3.3 #**18** $y'' + 2y' + 6y = 0, \quad y(0) = 2, \quad y'(0) = \alpha \geq 0$

(a) $e^{rt} \Longrightarrow r^2 + 2r + 6 = 0 \Longrightarrow r = \dfrac{-2 \pm \sqrt{4 - 24}}{2} = -1 \pm \sqrt{5}\, i$

$\Longrightarrow y_1(t) = e^{-t}\cos(\sqrt{5}\, t), \quad y_2(t) = e^{-t}\sin(\sqrt{5}\, t)$

general solution: $y(t) = c_1 e^{-t}\cos(\sqrt{5}\, t) + c_2 e^{-t}\sin(\sqrt{5}\, t)$

$y(0) = 2 \Longrightarrow 2 = c_1$ (since $\cos(0) = 1$, $\sin(0) = 0$)

$\Longrightarrow y(t) = 2e^{-t}\cos(\sqrt{5}\, t) + c_2 e^{-t}\sin(\sqrt{5}\, t)$

$y'(t) = -2e^{-t}\cos(\sqrt{5}\, t) - 2\sqrt{5}\, e^{-t}\sin(\sqrt{5}\, t)$
$\qquad - c_2 e^{-t}\sin(\sqrt{5}\, t) + c_2\sqrt{5}\, e^{-t}\cos(\sqrt{5}\, t)$

$y'(0) = \alpha \Longrightarrow \alpha = -2 + c_2\sqrt{5} \Longrightarrow c_2 = \dfrac{\alpha + 2}{\sqrt{5}}$

<u>Solution</u>: $y(t) = e^{-t}\left(2\cos(\sqrt{5}\, t) + \dfrac{\alpha + 2}{\sqrt{5}}\sin(\sqrt{5}\, t)\right)$

(b) $y = 0$ when $t = 1$:

$$0 = e^{-1}\left(2\cos(\sqrt{5}) + \frac{\alpha+2}{\sqrt{5}}\sin(\sqrt{5})\right)$$

$$\Longrightarrow \quad 0 = 2\cos(\sqrt{5}) + \frac{\alpha+2}{\sqrt{5}}\sin(\sqrt{5})$$

$$\Longrightarrow \quad \frac{\alpha+2}{\sqrt{5}}\sin(\sqrt{5}) = -2\cos(\sqrt{5})$$

$$\Longrightarrow \quad \alpha+2 = (-2\sqrt{5})\left(\frac{\cos(\sqrt{5})}{\sin(\sqrt{5})}\right) = 3.50877\ldots$$

$$\Longrightarrow \quad \underline{\underline{\alpha = 1.50877\ldots}}$$

(c) smallest t for which $y = 0$:

$$0 = e^{-t}\left(2\cos(\sqrt{5}\,t) + \frac{\alpha+2}{\sqrt{5}}\sin(\sqrt{5}\,t)\right)$$

$$\Longrightarrow \quad \frac{\alpha+2}{\sqrt{5}}\sin(\sqrt{5}\,t) = -2\cos(\sqrt{5}\,t)$$

$$\Longrightarrow \quad \frac{\sin(\sqrt{5}\,t)}{\cos(\sqrt{5}\,t)} = \frac{-2\sqrt{5}}{\alpha+2} \Longrightarrow \tan(\sqrt{5}\,t) = \frac{-2\sqrt{5}}{\alpha+2}$$

Since $\alpha \geq 0$, this says that $\tan(\sqrt{5}\,t) \leq 0 \implies \sqrt{5}\,t$ is between $\frac{\pi}{2}$ and π (smallest t for which $y = 0$),

so that $\tan(\sqrt{5}\,t) = \dfrac{-2\sqrt{5}}{\alpha+2} \implies \sqrt{5}\,t = \pi - \underbrace{\arctan\left(\dfrac{-2\sqrt{5}}{\alpha+2}\right)}_{\text{between } -\pi/2 \text{ and } 0}$

Thus, $t = \dfrac{\pi - \arctan\left(\dfrac{-2\sqrt{5}}{\alpha+2}\right)}{\sqrt{5}}$.

