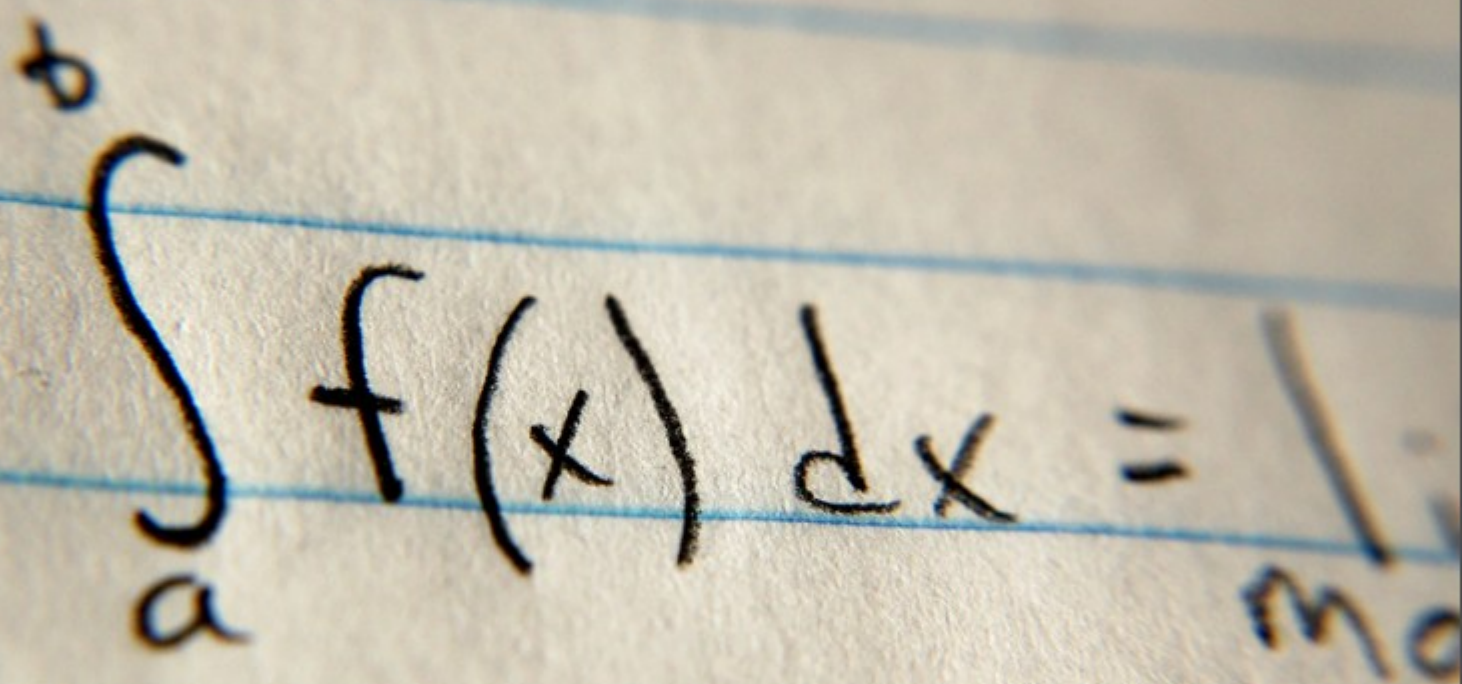


Engineering Mathematics: YouTube Workbook

Christopher C. Tisdell



A close-up photograph of a piece of lined paper with a handwritten mathematical formula in black ink. The formula is the definite integral of a function f(x) from a to b, set equal to a limit. The paper has light blue horizontal lines. The handwriting is in a cursive style. The formula is:
$$\int_a^b f(x) dx = \lim_{n \rightarrow \infty} \dots$$

Download free books at

bookboon.com

Christopher C. Tisdell

Engineering Mathematics: YouTube Workbook

Engineering Mathematics: YouTube Workbook
© 2012 Christopher C. Tisdell & Ventus Publishing ApS
ISBN 978-87-7681-961-3

Contents

	How to use this workbook	8
	About the author	9
	Acknowledgments	10
1	Partial derivatives & applications	11
1.1	Partial derivatives & partial differential equations	12
1.2	Partial derivatives & chain rule	14
1.3	Taylor polynomial approximations: two variables	16
1.4	Error estimation	18
1.5	Differentiate under integral signs: Leibniz rule	20
2	Some max/min problems for multivariable functions	22
2.1	How to determine & classify critical points	23
2.2	More on determining & classifying critical points	25
2.3	The method of Lagrange multipliers	27
2.4	Another example on Lagrange multipliers	29
2.5	More on Lagrange multipliers: 2 constraints	31

Please click the advert

DESTINATIONS

	GATE	ARRIVAL
INDUSTRY IMPACT	OW	FASTER
GLOBAL ASSIGNMENTS	OW	FASTER
SENIOR CLIENT CONTACT	OW	FASTER
CAREER DEVELOPMENT	OW	FASTER
MAKE PARTNER	OW	FASTER


OLIVER WYMAN



Oliver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies.

DISCOVER OUR WORLD

An equal opportunity employer.

GET THERE FASTER

Some people know precisely where they want to go. Others seek the adventure of discovering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers


MARSH & McLENNAN COMPANIES

3	A glimpse at vector calculus	33
3.1	Vector functions of one variable	34
3.2	The gradient field of a function	36
3.3	The divergence of a vector field	38
3.4	The curl of a vector field	40
3.5	Introduction to line integrals	42
3.6	More on line integrals	44
3.7	Fundamental theorem of line integrals	46
3.8	Flux in the plane + line integrals	48
4	Double integrals and applications	50
4.1	How to integrate over rectangles	51
4.2	Double integrals over general regions	53
4.3	How to reverse the order of integration	55
4.4	How to determine area of 2D shapes	57
4.5	Double integrals in polar co-ordinates	59
4.6	More on integration & polar co-ordinates	61
4.7	Calculation of the centroid	63
4.8	How to calculate the mass of thin plates	65
5	Ordinary differential equations	67
5.1	Separable differential equations	68

Please click the advert

Day one
and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future?
ey.com/careers

ERNST & YOUNG
Quality In Everything We Do

© 2010 EYGM Limited. All Rights Reserved.

5.2	Linear, first-order differential equations	70
5.3	Homogeneous, first-order ODEs	72
5.4	2nd-order linear ordinary differential equations	74
5.5	Nonhomogeneous differential equations	76
5.6	Variation of constants / parameters	78
6	Matrices and quadratic forms	80
6.1	Quadratic forms	81
7	Laplace transforms and applications	83
7.1	Introduction to the Laplace transform	84
7.2	Laplace transforms + the first shifting theorem	86
7.3	Laplace transforms + the 2nd shifting theorem	88
7.4	Laplace transforms + differential equations	90
8	Fourier series	93
8.1	Introduction to Fourier series	94
8.2	Odd + even functions + Fourier series	96
8.3	More on Fourier series	98
8.4	Applications of Fourier series to ODEs	100
9	PDEs & separation of variables	102
9.1	Deriving the heat equation	103

Please click the advert



Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.

Could it be 
Unilever



9.2	Heat equation & separation of variables	105
9.3	Heat equation & Fourier series	107
9.4	Wave equation and Fourier series	109
	Bibliography	111

Please click the advert



Discover the truth at www.deloitte.ca/careers

Deloitte.

© Deloitte & Touche LLP and affiliated entities.

How to use this workbook

This workbook is designed to be used in conjunction with the author's free online video tutorials. Inside this workbook each chapter is divided into learning modules (subsections), each having its own dedicated video tutorial.

View the online video via the hyperlink located at the top of the page of each learning module, with workbook and paper / tablet at the ready. Or click on the Engineering Mathematics YouTube Workbook playlist where all the videos for the workbook are located in chronological order:

Engineering Mathematics YouTube Workbook Playlist
<http://www.youtube.com/playlist?list=PL13760D87FA88691D> [1].

While watching each video, fill in the spaces provided after each example in the workbook and annotate to the associated text. You can also access the above via the author's YouTube channel

Dr Chris Tisdell's YouTube Channel
<http://www.youtube.com/DrChrisTisdell>

The delivery method for each learning module in the workbook is as follows:

- Briefly motivate the topic under consideration;
- Carefully discuss a concrete example;
- Mention how the ideas generalize;
- Provide a few exercises (with answers) for the reader to try.

Incorporating YouTube as an educational tool means enhanced eLearning benefits, for example, the student can easily control the delivery of learning by pausing, rewinding (or fast-forwarding) the video as needed.

The subject material is based on the author's lectures to engineering students at UNSW, Sydney. The style is informal. It is anticipated that most readers will use this workbook as a revision tool and have their own set of problems to solve – this is one reason why the number of exercises herein are limited.

Two semesters of calculus is an essential prerequisite for anyone using this workbook.

About the author

Dr Chris Tisdell is a mathematician within The School of Mathematics & Statistics at the University of New South Wales (UNSW) in Sydney, Australia.

Chris is interested in freely available learning materials, known as Open Educational Resources (OER). He has experimented with producing and sharing educational videos online through YouTube. Recognition of the success of this initiative has resulted in YouTube making Chris a “YouTube Partner in Education”. Chris has been an early Australian contributor to the online educational hub “YouTube EDU”.

Chris is also an active researcher, with interests in differential equations and their extensions. He has published over 70 research papers, most of which have been written during his 10 years at UNSW, Sydney. Chris has held visiting academic positions at: Imperial College London (John Yu Fellow); The University Of Hong Kong (Cheung Kong Fellow); and The University of Queensland (Ethel Raybould Fellow).

Before becoming a professional mathematician, Chris was a disc jockey (DJ) for over 10 years. He performed at nightclubs and music festivals throughout Australia and overseas alongside famous acts including: Fatboy Slim; Tiesto; Ferry Corsten; Chicane; Timo Maas; Faithless; Nick Warren; and Dave Seaman. He also ran a small record store. Some students believe this entertainment background helps Chris’ mathematical lectures to be more engaging than most.

Acknowledgments

The author thanks those who have read earlier drafts of this ebook and suggested improvements. This includes: Dr Bill Ellis; Mr Nicholas Fewster; and Mr Pingshun Huang – all at UNSW, Sydney.

Gratitude is also expressed to Ms Sophie Tergeist from bookboon.com Ltd. for inviting the author to undertake this work.

Chapter 1

Partial derivatives & applications

Please click the advert

Grant Thornton—^{REALLY}a great place to work.

We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute™ for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant
Manager



Audit • Tax • Advisory
www.GrantThornton.ca/Careers



Grant Thornton
An instinct for growth™

© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd

Download free ebooks at bookboon.com

1.1 Partial derivatives & partial differential equations

View this lesson at <http://www.youtube.com/watch?v=SV56UC31rbk>, [2].

Motivation.

Partial differential equations (PDEs) are very important in modelling as their solutions unlock the secrets to a range of important phenomena in engineering and physics. The PDE known as the wave equation models sound waves, light waves and water waves. It arises in fields such as acoustics, electromagnetics and fluid dynamics.

Example.

Consider the wave equation

$$\frac{\partial^2 w}{\partial t^2} = c^2 \frac{\partial^2 w}{\partial x^2}, \quad c \text{ is a constant.}$$

Show that a solution is given by

$$w(t, x) := \cos(2x + 2ct).$$

The bigger picture.

- When verifying solutions to PDEs, compute the necessary derivatives and show that the PDE holds.
- In certain circumstances, the chain rule will be required to compute the partial derivatives of interest.

Exercises.

Consider the wave equation

$$\frac{\partial^2 w}{\partial t^2} = c^2 \frac{\partial^2 w}{\partial x^2}, \quad c \text{ is a constant.}$$

Show that another solution is given by

$$w(t, x) = \ln(3x + 3ct).$$

Show that the wave equation has solutions of a more general form

$$w(t, x) = f(x + ct)$$

where f is a sufficiently smooth function. (Hint: use the chain rule.)

1.2 Partial derivatives & chain rule

View this lesson at <http://www.youtube.com/watch?v=H0zMR22HsiA>, [3].

Motivation.

The chain rule is an important technique for computing derivatives and better-understanding rates of change of functions. For functions of two (or more) variables, the chain rule takes various forms.

Example.

Let the function $w := f(x, y)$ have continuous partial derivatives. If we make a change of variables: $x = r \cos \theta$; $y = r \sin \theta$ then show that

$$\frac{\partial w}{\partial r} = \frac{\partial f}{\partial x} \cos \theta + \frac{\partial f}{\partial y} \sin \theta.$$

The bigger picture.

- It is generally helpful to draw a simple diagram to understand which form of the chain rule to apply.
- For functions of two (or more) variables, the chain rule takes a more profound form than the one-variable case.

Exercises.

Let the function $w := f(x, y)$ have continuous partial derivatives. If we make a change of variables: $x = r \cos \theta$; $y = r \sin \theta$ then show that

$$\frac{\partial w}{\partial \theta} = -\frac{\partial f}{\partial x} r \sin \theta + \frac{\partial f}{\partial y} r \cos \theta.$$

Please click the advert

The Wake

the only emission we want to leave behind

Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758.

MAN Diesel & Turbo



1.3 Taylor polynomial approximations: two variables

View this lesson at http://www.youtube.com/watch?v=ez_HZZ9H2ao, [4].

Motivation.

Taylor polynomials are a very simple and useful way of approximating complicated functions. Taylor polynomials are desirable types of approximations as their polynomial structure make them easy to work with.

Example.

Using an appropriate Taylor polynomial, compute an approximation to

$$\sqrt{(1.02)^3 + (1.97)^3}.$$

The bigger picture.

- The Taylor polynomial up to and including linear terms is usually a good starting approximation (unless a greater degree of accuracy is required)

$$T(x, y) := f(a, b) + f_x(a, b)(x - a) + f_y(a, b)(y - b).$$

- The use of a linear Taylor polynomial approximation geometrically equates to approximating surfaces by a suitable tangent plane.

Exercises.

Using an appropriate Taylor polynomial, compute an approximation to

$$\sqrt{(0.98)^3 + (2.03)^3}.$$

[Ans: 2.9].

