

# Homework 5 Oracle

MATH 220 Spring 2021

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## Section 3.1

### Problem 9

$$y'' + 3y' = 0, \quad y(0) = -2, \quad y'(0) = 3$$

Since this is a linear homogeneous constant-coefficient ODE, the solution is of the form  $y = e^{rt}$

$$y = e^{rt} \implies y' = r e^{rt} \implies y'' = r^2 e^{rt}$$

Substitute those expressions into the ODE

$$r^2 e^{rt} + 3(r e^{rt}) = 0$$

Divide both sides by  $e^{rt}$

$$r^2 + 3r = 0$$

Roots of this polynomial are  $r_0 = -3$  and  $r_1 = 0$ . Two solutions to the ODE are  $y = e^{-3t}$  and  $y = e^0 = 1$ . Therefore, the general solution is

$$y(t) = C_1 e^{-3t} + C_2$$

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Differentiating  $y$  gives us

$$y'(t) = -3C_1 e^{-3t}$$

Now, we can determine our constants by applying the two initial conditions we know

$$\begin{cases} y(0) = C_1 + C_2 = -2 \\ y'(0) = -3C_1 = 3 \end{cases}$$

Therefore  $C_1 = -1$  and  $C_2 = -1$ , therefore

$$y(t) = -e^{-3t} - 1$$

This solution converges to  $-1$  as  $t \rightarrow \infty$ .

### **Problem 13 [FOR GRADE]**

Find a differential equation whose general solution is

$$y = c_1 e^{2t} + c_2 e^{-3t}$$

We see the roots are  $r_0 = -3$  and  $r_1 = 2$ . Alternatively, you can make a set of solutions, and call it  $r = \{-3, 2\}$ . So

$$\begin{aligned} (r+3)(r-2) &= 0 \\ \implies r^2 + r - 6 &= 0 \end{aligned}$$

Multiply both sides by  $e^{rt}$

$$r^2 e^{rt} + r e^{rt} - 6 e^{rt} = 0$$

Therefore, the differential equation is

$$y'' + y' - 6y = 0$$

### Problem 16

This is a linear homogeneous constant-coefficient ODE, apply the same method as in Problem 9. Find that  $r = \{-1, 2\}$  and the general solution is

$$y(t) = C_1 e^{-t} + C_2 e^{2t}$$

The derivative would be

$$y'(t) = -C_1 e^{-t} + 2C_2 e^{2t}$$

Let us solve the initial conditions

$$\begin{cases} y(0) = C_1 + C_2 = \alpha \\ y'(0) = -C_1 + 2C_2 = 2 \end{cases} \implies \begin{cases} C_1 = \frac{2}{3}(\alpha - 1) \\ C_2 = \frac{1}{3}(\alpha + 2) \end{cases}$$

Therefore,

$$y(t) = \frac{2}{3}(\alpha - 1)e^{-t} + \frac{1}{3}(\alpha + 2)e^{2t}$$

We can see that if  $t \rightarrow \infty$ , then  $y \rightarrow \infty$ . Therefore, set  $\alpha = -2$ .

### Problem 19

$$y'' + 5y' + 6y = 9, \quad y(0) = 2, \quad y'(0) = \beta,$$

where  $\beta > 0$ .

#### Part (a)

This is a linear homogeneous constant-coefficient ODE, find that  $r = -\frac{1}{2}, \frac{1}{2}$ . The two solutions are

$$y(t) = C_1 e^{-\frac{t}{2}} + C_2 e^{\frac{t}{2}}$$

Then

$$y'(t) = -\frac{C_1}{2}e^{-\frac{t}{2}} + \frac{C_2}{2}e^{\frac{t}{2}}$$

Solve

$$\begin{cases} y(0) = C_1 + C_2 = 2 \\ y'(0) = -\frac{C_1}{2} + \frac{C_2}{2} = \beta \end{cases} \implies \begin{cases} C_1 = 1 - \beta \\ C_2 = 1 + \beta \end{cases}$$

Finally,

$$y(t) = (1 - \beta)e^{-\frac{t}{2}} + (1 + \beta)e^{\frac{t}{2}}$$

To prevent the solution from going to the infinity and beyond, set  $\beta = -1$ .

**Part (b, c, d)**

See Professor Van Vleck's notes on this problem.

### Problem 21 [FOR GRADE]

$$a y'' + b y' + c y = 0,$$

where  $a, b, c \in \mathbb{R}$  and  $a > 0$ .

This is yet again another linear homogeneous constant-coefficient ODE. Find that

$$a(r^2 e^{rt}) + b(re^{rt}) + c(e^{rt}) = 0$$

Divide both sides by  $e^{rt}$

$$\begin{aligned} ar^2 + br + c &= 0 \\ \implies r &= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \end{aligned}$$

**Part (a)**

For the roots to be real, different and negative,  $b^2 - 4ac > 0$  and  $b > 0$  and  $c > 0$ .

