Differential Equations Notes

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Contents

Remarks

This notes thing was started on 10/19/2025.
I am to work through the WHOLE of the textbook (Elementary Differential Equations and Boundary Value Problems (11th ed)) by the end of this quarter (12/13/2025).
Hopefully, I'll also get around 20-40% of the problems in the textbook done.

1 A

2 B

3 Second-Order Linear Differential Equations

Or differential equations of the form

$$y'' + p(t)y' + q(t)y = g(t).$$

3.1 Homogenous Second-Order Equations

Remember, a **linear** second-order differential equation is of the form

$$P(t)y'' + Q(t)y' + R(t)y = G(t).$$

Nonlinear differential equations are super hard and annoying to tackle and as such they're just not tackled in this book :/.
In second-order differential equations, a problem with an initial condition has initial condition of the form

$$\begin{cases} y(t_0) = y_0 \\ y'(t_0) = y_0' \end{cases}.$$

Note that there are two initial equations given - the location of y at time t_0, and the slope of y at time t_0.

Definition 3.1 (*Homogenous*)

A **homogenous** differential equation has no 'constant' terms (terms without y). In the case for our second-order linear differential equations, a homogenous equation of that form can be written as

$$P(t)y'' + Q(t)y' + R(t)y = 0.$$

Anyways, it turns out if we solve the homogenous version of the differential equation $P(t)y'' + Q(t)y' + R(t)y = G(t)$, we can actually find an expression for y (that may or may not have an integral in it). That's pretty cool.

For this chapter (unfortunately), we will only consider the cases when $\boxed{P,\ Q,\ \text{and } R \text{ are } \textbf{constants}}$.

Thus, our differential equation becomes $ay'' + by' + cy = 0$. Letting $y = e^{rt}$, we find that our equation now becomes

$$\to ar^2e^{rt} + bre^{rt} + ce^{rt} = e^{rt}(ar^2 + br + c) = 0$$

with $ar^2 + br + c$ called the **characteristic equation** for the general differential equation with constant coefficients shown above.

If we let r_1 and r_2 be two real roots that satisfy the characteristic equation above, then the **general solution** to our differential equation is $y = c_1e^{r_1t} + c_2e^{r_2t}$ with c_1 and c_2 being arbitrary constants. Initial conditions can be solved for summarily.

Exercise 1-4.
1. $y = c_1e^t + c_2e^{-3t}$.
2. $y = c_1e^t + c_2e^{2t}$.
3. $y = c_1e^{t/2} + c_2e^{-t/3}$.
4. $y = c_1 + c_2e^{-5t}$.

□

Exercise 13.
If a differential equation's solution is $c_1e^2t + c_2e^{-3t}$, we have $r_1 = 2$, $r_2 = -3$ and as such our differential equation is $y'' + y' - 6y = 0$.
It probably can be shown that no other differential equation produces the general solution given in the problem. □

Exercise 16.
The characteristic equation for our differential equation is $n^2 - n - 2 = 0$ and as such we have roots $r_1 = 2$, $r_2 = -1$. As such, the general solution to the equation is $y = c_1 e^{2t} + c_2 e^{-t}$.
To make the solution approach 0 as $t \to \infty$, we need $c_1 = 0$ as in any other case, e^{2t} will spiral out to infinity and our solution is unbounded. Thus, we can plug this solution into the second part of the initial value problem $y'(0) = 2$:

$$y'(0) = 2 \to 2 = 2 \cdot 0e^{2t} + (-1) \cdot c_2 e^{-0} \to c_2 = -2.$$

Thus, our final solution to the differential equation is $y_{sol} = -2e^{-t}$ and $y_{sol}(0) = \alpha = -2$. $\square$

3.2 Solutions of Linear Homogenous Equations — the Wronskian

Definition 3.2 (*Differential Operator L*)

A general differential operator *does stuff.*
For now, for continuous functions α and β on some open interval I and for any function ϕ twice differentiable on I, we define the **differential operator L** as

$$L[\phi] = \phi'' + \alpha\phi' + \beta\phi.$$

Note that the result of applying L to some function f is another function g.

In this section we wil examine the equation $L[y] = 0$.

Definition 3.3 (*Existence and Uniqueness Theorem*)

(Reproduced from page 110.)
Consider the initial value problem

$$y'' + p(t)y' + q(t)y = g(t), \quad y(t_0) = y_0, \; y'(t_0) = y_0',$$

where p, q, and g are continuous on an open interval I with $t_0 \in I$. This problem has exactly one solution $y = \phi(t)$, and the solution exists throughout the interval I.

This existence theorem is pretty similar to Theorem 2.4.1 but generalized to second-order linear differential equations. Note once again the guarantee and uniqueness of a solution to the given differential equation over a certain interval.

Definition 3.4 (*Principle of Superposition*)

If y_1 and y_2 are two solutions to the differential equation $L[y] = 0$, then $c_1y_1 + c_2y_2$ is also a solution to the given differential equation for any $(c_1, c_2) \in \mathbb{R}^2$.

Definition 3.5

Wronskian Determinant The **Wronskian Determinant** for the system

$$\begin{cases} c_1y_1(t_0) + c_2y_2(t_0) = y_0, \\ c_1y_1'(t_0) + c_2y_2'(t_0) = y_0' \end{cases}$$

is

$$W = \begin{vmatrix} y_1(t_0) & y_2(t_0) \\ y_1'(t_0) & y_2'(t_0) \end{vmatrix} = y_1(t_0)y_2'(t_0) - y_1'(t_0)y_2(t_0).$$

If W is non-zero, then there is a unique solution to the differential equation $L[y] = 0$ with **any** given initial condition. Otherwise, there are initial conditions to the differential equation that cannot be satisfied no matter how c_1 and c_2 are chosen (113).