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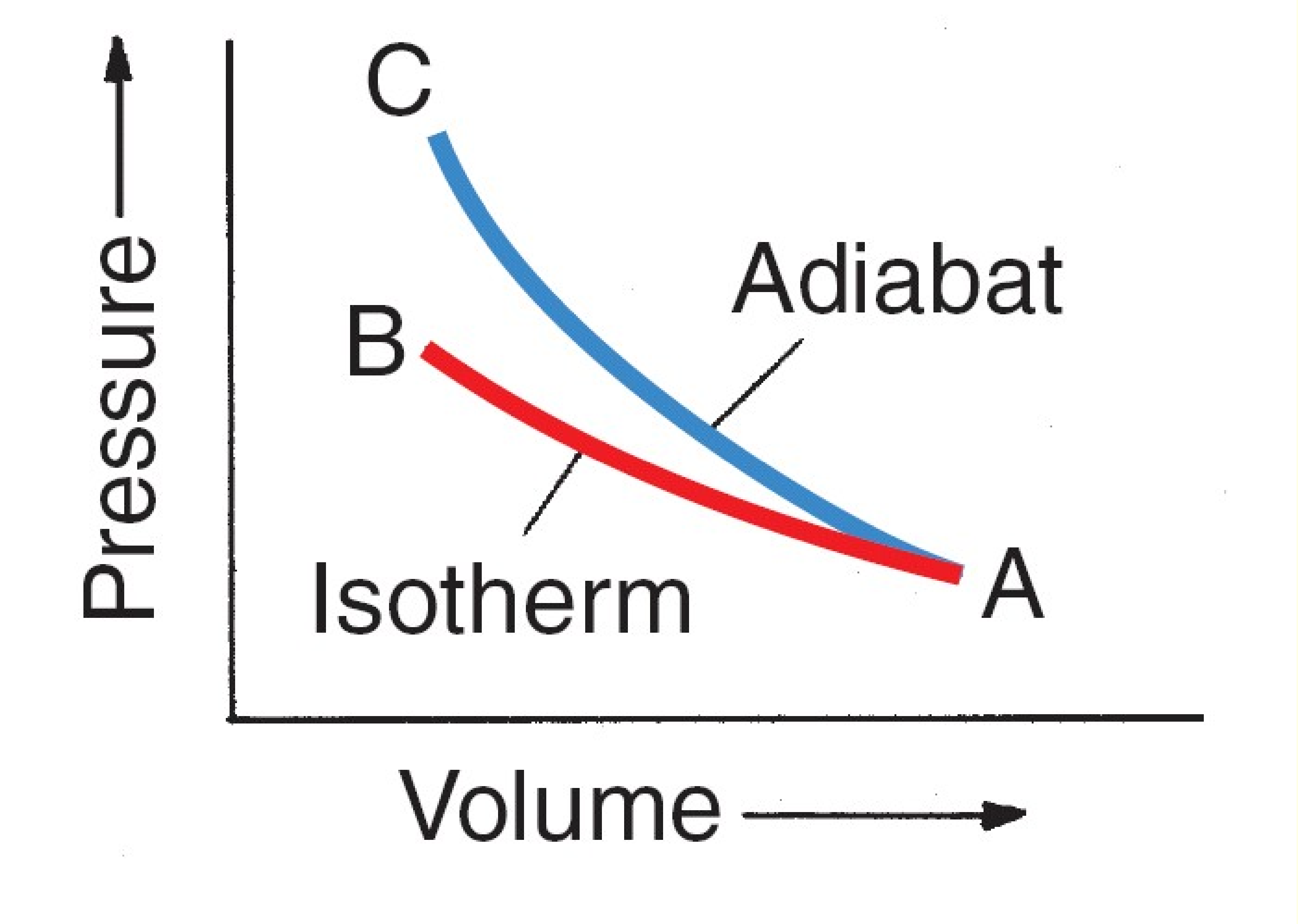
If the same material undergoes a similar change in volume but under *adiabatic* conditions, the transformation would be represented by a curve such as AC, which is called an *adiabat*.