**Part (b)**

For the roots to be real with opposite signs,  $b^2 - 4ac > 0$ ,  $b = 0$ .

**Part (c)**

For the roots to be real, different and positive,  $b^2 - 4ac > 0$  and  $b < 0$ .

**Section 3.2****Problem 5**

The Wronskian of these two functions is

$$\begin{aligned}
 W &= \begin{vmatrix} \cos^2 \theta & 1 + \cos 2\theta \\ \frac{d}{d\theta}(\cos^2 \theta) & \frac{d}{d\theta}(1 + \cos 2\theta) \end{vmatrix} \\
 &= \begin{vmatrix} \cos^2 \theta & 1 + \cos 2\theta \\ 2 \cos \theta (-\sin \theta) & -2 \sin 2\theta \end{vmatrix} \\
 &= \cos^2 \theta (-2 \sin 2\theta) - (1 + \cos 2\theta) [2 \cos \theta (-\sin \theta)] \\
 &= -2 \cos^2 \theta \sin 2\theta + 2 \sin \theta \cos \theta (1 + \cos 2\theta) \\
 &= -2 \cos^2 \theta (2 \sin \theta \cos \theta) + 2 \sin \theta \cos \theta (1 + 2 \cos^2 \theta - 1) \\
 &= -4 \cos^2 \theta \sin \theta \cos \theta + 4 \sin \theta \cos \theta \cos^2 \theta \\
 &= 0
 \end{aligned}$$

**Problem 22 [FOR GRADE]**

$$y'' - y' - 2y = 0$$

**Note:** Solutions for this problem are based on Jock's solutions.

**Part (a)**

Calculate  $W(y_1, y_2)$  the Wronskian of  $y_1$  and  $y_2$ .

$$\begin{aligned}
W(y_1, y_2) &= \begin{vmatrix} y_1 & y_2 \\ y_1' & y_2' \end{vmatrix} \\
&= \begin{vmatrix} e^{-t} & e^{2t} \\ -e^{-t} & 2e^{2t} \end{vmatrix} \\
&= e^{-t}(2e^{2t}) - e^{2t}(-e^{-t}) \\
&= 2e^t + e^t \\
&= 3e^t
\end{aligned}$$

Since  $W(y_1, y_2) \neq 0$ ,  $y_1$  and  $y_2$  form a fundamental set of solutions.

### Part (b)

Check that  $y_3$  is a solution of the ODE.

$$\begin{aligned}
y_3'' - y_3' - 2y_3 &\stackrel{?}{=} 0 \\
\frac{d^2}{dt^2}(-2e^{2t}) - \frac{d}{dt}(-2e^{2t}) - 2(-2e^{2t}) &\stackrel{?}{=} 0 \\
(-8e^{2t}) - (-4e^{2t}) - 2(-2e^{2t}) &\stackrel{?}{=} 0 \\
-8e^{2t} + 4e^{2t} + 4e^{2t} &\stackrel{?}{=} 0 \\
0 &= 0
\end{aligned}$$

Now check that  $y_4 = e^{-t} + 2e^{2t}$  is a solution of the ODE.

$$\begin{aligned}
y_4'' - y_4' - 2y_4 &\stackrel{?}{=} 0 \\
\frac{d^2}{dt^2}(e^{-t} + 2e^{2t}) - \frac{d}{dt}(e^{-t} + 2e^{2t}) - 2(e^{-t} + 2e^{2t}) &\stackrel{?}{=} 0 \\
(e^{-t} + 8e^{2t}) - (-e^{-t} + 4e^{2t}) - 2(e^{-t} + 2e^{2t}) &\stackrel{?}{=} 0 \\
e^{-t} + 8e^{2t} + e^{-t} - 4e^{2t} - 2e^{-t} - 4e^{2t} &\stackrel{?}{=} 0 \\
0 &= 0
\end{aligned}$$

Now check that  $y_5 = 2y_1(t) - 2y_3(t) = 2e^{-t} - 2(-2e^{2t}) = 2e^{-t} + 4e^{2t}$  is a solution of the ODE.

$$\begin{aligned}
y_5'' - y_5' - 2y_5 &\stackrel{?}{=} 0 \\
\frac{d^2}{dt^2}(2e^{-t} + 4e^{2t}) - \frac{d}{dt}(2e^{-t} + 4e^{2t}) - 2(2e^{-t} + 4e^{2t}) &\stackrel{?}{=} 0 \\
(2e^{-t} + 16e^{2t}) - (-2e^{-t} + 8e^{2t}) - 2(2e^{-t} + 4e^{2t}) &\stackrel{?}{=} 0 \\
2e^{-t} + 16e^{2t} + 2e^{-t} - 8e^{2t} - 4e^{-t} - 8e^{2t} &\stackrel{?}{=} 0 \\
0 &= 0
\end{aligned}$$

