Course Outline for Mathematics 257/316 (3 credits) Term 1, Sept.-Dec., 2015
Partial Differential Equations

Prerequisites: One of Math 215, 255, 265.
Credit: 3 Credits. Credit only given for one of Math 256, 257, 316.
Instructor: Anthony Peirce, **Office:** Mathematics Building 108
Home Page: http://www.math.ubc.ca/~peirce
Office Hours: Monday: 10-11 am, Wed: 3-3:55 pm, Fri: 10-11 am.
Assessment: The final grades will be based on homework (15%) (including EXCEL/MATLAB projects), two in class midterm exams (35%) and one final exam (50%). **Assignments are to be submitted in hard-copy from at the designated class – no late assignments can be accepted. There will be no make-up midterms.**
Test Dates: Wednesday, October 21st, Wednesday, November 18th.
Text: (recommended) Elementary Differential Equations and Boundary Value Problems (10th Ed), W.E. Boyce and R.C. DiPrima (John Wiley & Sons) 2012

Other References:
1. Partial Differential Equations with Fourier Series and Boundary Value Problems (2nd Ed), by N.H. Asmar , (Pearson), 2004.
2. Applied Partial Differential Equations with Fourier Series and Boundary Value Problems (4nd Ed), R. Haberman, (Pearson), 2004.
3. http://www.math.ubc.ca/~rfroese/notes/Lecs316.pdf, Richard Froese, Partial Differential Equations, UBC M257/316 lecture notes free on the web.

Topics:	**Approx Time**
1. Review of techniques to solve ODEs	1 hr
2. Series Solutions of variable coefficient ODEs (Chapter 5)	
a. Series solutions at ordinary points (5.1-5.3)	3 hrs
b. Regular singular points (5.4-5.7, 5.8 briefly)	4 hrs
3. Introduction to Partial differential equations (Chapter 10)	
The heat equation (10.5), the wave equation (10.7), Laplace's equation (10.8)	2 hrs
4. Introduction to numerical methods for PDEs using spread sheets	3 hrs
a. First and second derivative approximations using finite differences - errors	
b. Explicit finite difference schemes for the heat equation	
• Stability and derivative boundary conditions	
c. Explicit finite difference schemes for the wave equation	
d. Finite difference approximation of Laplace's Equation – iterative methods	
5. Fourier Series and Separation of Variables (Chapter 10)	
a. The heat equation and Fourier Series (10.1-10.6)	9 hrs
b. The wave equation (10.7)	3 hrs
c. Laplace's equation (10.8)	5 hrs
6. Boundary Value Problems and Sturm-Liouville Theory (Chapter 11)	
a. Eigenfunctions and eigenvalues (11.1)	1 hr
b. Sturm-Liouville boundary value problems (11.2)	1 hr
c. Nonhomogeneous boundary value problems (11.3)	2 hrs
Tests	2 hrs
	36 hrs

Math 257-316 PDE Formula sheet - final exam

Trigonometric and Hyperbolic Function identities

$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \sin\beta\cos\alpha$ $\qquad \sin^2 t + \cos^2 t = 1$

$\cos(\alpha \pm \beta) = \cos\alpha\cos\beta \mp \sin\beta\sin\alpha.$ $\qquad \sin^2 t = \frac{1}{2}(1-\cos(2t))$

$\sinh(\alpha \pm \beta) = \sinh\alpha\cosh\beta \pm \sinh\beta\cosh\alpha$ $\qquad \cosh^2 t - \sinh^2 t = 1$

$\cosh(\alpha \pm \beta) = \cosh\alpha\cosh\beta \pm \sinh\beta\sinh\alpha.$ $\qquad \sinh^2 t = \frac{1}{2}(\cosh(2t)-1)$

Basic linear ODE's with real coefficients

	constant coefficients	**Euler eq**
ODE	$ay''+by'+cy=0$	$ax^2y''+bxy'+cy=0$
indicial eq.	$ar^2+br+c=0$	$ar(r-1)+br+c=0$
$r_1 \neq r_2$ real	$y = Ae^{r_1 x}+Be^{r_2 x}$	$y = Ax^{r_1}+Bx^{r_2}$
$r_1 = r_2 = r$	$y = Ae^{rx}+Bxe^{rx}$	$y = Ax^r + Bx^r\ln\|x\|$
$r = \lambda \pm i\mu$	$e^{\lambda x}[A\cos(\mu x)+B\sin(\mu x)]$	$x^\lambda[A\cos(\mu\ln\|x\|)+B\sin(\mu\ln\|x\|)]$

Series solutions for $y''+p(x)y'+q(x)y=0$ $(\star)$ around $x=x_0$.