1.4 Error estimation

View this lesson at <http://www.youtube.com/watch?v=wLrHCkes0A8>, [5].

Motivation.

When taking measurements (say, some physical dimensions), errors in the recorded measurements are a fact of life. In many cases we require measurements to be within some prescribed degree of accuracy. We now look at the effects of small variations in measurements and estimate the errors involved.

Example.

A cylindrical can has height h and radius r . We measure the height and radius and obtain 12cm and 5cm respectively, with errors in our measurements being no more than 0.5mm. As a result of the errors in our measurements for h and r , obtain an estimate on the percentage error in calculating the volume of the can.

The bigger picture.

- The main inequality used can be derived from the linear Taylor polynomial approximation for the function involved.
- Don't forget to unify the units involved!

Exercises.

- Re-examine the previous example by switching the recorded measurements for height and radius and then estimate the percentage error in V . Compare your estimate with the estimate of the previous example. [Ans 11/6%]
- We measure the length l and width w of a plot of land to be 40m and 10m respectively, with the errors in these measurements being no more than 0.5cm.. As a result of the errors in l and w , obtain an estimate on the percentage error in calculating the area of the plot. [Ans: 1/16%]

Please click the advert

**I WANT TO CHANGE DIRECTION,
AND THE WORLD.**

GOT-THE-ENERGY-TO-LEAD.COM

We believe that energy suppliers should be renewable, too. We are therefore looking for enthusiastic new colleagues with plenty of ideas who want to join RWE in changing the world. Visit us online to find out what we are offering and how we are working together to ensure the energy of the future.

RWE
The energy to lead™

1.5 Differentiate under integral signs: Leibniz rule

View this lesson at <http://www.youtube.com/watch?v=cipIYpDu9YY>, [6].

Motivation.

Leibniz rule:

$$I(x) := \int_a^b f(t, x) dt$$

has derivative

$$I'(x) = \int_a^b \frac{\partial f}{\partial x}(t, x) dt.$$

There are two important motivational points concerning Leibniz' rule:

- If a function I defined by an integral is useful for modelling purposes, then it would seem to make sense that the derivative I' would also give us insight into the problem under consideration;
- Leibniz' rule can be applied to evaluate very challenging integrals.

Example.

If

$$F(x) := \int_1^2 \frac{\cos tx}{t} dt$$

then calculate $F'(x)$.

The bigger picture.

Let $a = u(x)$ and $b = v(x)$ be differentiable functions. If f and $\partial f / \partial x$ are continuous on the region

$$S := \{(t, x) : u(x) \leq t \leq v(x), c \leq x \leq d\}$$

then

$$I(x) := \int_{u(x)}^{v(x)} f(t, x) dt$$

has derivative

$$I'(x) = \int_{u(x)}^{v(x)} \frac{\partial f}{\partial x}(t, x) dt + f(v(x), x)v'(x) - f(u(x), x)u'(x).$$

Exercises.

If

$$F(x) := \int_2^3 \frac{\sin tx}{t} dt$$

then calculate $F'(x)$.

[Ans: $(\sin 3x - \sin 2x)/x$.]

Chapter 2

Some max/min problems for multivariable functions

Please click the advert



You're full of *energy*
and ideas. And that's
just what we are looking for.

Looking for a career where your ideas could really make a difference? UBS's Graduate Programme and internships are a chance for you to experience for yourself what it's like to be part of a global team that rewards your input and believes in succeeding together.

Wherever you are in your academic career, make your future a part of ours by visiting www.ubs.com/graduates.

www.ubs.com/graduates



© UBS 2010. All rights reserved.

2.1 How to determine & classify critical points

View this lesson at <http://www.youtube.com/watch?v=LGF1LcLnSfE>, [7].

Motivation.

Functions of two (or more) variables enable us to model complicated phenomena in a more accurate way than, for example, by using functions of one variable. The determination and classification of critical points of functions is very important in engineering and the applied sciences as this information is sought in a wide range of problems involving modelling.

Example.

Determine and classify all the critical points of the function

$$f(x, y) := x^3 + y^3 - 3xy + 15.$$

The bigger picture.

Assume that f is continuous and has continuous partial derivatives up to and including all those of the second-order.

- Determine the critical points of f by solving the simultaneous equations: $f_x = 0$ and $f_y = 0$.
- If (a, b) is a critical point determined from above and defining

$$D(a, b) := f_{xx}(a, b)f_{yy}(a, b) - [f_{xy}(a, b)]^2$$

then the nature of the critical points can be then determined via the **2nd-derivative test**:

- (i) If $D(a, b) > 0$ and $f_{xx}(a, b) < 0$ then f has a local maximum at (a, b) ;
- (ii) If $D(a, b) > 0$ and $f_{xx}(a, b) > 0$ then f has a local minimum at (a, b) ;
- (iii) If $D(a, b) < 0$ then f has a saddle point at (a, b) ;
- (iv) If $D(a, b) = 0$ then the 2nd-derivative test cannot be used and some other method or technique must be sought to classify our critical points.

Exercises.

Determine and classify all the critical points of the function

$$f(x, y) := x^2 + xy + 3x + 2y + 5.$$

[Ans: This f has one critical point at $(-2, 1)$ with our f having a saddle point at $(-2, 1)$.]

2.2 More on determining & classifying critical points

View this lesson at <http://www.youtube.com/watch?v=1q2kdnRY5h8>, [8].

Motivation.

The determination and classification of critical points of functions is very important in engineering and the applied sciences as this information is sought in a wide range of problems involving modelling. We now look at a more involved example.

Example.

Let $A > 0$ be a constant. Determine and classify all the critical points of the function

$$f(x, y) := x^2 - Axy + y^2 + 7.$$

Hint – Discuss the cases: $A = 2$; $0 < A < 2$; $A > 2$.

Please click the advert

 RBS Group

CAREER KICKSTART

An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

Click [here](#) to get started.

The bigger picture.

Assume that f is continuous and has continuous partial derivatives up to and including all those of the second-order.

- Determine the critical points of f by solving the simultaneous equations: $f_x = 0$ and $f_y = 0$.
- If (a, b) is a critical point determined from above and defining

$$D(a, b) := f_{xx}(a, b)f_{yy}(a, b) - [f_{xy}(a, b)]^2$$

then the nature of the critical points can be then determined via the **2nd-derivative test**:

- (i) If $D(a, b) > 0$ and $f_{xx}(a, b) < 0$ then f has a local maximum at (a, b) ;
- (ii) If $D(a, b) > 0$ and $f_{xx}(a, b) > 0$ then f has a local minimum at (a, b) ;
- (iii) If $D(a, b) < 0$ then f has a saddle point at (a, b) ;
- (iv) If $D(a, b) = 0$ then the 2nd-derivative test cannot be used and some other method or technique must be sought to classify our critical points.

Exercises.

Determine and classify all the critical points of the functions:

- (a) $f(x, y) := x^2 + xy + y^2 + 3y + 3$;
- (b) $f(x, y) := -x^2 - 1 - y^2$.

[Ans: (a) This f has one critical point at $(1, -2)$ with f having a local minimum at $(1, -2)$. (b) This f has one critical point at $(0, 0)$ with f having a local maximum at $(0, 0)$.]

2.3 The method of Lagrange multipliers

View this lesson at <http://www.youtube.com/watch?v=4E-uLaRhrcA>, [9].

Motivation.

The method of Lagrange multipliers is a very powerful technique enabling us to maximize or minimize a function that is subject to a constraint. Such kinds of problems frequently arise in engineering and applied mathematics, eg, designing a cylindrical silo to maximize its volume subject to a certain fixed amount of building material.

Example.

Consider a thin, metal plate that occupies the region in the XY -plane

$$\Omega := \{(x, y) : x^2 + y^2 \leq 25\}.$$

If $f(x, y) := 4x^2 - 4xy + y^2$ denotes the temperature (in degrees C) at any point (x, y) in Ω then determine the highest and lowest temperatures on the edge of the plate.

The bigger picture.

Suppose f and g have continuous partial derivatives and: $\partial g/\partial x \neq 0$; $\partial g/\partial y \neq 0$; when $g = 0$.

- If f is our function to maximize/minimize and $g = 0$ is our constraint then the method of Lagrange multipliers involves calculating the critical points of the Lagrangian function

$$L := f - \lambda g$$

where λ is the Lagrange multiplier.

- To solve the resulting simultaneous equations, some creativity is often required.
- If L has more than one critical point then compare values of f at each critical point to determine which gives max/min values of f .

Exercises.

Determine the maximum value of $f(x, y) := xy$ subject to the constraint $g(x, y) := x + y - 16 = 0$.
[Ans: At $(8, 8)$, f has a maximum value of 64.]

Please click the advert

ORACLE®

Be BRAVE

enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

<https://campus.oracle.com>



ORACLE®

ORACLE IS THE INFORMATION COMPANY

2.4 Another example on Lagrange multipliers

View this lesson at <http://www.youtube.com/watch?v=5w-b1yU9hy4>, [10].

Motivation.

The method of Lagrange multipliers is a very powerful technique enabling us to maximize or minimize a function that is subject to a constraint. Such kinds of problems frequently arise in engineering and applied mathematics.

Example.

The temperature at a point (x, y) on a metal plate in the XY -plane is given by

$$T(x, y) := 6xy.$$

Use the method of Lagrange to determine the maximum temperature on the circle $x^2 + y^2 = 8$.

The bigger picture.

Suppose f and g have continuous partial derivatives and: $\partial g/\partial x \neq 0$; $\partial g/\partial y \neq 0$; when $g = 0$.

- If f is our function to maximize/minimize and $g = 0$ is our constraint then the method of Lagrange multipliers involves calculating the critical points of the Lagrangian function

$$L := f - \lambda g$$

where λ is the Lagrange multiplier.

- To solve the resulting simultaneous equations, some creativity is often required.
- If L has more than one critical point then compare values of f at each critical point to determine which gives max/min values of f .

Exercises.

Minimize $f(x, y, z) := x^2 + y^2 + z^2$ subject to the constraint $g(x, y, z) := 2x - y + z - 1 = 0$.
[Ans: At $(1/3, 1/6, -1/6)$, f has a maximum value of $2/9$.]

2.5 More on Lagrange multipliers: 2 constraints

View this lesson at <http://www.youtube.com/watch?v=7fRYd8PKeGY>, [11].

Motivation.

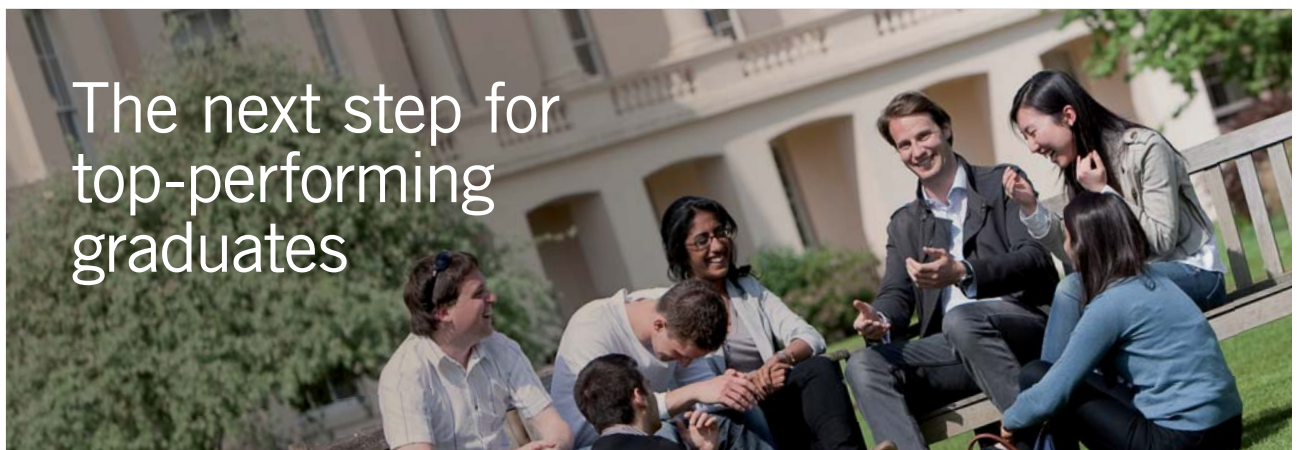
The method of Lagrange multipliers is a very powerful technique enabling us to maximize or minimize a function that is subject to a constraint. Sometimes we have two (or more) constraints. Such kinds of problems frequently arise in engineering and applied mathematics.

Example.

Maximize the function $f(x, y, z) := x^2 + 2y - z^2$ subject to the constraints:

$$g_1(x, y, z) := 2x - y = 0; \quad g_2(x, y, z) := y + z = 0.$$

Please click the advert



Masters in Management



Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation*; the majority of graduates choosing to work in consulting or financial services.

As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit www.london.edu/mm, email mim@london.edu or give us a call on **+44 (0)20 7000 7573**.

* Figures taken from London Business School's Masters in Management 2010 employment report

The bigger picture.

- If f is our function to maximize/minimize and $g_1 = 0$, $g_2 = 0$ are our constraints then the method of Lagrange multipliers involves calculating and comparing the critical points of the Lagrangian function

$$L := f - [\lambda_1 g_1 + \lambda_2 g_2]$$

where λ_1, λ_2 are the Lagrange multipliers.

- To solve the resulting simultaneous equations, some creativity is often required.
- If L has more than one critical point then compare values of f at each critical point to determine which gives max/min values of f .

Exercises.

Determine the minimum value of $f(x, y, z) := x^2 + y^2 + z^2$ subject to the constraints:

$$g_1(x, y, z) := x + 2y + 3z - 6 = 0; \quad g_2(x, y, z) := x + 3y + 9z - 9 = 0.$$

[Ans: Min value occurs at $(1 + 22/59, 2 + 5/59, 9/59)$.]

Chapter 3

A glimpse at vector calculus

Please click the advert

Destination MMU



Manchester
Metropolitan
University

MMU is proud to be one of the most popular universities in the UK. Some 34,000 students from all parts of the globe select from its curricula of over 1,000 courses and qualifications.

