. Solution of ODEs and PDEs.

2. **Materials and energy balancing with and without chemical reaction, materials and energy balances in multiphase systems such as crystallization, evaporation, drying, humidification, dehumidification, absorption, distillation, extraction and filtration. An introduction to the most important unit operations in the chemical industry, design concept and safety as applied to processing.**

3. **Many mathematical models occurring in Science and Engineering cannot be solved exactly using algebra and calculus. Students are introduced to computer-based methods that can be used to find approximate solutions to these problems. The methods covered in the course are powerful yet simple to use. This is a core course for students who wish to advance in Applied Mathematics.**

**Syllabus:**
1. Review of Matlab
2. Iterative methods for linear algebraic equations - Jacobi, Gauss-Seidel (4 lectures)
3. Scalar non-linear equations – Linear models, iterative schemes, convergence, difficulties with methods (5 lectures)
4. Direct methods for linear algebraic equations - LU factoring, pivoting, conditioning (4 lectures)
5. Systems of non-linear equations – Newton’s method, finite differencing, continuation, use in unconstrained optimization
6. Interpolation – Newton divided differences, uniqueness of the interpolant, interpolation error, Vandermonde approach for general interpolation problems, Hermite cubic interpolation
7. Numerical differentiation, Quadrature - Newton-Cotes, error estimation, Gauss-Legendre, composite rules (6 lectures)

4. **A systematic development of Maxwell’s theory of electromagnetism and its applications to optics. Topics include: electrostatics, dielectrics, polarisation, charge conservation, magnetostatics, scalar and vector potentials, magnetic materials, Maxwell’s equations, the wave equation. Propagation of electromagnetic waves in vacuum, dielectrics and conducting media. Energy and momentum in electromagnetic waves.**
Students may select experiments from a wide spectrum of physics that are appropriate to the lecture courses being taken from PHYSICS 315--356.

Principles of continuous and staged processes. Mass transfer in various media, systems and phases. Interrelating reactor design to mass transfer processes. Studies of selected separation processes such as absorption, solvent extraction, and distillation. Heat transfer with phase change; nucleate and film boiling of liquids.

The study of differential equations is central to mathematical modeling of systems that change. Develops methods for understanding the behavior of solutions to ordinary differential equations. Qualitative and elementary numerical methods for obtaining information about solutions are discussed, as well as some analytical techniques for finding exact solutions in certain cases. Some applications of differential equations to scientific modeling are discussed.

Lecture Plan:
1. **First order differential equations [12 lectures]**
   - Introduction to differential equations and modeling with differential equations.
   - The phase line, equilibria, and bifurcations.

2. **First order systems of differential equations [16 lectures]**
   - Phase plane and qualitative analysis. Linear systems, including classification of equilibria. Nonlinear systems, including classification of equilibria.

3. **Higher order differential equations [5 lectures].**

Offers an introduction to the workings of market systems. This course deals with the economic behavior of consumers and firms, covering analysis of demand and supply of goods, services and resources within an economy. The framework developed is used to examine and evaluate the operation of the market mechanism for various market structures and government policies

**Syllabus:**
1. Scarcity and Choice; Opportunity Cost; Supply and Demand Functions
2. Supply and Demand Functions and Applications
3. Consumer Behavior
4. Theory of the Firm: Production and Costs
5. Perfect Competition: Implications
6. Perfect Competition: Limitations of the Model
7. Introduction to Imperfect Markets and Market Failure
8. Monopoly and Monopolistic Competition
9. Oligopoly and Game Theory
10. Imperfect Information, Externalities and Public Goods

Covers topics in linear algebra and multi-variable calculus including linear transformations, quadratic forms, double and triple integrals and constrained optimization. It is a preparation for a large number of Stage III courses in mathematics and statistics, and for many advanced courses in physics and other applied sciences. All students intending to advance in mathematics should take this course.

Lecture Plan:
2. Bases & dimension. The coordinate mapping.
3. Linear transformations and their matrices.
5. Eigenvectors and eigenvalues. Algebraic and geometric multiplicities of eigenvalues.
6. Invariant subspaces.
11. Orthogonal bases for vector space of polynomials and trigonometric polynomials.
17. Conics and Quadrics.
20. Functions of several variables. Limits and continuity.
22. Linear approximations, differentiability, tangent planes.
23. Differentials and the chain rule.
24. Gradient, directional derivatives, tangent planes.
27. Double integrals over rectangles.
28. Fubini’s theorem.
29. Double integrals over general domains.
30. Change of variables in double integrals.
32. Arc length parametrization.
33. Line integral of a vector function. Work as a line integral.
34. Fundamental theorem on line integrals.
36. A test for conservative vector field.
37. Green’s theorem


Introduces further principles of chemistry. Physical chemistry and qualitative inorganic analysis, including chemical kinetics and chemical equilibrium. Organic chemistry, including hydrocarbons, oxygen-containing functional groups, isomerism and reaction classifications, acids, bases, buffer solutions and titrations. Laboratories include reactions of hydrocarbon and oxygen-containing organic compounds, chromatography, testing for anions and cations in solution, acid-base titrations.

Non-relativistic quantum mechanics will be developed using the three-dimensional Schrödinger equation, and will be applied particularly to the physics of atoms and molecules. The interaction of like particles and the quantisation of angular momentum will be studied.

Materials and energy balancing with and without chemical reaction, materials and energy balances in multiphase systems such as crystallization, evaporation, drying, humidification, dehumidification, absorption, distillation, extraction and filtration. An introduction to the most important unit operations in the chemical industry, design concept and safety as applied to processing.