Course Outline for Mathematics 257/316 (3 credits) Term 1, Sept.-Dec., 2017
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

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Office Hours: Monday: 10-11 am, Wed: 3-3:55 pm, Fri: 10-11 am.

Assessment: The final grades will be based on homework (10%) (including EXCEL/MATLAB projects), two in class midterm exams (40%) 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. A student must get at least 35% on the final exam to pass this course.**

Test Dates: Wednesday, October 18th, Wednesday, November 15th.

Text: (recommended but not required) Elementary Differential Equations and Boundary Value Problems (10th Ed), W.E. Boyce & R.C. DiPrima (John Wiley & Sons) 2012

Other References: 1.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

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

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	$y = Ae^{r_1x} + Be^{r_2x}$	$y = Ax^{r_1} + Bx^{r_2}$
$r_1 = r_2 = r$	$y = Ae^{rx} + Bxe^{rx}$	$y = Ax^r + Bx^r\ln\lvert x\rvert$
$r = \lambda \pm i\mu$	$e^{\lambda x}[A\cos(\mu x) + B\sin(\mu x)]$	$x^\lambda[A\cos(\mu\ln\lvert x\rvert) + B\sin(\mu\ln\lvert x\rvert)]$

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:

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

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

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

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

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