

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.

Introduction To Partial Differential Equations

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Table of Contents Introduction To Partial Differential Equations

1. Understanding the eBook Introduction To Partial Differential Equations
 - The Rise of Digital Reading Introduction To Partial Differential Equations
 - Advantages of eBooks Over Traditional Books
2. Identifying Introduction To Partial Differential Equations
 - 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
 - User-Friendly Interface
4. Exploring eBook Recommendations from Introduction To Partial Differential Equations
 - Personalized Recommendations
 - Introduction To Partial Differential Equations User Reviews and Ratings
 - Introduction To Partial Differential Equations and Bestseller Lists
5. Accessing Introduction To Partial Differential Equations Free and Paid eBooks
 - Introduction To Partial Differential Equations Public Domain eBooks
 - Introduction To Partial Differential Equations eBook Subscription Services
 - Introduction To Partial Differential Equations Budget-Friendly Options

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