Ordinary point x_0: Two linearly independent solutions of the form:

$$y(x) = \textstyle\sum_{n=0}^\infty a_n(x-x_0)^n$$

Regular singular point x_0: Rearrange $(\star)$ as:
$(x-x_0)^2y''+[(x-x_0)p(x)](x-x_0)y'+[(x-x_0)^2q(x)]y=0$
If $r_1>r_2$ are roots of the indicial equation: $r(r-1)+br+c=0$ where $b=\lim_{x\to x_0}(x-x_0)p(x)$ and $c=\lim_{x\to x_0}(x-x_0)^2q(x)$ then a solution of $(\star)$ is

$$y_1(x) = \textstyle\sum_{n=0}^\infty a_n(x-x_0)^{n+r_1} \quad \text{where } a_0=1.$$

The second linerly independent solution y_2 is of the form:
Case 1: If r_1-r_2 is neither 0 nor a positive integer:

$$y_2(x) = \sum_{n=0}^\infty b_n(x-x_0)^{n+r_2} \text{ where } \ b_0=1.$$

Case 2: If $r_1-r_2=0$:

$$y_2(x) = y_1(x)\ln(x-x_0)+\sum_{n=1}^\infty b_n(x-x_0)^{n+r_2} \text{ for some } b_1, b_2 ...$$

Case 3: If r_1-r_2 is a positive integer:

$$y_2(x) = ay_1(x)\ln(x-x_0)+\sum_{n=0}^\infty b_n(x-x_0)^{n+r_2} \text{ where } \ b_0=1.$$

Fourier, sine and cosine series

Let $f(x)$ be defined in $[-L,L]$then its Fourier series $Ff(x)$ is a $2L$-periodic function on $\mathbf{R}$:

$$Ff(x) = \frac{a_0}{2}+\sum_{n=1}^\infty\left\{a_n\cos(\frac{n\pi x}{L})+b_n\sin(\frac{n\pi x}{L})\right\}$$

where $a_n = \frac{1}{L}\int_{-L}^L f(x)\cos(\frac{n\pi x}{L})\,dx$ and $b_n=\frac{1}{L}\int_{-L}^L f(x)\sin(\frac{n\pi x}{L})\,dx$
Theorem (Pointwise convergence) If $f(x)$ and $f'(x)$ are piecewise continuous, then $Ff(x)$ converges for every x to $\frac{1}{2}[f(x-)+f(x+)]$.
Parseval's indentity

$$\frac{1}{L}\int_{-L}^L |f(x)|^2dx = \frac{|a_0|^2}{2}+\sum_{n=1}^\infty\left(|a_n|^2+|b_n|^2\right).$$

For $f(x)$ defined in $[0,L]$, its cosine and sine series are

$$Cf(x) = \frac{a_0}{2}+\sum_{n=1}^\infty a_n\cos(\frac{n\pi x}{L}), \quad a_n = \frac{2}{L}\int_0^L f(x)\cos(\frac{n\pi x}{L})\,dx,$$

$$Sf(x) = \sum_{n=1}^\infty b_n\sin(\frac{n\pi x}{L}), \quad b_n = \frac{2}{L}\int_0^L f(x)\sin(\frac{n\pi x}{L})\,dx.$$

Sturm-Liouville Eigenvalue Problems

ODE: $[p(x)y']'-q(x)y+\lambda r(x)y=0, \quad a<x<b.$
BC: $\alpha_1 y(a)+\alpha_2 y'(a)=0, \quad \beta_1 y(b)+\beta_2 y'(b)=0.$
Hypothesis: p, p', q, r continuous on $[a,b]$. $p(x)>0$ and $r(x)>0$ for $x\in[a,b]$. $\alpha_1^2+\alpha_2^2>0$. $\beta_1^2+\beta_2^2>0$.
Properties (1) The differential operator $Ly=[p(x)y']'-q(x)y$ is symmetric in the sense that $(f,Lg)=(Lf,g)$ for all f,g satisfying the BC, where $(f,g)=\int_a^b f(x)g(x)\,dx$. (2) All eigenvalues are real and can be ordered as $\lambda_1<\lambda_2<\cdots<\lambda_n<\cdots$ with $\lambda_n\to\infty$ as $n\to\infty$, and each eigenvalue admits a unique (up to a scalar factor) eigenfunction ϕ_n.
(3) **Orthogonality**: $(\phi_m, r\phi_n)=\int_a^b\phi_m(x)\phi_n(x)r(x)\,dx=0$ if $\lambda_m\neq\lambda_n$.
(4) **Expansion**: If $f(x):[a,b]\to\mathbf{R}$ is square integrable, then

$$f(x)=\sum_{n=1}^\infty c_n\phi_n(x), \ a<x<b \ , \ c_n=\frac{\int_a^b f(x)\phi_n(x)r(x)\,dx}{\int_a^b\phi_n^2(x)r(x)\,dx}, \ n=1,2,\ldots$$