We are based in the dynamic yet conveniently compact city of Manchester, located at the heart of a sophisticated transport network including a major international airport on the outskirts. Parts of the campus are acclaimed for their architectural style and date back over 150 years, in direct contrast to our teaching style which is thoroughly modern, innovative and forward-thinking.

MMU offers undergraduate and postgraduate courses in the following subject areas:

- Art, Design & Performance
- Computing, Engineering & Technology
- Business & Management
- Science, Environmental Studies & Geography
- Law, Education & Psychology
- Food, Hospitality, Tourism & Leisure Studies
- Humanities & Social Science

A photograph of a young man with dark hair and glasses, wearing a light-colored shirt and a grey blazer. He is sitting at a desk, looking towards the right side of the frame, possibly at a laptop screen. The background is slightly blurred, showing what appears to be a modern interior.

For more details or an application form please contact MMU International.
email: international@mmu.ac.uk
telephone: +44 (0)161 247 1022
www.mmu.ac.uk/international

3.1 Vector functions of one variable

View this lesson at <http://www.youtube.com/watch?v=hmN1Duk08Yk>, [12].

Motivation.

Vector-valued functions allow us more flexibility in the modelling of phenomena in two and three dimensions, such as the orbits of planets. The most basic of vector-valued functions are those involving one variable which can be used to describe and analyze curves in space.

Example.

Consider the function $\mathbf{r}(t) := (\cos t, \sin t, t)$ for $t \geq 0$.

1. Sketch and describe the curve associated with \mathbf{r} .
2. If a particle travels along this curve (with t representing time) then calculate $\mathbf{r}'(t)$ and show that its speed is constant.
3. Calculate

$$\int_0^{\pi} \mathbf{r}(t) \, dt.$$

The bigger picture.

- Differentiation, integration and limits of vector-valued functions of one variable involve differentiation, integration and limits of each component function.
- For smooth curves, $\mathbf{r}'(t)$ is a tangent vector to the curve and points in the direction of motion $\mathbf{r}'(t)/\|\mathbf{r}'(t)\|$.

Exercises.

Consider the function $\mathbf{r}(t) := (2 \cos t, 3 \sin t)$ for $t \geq 0$.

1. Sketch and describe the curve associated with \mathbf{r} .
2. If a particle travels along this curve (with t representing time) then calculate $\mathbf{r}'(t)$. Is the speed constant?
3. Calculate

$$\int_{-\pi}^{\pi} \mathbf{r}(t) \, dt.$$

[Ans: 1. The curve is the ellipse $x^2/4 + y^2/9 = 1$; 2. $\mathbf{r}'(t) = (-2 \sin t, 3 \cos t)$. No.; 3. $(0, 0)$.]

3.2 The gradient field of a function

View this lesson at <http://www.youtube.com/watch?v=Xw5wsWDt1Cg>, [13].

Motivation.

The gradient field of a function is one of the basic concepts of vector calculus. It can be used to construct normal vectors to curves and surfaces, it can be applied to calculate slopes of tangent lines to surfaces in any direction, and can be very useful when integrating over curves (line integrals) to compute work done.

Example.

Consider the function $f(x, y) := x^2 + 4y^2$.

1. Compute ∇f .
2. Show that ∇f is normal to the level curve $f(x, y) = 16$.
3. Calculate the rate of change (directional derivative) of f at $(1, 1)$ in the direction $\mathbf{u} = (1, 1)$.



Get Internationally Connected at the University of Surrey

MA Intercultural Communication with International Business
MA Communication and International Marketing



MA Intercultural Communication with International Business

Provides you with a critical understanding of communication in contemporary socio-cultural contexts by combining linguistic, cultural/media studies and international business and will prepare you for a wide range of careers.

MA Communication and International Marketing

Equips you with a detailed understanding of communication in contemporary international marketing contexts to enable you to address the market needs of the international business environment.

For further information contact:

T: +44 (0)1483 681681

E: pg-enquiries@surrey.ac.uk

www.surrey.ac.uk/downloads

Please click the advert

The bigger picture.

- The gradient readily generalizes to equations involving three or more variables, $\nabla f = (f_x, f_y, f_z)$.
- For differentiable functions f the vector ∇f will always be normal to level curves / level surfaces of f .
- For differentiable functions of two variables the directional derivative of f at $P(x_0, y_0)$ in the direction of \mathbf{u} is just the slope of the tangent line to the surface of f with the tangent line lying in the vertical plane that contains $(x_0, y_0, f(x_0, y_0))$ and \mathbf{u} .
- Directional derivatives are generalizations of partial derivatives.

Exercises.

Consider the function $f(x, y, z) := x^2 + y^2 - z^2$.

1. Compute ∇f .
2. Compute a normal vector to the surface $f(x, y, z) = -7$ at $(1, 1, 3)$.
3. Calculate the rate of change (directional derivative) of f at $(1, 1, 1)$ in the direction $\mathbf{u} = (1, 1, 1)$.

[Ans: 1. $(2x, 2y, -2z)$; 2. $(2, 2, -6)$; 3. $2/\sqrt{3}$.]

3.3 The divergence of a vector field

View this lesson at <http://www.youtube.com/watch?v=quZlfp59iJg>, [14].

Motivation.

The divergence of a vector field is one of the basic concepts of vector calculus. It measures expansion and compression of a vector field and can be very useful when integrating over curves (line integrals) and surfaces to compute flux.

Example.

- (a) If $\mathbf{F}(x, y, z) := (x^2 - y, y + z, z^2 - x)$ then compute $\nabla \bullet \mathbf{F}$ at $(1, 2, 3)$.
- (b) If $\mathbf{G}(x, y) := (0, x)$ then compute $\nabla \bullet \mathbf{G}$. Sketch \mathbf{G} and show that there is a zero net outflow over each rectangle.

The bigger picture.

- The divergence measures net outflow of a vector field.
- If the divergence is positive everywhere, then there is a net outflow over every closed curve / surface.
- If the divergence is negative everywhere, then there is a net inflow over every closed curve / surface.
- A vector field with zero divergence everywhere is called “incompressible” with zero net outflow over every closed curve / surface.

Exercises.

Consider $\mathbf{F}(x, y, z) := (x \cos y, y \sin x, z^2 - 1)$ and $\mathbf{G}(x, y) := (x, y)$.

1. Compute $\nabla \bullet \mathbf{F}$ and $\nabla \bullet \mathbf{G}$.
2. Sketch \mathbf{G} and show that there is a net outflow over each circle in the plane.

[Ans: 1. $\cos y + \sin x + 2z$, 2; 2. Sketch \mathbf{G} and graphically show the net outflow is positive.]

3.4 The curl of a vector field

View this lesson at <http://www.youtube.com/watch?v=qeOT0YufpSY>, [15].

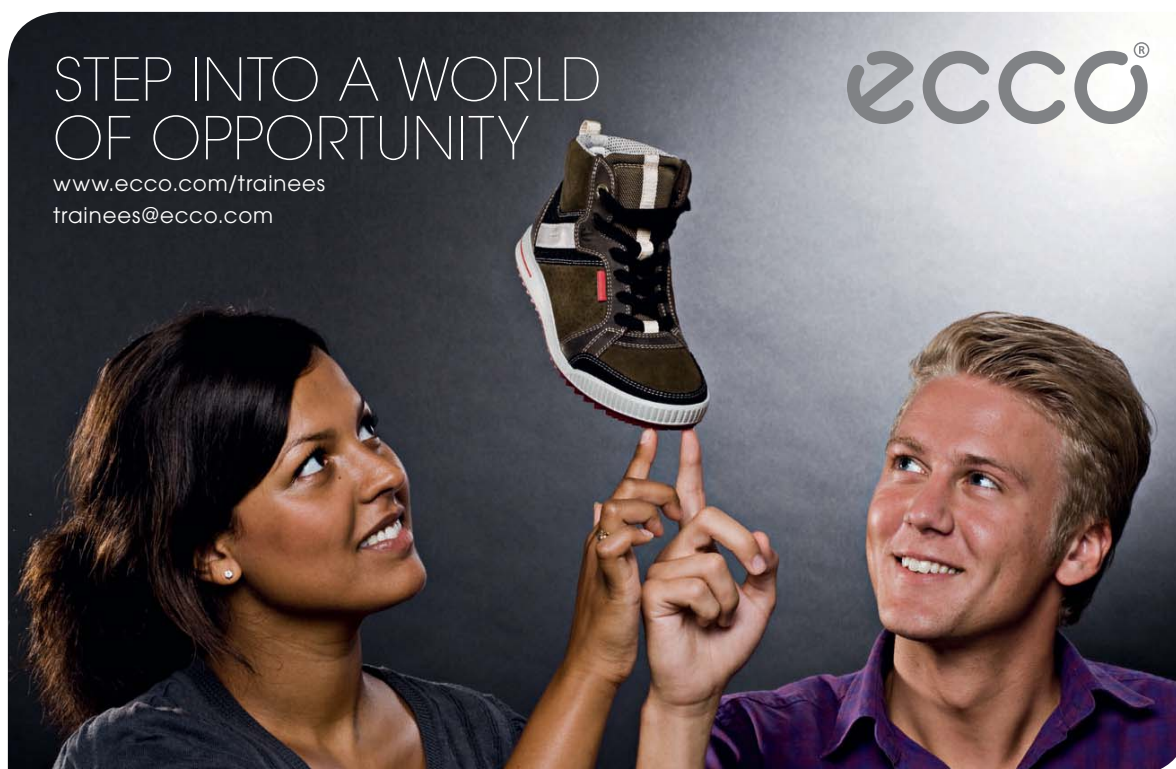
Motivation.

The curl of a vector field is one of the basic concepts of vector calculus. It measures rotation in a vector field and can be very useful when integrating over curves (line integrals) and surfaces.

Example.

- (a) If $\mathbf{F}(x, y, z) := (x^2 - y, y + z, z^2 - x)$ then compute $\nabla \times \mathbf{F}$ at $(1, 2, 3)$.
- (b) If $\mathbf{G}(x, y) := (y, 0)$ then compute the scalar curl of \mathbf{G} . Sketch \mathbf{G} and discuss the rotation in \mathbf{G} .

Please click the advert



The bigger picture.

- The curl measures rotation in a vector field.
- If the scalar curl is positive everywhere in the plane, then there is an anti-clockwise rotation of a paddlewheel in the plane about its axis.
- If the scalar curl is negative everywhere in the plane, then there is clockwise rotation of a paddlewheel in the plane about its axis.
- A vector field with zero curl everywhere is called “irrotational”. In the plane this means a paddlewheel in the vector field not spinning about its axis.

Exercises.

Consider $\mathbf{F}(x, y, z) := (z \cos y, z \sin x, z^2 - y^3)$ and $\mathbf{G}(x, y) := (x, y)$.

1. Compute $\nabla \times \mathbf{F}$ and the scalar curl of \mathbf{G} .
2. Sketch \mathbf{G} and graphically show that \mathbf{G} is irrotational.

[Ans: 1. $(-3y^2 - \sin x, \cos y, z \cos x + z \sin y)$, 0; 2. Sketch \mathbf{G} and graphically show a paddlewheel cannot rotate about its axis.]

3.5 Introduction to line integrals

View this lesson at <http://www.youtube.com/watch?v=6YuyBnXBFXg>, [16].

Motivation.

A line integral involves the integration of functions over curves. Applications include: calculating work done; determining the total mass and center of mass of thin wires; and also finding flux over curves.

Example.

(a) If $f(x, y) := x + y$ and \mathcal{C} is the unit circle with center at $(0, 0)$ then compute the line integral

$$\int_{\mathcal{C}} f \, ds.$$

(b) If $\mathbf{F}(x, y) := (-y + 1)\mathbf{i} + x\mathbf{j}$ and \mathcal{C} is oriented via an anticlockwise rotation then compute the line integral

$$\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r}.$$

The bigger picture.

- For a smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$

$$\int_{\mathcal{C}} f \, ds = \int_a^b f(\mathbf{r}(t)) \|\mathbf{r}'(t)\| dt.$$

- For an oriented smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$

$$\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r} = \int_{\mathcal{C}} \mathbf{F} \bullet \hat{\mathbf{T}} \, ds$$

where $\hat{\mathbf{T}}$ is the unit tangent vector in the direction of motion.

Exercises.

Let \mathcal{C} be part of a parabola $y = x^2$ parametrized by $\mathbf{r}(t) = t\mathbf{i} + t^2\mathbf{j}$, $0 \leq t \leq 2$.

1. If $f(x, y) := x^2 - y + x$ then compute

$$\int_{\mathcal{C}} f \, ds.$$

2. If \mathcal{C} is oriented in the direction from $(0, 0)$ to $(1, 1)$ and if $\mathbf{F}(x, y) := 2x\mathbf{i} + y\mathbf{j}$ then compute

$$\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r}.$$

What answer would we obtain if we reversed the orientation of \mathcal{C} ?

[Ans: 1. $27/12$; 2. $3/2$, while reversing the orientation would give $-3/2$.]

3.6 More on line integrals

View this lesson at <http://www.youtube.com/watch?v=S2rT2zK2bdo>, [17].

Motivation.

A line integral involves the integration of functions over curves. Applications include: calculating work done; determining the total mass and center of mass of thin wires; and also finding flux over curves. An important part of the integration process is to appropriately describe the curve of integration by “parametrization”.

Example.

For the vector field

$$\mathbf{F} = 8e^{-x}\mathbf{i} + \cosh z\mathbf{j} - y^2\mathbf{k}$$

calculate:

- (i) $\nabla \bullet \mathbf{F}$ (i.e. $\text{div } \mathbf{F}$) and $\nabla \times \mathbf{F}$ (i.e. $\text{curl } \mathbf{F}$);
- (ii) The line integral of \mathbf{F} along the straight line from $A(0, 1, 0)$ to $B(\ln(2), 1, 2)$.



Please click the advert

As a leading technology company in the field of geophysical science, PGS can offer exciting opportunities in offshore seismic exploration.

We are looking for new BSc, MSc and PhD graduates with Geoscience, engineering and other numerate backgrounds to join us.

To learn more our career opportunities, please visit www.pgs.com/careers

A Clearer Image
www.pgs.com



The bigger picture.

