

Some Details on Content

This section is very important, because from it the student should learn not only techniques (linearization, etc.) but also the fact that phase plane methods are particularly powerful and important in application to systems or single equations that cannot be solved explicitly. The student should also recognize that it is quite surprising how much information these methods can give. This is demonstrated by the **pendulum equation** (Examples 1 and 2) for a relatively simple system, and by the famous **van der Pol equation** for a single equation, which has become a prototype for self-sustained oscillations of electrical systems of various kinds.

We also discuss the famous **Lotka–Volterra predator–prey model**.

For the **Rayleigh** and **Duffing equations**, see the problem set.

SOLUTIONS TO PROBLEM SET 3.5, page 183

2. $y = A \cos t + B \sin t$, radius $\sqrt{A^2 + B^2}$

4. $(\pi n, 0)$ saddle points for even n and centers for odd n

6. At $(0, 0)$, $y_1' = y_2$, $y_2' = -y_1$, $p = 0$, $q = 1$, $\Delta = -4$, center. The other critical point is at $(-1, 0)$. We set $y_1 = -1 + \tilde{y}_1$, $y_2 = \tilde{y}_2$. Then $-y_1 = y_1^2 \approx \tilde{y}_1$. Hence $\tilde{y}_1' = \tilde{y}_2$, $\tilde{y}_2' = \tilde{y}_1$. This gives a saddle point.

8. $y'' + y - y^2 = 0$ written as a system is

$$\begin{aligned} y_1' &= y_2 \\ y_2' &= -y_1 + y_1^3. \end{aligned}$$

Now $-y_1 + y_1^3 = y_1(-1 + y_1^2) = 0$ shows that there are three critical points, at $(y_1, y_2) = (0, 0)$, $(-1, 0)$, and $(1, 0)$.

The linearized system at $(0, 0)$ is

$$\begin{aligned} y_1' &= y_2 \\ y_2' &= -y_1 \end{aligned} \quad \text{Matrix: } \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}.$$

From the matrix we see that $p = a_{11} + a_{22} = 0$, $q = 1$. Hence $(0, 0)$ is a center (see Sec. 3.4).

For the next critical point we have to linearize at $(-1, 0)$ by setting

$$y_1 = -1 + \tilde{y}_1, \quad y_2 = \tilde{y}_2.$$

Then

$$\begin{aligned} y_1(-1 + y_1^2) &= (-1 + \tilde{y}_1)[-1 + (-1 + \tilde{y}_1)^2] \\ &= (-1 + \tilde{y}_1)[-2\tilde{y}_1 + \tilde{y}_1^2] \approx 2\tilde{y}_1. \end{aligned}$$

Hence the linearized system is

$$\begin{aligned} \tilde{y}_1' &= \tilde{y}_2 \\ \tilde{y}_2' &= 2\tilde{y}_1. \end{aligned} \quad \text{Matrix: } \begin{bmatrix} 0 & 1 \\ 2 & 0 \end{bmatrix}.$$

Hence $q = \det \mathbf{A} = -2 < 0$, that is, the critical point at $(-1, 0)$ is a saddle point.

Similarly, to linearize at $(1, 0)$, set

$$y_1 = 1 + \tilde{y}_1, \quad y_2 = \tilde{y}_2.$$

Then

$$-y_1 + y_1^3 \approx -2\tilde{y}_1$$

and we obtain another saddle point, as just before.

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Guillaume Favre



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