53

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) $a\dfrac{\partial u}{\partial x} + b\dfrac{\partial u}{\partial y} = c$

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

(known as the heat conduction equation)

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

(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:

(a) partial integration,

(b) first and second order partial differentiation — as explained in Chapter 34, and

(c) 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, $\dfrac{\partial u}{\partial t} = 5\cos x \sin t$ is integrated partially with respect to t, then the $5\cos x$ term is considered as a constant,

and $u = \displaystyle\int 5\cos x \sin t\, dt = (5\cos x)\int \sin t\, dt$

$\qquad = (5\cos x)(-\cos t) + c$

$\qquad = \mathbf{-5\cos x \cos t} + f(x)$

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

then $\dfrac{\partial u}{\partial x} = \displaystyle\int 6x^2\cos 2y\, dy = (6x^2)\int \cos 2y\, dy$

$\qquad = (6x^2)\left(\dfrac{1}{2}\sin 2y\right) + f(x)$

$\qquad = 3x^2\sin 2y + f(x)$

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

$u = \displaystyle\int [3x^2\sin 2y + f(x)]\, dx$

$\qquad = x^3\sin 2y + (x)f(x) + g(y)$

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

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