- For a smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$

$$\int_{\mathcal{C}} f \, ds = \int_a^b f(\mathbf{r}(t)) \|\mathbf{r}'(t)\| dt.$$

- For an oriented smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$

$$\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r} = \int_{\mathcal{C}} \mathbf{F} \bullet \hat{\mathbf{T}} \, ds$$

where $\hat{\mathbf{T}}$ is the unit tangent vector in the direction of motion.

Exercises.

Let \mathcal{C} be the curve parametrized by $\mathbf{r}(t) = t^2\mathbf{i} + \sqrt{t}\mathbf{j} + \sqrt{t}\mathbf{k}$, from $t = 2$ to $t = 4$.
If $\mathbf{F}(x, y, z) := x^2\mathbf{i} - z\mathbf{j} + 2xy\mathbf{k}$ then compute

$$\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r}.$$

[Ans: 49013/3.]

3.7 Fundamental theorem of line integrals

View this lesson at <http://www.youtube.com/watch?v=nH5KCrEuvyA>, [18].

Motivation.

A line integral involves the integration of functions over curves. In certain cases the value of the line integral is independent of the curve between two points. In such a case we may apply a “fundamental theorem of line integrals”.

Example.

Consider the vector field

$$\mathbf{F} := (2xyz + \cos x)\mathbf{i} + x^2z\mathbf{j} + (x^2y + e^z)\mathbf{k}.$$

- i) Show that $\nabla \times \mathbf{F} = \text{curl } \mathbf{F} = \mathbf{0}$.
- ii) Find a scalar field ϕ such that $\nabla\phi = \text{grad } \phi = \mathbf{F}$.
- iii) Hence or otherwise evaluate $\int_{\mathcal{C}} \mathbf{F} \bullet d\mathbf{r}$ where the path \mathcal{C} is parametrized by

$$\mathbf{r}(t) := (\sin t, \cos t, t), \quad \text{from } t = 0 \text{ to } t = 2\pi.$$

The bigger picture.

- If there is a scalar-valued function ϕ such that $\nabla\phi = \mathbf{F}$ then the line integral

$$\int_C \mathbf{F} \cdot d\mathbf{r}$$

is independent of the path C from starting point A to ending point B . Furthermore,

$$\int_C \mathbf{F} \cdot d\mathbf{r} = \phi(B) - \phi(A).$$

- If $\text{curl } \mathbf{F} = \mathbf{0}$ then a ϕ will exist such that $\nabla\phi = \mathbf{F}$.

Exercises.

Consider the vector field

$$\mathbf{F} := yz\mathbf{i} + xz\mathbf{j} + xy\mathbf{k}.$$

Evaluate $\int_C \mathbf{F} \cdot d\mathbf{r}$ where C is any path from $(0, 0, 0)$ to $(2, 1, 3)$.

[Ans: 3.]

Please click the advert



5365/07/09

Going up in the world...

You'll be going up in the world after graduating from Nottingham Trent University. We are one of the best universities in England for graduate employment with over 97% of our students employed or in further study within six months of graduating.*

- Consistently ranked as one of the leading modern universities in *The Independent Good University Guide*.
- Courses informed by businesses and industry – strong commercial partnerships with over 6,000 companies globally.
- Many courses include professional accreditation and / or the opportunity to undertake a work placement. This gives our graduates a competitive edge when entering the job market.
- An exciting student city in the middle of England. Ideally located for travel across the UK and with direct flights to destinations across Europe from East Midlands Airport.
- Investing £130 million across our three campuses to create an inspiring learning environment.
- In the most recent QAA institutional review, the University received the highest commendation for its consistent commitment to supporting students and their learning.

If you would like any guidance on applying to Nottingham Trent University please contact Laura Vella, our International Officer for Europe, on

Tel: +44 (0)115 848 8180

Email: laura.vella@ntu.ac.uk

www.ntu.ac.uk/book

NOTTINGHAM
TRENT UNIVERSITY

* HESA DHLE 2006-07

3.8 Flux in the plane + line integrals

View this lesson at <http://www.youtube.com/watch?v=YHiTuLNu3Sc>, [19].

Motivation.

We show how line integrals can be used to calculate the outward flux (flow rate) of a vector field over a closed curve in the plane. Such ideas have important applications to fluid flow.

Example.

Let \mathcal{C} be the ellipse $x^2/4 + y^2 = 1$.

- (a) Compute an outward-pointing normal vector \mathbf{n} to \mathcal{C} .
- (b) If $\mathbf{F}(x, y) := 4x\mathbf{i} + y\mathbf{j}$ then compute the outward flux over \mathcal{C} .

The bigger picture.

- For a closed, smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$ a normal vector to \mathcal{C} may be produced by calculating $\mathbf{r}' \times \mathbf{k}$ (or $\mathbf{k} \times \mathbf{r}'$).
- For a smooth curve \mathcal{C} with parametrization $\mathbf{r} = \mathbf{r}(t)$, $a \leq t \leq b$ and with outward pointing unit normal vector $\hat{\mathbf{n}}$ we can compute the outward flux over \mathcal{C} via

$$\oint_{\mathcal{C}} \mathbf{F} \cdot \hat{\mathbf{n}} \, ds.$$

Exercises.

Let \mathcal{C} be the circle with centre $(0, 0)$ and radius 2.

1. Compute an outward-pointing normal vector \mathbf{n} to \mathcal{C} .
2. If $\mathbf{F}(x, y) := (x + 1)\mathbf{i} + y\mathbf{j}$ then compute the outward flux over \mathcal{C} .
3. Compute

$$\iint_{\Omega} \nabla \cdot \mathbf{F} \, dA$$

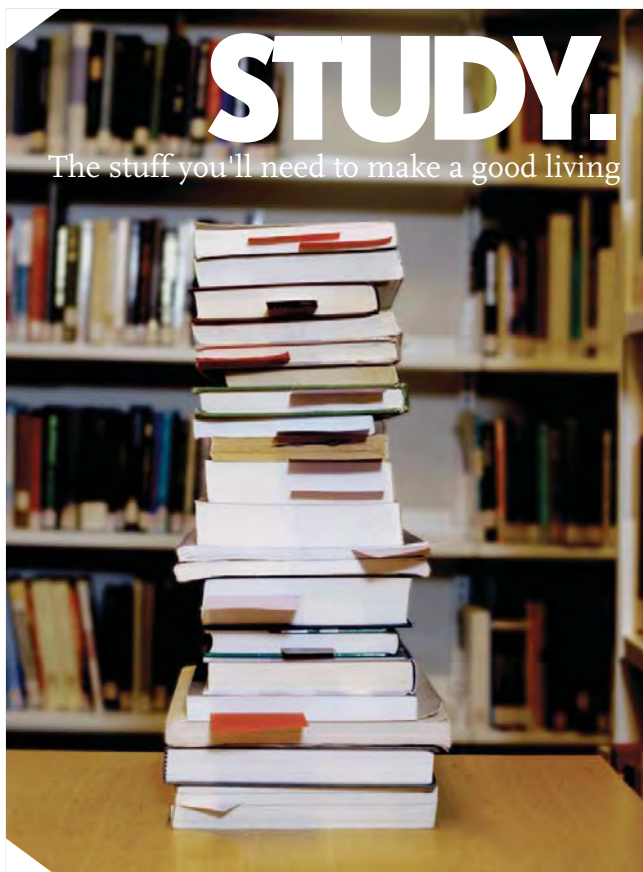
where Ω is the disc (bounded by \mathcal{C}). Compare your answer with (b).

[Ans: 1. If $\mathbf{r}(t) = (2 \cos t, 2 \sin t)$, $0 \leq t \leq 2\pi$ then $\hat{\mathbf{n}} = (\cos t, \sin t)$; 2. 8π , 3. 8π .]

Chapter 4

Double integrals and applications

Please click the advert



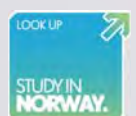
The stuff you'll need to make a good living



The stuff that makes life worth living

NORWAY.
YOUR IDEAL STUDY DESTINATION.

WWW.STUDYINNORWAY.NO
FACEBOOK.COM/STUDYINNORWAY



4.1 How to integrate over rectangles

View this lesson at <http://www.youtube.com/watch?v=My6sdEekbHM>, [20].

Motivation.

Double integrals are a generalisation of the basic single integral seen in high-school. Double integrals enable us to work with more complicated problems in higher dimensions and find many engineering applications, for example, in calculating centre of mass and moments of inertia of thin plates.

Example.

Evaluate

$$I := \int_1^3 \int_2^3 (x^2 - 2xy + 2y^3) \, dy \, dx.$$

The bigger picture.

- When evaluating a given double integral, perform the “inside” integral first and then move to the outside integral.
- Fubini’s Theorem (simple version): If $f = f(x, y)$ is continuous on the rectangle

$$R := \{(x, y) : a \leq x \leq b, c \leq y \leq d\}$$

then

$$\iint_R f(x, y) \, dA = \int_c^d \int_a^b f(x, y) \, dx \, dy = \int_a^b \int_c^d f(x, y) \, dy \, dx.$$

- It is generally a good idea to sketch the region of integration so as to better understand the geometry of the problem.

Exercises.

Evaluate:

- (a) $\int_0^1 \int_1^2 (x^2 - 2x + y) \, dy \, dx;$
- (b) $\int_0^2 \int_0^1 (x^2 + y^2) \, dx \, dy.$

[Ans: (a) 5/6; (b) 10/3.]

4.2 Double integrals over general regions

View this lesson at <http://www.youtube.com/watch?v=9cAVY9niDnI>, [21].

Motivation.

We now learn how to integrate over more general two-dimensional regions than just rectangles.

Example.

Evaluate

$$I := \iint_{\Omega} (x^2 y + y^3) \, dy \, dx$$

where

$$\Omega := \{(x, y) : x^2 + y^2 \leq 1, x \geq 0, y \geq 0\}.$$

Please click the advert

Are you considering a European business degree?

LEARN BUSINESS at university level. We mix cases with cutting edge research working individually or in teams and everyone speaks English. Bring back valuable knowledge and experience to boost your career.

MEET a culture of new foods, music and traditions and a new way of studying business in a safe, clean environment – in the middle of Copenhagen, Denmark.

ENGAGE in extra-curricular activities such as case competitions, sports, etc. – make new friends among CBS' 18,000 students from more than 80 countries.

Copenhagen Business School
HANDELSHØJSKOLEN

EFMD **EQUIS** AACSB Accredited by Association of MBAs CEMS PEFM

See what we look like and how we work on cbs.dk

The bigger picture.

- To form a integral over more general two-dimensional regions we appropriately describe its boundary (or edges).
- When evaluating a given double integral, perform the “inside” integral first and then move to the outside integral.
- It is generally a good idea to sketch the region of integration so as to better-understand the geometry of the problem.

Exercises.

Evaluate:

$$(a) \quad \int_0^1 \int_0^x (x^2 - 2x + y) \, dy \, dx;$$

$$(b) \quad \int_0^1 \int_0^y (x^2 + y^2) \, dx \, dy.$$

[Ans: (a) 3/4; (b) 1/3.]

4.3 How to reverse the order of integration

View this lesson at <http://www.youtube.com/watch?v=zxyx73HAtfQ>, [22].

Motivation.

The order of integration in double integrals can sometimes be reversed and can lead to a greatly simplified (but equivalent) double integral that is easier to evaluate than the original one. This “order reversion” technique can be used when performing calculations involving the applications associated with double integrals.

Example.

Evaluate the following integral by reversing the order of integration

$$I := \int_0^1 \int_{\sqrt{x}}^1 \sqrt{1+y^3} \, dy \, dx.$$

The bigger picture.

When reversing the order of integration, the region of integration needs to be suitably redescribed. Appropriate diagrams will help with understanding the geometry of the problem and hence will assist with the redescription of the region of integration.

Exercises.

Evaluate the following integral by reversing the order of integration

$$I := \int_0^4 \int_{3x}^{12} \sin(y^2) \, dy \, dx.$$

[Ans: $(1 - \cos 144)/6$.]

Please click the advert



Technical training on *WHAT* you need, *WHEN* you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today
 at training@idc-online.com or visit our website
 for more information: www.idc-online.com/onsite/

**OIL & GAS
ENGINEERING**

ELECTRONICS

**AUTOMATION &
PROCESS CONTROL**

**MECHANICAL
ENGINEERING**

**INDUSTRIAL
DATA COMMS**

**ELECTRICAL
POWER**

Phone: **+61 8 9321 1702**

Email: training@idc-online.com

Website: www.idc-online.com



4.4 How to determine area of 2D shapes

View this lesson at <http://www.youtube.com/watch?v=wiFUGkHTm00>, [23].

Motivation.

Double integrals are a generalisation of the basic single integral seen in high-school. They can be used to determine the area of two-dimensional shapes, which can be an important part of, for example, determining the centroid.

Example.

Using double integrals, calculate the area of the region bounded by the curves:

$$y = \sqrt{x}; \quad y = x; \quad y = x/2.$$

The bigger picture.

- Assume that f is continuous on a two-dimensional region Ω . We can calculate the area of Ω by evaluating

$$\iint_{\Omega} dA.$$

- If Ω is not a simple region then it may be possible to deconstruct Ω into simple parts in order to calculate the integral(s) involved.
- It is generally a good idea to sketch the region of integration so as to better-understand the geometry of the problem.

Exercises.

- (a) Use double integrals to determine the area of the region bounded by the lines:

$$y = x^3; \quad y = x^2.$$

- (b) If you are familiar with double integrals in polar coordinates, then prove that the area of a circle with radius $R > 0$ is πR^2 using double integration.

[Ans: (a) $1/12 u^2$ where u^2 means “square units”.]

4.5 Double integrals in polar co-ordinates

View this lesson at <http://www.youtube.com/watch?v=zknGq9CvZTQ>, [24].

Motivation.

We know from basic calculus that sometimes a change of variables can greatly simplify very complicated integrals. We now explore this idea in the more general setting of double integrals under a specific change of variables known as polar co-ordinates.