~~(d) $\lim_{\alpha \to 0}$~~

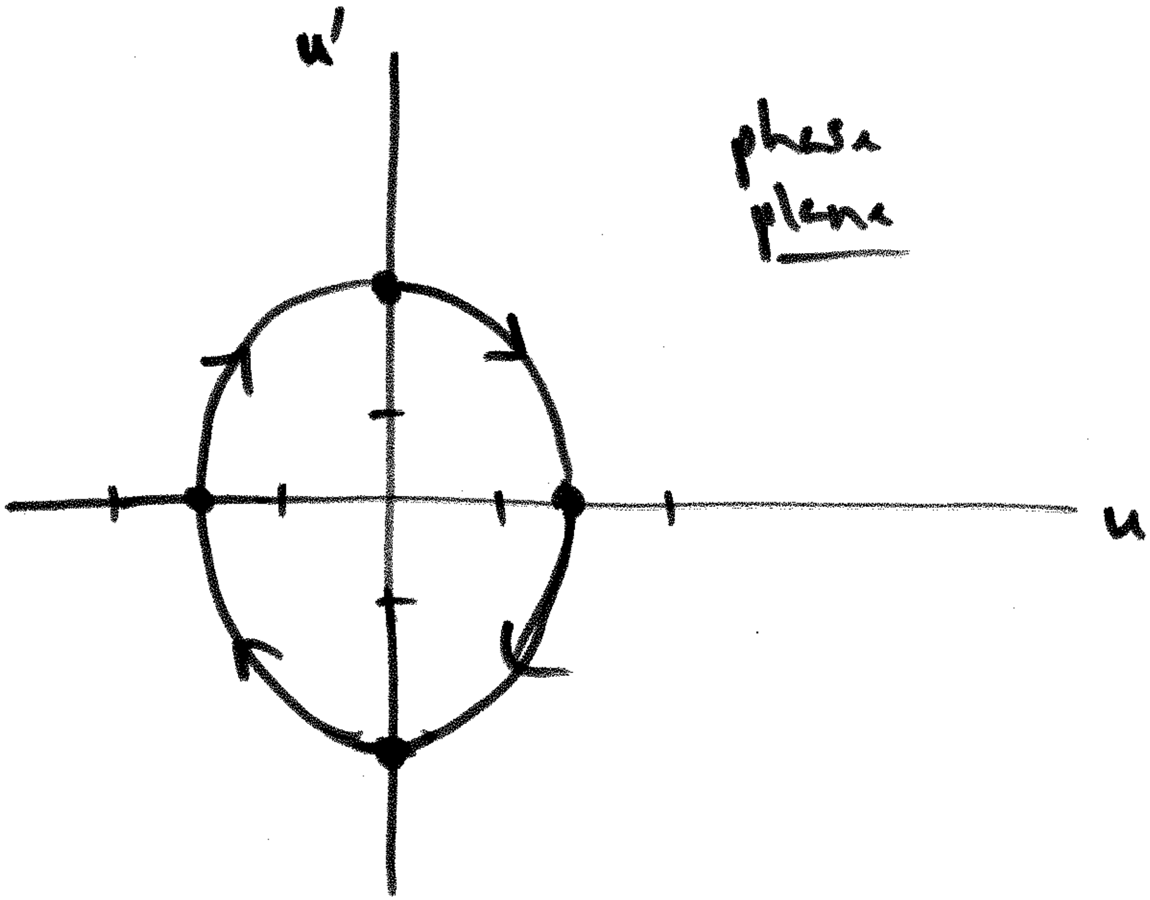
(d) $\displaystyle\lim_{\alpha \to \infty} \left(\frac{\pi - \arctan\left(\frac{-2\sqrt{5}}{\alpha+2}\right)}{\sqrt{5}} \right) = \frac{\pi}{\sqrt{5}}$

since $\arctan(0) = 0$.

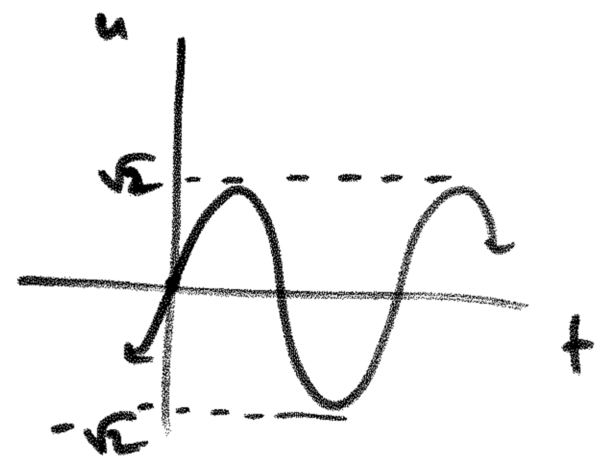
#20 $\quad u'' + 2u = 0, \quad u(0) = 0, \quad u'(0) = 2$

$$\Longrightarrow \left.\begin{aligned} u(t) &= \sqrt{2}\,\sin(\sqrt{2}\,t) \\ u'(t) &= 2\cos(\sqrt{2}\,t) \end{aligned}\right\} \quad \begin{aligned} (u)^2 &= 2\sin^2(\sqrt{2}\,t) \\ (u')^2 &= 4\cos^2(\sqrt{2}\,t) \end{aligned}$$

