NON-INDEPENDENT VARIABLES

This paradox points to a serious problem. In computing partial derivatives of $f(x, y, z)$, we assumed that x, y, z were independent. Up to now, x could move while y and z were fixed. In physics and chemistry and economics that may not be possible. If there is a relation between x, y, z, then x can't move by itself.

EXAMPLE 5 The gas law $PV = nRT$ relates pressure to volume and temperature. *P, V, T are not independent.* What is the meaning of $\partial V/\partial P$? Does it equal $1/(\partial P/\partial V)$?

Those questions have no answers, until we say what is held constant. In the paradox, $\partial r/\partial x$ had one meaning for fixed y and another meaning for fixed θ. ***To indicate what is held constant, use an extra subscript*** (not denoting a derivative):

$$(\partial r/\partial x)_y = \cos\theta \qquad (\partial r/\partial x)_\theta = 1/\cos\theta. \tag{12}$$

$(\partial f/\partial P)_V$ has constant volume and $(\partial f/\partial P)_T$ has constant temperature. The usual $\partial f/\partial P$ has both V and T constant. But then the gas law won't let us change P.

EXAMPLE 6 Let $f = 3x + 2y + z$. Compute $\partial f/\partial x$ on the plane $z = 4x + y$.

Solution 1 Think of x and y as independent. Replace z by $4x + y$:

$$f = 3x + 2y + (4x + y) \quad \text{so} \quad (\partial f/\partial x)_y = 7.$$

Solution 2 Keep x and y independent. Deal with z by the chain rule:

$$(\partial f/\partial x)_y = \partial f/\partial x + (\partial f/\partial z)(\partial z/\partial x) = 3 + (1)(4) = 7.$$

Solution 3 (***different***) Make x and z independent. Then $y = z - 4x$:

$$(\partial f/\partial x)_z = \partial f/\partial x + (\partial f/\partial y)(\partial y/\partial x) = 3 + (2)(-4) = -5.$$

Without a subscript, $\partial f/\partial x$ means: Take the x derivative the usual way. The answer is $\partial f/\partial x = 3$, when y and z don't move. But on the plane $z = 4x + y$, one of them must move! 3 is only part of the total answer, which is $(\partial f/\partial x)_y = 7$ or $(\partial f/\partial x)_z = -5$.

Here is the geometrical meaning. We are on the plane $z = 4x + y$. The derivative $(\partial f/\partial x)_y$ moves x but not y. To stay on the plane, dz is $4dx$. The change in $f = 3x + 2y + z$ is $df = 3dx + 0 + dz = 7dx$.

EXAMPLE 7 On the world line $x^2 + y^2 + z^2 = t^2$ find $(\partial f/\partial y)_{x,z}$ for $f = xyzt$.

The subscripts x, z mean that x and z are fixed. The chain rule skips $\partial f/\partial x$ and $\partial f/\partial z$:

$$(\partial f/\partial y)_{x,z} = \partial f/\partial y + (\partial f/\partial t)(\partial t/\partial y) = xzt + (xyz)(y/t). \ \textit{Why } y/t?$$

EXAMPLE 8 From the law $PV = T$, compute the product $(\partial P/\partial V)_T(\partial V/\partial T)_P(\partial T/\partial P)_V$.

Any intelligent person cancels ∂V's, ∂T's, and ∂P's to get 1. The right answer is -1:

$$(\partial P/\partial V)_T = -T/V^2 \qquad (\partial V/\partial T)_P = 1/P \qquad (\partial T/\partial P)_V = V.$$

The product is $-T/PV$. ***This is*** -1 ***not*** $+1$! The chain rule is tricky (Problem 42).

EXAMPLE 9 Implicit differentiation was used in Chapter 4. The chain rule explains it:

$$\textit{If } F(x, y) = 0 \textit{ then } F_x + F_y y_x = 0 \textit{ so } dy/dx = -F_x/F_y. \tag{13}$$