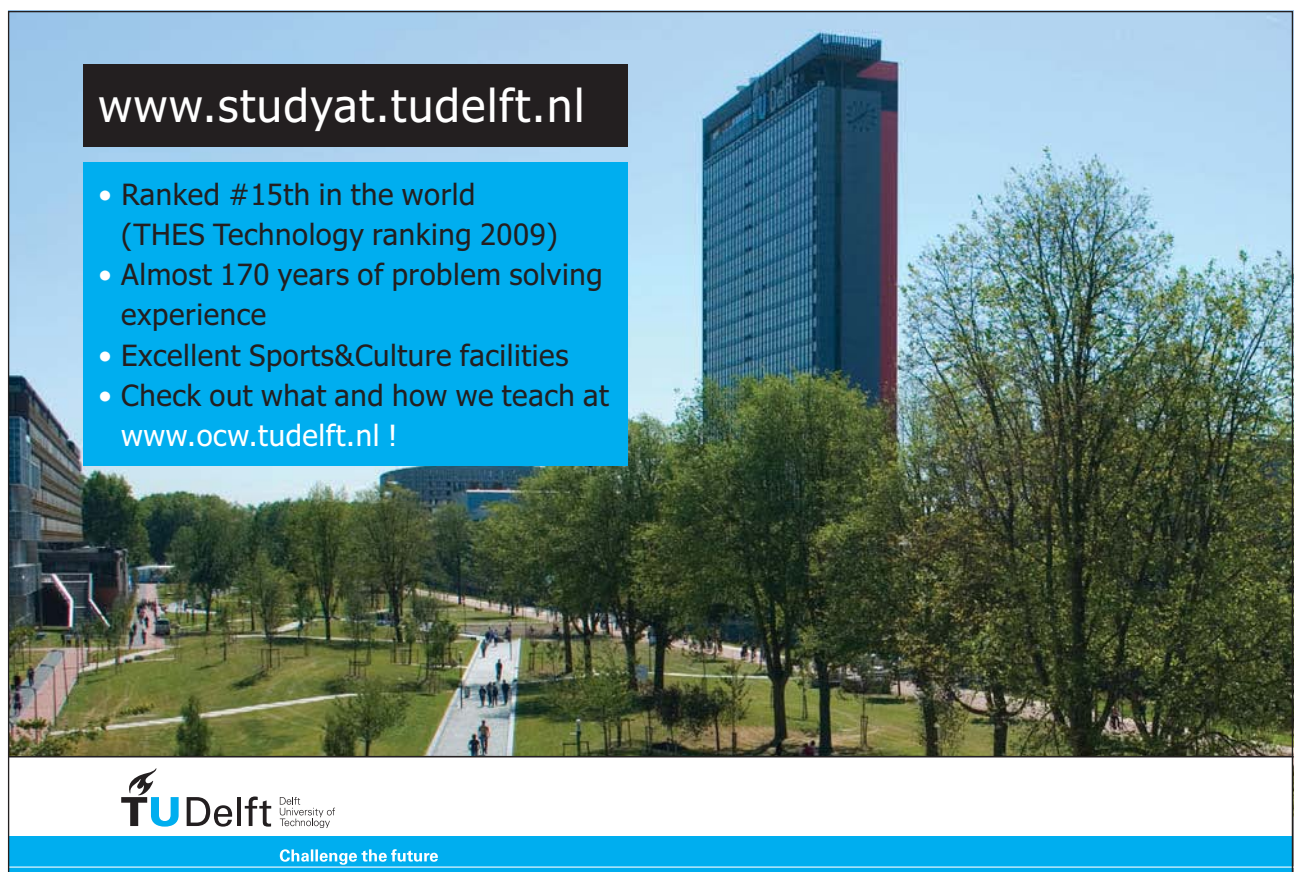
Example.

Consider the double integral

$$\int_0^{1/\sqrt{2}} \int_y^{\sqrt{1-y^2}} 3y \, dx \, dy.$$

- (i) Sketch of the region of integration.
- (ii) Evaluate the double integral by applying polar coordinates.

Please click the advert



www.studyat.tudelft.nl

- Ranked #15th in the world (THES Technology ranking 2009)
- Almost 170 years of problem solving experience
- Excellent Sports&Culture facilities
- Check out what and how we teach at www.ocw.tudelft.nl !

TU Delft Delft University of Technology

Challenge the future

The bigger picture.

When transferring double integrals from Cartesian co-ordinates to polar co-ordinates, the three essential substitutions are:

$$x = r \cos \theta; \quad y = r \sin \theta; \quad dA = r \, dr \, d\theta.$$

It is generally a good idea to sketch the region of integration so as to better-understand the geometry of the problem.

Exercises.

Describe, in polar co-ordinates, the set of points of the unit disc Ω that has centre $(0, 0)$ and that lie in the first quadrant ($x \geq 0, y \geq 0$). Hence, evaluate

$$I := \int \int_{\Omega} \sqrt{x^2 + y^2} \, dA.$$

[Ans: $\pi/6$].

4.6 More on integration & polar co-ordinates

View this lesson at <http://www.youtube.com/watch?v=T0a3hgRT7iA>, [25].

Motivation.

We know from basic calculus that sometimes a change of variables can greatly simplify very complicated integrals. We now explore this idea in the more general setting of double integrals under a specific change of variables known as polar co-ordinates.

Example.

Evaluate by using polar co-ordinates

$$I := \int_0^2 \int_{-\sqrt{2y-y^2}}^{\sqrt{2y-y^2}} \sqrt{x^2 + y^2} \, dx \, dy.$$

The bigger picture.

- When transferring double integrals from Cartesian co-ordinates to polar co-ordinates, the three essential substitutions are:

$$x = r \cos \theta; \quad y = r \sin \theta; \quad dA = r \, dr \, d\theta.$$

- It is generally a good idea to sketch the region of integration so as to better understand the geometry of the problem.

Exercises.

Evaluate by using polar co-ordinates

$$I := \int_0^2 \int_{-\sqrt{4-x^2}}^{\sqrt{4-x^2}} x^2 y^2 \, dy \, dx.$$

[Ans: $4\pi/3$].

Study at one of Europe's leading universities



Please click the advert

DTU, Technical University of Denmark, is ranked as one of the best technical universities in Europe, and offers internationally recognised Master of Science degrees in 39 English-taught programmes.

DTU offers a unique environment where students have hands-on access to cutting edge facilities and work

closely under the expert supervision of top international researchers.

DTU's central campus is located just north of Copenhagen and life at the University is engaging and vibrant. At DTU, we ensure that your goals and ambitions are met. Tuition is free for EU/EEA citizens.

Visit us at www.dtu.dk



Download free ebooks at bookboon.com

4.7 Calculation of the centroid

View this lesson at <http://www.youtube.com/watch?v=rIVB-0sNJvY>, [26].

Motivation.

In engineering, the word centroid means the geometric center of an object's shape. If a physical object (for example, a thin plate) has uniform density, then its center of mass is the same as the centroid of its shape. Double integrals can be used to calculate the centroid of simple two-dimensional regions.

Example.

Calculate the centroid of the region that lies in the first quadrant of the XY -plane, bounded by the circle

$$x^2 + y^2 = a^2, \quad a > 0.$$

The bigger picture.

- The co-ordinates (\bar{x}, \bar{y}) of the centroid of a two-dimensional region Ω can be calculated by the use of double integrals via:

$$\bar{x} = \frac{\iint_{\Omega} x \, dA}{\iint_{\Omega} dA}, \quad \bar{y} = \frac{\iint_{\Omega} y \, dA}{\iint_{\Omega} dA}$$

- It is generally a good idea to sketch the region of integration so as to better-understand the geometry of the problem. Look for symmetry.

Exercises.

Calculate the centroid of the region lying in the first quadrant which is bounded by the curves:

$$y = 0; \quad y^2 = 2x; \quad x + y = 4.$$

$$[\text{Ans: } (\bar{x}, \bar{y}) = (64/35, 5/7).]$$

4.8 How to calculate the mass of thin plates

View this lesson at http://www.youtube.com/watch?v=oty3f7wHY_M, [27].

Motivation.

A common and important challenge in engineering is that of calculating the mass of a given object. Double integrals can be used to calculate the mass of simple two-dimensional objects, such as thin plates or sheets, if the object has a known density function.

Example.

A thin plate occupies the region bounded by the curves:

$$y = \sqrt{a^2 - x^2}; \quad x = \pm a; \quad y = -a.$$

If we associate the density function

$$\rho(x, y) := y + a$$

with each point in the plate, then calculate the total mass of the plate.



MSM

MAASTRICHT SCHOOL OF MANAGEMENT

Increase your impact with MSM Executive Education



For almost 60 years Maastricht School of Management has been enhancing the management capacity of professionals and organizations around the world through state-of-the-art management education.

Our broad range of Open Enrollment Executive Programs offers you a unique interactive, stimulating and multicultural learning experience.

Be prepared for tomorrow's management challenges and apply today.

For more information, visit www.msm.nl or contact us at +31 43 38 70 808 or via admissions@msm.nl

the globally networked management school

Please click the advert

The bigger picture.

- If a thin plate occupies a simple region in the XY -plane and has a known density function $\rho = \rho(x, y)$ then the mass of the plate may be calculated by using double integrals via

$$\text{mass} = \iint_{\Omega} \rho(x, y) \, dA.$$

- It is generally a good idea to sketch the region of integration Ω so as to better-understand the geometry of the problem.

Exercises.

If we change the density function in the previous example to

$$\rho(x, y) = x + a$$


then recalculate the total mass of the thin plate.

[Ans: $a^3(2 + \pi/2)$].

Chapter 5

Ordinary differential equations

Please click the advert



What do the telephone handset and
the refrigerator have in common with
the pacemaker and the computer mouse?

They are all
Swedish inventions
used every day worldwide.

Challenge Yourself – Study in Sweden

www.studyinsweden.se

5.1 Separable differential equations

View this lesson at <http://www.youtube.com/watch?v=uQuBVa5PPy4>, [28].

Motivation.

Ordinary differential equations (ODEs) are used to mathematically model a range of phenomena from science and engineering. ODEs naturally arise when making simple physical assumptions about the model under consideration. By computing a solution to an ODE we can make precise predictions about future and past states of the model of interest.

Separable ODEs are a special type of ODE and have the form

$$\frac{dy}{dx} = f(x)g(y).$$

Example.

(a) Solve the separable ODE

$$\frac{dy}{dx} = -\frac{x}{2y}.$$

(b) If we have the extra information $y(0) = 1$ then determine the constant in the solution in (a).

The bigger picture.

- To solve a separable ODE simply: separate the variables (via division and / or multiplication) and then integrate both sides.
- Sometimes some algebraic manipulation is required to identify a separable ODE.
- If an initial condition is known, then the arbitrary constant from the general solution can be determined.

Exercises.

Solve the following separable ODEs:

$$(a) \frac{dy}{dx} = \frac{2x}{3(y+1)^2} \qquad (b) \frac{dy}{dx} = 2xy, \quad y(0) = 1.$$

[Ans: (a) $y(x) = -1 + (x^2 + c)^{1/3}$; (b) $y(x) = Ae^{x^2}$ is the general solution (where A is a constant); and $y(x) = e^{x^2}$ is the particular solution yielded from the initial condition.]

5.2 Linear, first–order differential equations

View this lesson at <http://www.youtube.com/watch?v=hIsLGmrpoPo>, [29].

Motivation.

Ordinary differential equations (ODEs) are used to mathematically model a range of phenomena from science and engineering. ODEs naturally arise when making simple physical assumptions about the model under consideration. By computing a solution to an ODE we can make precise predictions about future and past states of the model of interest.

Linear ODEs are a special type of ODE and have the form

$$\frac{dy}{dx} + p(x)y = q(x).$$

Example.

(a) Solve the linear ODE

$$\frac{dy}{dx} + \frac{1}{x}y = x^2$$

for the solution $y(x)$ for $x > 0$.

(b) If we have the extra information $y(1) = 0$ then determine the constant in the solution in (a).

The bigger picture.

- Construct the integrating factor $u(x) := e^{\int p(x) dx}$
- Multiply both sides of the ODE by u and collapse the left-hand-side to the derivative of $y \cdot u(x)$, ie $\frac{d}{dx}(y \cdot u(x))$.
- Integrate both sides and solve for y .
- If an initial condition is known, then the constant from the general solution can be determined.

Exercises.

Solve the following separable ODEs:

(a) $\frac{dy}{dx} - 2xy = e^{x^2}, \quad y(0) = 1.$

(b) $\frac{dy}{dx} + 2xy = 2x.$

[Ans: (a) $y(x) = e^{x^2}(x + c)$ is the general solution and the initial condition yields $y(x) = e^{x^2}(x + 1)$; (b) $y(x) = 1 + ce^{-x^2}$.]

Please click the advert

DESTINATIONS

	GATE	ARRIVAL
INDUSTRY IMPACT	OW	FASTER
GLOBAL ASSIGNMENTS	OW	FASTER
SENIOR CLIENT CONTACT	OW	FASTER
CAREER DEVELOPMENT	OW	FASTER
MAKE PARTNER	OW	FASTER





Oliver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies.

DISCOVER OUR WORLD

An equal opportunity employer.

GET THERE FASTER

Some people know precisely where they want to go. Others seek the adventure of discovering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers



MARSH & McLENNAN
COMPANIES

5.3 Homogeneous, first-order ODEs

View this lesson at <http://www.youtube.com/watch?v=UpLQUGBznE4>, [30].

Motivation.

Ordinary differential equations (ODEs) are used to mathematically model a range of phenomena from science and engineering. By computing a solution to an ODE we can make precise predictions about future and past states of the model of interest. A homogenous, first order ODE is of the form

$$y' = f\left(\frac{y}{x}\right).$$

Example.

Solve the homogeneous, first-order ODE

$$y' = \frac{y - x}{y + x}$$

for $y = y(x)$ with $x > 0$.

The bigger picture.

To solve a first-order, homogeneous ODE:

- Make the substitution $u = \frac{y}{x}$
- compute the derivative y' in terms of u'
- obtain a separable ODE in u
- solve for u and then backsubstitute for to obtain y .

Exercises.

Solve

$$y' = (2x + y)/x, \quad x > 0$$

[Ans: $y = 2x \ln x + Cx$]

5.4 2nd-order linear ordinary differential equations

View this lesson at <http://www.youtube.com/watch?v=2symahFSBd8>, [31].