$$\Longrightarrow \underline{\underline{2(u^2) + (u')^2 = 4}}$$



phase
plane

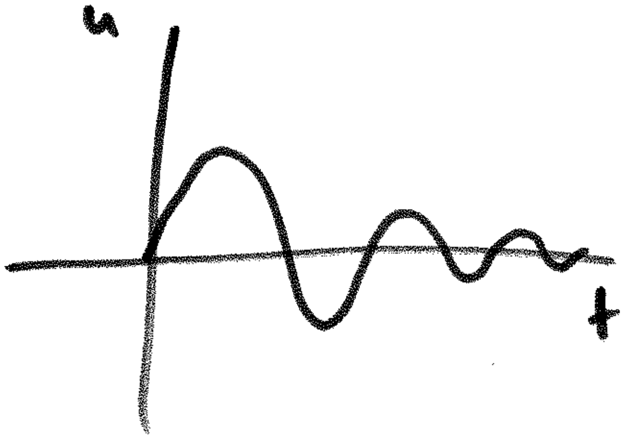


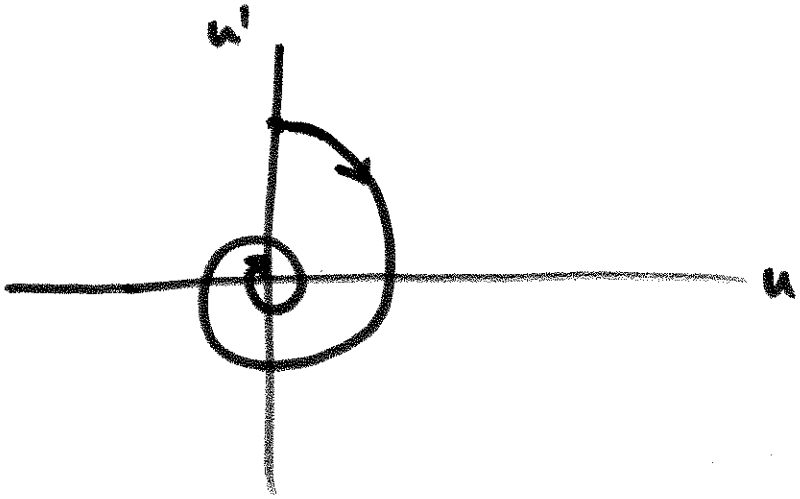
#21 $u'' + \frac{1}{4}u' + 2u = 0$, $u(0) = 0$, $u'(0) = 2$

$$\Rightarrow r^2 + \frac{1}{4}r + 2 = 0 \Longrightarrow r = \frac{-\frac{1}{4} \pm \sqrt{\frac{1}{16} - 8}}{2}$$

$$= \frac{-\frac{1}{4} \pm \alpha i}{2}$$

$$= -\frac{1}{8} \pm \boxed{\cdot}\, i$$





#10 $\quad y'' - 6y' + 9y = 0, \quad y(0) = 0, \quad y'(0) = 2$

$$y = e^{rt} \Longrightarrow r^2 - 6r + 9 = 0 \Longrightarrow (r-3)^2 = 0$$

$$\underline{\underline{r = 3}} \qquad \underline{\underline{y_1 = e^{3t}}}$$

reduction of order : $\quad y_2 = u y_1 = u e^{3t}$

$$y_2' = u'e^{3t} + 3ue^{3t}$$

$$y_2'' = u''e^{3t} + 3u'e^{3t} + 3u'e^{3t} + 9ue^{3t}$$

$$= u''e^{3t} + 6u'e^{3t} + 9ue^{3t}$$

$$\Longrightarrow \overbrace{u'' + \cancel{6u'} + \cancel{9u}}^{y_2''} \overbrace{- \cancel{6u'} - \cancel{18u}}^{-6y'} \overbrace{+ \cancel{9u}}^{+9y} = 0$$

$$\Longrightarrow u'' = 0 \Longrightarrow u(t) = a + bt \Longrightarrow y_2 = te^{3t}$$

$$y(0) = 0 \Longrightarrow c_1 = 0$$

$$y = cte^{3t}$$

General sol'n : $\quad \underline{y(t) = c_1 e^{3t} + c_2 t e^{3t}}$

$$y' = ce^{3t} + 3cte^{3t}$$

$$y' = 2 \Longrightarrow c = 2$$

$$\boxed{y(t) = 2te^{3t}}$$

3.6 #1 $y'' - 5y' + 6y = 2e^t$

step 1: Solve the homogeneous ODE,

$$y'' - 5y' + 6y = 0$$

$$\Longrightarrow \quad r^2 - 5r + 6 = 0 \Longrightarrow r = 2, 3$$

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

step 2: find a particular solution of the nonhomogeneous ODE, $y'' - 5y' + 6y = 2e^t$

$$y_p = u_1 y_1 + u_2 y_2 \quad \text{Ansatz}$$

$$y_p' = \cancel{u_1' y_1} + u_1 y_1' + \cancel{u_2' y_2} + u_2 y_2'$$

$$\boxed{u_1' y_1 + u_2' y_2 = 0}$$

$$y_p'' = u_1' y_1' + u_1 y_1'' + u_2' y_2' + u_2 y_2''$$

$$u_1'y_1' + u_1y_1'' + u_2'y_2' + u_2y_2'' - 5u_1y_1' - 5u_2y_2'$$

$$+ 6u_1y_1 + 6u_2y_2 = 2e^t$$

$$u_1'y_1' + u_2'y_2' + u_1\cancelto{0}{(y_1'' - 5y_1' + 6y_1)} + u_2\cancelto{0}{(y_2' - 5y_2' + 6y_2)}$$

$$= 2e^t$$

$$\Longrightarrow \left.\begin{aligned} & u_1'y_1' + u_2'y_2' = 2e^t \\ \& \quad & u_1'y_1 + u_2'y_2 = 0 \end{aligned}\right\}$$