2.5 Parcel concepts

We have just discussed adiabatic processes for a mass of air contained in a cylinder. To apply similar concepts to the atmosphere, we introduce the idea of an *air parcel* – a small mass of air that is imagined to be 'marked' in some way, so that its passage through the surrounding air ("the environment") can in principle be traced. The parcel is influenced by the environment, but we assume that it does not itself change the environment. The pressure within the parcel is taken to equal that of the surrounding environment, but its temperature, density and composition may differ from those of the environment. The parcel concept is useful, but should not be taken too literally; for example, a real mass of air will rapidly mix with its surroundings and will also inevitably influence the surrounding air.

One simple way to think of an air parcel is to imagine it to be enclosed in a thin balloon of negligible surface tension and heat capacity. We may also take the balloon to have negligible thermal conductivity, in which case the parcel moves adiabatically if there are no sources or sinks of heat within it*. In the adiabatic case, we can extend the definition of the potential temperature from a cylinder to a parcel of air; it is the final temperature θ of a parcel that is imagined to be brought adiabatically from pressure p and temperature T to pressure p_0.

For an adiabatically rising parcel, the potential temperature and entropy are constant as its height changes, so we can write

$$\left(\frac{d\theta}{dz}\right)_{\text{parcel}} = 0, \qquad \left(\frac{dS}{dz}\right)_{\text{parcel}} = 0.$$

From equation (2.23) we therefore have the following relation between the vertical derivatives of temperature and pressure, following the parcel:

$$0 = \frac{c_p}{T}\left(\frac{dT}{dz}\right)_{\text{parcel}} - \frac{R}{p}\left(\frac{dp}{dz}\right)_{\text{parcel}},$$

* Such heat sources could be due, for example, to latent heating or cooling; see Section 2.7.

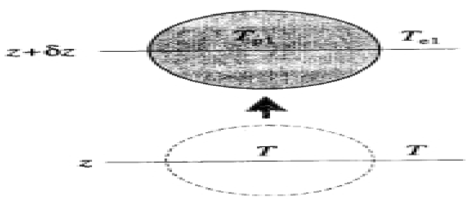

Figure 2.3 A parcel (shown shaded) displaced a height δz from its equilibrium position at height z (shown dashed).

so that

$$-\left(\frac{dT}{dz}\right)_{\text{parcel}} = -\frac{RT}{c_p p}\left(\frac{dp}{dz}\right)_{\text{parcel}} = \frac{g}{c_p} = \Gamma_a, \tag{2.26}$$

say, where equations (2.12) and (2.1) have been used. The quantity Γ_a is the rate of decrease of temperature with height, following the adiabatic parcel as it rises. It is called the *adiabatic lapse rate*; when applied to a mass of dry air, it is called the *dry adiabatic lapse rate* (DALR) and is approximately 9.8 K km^{-1}.

An alternative derivation of the expression (2.26) for the DALR is to note that, for unit mass,

$$\delta Q = T\,\delta S = c_p\,\delta T - \frac{RT}{p}\,\delta p = c_p\,\delta T - \frac{\delta p}{\rho} = c_p\,\delta T + g\,\delta z, \tag{2.27}$$

from equations (2.19), (2.22), the ideal gas law (2.2) and the hydrostatic equation (2.12). For adiabatic motion of the parcel $\delta Q = 0$ and so, letting $\delta z \to 0$,

$$-\frac{dT}{dz} = \frac{g}{c_p} = \Gamma_a,$$

as before.

The actual lapse rate $-dT/dz$ in the atmosphere will generally differ from the DALR. To investigate the implications of this, consider a parcel that is originally at equilibrium at height z, with temperature T, pressure p and density ρ, all equal to the values for the surroundings. Now suppose that an instantaneous upward force is applied to the parcel, so that it rises adiabatically through a small height δz, without influencing its surroundings; see Figure 2.3.

At the displaced position $z_1 = z + \delta z$ the parcel temperature has increased to T_{p1}, say, according to the adiabatic lapse rate:

$$T_{p1} = T + \left(\frac{dT}{dz}\right)_{\text{parcel}}\delta z = T - \Gamma_a\,\delta z. \tag{2.28}$$