Motivation.

Ordinary differential equations (ODEs) are used to mathematically model a range of phenomena from science and engineering. ODEs naturally arise when making simple physical assumptions about the model under consideration. By computing a solution to an ODE we can make precise predictions about future and past states of the model of interest.

We shall discuss “the method of undetermined coefficients” for the case

$$ay'' + by' + cy = 0$$

where a , b and c are given constants. These kinds of problems arise in the study of vibrating systems.

Example.

Solve the ODEs:

(a) $y'' + 4y' + 3y = 0$; (b) $y'' + 4y' + 4y = 0$; (c) $y'' + 2y' + 5y = 0$.

The bigger picture.

To solve the ODE $ay'' + by' + cy = 0$

- Solve the corresponding quadratic (characteristic) equation $a\lambda^2 + b\lambda + c = 0$ for λ .
- If the solutions λ_1, λ_2 are real and unequal then

$$y(x) = Ae^{\lambda_1 x} + Be^{\lambda_2 x}.$$

- If the solutions are equal, ie $\lambda_1 = \lambda_2 = \lambda$ then

$$y(x) = Ae^{\lambda x} + Bxe^{\lambda x}.$$

- If the solutions λ_1, λ_2 are complex conjugate pairs, ie $\lambda_1 = \alpha + \beta i$, $\lambda_2 = \alpha - \beta i$ then

$$y(x) = e^{\alpha x}(A \cos \beta x + B \sin \beta x).$$

Exercises.

Solve the following ODEs:

(a) $y'' + 3y' + 2y = 0$; (b) $y'' + 2y' + y = 0$; (c) $y'' + 4y' + 5y = 0$.

[Ans: (a) $y(x) = Ae^{-x} + Be^{-2x}$; (b) $y(x) = Ae^{-x} + Bxe^{-x}$; (c) $y(x) = e^{-2x}(A \cos x + B \sin x)$.]

5.5 Nonhomogeneous differential equations

View this lesson at http://www.youtube.com/watch?v=haAV-_6R5VU , [32].

Motivation.

Ordinary differential equations (ODEs) are used to mathematically model a range of phenomena from science and engineering. ODEs naturally arise when making simple physical assumptions about the model under consideration. By computing a solution to an ODE we can make precise predictions about future and past states of the model of interest.

We shall discuss the case

$$ay'' + by' + cy = f(x)$$

where a , b and c are given constants and f is a reasonably simple type of function. These kinds of problems arise in the study of vibrating systems with f representing an external forcing function.

Example.

Solve the ODEs:

(a) $y'' - 5y' + 6y = 2x + 3$; (b) $y'' - 5y' + 6y = 12e^{5x}$; (c) $y'' - 5y' + 6y = 10e^{2x}$.

Please click the advert



Day one
and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future?
ey.com/careers

ERNST & YOUNG
Quality In Everything We Do

© 2010 EYGM Limited. All Rights Reserved.

The bigger picture.

To solve the ODE $ay'' + by' + cy = f(x)$

- Solve the corresponding homogeneous problem $ay'' + by' + cy = 0$ for y_H .
- Construct a particular solution y_P to the nonhomogeneous ODE, based on the form of $f(x)$
- The general solution is then $y = y_P + y_H$.

Exercises.

Solve the following ODEs:

(a) $y'' + 3y' + 2y = e^x$; (b) $y'' + 2y' + y = 2x$ (c) $y'' + 4y' + 5y = 3$.

[Ans: (a) $y(x) = Ae^{-x} + Be^{-2x} + e^x/6$; (b) $y(x) = Ae^{-x} + Bxe^{-x} + 2x - 4$; (c) $y(x) = e^{-2x}(A \cos x + B \sin x) + 3/5$.]

5.6 Variation of constants / parameters

View this lesson at <http://www.youtube.com/watch?v=rhKoNLj0hJg>, [33].

Motivation.

The method of variation of constants is a very powerful technique for solving 2nd-order, linear ODEs. It is useful when the method of undetermined coefficients does not apply.

We shall discuss the case

$$ay'' + by' + cy = f(x)$$

where a , b and c are given constants and f is a given function. These kinds of problems arise in the study of vibrating systems.

Example.

Solve the ODE

$$y'' + 4y = \operatorname{cosec} 2x.$$

The bigger picture.

To solve the ODE $ay'' + by' + cy = f(x)$

- Formulate the general solution y_H to the homogeneous ODE $ay'' + by' + cy = 0$, that is, $y_H = Ay_1(x) + By_2(x)$ with y_1 and y_2 being linearly independent.
- Construct a particular solution y_p to the inhomogeneous ODE $ay'' + by' + cy = f(x)$ by using the y_1 and y_2 in

$$y_p = -y_1(x) \int \frac{y_2(x)f(x)}{aW(x)} dx + y_2(x) \int \frac{y_1(x)f(x)}{aW(x)} dx$$

where $W(x) := y_1(x)y_2'(x) - y_2(x)y_1'(x)$.

- The final (general) solution will have the form $y = y_H + y_p$.

Exercises.

Solve:

$$y'' + y = \sec x.$$

$$[\text{Ans: } y(x) = A \cos x + B \sin x + (\cos x) \ln |\cos x| + x \sin x.]$$

Chapter 6

Matrices and quadratic forms

Please click the advert



Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.

Could it be 
Unilever



6.1 Quadratic forms

View this lesson at <http://www.youtube.com/watch?v=ATd3FzR4wpI>, [34].

Motivation.

Many complicated equations of two and three variables can be simplified via a change of variables / co-ordinate axes. Our investigation involves quadratic forms and symmetric matrices.

Example.

Consider the quadratic form

$$S := \{(x, y) : x^2 - 4xy + y^2 = 6\}.$$

Determine the point(s) that lie on S which are closest to the origin.

The bigger picture.

- Eigenvalues and eigenvectors play a major role in our method.
- If A is a symmetric matrix with eigenvalues λ_1, λ_2 then the Principal Axes Theorem says that we may write our quadratic form as

$$\lambda_1 y_1^2 + \lambda_2 y_2^2$$

where (y_1, y_2) are the new set of axes, which lie along the eigenvectors of A .

- If P is an orthogonal matrix formed from normalized eigenvectors of A as columns, then the relationship between co-ordinates is

$$\mathbf{x} = P\mathbf{Y}$$

where $\mathbf{x} = (x, y)^T$ and $\mathbf{Y} = (y_1, y_2)^T$.

- The ideas readily generalize to surfaces in 3-dimensional space.

Exercises.

Calculate the point(s) on the curve

$$x^2 + 8xy + 7y^2 = 36$$

that lie closest to the origin. [Ans: $(y_1, y_2) = (\pm 2, 0)$, that is, $(x, y) = \pm(2/\sqrt{5}, 4/\sqrt{5})$].

Chapter 7

Laplace transforms and applications

Please click the advert



Discover the truth at www.deloitte.ca/careers

Deloitte.

© Deloitte & Touche LLP and affiliated entities.

7.1 Introduction to the Laplace transform

View this lesson at <http://www.youtube.com/watch?v=a7BzF01JtKw>, [35].

Motivation.

Laplace transforms are used in solving initial value problems that involve linear, ordinary differential equations with constant coefficients. These types of problems usually arise in modelling of phenomena. Laplace transforms offer an advantage over other solution methods to initial value problems as they streamline the process and can easily deal with discontinuous forcing functions.

Example.

Define and denote the Laplace transform of a function $f = f(t)$ by

$$\mathcal{L}\{f(t)\} := \int_0^{\infty} e^{-st} f(t) dt = F(s). \quad (7.1.1)$$

(i) From the above definition, calculate

$$\mathcal{L}\{e^{-2t}\}, \quad \text{for all } s > -2.$$

(ii) If a is a constant then use (i) to make a conjecture concerning

$$\mathcal{L}\{e^{-at}\}, \quad \text{for all } s > -a.$$

The bigger picture.

- While it is possible to directly use the definition of the Laplace transform to perform calculations, it is standard practice to use a table of Laplace transforms. This can save a lot of time!
- The *inverse* of the Laplace transform is denoted by \mathcal{L}^{-1} . Roughly speaking, it “undoes” the Laplace transform and vice-versa. From (ii) we deduce

$$\mathcal{L}^{-1} \left\{ \frac{1}{s+3} \right\} = e^{-3t}.$$

Exercises.

- (a) From the above definition (7.1.1), calculate

$$\mathcal{L}\{5t + 3\}, \quad \text{for all } s > 0.$$

- (b) If c and d are constants, then use (a) to make a conjecture about what

$$\mathcal{L}\{ct + d\}, \quad \text{for all } s > 0.$$

should be.

- (c) Use (b) to calculate

$$\mathcal{L}^{-1} \left\{ \frac{1}{s^2} \right\}.$$

[Ans: (a) $5/s^2 + 3/s$; (b) $c/s^2 + d/s$; (c) t .]

7.2 Laplace transforms + the first shifting theorem

View this lesson at <http://www.youtube.com/watch?v=WpUbbsULIds>, [36].

Motivation.

The first shifting theorem provides a convenient way of calculating the Laplace transform of functions that are of the form

$$f(t) := e^{-at}g(t)$$

where a is a constant and g is a given function.

Example.

Consider the first shifting theorem

$$\mathcal{L}\{e^{-at}g(t)\} = G(s+a) \quad \text{where} \quad G(s) = \mathcal{L}\{g(t)\}.$$

Apply the result to calculate:

(a)

$$\mathcal{L}\{e^{2t}t^3\};$$

(b)

$$\mathcal{L}^{-1}\left\{\frac{1}{(s-1)^3}\right\}.$$

The bigger picture.

- For the Laplace transform via the first shifting theorem, calculate $G(s)$ from $g(t)$ and then shift it by a units in an appropriate manner.
- For the inverse Laplace transform via the first shifting theorem, identify a and $G(s)$ from $G(s + a)$. Then calculate $g(t)$ from $G(s)$ and multiply by e^{-at} .

Exercises.

Calculate

(a)

$$\mathcal{L}\{e^t \sin t\};$$

(b)

$$\mathcal{L}^{-1}\left\{\frac{1}{(s+2)^2}\right\}.$$

[Ans: (a) $1/[1 + (s - 1)^2]$; (b) te^{-2t} .]

Grant Thornton—^{REALLY}a great place to work.

We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute™ for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant
Manager



Audit • Tax • Advisory
www.GrantThornton.ca/Careers



Grant Thornton
An instinct for growth™

© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd

Please click the advert

7.3 Laplace transforms + the 2nd shifting theorem

View this lesson at <http://www.youtube.com/watch?v=Uyoxbr03eFU>, [37].

Motivation.

Laplace transforms offer an advantage over other solution methods to initial value problems as they streamline the process and can easily deal with discontinuous forcing functions.

The second shifting theorem gives us a way of computing the Laplace transform of certain types of discontinuous functions.

Example.

Consider the second shifting theorem

$$\mathcal{L}\{u(t-c)g(t-c)\} = e^{-cs}G(s) \quad \text{where } G(s) = \mathcal{L}\{g(t)\}$$

and $u(t-c)$ is the Heaviside step function.

Apply the result to calculate:

(a)

$$\mathcal{L}\{u(t-1)(t-1)^2\};$$

(b)

$$\mathcal{L}^{-1} \left\{ \frac{2e^{-4s}}{s^3} \right\}.$$

The bigger picture.

- For the Laplace transform via the second shifting theorem, identify c and $g(t)$ and then calculate $G(s)$.
- For the inverse Laplace transform via the second shifting theorem, identify c and $G(s)$. Then calculate $g(t)$ from $G(s)$ and shift it to form $g(t - c)$.

Exercises.

Apply the second shifting theorem to calculate:

(a)

$$\mathcal{L}\{u(t - 2)(t - 2)^3\};$$

(b)

$$\mathcal{L}^{-1}\left\{\frac{e^{-2s}}{s^5}\right\}.$$

[Ans: (a) $6e^{-2s}/s^4$; (b) $u(t - 2)(t - 2)^4/24$].

7.4 Laplace transforms + differential equations

View this lesson at http://www.youtube.com/watch?v=SNVfyQ4_avY, [38].

Motivation.

Laplace transforms offer an advantage over other solution methods to initial value problems as they streamline the process and can easily deal with discontinuous forcing functions.

Example.

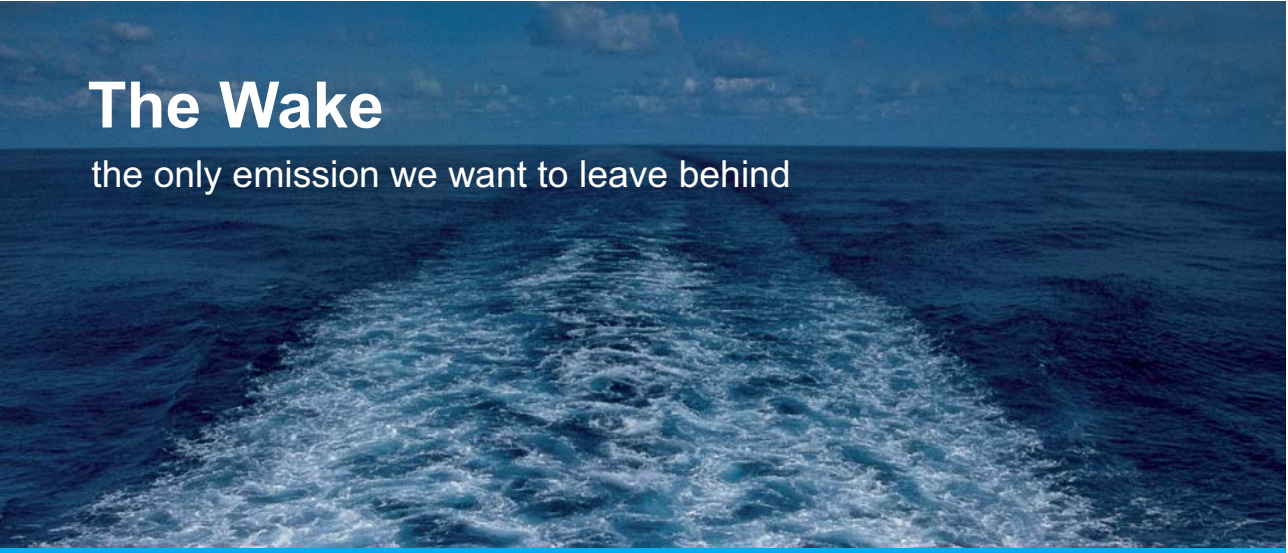
Consider the transform of derivatives identities

$$\begin{aligned}\mathcal{L}\{y'(t)\} &= sY(s) - y(0), \quad \text{where } Y(s) = \mathcal{L}\{y(t)\} \\ \mathcal{L}\{y''(t)\} &= s^2Y(s) - sy(0) - y'(0),\end{aligned}$$

Apply the result to solve the initial value problem:

$$y'' + y = u(t - 1), \quad y(0) = 1, \quad y'(0) = 0.$$

Please click the advert



The Wake


the only emission we want to leave behind

Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758.

