

An introduction to partial differential equations

53.1 Introduction

A partial differential equation is an equation that contains one or more partial derivatives. Examples include:

$$(i) \quad a \frac{\partial u}{\partial x} + b \frac{\partial u}{\partial y} = c$$

$$(ii) \quad \frac{\partial^2 u}{\partial x^2} = \frac{1}{c^2} \frac{\partial u}{\partial t}$$

(known as the heat conduction equation)

$$(iii) \quad \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = 0$$

(known as Laplace's equation)

Equation (i) is a **first order partial differential equation**, and equations (ii) and (iii) are **second order partial differential equations** since the highest power of the differential is 2.

Partial differential equations occur in many areas of engineering and technology; electrostatics, heat conduction, magnetism, wave motion, hydrodynamics and aerodynamics all use models that involve partial differential equations. Such equations are difficult to solve, but techniques have been developed for the simpler types. In fact, for all but for the simplest cases, there are a number of numerical methods of solutions of partial differential equations available.

To be able to solve simple partial differential equations knowledge of the following is required:

- partial integration,
- first and second order partial differentiation — as explained in Chapter 34, and
- the solution of ordinary differential equations — as explained in Chapters 46–51.

It should be appreciated that whole books have been written on partial differential equations and their

solutions. This chapter does no more than introduce the topic.

53.2 Partial integration

Integration is the reverse process of differentiation. Thus, if, for example, $\frac{\partial u}{\partial t} = 5 \cos x \sin t$ is integrated partially with respect to t , then the $5 \cos x$ term is considered as a constant,

$$\begin{aligned} \text{and } u &= \int 5 \cos x \sin t \, dt = (5 \cos x) \int \sin t \, dt \\ &= (5 \cos x)(-\cos t) + c \\ &= -5 \cos x \cos t + f(x) \end{aligned}$$

Similarly, if $\frac{\partial^2 u}{\partial x \partial y} = 6x^2 \cos 2y$ is integrated partially with respect to y ,

$$\begin{aligned} \text{then } \frac{\partial u}{\partial x} &= \int 6x^2 \cos 2y \, dy = (6x^2) \int \cos 2y \, dy \\ &= (6x^2) \left(\frac{1}{2} \sin 2y \right) + f(x) \\ &= 3x^2 \sin 2y + f(x) \end{aligned}$$

and integrating $\frac{\partial u}{\partial x}$ partially with respect to x gives:

$$\begin{aligned} u &= \int [3x^2 \sin 2y + f(x)] \, dx \\ &= x^3 \sin 2y + (x)f(x) + g(y) \end{aligned}$$

$f(x)$ and $g(y)$ are functions that may be determined if extra information, called **boundary conditions** or **initial conditions**, are known.

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Lei Shi



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Table of Contents Introduction To Partial Differential Equations Solution Manual

1. Understanding the eBook Introduction To Partial Differential Equations Solution Manual
 - The Rise of Digital Reading Introduction To Partial Differential Equations Solution Manual
 - Advantages of eBooks Over Traditional Books
2. Identifying Introduction To Partial Differential Equations Solution 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 Introduction To Partial Differential Equations Solution Manual
 - User-Friendly Interface
4. Exploring eBook Recommendations from Introduction To Partial Differential Equations Solution Manual
 - Personalized Recommendations
 - Introduction To Partial Differential Equations Solution Manual User Reviews and Ratings
 - Introduction To Partial Differential Equations Solution Manual and Bestseller Lists

5. Accessing Introduction To Partial Differential Equations Solution Manual Free and Paid eBooks
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 - Introduction To Partial Differential Equations Solution Manual eBook Subscription Services
 - Introduction To Partial Differential Equations Solution Manual Budget-Friendly Options
6. Navigating Introduction To Partial Differential Equations Solution Manual eBook Formats
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 - Introduction To Partial Differential Equations Solution Manual Compatibility with Devices
 - Introduction To Partial Differential Equations Solution Manual Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Introduction To Partial Differential Equations Solution Manual
 - Highlighting and Note-Taking Introduction To Partial Differential Equations Solution Manual
 - Interactive Elements Introduction To Partial Differential Equations Solution Manual
8. Staying Engaged with Introduction To Partial Differential Equations Solution Manual
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Introduction To Partial Differential Equations Solution Manual
9. Balancing eBooks and Physical Books Introduction To Partial Differential Equations Solution Manual
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Introduction To Partial Differential Equations Solution Manual
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Introduction To Partial Differential Equations Solution Manual
 - Setting Reading Goals Introduction To Partial Differential Equations Solution Manual
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Introduction To Partial Differential Equations Solution Manual
 - Fact-Checking eBook Content of Introduction To Partial Differential Equations Solution 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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