**Part (c)**

Calculate  $W(y_1, y_3)$ , the Wronskian of  $y_1$  and  $y_3$ .

$$\begin{aligned} W(y_1, y_3) &= \begin{vmatrix} y_1 & y_3 \\ y_1' & y_3' \end{vmatrix} \\ &= \begin{vmatrix} e^{-t} & -2e^{2t} \\ -e^{-t} & -4e^{2t} \end{vmatrix} \\ &= e^{-t}(-4e^{2t}) - (-2e^{2t})(-e^{-t}) \\ &= -4e^t - 2e^t \\ &= -6e^t \end{aligned}$$

Since  $W(y_1, y_3) \neq 0$ ,  $y_1$  and  $y_3$  form a fundamental set of solutions.

Now calculate  $W(y_2, y_3)$ , the Wronskian of  $y_2$  and  $y_3$

$$\begin{aligned} W(y_2, y_3) &= \begin{vmatrix} y_2 & y_3 \\ y_2' & y_3' \end{vmatrix} \\ &= \begin{vmatrix} e^{2t} & -2e^{2t} \\ 2e^{2t} & -4e^{2t} \end{vmatrix} \\ &= e^{2t}(-4e^{2t}) - (-2e^{2t})(2e^{2t}) \\ &= -4e^{4t} + 4e^{4t} \\ &= 0 \end{aligned}$$

Since  $W(y_2, y_3) = 0$ ,  $y_2$  and  $y_3$  do not form a fundamental set of solutions. Now calculate  $W(y_1, y_4)$ , the Wronskian of  $y_1$  and  $y_4$

$$\begin{aligned} W(y_1, y_4) &= \begin{vmatrix} y_1 & y_4 \\ y_1' & y_4' \end{vmatrix} \\ &= \begin{vmatrix} e^{-t} & e^{-t} + 2e^{2t} \\ -e^{-t} & -e^{-t} + 4e^{2t} \end{vmatrix} \\ &= e^{-t}(-e^{-t} + 4e^{2t}) - (e^{-t} + 2e^{2t})(-e^{-t}) \\ &= -e^{-2t} + 4e^t + e^{-2t} + 2e^t \\ &= 6e^t \end{aligned}$$

Since  $W(y_1, y_4) \neq 0$ ,  $y_1$  and  $y_4$  form a fundamental set of solutions. Now calculate  $W(y_4, y_5)$ , the Wronskian of  $y_4$  and  $y_5$ .

$$\begin{aligned}
W(y_4, y_5) &= \begin{vmatrix} y_4 & y_5 \\ y_4' & y_5' \end{vmatrix} \\
&= \begin{vmatrix} e^{-t} + 2e^{2t} & 2e^{-t} + 4e^{2t} \\ -e^{-t} + 4e^{2t} & -2e^{-t} + 8e^{2t} \end{vmatrix} \\
&= (e^{-t} + 2e^{2t})(-2e^{-t} + 8e^{2t}) - (2e^{-t} + 4e^{2t})(-e^{-t} + 4e^{2t}) \\
&= -2e^{-2t} + 8e^t - 4e^t + 16e^{4t} - (-2e^{-2t} + 8e^t - 4e^t + 16e^{4t}) \\
&= 0
\end{aligned}$$

Since  $W(y_4, y_5) = 0$ ,  $y_4$  and  $y_5$  do not form a fundamental set of solutions.

## Problem 24

$$(\cos t)y'' + (\sin t)y' - ty = 0$$

Then

$$y'' + \frac{\sin t}{\cos t}y' - \frac{t}{\cos t}y = 0$$

so

$$p(t) = \tan t$$

Then

$$W = C \exp\left(-\int \tan t \, dt\right)$$

By Abel's Theorem

$$W = C \exp(\ln(\cos t)) \implies W = C \times \cos t$$



### Problem 31

The equation

$$P(x)y'' + Q(x)y' + R(x)y = 0$$

is said to be exact if it can be written in the form

$$(P(x)y')' + (f(x)y)' = 0$$

where  $f(x)$  is to be determined in terms of  $P(x)$ ,  $Q(x)$ , and  $R(x)$ . The latter equation can be integrated once immediately, resulting in a first-order linear equation for  $y$  that can be solved as in Section 2.1. By equating the coefficients of the preceding equations and then eliminating  $f(x)$ , show that a necessary condition for exactness is

$$P''(x) - Q'(x) + R(x) = 0$$

It can be shown that this is also a sufficient condition.