MAN Diesel & Turbo



The bigger picture.

When applying Laplace transforms to solve initial value problems:

1. take the Laplace transform of both sides of the differential equation
2. apply the transform of derivatives identities
3. incorporate the initial conditions
4. solve for $Y(s)$
5. use inverse Laplace transforms to produce the solution $y(t)$.

Exercises.

Apply the transform of derivatives identities to solve:

$$y'' + y = 2u(t - 1), \quad y(0) = 0, \quad y'(0) = 1.$$

$$[\text{Ans: } y(t) = \sin t + 2u(t - 1)[1 - \cos(t - 1)].]$$

LAPLACE TRANSFORMS

$$\mathcal{L}\{f(t)\} = \int_0^{\infty} e^{-st} f(t) dt = F(s)$$

$f(t)$	$F(s)$
1	$1/s$
t	$1/s^2$
$t^m,$	$m!/s^{m+1}$
$t^\nu, (\nu > -1)$	$\Gamma(\nu + 1)/s^{\nu+1}$
e^{-at}	$1/(s + a)$
$\sin bt$	$b/(s^2 + b^2)$
$\cos bt$	$s/(s^2 + b^2)$
$\sinh bt$	$b/(s^2 - b^2)$
$\cosh bt$	$s/(s^2 - b^2)$
$\sin bt - bt \cos bt$	$2b^3/(s^2 + b^2)^2$
$\sin bt + bt \cos bt$	$2bs^2/(s^2 + b^2)^2$
$t \sin bt$	$2bs/(s^2 + b^2)^2$
te^{-at}	$1/(s + a)^2$
$u(t - c)$	e^{-cs}/s
$e^{-at}g(t)$	$G(s + a)$
$tg(t)$	$-G'(s)$
$u(t - c)g(t - c)$	$e^{-cs}G(s)$
$g'(t)$	$sG(s) - g(0)$
$g''(t)$	$s^2G(s) - sg(0) - g'(0)$
$g'''(t)$	$s^3G(s) - s^2g(0) - sg'(0) - g''(0)$
$\int_0^t g(\tau) d\tau$	$G(s)/s.$

In this table, a and b are any real numbers, c is any non-negative real number, m is any non-negative integer, ν is any real number larger than -1 , $\Gamma(\nu + 1) = \int_0^{\infty} e^{-x} x^\nu dx$ and $u(t)$ is defined by $u(t) = 0$, for $t < 0$, $u(0) = 1/2$; $u(t) = 1$ for $t > 0$.

Chapter 8

Fourier series

The **Fourier series** of a function $f = f(t)$ with period $2L$ is defined by

$$Sf(t) := a_0 + \sum_{n=1}^{\infty} \left[a_n \cos \frac{n\pi t}{L} + b_n \sin \frac{n\pi t}{L} \right]$$

where

$$a_0 := \frac{1}{2L} \int_{-L}^L f(t) dt$$

$$a_n := \frac{1}{L} \int_{-L}^L f(t) \cos \frac{n\pi t}{L} dt$$

$$b_n := \frac{1}{L} \int_{-L}^L f(t) \sin \frac{n\pi t}{L} dt$$

and f and f' are piecewise continuous on $(-L, L)$.

8.1 Introduction to Fourier series

View this lesson at <http://www.youtube.com/watch?v=3Ai3dKVPLcQ>, [39].

Motivation.

Fourier series are used in solving differential equations that arise in the study of heat flow and vibrations. Fourier series provide a means of approximating discontinuous periodic functions over intervals (rather than just near certain points).

Example.

Calculate the Fourier series of

$$f(t) := \begin{cases} 1, & \text{for } 0 < t < \pi; \\ 0, & \text{for } t = 0, \pm\pi; \\ -1, & \text{for } -\pi < t < 0; \end{cases} \quad (8.1.1)$$

with $f(t) = f(t + 2\pi)$ for all t .

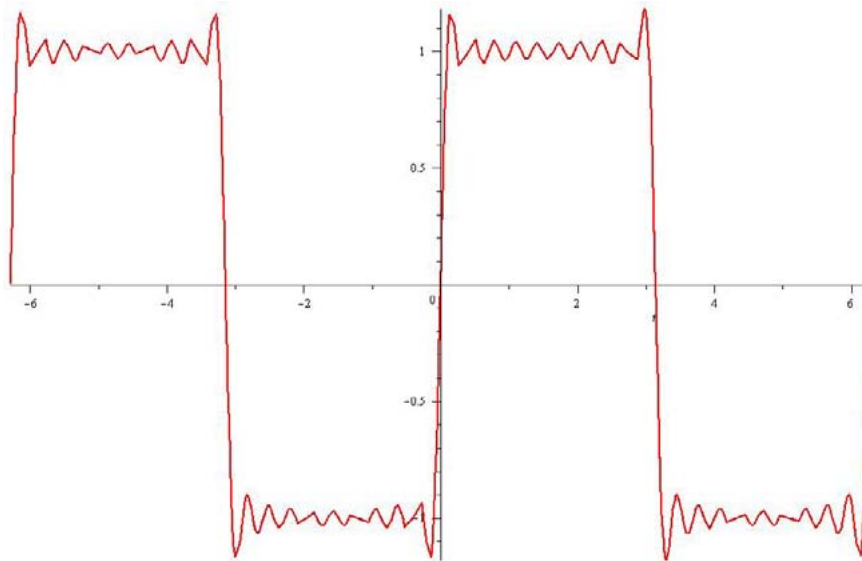
Please click the advert



GOT-THE-ENERGY-TO-LEAD.COM

We believe that energy suppliers should be renewable, too. We are therefore looking for enthusiastic new colleagues with plenty of ideas who want to join RWE in changing the world. Visit us online to find out what we are offering and how we are working together to ensure the energy of the future.

RWE
The energy to lead™



Maple has been used to plot the 10th partial sum of Fourier series of f .

The bigger picture.

- Integration is required to compute the Fourier coefficients a_0 , a_n and b_n and the calculations will simplify when f is odd or even.
- If f is continuous at a point c then $Sf(c) = f(c)$.
- If f has a jump discontinuity at c then $Sf(c) = [f(c^+) + f(c^-)]/2$.

Exercises.

Calculate the Fourier series of

$$f(t) := \begin{cases} 1, & \text{for } 0 < t < 1; \\ 0, & \text{for } -1 < t < 0; \end{cases} \quad (8.1.2)$$

with $f(t) = f(t + 2)$ for all t . [Ans: $Sf(t) = \frac{1}{2} + \sum_{k=1}^{\infty} \frac{2}{(2k-1)\pi} \sin(2k-1)\pi t$. Note that f is neither even nor odd, but can you see how to write it in terms of an odd function plus a constant? This can help to simplify the calculations!]

8.2 Odd + even functions + Fourier series

View this lesson at <http://www.youtube.com/watch?v=1Bj0vv6G3dA>, [40].

Motivation.

Simplifications occur in the construction of Fourier series when dealing with odd or even functions.

Example.

Let

$$f(x) := x, \quad 0 < x \leq 1.$$

Extend f as an odd (even) function f_o (f_e) with period 2 and sketch their graphs on $[-3, 3]$. Find Sf_e and Sf_o . Show

$$\sum_{k=1}^{\infty} \frac{1}{(2k-1)^2} = \frac{\pi^2}{8}.$$

The bigger picture.

- Integration is required to compute the Fourier coefficients a_0 , a_n and b_n and the calculations will simplify when f is odd or even.
- Simplifications occur when dealing with odd or even functions.
- If f is continuous at a point c then $Sf(c) = f(c)$.
- If f has a jump discontinuity at c then $Sf(c) = [f(c^+) + f(c^-)]/2$.

Exercises.

Calculate the Fourier series of

$$f(x) := \begin{cases} 3, & \text{for } 0 \leq x < 1, \\ -3, & \text{for } -1 < x < 0, \end{cases}$$

where $f(x) = f(x + 2)$. What is the value of $Sf(0)$ and $Sf(1/2)$? [Ans: $Sf(x) = \sum_{k=1}^{\infty} \frac{12}{(2k-1)\pi} \sin(2k-1)\pi x$; $Sf(0) = 0$; $Sf(1/2) = 3$.]



You're full of *energy*
and ideas. And that's
just what we are looking for.

Looking for a career where your ideas could really make a difference? UBS's Graduate Programme and internships are a chance for you to experience for yourself what it's like to be part of a global team that rewards your input and believes in succeeding together.

Wherever you are in your academic career, make your future a part of ours by visiting www.ubs.com/graduates.

www.ubs.com/graduates



Please click the advert

© UBS 2010. All rights reserved.

8.3 More on Fourier series

View this lesson at <http://www.youtube.com/watch?v=toBJWQGPRB4>, [41].

Motivation.

Fourier series are used in solving differential equations that arise in the study of heat flow and vibrations. Fourier series provide a means of approximating discontinuous periodic functions over intervals (rather than just near certain points).

Example.

Let $f(x) = |x|$ for $x \in [-\pi, \pi]$ with $f(x + 2\pi) = f(x)$.

i) Make a sketch of f on the interval $[-3\pi, 3\pi]$.

ii) Calculate the Fourier series of f .

iii) Let

$$g(x) = \begin{cases} 1, & 0 < x < \pi \\ -1, & -\pi < x < 0, \end{cases}$$

with $g(x + 2\pi) = g(x)$. By differentiating the Fourier series in b) ii) (or otherwise) obtain the Fourier series of g .

iv) What does the Fourier series of g converge to at $x = \pi$?

v) Use the Fourier series for g to obtain a series representation for $\pi/4$.

The bigger picture.

- Integration is required to compute the Fourier coefficients a_0 , a_n and b_n and the calculations will simplify when f is odd or even.
- If f is continuous at a point c then $Sf(c) = f(c)$.
- If f has a jump discontinuity at c then $Sf(c) = [f(c^+) + f(c^-)]/2$.
- Simplifications occur when dealing with odd or even functions.

Exercises.

Calculate the Fourier series of

$$f(x) := 3(x + 1), \quad -2 < x < 2$$

where $f(x) = f(x + 4)$.

$$[\text{Ans: } Sf(x) = 3 - 12 \sum_{n=1}^{\infty} \frac{(-1)^n}{n\pi} \sin \frac{n\pi x}{2}.]$$

8.4 Applications of Fourier series to ODEs

View this lesson at <http://www.youtube.com/watch?v=70KZhL7eVN8>, [42].

Motivation.

Fourier series can be useful in solving differential equations that arise in the study of vibrations. They provide a means of approximating discontinuous periodic “forcing” functions over intervals (rather than just near certain points).

Example.

Calculate the solution of the initial value problem

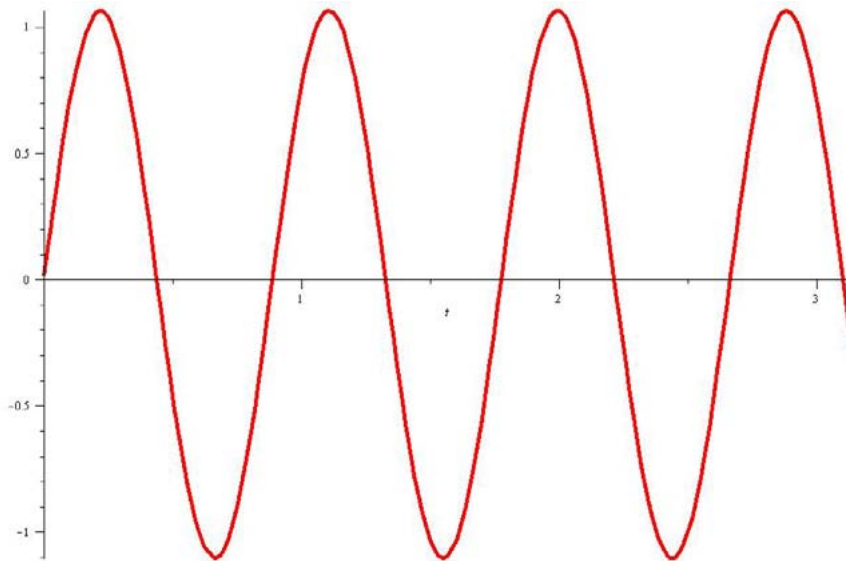
$$x'' + 50x = f(t), \quad x(0) = 0, \quad x'(0) = 0$$

where

$$f(t) := \begin{cases} 1, & \text{for } 0 < t < \pi; \\ 0, & \text{for } t = 0, \pi, 2\pi; \\ -1, & \text{for } \pi < t < 2\pi; \end{cases} \quad (8.4.3)$$

with $f(t) = f(t + 2\pi)$ for all t . Hint: the Fourier sine series of f is

$$\sum_{k=1}^{\infty} \frac{4}{(2k-1)\pi} \sin(2k-1)t.$$



Maple has been used to plot the solution.

The bigger picture.

When applying Fourier series to solve initial value problems:

- If it is not already given, then calculate the Fourier series of the forcing function.
- Apply the basic theory of differential equations to calculate y_H and y_p .

Chapter 9

PDEs & separation of variables

Please click the advert

 **RBS Group**

CAREERKICKSTART

An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

Click [here](#) to get started.

