

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

- $y = A \cos t + B \sin t$, radius $\sqrt{A^2 + B^2}$.
- $(\pi n, 0)$ saddle points for even n and centers for odd n .
- 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.
- $y'' + y - y^2 = 0$ 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.

Kreyszig Calculus 6th Manual

Xiaolong Qi



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Table of Contents Kreyszig Calculus 6th Manual

1. Understanding the eBook Kreyszig Calculus 6th Manual
 - The Rise of Digital Reading Kreyszig Calculus 6th Manual
 - Advantages of eBooks Over Traditional Books
2. Identifying Kreyszig Calculus 6th Manual
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Kreyszig Calculus 6th Manual
 - User-Friendly Interface
4. Exploring eBook Recommendations from Kreyszig Calculus 6th Manual
 - Personalized Recommendations
 - Kreyszig Calculus 6th Manual User Reviews and Ratings
 - Kreyszig Calculus 6th Manual and Bestseller Lists
5. Accessing Kreyszig Calculus 6th Manual Free and Paid eBooks
 - Kreyszig Calculus 6th Manual Public Domain eBooks
 - Kreyszig Calculus 6th Manual eBook Subscription Services

- Kreyszig Calculus 6th Manual Budget-Friendly Options
- 6. Navigating Kreyszig Calculus 6th Manual eBook Formats
 - ePub, PDF, MOBI, and More
 - Kreyszig Calculus 6th Manual Compatibility with Devices
 - Kreyszig Calculus 6th Manual Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Kreyszig Calculus 6th Manual
 - Highlighting and Note-Taking Kreyszig Calculus 6th Manual
 - Interactive Elements Kreyszig Calculus 6th Manual
- 8. Staying Engaged with Kreyszig Calculus 6th Manual
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Kreyszig Calculus 6th Manual
- 9. Balancing eBooks and Physical Books Kreyszig Calculus 6th Manual
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Kreyszig Calculus 6th Manual
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Kreyszig Calculus 6th Manual
 - Setting Reading Goals Kreyszig Calculus 6th Manual
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Kreyszig Calculus 6th Manual
 - Fact-Checking eBook Content of Kreyszig Calculus 6th Manual
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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