9.1 Deriving the heat equation

View this lesson at <http://www.youtube.com/watch?v=K-CI61wV6JQ>, [43].

Motivation.

In the early 1800s, J. Fourier began a mathematical study of heat. A deeper understanding of heat flow had significant applications in science and within industry. A basic version of Fourier's efforts is the problem

$$\alpha^2 u_{xx} = u_t; \quad u(0, t) = 0 = u(L, t); \quad u(x, 0) = f(x)$$

where: $u(x, t)$ is the temperature at position x at time t ; α^2 is a constant; and f is a given function.

Example.

Derive the heat equation

$$u_t = \alpha^2 u_{xx} \tag{9.1.1}$$

where $\alpha^2 := \kappa/\rho c$ called the thermal diffusivity (in $(\text{length})^2/\text{time}$) and κ , ρ and c are positive constants that depend on the material of the bar.

The bigger picture.

Our assumptions and method may be summarized as:

- The total amount of heat $H = H(t)$ in D (say, in calories) is

$$H(t) = \int_{x_0}^{x_1} c\rho u(x, t) dx.$$

- Fourier's law of heat flow says that heat flows from hotter regions to colder regions and the flow rate is proportional to u_x

$$\frac{dH}{dt} = -\kappa u_x(x_0, t) - (-\kappa u_x(x_1, t)).$$

- Differentiation then gives us two expressions for dH/dt which can be equated to form the heat equation.

Please click the advert

ORACLE®

Be BRAVE

enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

<https://campus.oracle.com>



ORACLE®

ORACLE IS THE INFORMATION COMPANY

9.2 Heat equation & separation of variables

View this lesson at <http://www.youtube.com/watch?v=Jfn6A1jZF5g>, [44].

Motivation.

The method of “separation of variables” is a powerful technique that enables us to solve linear partial differential equations that arise in the modelling of various physical processes. In some problems, Fourier series are an important element of the approach.

Example.

Solve

$$4u_{xx} = u_t, \quad 0 < x < \pi, \quad t > 0; \quad (9.2.2)$$

$$u(0, t) = 0, \quad t > 0; \quad (9.2.3)$$

$$u(\pi, t) = 0, \quad t > 0; \quad (9.2.4)$$

$$u(x, 0) = f(x), \quad 0 \leq x \leq \pi. \quad (9.2.5)$$

with $f(x) = \sin x - 2 \sin 2x$.

The bigger picture.

Our method may be summarized as:

- Assume a solution is in the form $u(x, t) = X(x)T(t)$.
- Formulate and solve two ODEs for X and T determining which values of the separation constant γ are relevant.
- If required incorporate Fourier series.

Exercises.

Solve (9.2.2) - (9.2.5) but with $f(x) = -\sin 2x + 3 \sin 5x$ as the initial temperature.
[Ans: $(u(x, t) = -e^{-16t} \sin 2x + 3e^{-200t} \sin 5x)$.]

9.3 Heat equation & Fourier series

View this lesson at <http://www.youtube.com/watch?v=4jYgpHLP6xs>, [45].

Motivation.

The method of “separation of variables” is a powerful technique that enables us to solve linear partial differential equations that arise in the modelling of various physical processes. In many problems Fourier series are an important element of the solution method.

Example.

Solve

$$4u_{xx} = u_t, \quad 0 < x < \pi, \quad t > 0; \quad (9.3.6)$$

$$u(0, t) = 0, \quad t > 0; \quad (9.3.7)$$

$$u(\pi, t) = 0, \quad t > 0; \quad (9.3.8)$$

$$u(x, 0) = x, \quad 0 \leq x \leq \pi. \quad (9.3.9)$$

In previous lectures, we have applied the method of separation of variables to the above problem, obtaining

$$u(x, t) = \sum_{n=1}^{\infty} b_n e^{-4n^2 t} \sin nx.$$

where b_n are constants to be determined. In particular, (9.2.5) yields

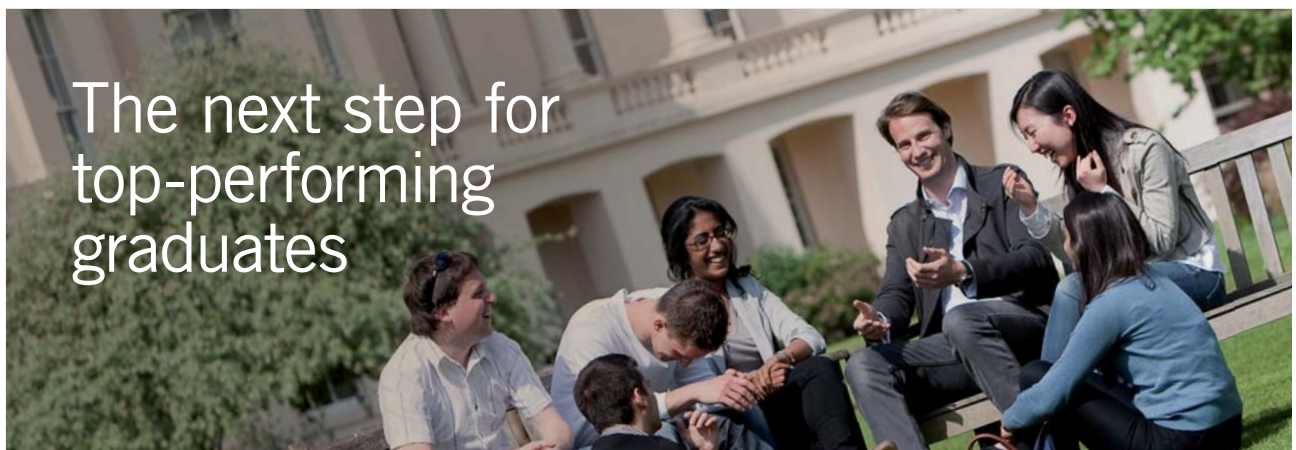
$$u(x, 0) = x = \sum_{n=1}^{\infty} b_n \sin nx, \quad 0 \leq x \leq \pi.$$

The bigger picture.

Our method may be summarized as:

- Assume a solution is in the form $u(x, t) = X(x)T(t)$.
- Formulate and solve two ODEs for X and T determining which values of the separation constant γ are relevant from the associated boundary conditions.
- If required incorporate Fourier series.

Please click the advert



The next step for
top-performing
graduates

Masters in Management



Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation*; the majority of graduates choosing to work in consulting or financial services.

As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit www.london.edu/mm, email mim@london.edu or give us a call on **+44 (0)20 7000 7573**.

* Figures taken from London Business School's Masters in Management 2010 employment report

9.4 Wave equation and Fourier series

View this lesson at <http://www.youtube.com/watch?v=4UtGyd86FjI>, [46].

Motivation.

The method of “separation of variables” is a powerful technique that enables us to solve linear partial differential equations that arise in the modelling of various physical processes. In some problems, Fourier series are an important element of the approach. We now apply these ideas to solve the wave equation.

Example.

Solve

$$9u_{xx} = u_{tt}, \quad 0 < x < \pi, \quad t > 0; \quad (9.4.10)$$

$$u(0, t) = 0, \quad u(\pi, t) = 0, \quad t > 0; \quad (9.4.11)$$

$$u(x, 0) = f(x), \quad u_t(x, 0) = 0, \quad 0 \leq x \leq \pi. \quad (9.4.12)$$

where

$$f(x) := \begin{cases} x, & \text{for } 0 \leq x \leq \pi/2; \\ \pi - x, & \text{for } \pi/2 \leq x \leq \pi. \end{cases}$$

The bigger picture.

Our method may be summarized as:

- Assume a solution is in the form $u(x, t) = X(x)T(t)$.
- Formulate and solve two ODEs for X and T determining which values of γ are relevant from the associated boundary conditions.
- If required incorporate Fourier series.

Bibliography

- [1] Tisdell, Chris. "Engineering mathematics YouTube workbook playlist" <http://www.youtube.com/playlist?list=PL13760D87FA88691D>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [2] Tisdell, Chris. "Partial derivatives + PDEs tutorial" <http://www.youtube.com/watch?v=SV56UC31rbk>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [3] Tisdell, Chris. "Chain rule + partial derivatives" <http://www.youtube.com/watch?v=H0zMR22HsiA>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [4] Tisdell, Chris. "Taylor polynomials + functions of two variables" <http://www.youtube.com/watch?v=Z7yTsoMTjnM>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [5] Tisdell, Chris. "Partial derivatives + error estimation" <http://www.youtube.com/watch?v=wLrHCkesOA8>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [6] Tisdell, Chris. "Differentiate under integral signs: Leibniz rule" <http://www.youtube.com/watch?v=cipIYpDu9YY>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [7] Tisdell, Chris. "How to find + classify critical points of functions" <http://www.youtube.com/watch?v=LGFlLcLnSfE>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [8] Tisdell, Chris. "Finding critical points of functions" <http://www.youtube.com/watch?v=lq2kdnRY5h8>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [9] Tisdell, Chris. "Method of Lagrange multipliers" <http://www.youtube.com/watch?v=4E-uLaRhrcA>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [10] Tisdell, Chris. "Lagrange multipliers: an example" <http://www.youtube.com/watch?v=5w-b1yU9hy4>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.

- [11] Tisdell, Chris. "Lagrange multipliers: 2 constraints" <http://www.youtube.com/watch?v=7fRYd8PKeGY>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [12] Tisdell, Chris. "Vector functions of one variable tutorial. Chris Tisdell UNSW Sydney" <http://www.youtube.com/watch?v=hmN1Duk08Yk>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [13] Tisdell, Chris. "Gradient of a function." <http://www.youtube.com/watch?v=Xw5wsWDt1Cg>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [14] Tisdell, Chris. "Divergence of a vector field." <http://www.youtube.com/watch?v=quZlfp59iJg>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [15] Tisdell, Chris. "Curl of a vector fields." <http://www.youtube.com/watch?v=qeOT0YufpSY>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [16] Tisdell, Chris. "Line integrals." <http://www.youtube.com/watch?v=6YuyBnXBFXg>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [17] Tisdell, Chris. "Curl, grad and line integral example." <http://www.youtube.com/watch?v=S2rT2zK2bdo>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [18] Tisdell, Chris. "Div, curl + line integral example." <http://www.youtube.com/watch?v=nH5KCrEuvyA>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [19] Tisdell, Chris. "Flux in the plane." <http://www.youtube.com/watch?v=YHiTuLNu3Sc>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [20] Tisdell, Chris. "Double integral introduction." <http://www.youtube.com/watch?v=My6sdEekbHM>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [21] Tisdell, Chris. "Tutorial - double integrals." <http://www.youtube.com/watch?v=9cAVY9niDnI>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [22] Tisdell, Chris. "Reverse the order in double integrals." <http://www.youtube.com/watch?v=zxyx73HAtfQ>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.

- [23] Tisdell, Chris. "Double integrals + area." <http://www.youtube.com/watch?v=wiFUGkHTm00>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [24] Tisdell, Chris. "Polar coordinates and double integrals." <http://www.youtube.com/watch?v=zknGq9CvZTQ>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [25] Tisdell, Chris. "Double integrals & polar co-ordinates." <http://www.youtube.com/watch?v=T0a3hgRT7iA>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [26] Tisdell, Chris. "Centriod & double integrals." <http://www.youtube.com/watch?v=rIVB-0sNJvY>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [27] Tisdell, Chris. "Center of mass + double integrals." http://www.youtube.com/watch?v=oty3f7wHY_M, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [28] Tisdell, Chris. "Separable differential equations." <http://www.youtube.com/watch?v=uQuBVa5PPy4>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [29] Tisdell, Chris. "Linear, first-order differential equations." <http://www.youtube.com/watch?v=hIsLGmrpoPo>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [30] Tisdell, Chris. "Homogeneous first order ordinary differential equation." <http://www.youtube.com/watch?v=UpLQUGBznE4>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [31] Tisdell, Chris. "How to solve 2nd-order differential equations." <http://www.youtube.com/watch?v=2symahFSBd8>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [32] Tisdell, Chris. "Nonhomogeneous 2nd-order differential equations." http://www.youtube.com/watch?v=haAV-_6R5VU, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [33] Tisdell, Chris. "Variation of constants / parameters." <http://www.youtube.com/watch?v=rhKoNLj0hJg>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [34] Tisdell, Chris. "Principal axes theorem." <http://www.youtube.com/watch?v=ATd3FzR4wpI>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.

- [35] Tisdell, Chris. "Intro to Laplace transform + how to calculate them." <http://www.youtube.com/watch?v=a7BzF0lJtKw>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [36] Tisdell, Chris. "First shifting theorem of Laplace transforms." <http://www.youtube.com/watch?v=WpUbbsULIdS>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [37] Tisdell, Chris. "Second shifting theorem: Laplace transforms." <http://www.youtube.com/watch?v=Uyoxbr03eFU>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [38] Tisdell, Chris. "Laplace transforms + differential equations." http://www.youtube.com/watch?v=SNVfyQ4_avY, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [39] Tisdell, Chris. "Intro to Fourier series & how to calculate them." <http://www.youtube.com/watch?v=3Ai3dKVPLcQ>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [40] Tisdell, Chris. "Fourier series: odd & even functions." <http://www.youtube.com/watch?v=1Bj0vv6G3dA>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [41] Tisdell, Chris. "Fourier series review." <http://www.youtube.com/watch?v=toBJWQGPRB4>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [42] Tisdell, Chris. "Fourier series & differential equations." <http://www.youtube.com/watch?v=70KZhL7eVN8>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [43] Tisdell, Chris. "Heat equation derivation." <http://www.youtube.com/watch?v=K-CI61wV6JQ>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [44] Tisdell, Chris. "Heat equation: separation of variables." <http://www.youtube.com/watch?v=Jfn6A1jZF5g>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [45] Tisdell, Chris. "Heat equation + Fourier series." <http://www.youtube.com/watch?v=4jYgpHLP6xs>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.
- [46] Tisdell, Chris. "Wave equation + Fourier series + Separation of variables." <http://www.youtube.com/watch?v=4UtGyd86FjI>, accessed on 1/11/2011 at DrChrisTisdell's YouTube Channel <http://www.youtube.com/DrChrisTisdell>.