An *isotherm* and an *adiabat* on a p–V-diagram.

The adiabat AC is steeper than the isotherm AB. The reason for this is easily seen.

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$$dq = du + p\,d\alpha \quad \textbf{and} \quad dq = 0 \qquad \Longrightarrow \qquad du = -p\,d\alpha > 0$$

and therefore *the temperature of the system rises*:

$$du = c_v\,dT > 0 \qquad \Longrightarrow \qquad T_C > T_A$$

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$$p_B = \frac{RT_B}{\alpha_B} < \frac{RT_C}{\alpha_C} = p_C$$

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Thus, the adiabat is steeper than the isotherm.

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Recall Richardson's rhyme:

```
Big whirls have little whirls that feed on their velocity,
And little whirls have lesser whirls and so on to viscosity
                                   --- in the molecular sense.
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This simple, idealized model is helpful in understanding some of the physical processes that influence the distribution of vertical motions and vertical mixing in the atmosphere.

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Since the air parcel undergoes only adiabatic transformations ($dq = 0$), and the atmosphere is in hydrostatic equilibrium, for a unit mass of air in the parcel we have:

$$\begin{aligned} c_v\,dT + p\,d\alpha &= 0 \\ c_v\,dT + d(p\,\alpha) - \alpha\,dp &= 0 \\ c_v\,dT + d(R\,T) - \alpha\,dp &= 0 \\ (c_v + R)dT + g\,dz &= 0 \\ c_p\,dT + g\,dz &= 0 \end{aligned}$$

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Dividing through by dz, we obtain

$$-\left(\frac{dT}{dz}\right) = \frac{g}{c_p} \equiv \Gamma_d$$

where Γ_d is called the *dry adiabatic lapse rate*.

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Substituting $g = 9.81\,\mathbf{m\,s^{-2}}$ and $c_p = 1004\,\mathbf{J\,K^{-1}kg^{-1}}$ gives

$$\Gamma_d = \frac{g}{c_p} = 0.0098\,\mathrm{K\,m^{-1}} = 9.8\,\mathrm{K\,km^{-1}} \approx 10\,\mathrm{K\,km^{-1}}$$

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The *actual lapse rate* of temperature in a column of air, which we will indicate by

$$\Gamma = -\frac{dT}{dz},$$

as measured for example by a radiosonde, averages 6 or $7\,\mathbf{K\,km^{-1}}$ in the troposphere, but it takes on a wide range of values at individual locations.

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Using the gas equation $p\alpha = RT$ yields

$$c_p \, dT - \frac{RT}{p} dp = 0 \qquad \textbf{or} \qquad \frac{dT}{T} = \frac{R}{c_p} \frac{dp}{p}$$

Integrating from standard ressure p_0 (where, by definition, $T = \theta$) to p (with temperature T), we write:

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$$\log\left(\frac{T}{\theta}\right) = \frac{R}{c_p} \log\left(\frac{p}{p_0}\right) = \log\left(\frac{p}{p_0}\right)^{R/c_p}$$

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Solving for θ,

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Recall that, for a diatomic gas, $R : c_p = 2 : 7$, so

$$\kappa = \frac{2}{7} \approx 0.286$$

$\star \qquad \star \qquad \star$

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Recall the thermodynamic equation in the form

$$ds \equiv \frac{dq}{T} = c_p \frac{dT}{T} - R\frac{dp}{p} = c_p \frac{d\theta}{\theta} \qquad (*)$$

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The potential temperature is constant for adiabatic flow.
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Potential temperature is an extremely useful parameter in atmospheric thermodynamics, since *atmospheric processes are often close to adiabatic*, in which case θ remains essentially constant.

Later, we will consider a more complicated quantity, the *isentropic potential vorticity*, which is approximately conserved for a broad range of atmospheric conditions.

Thermodynamic Diagrams

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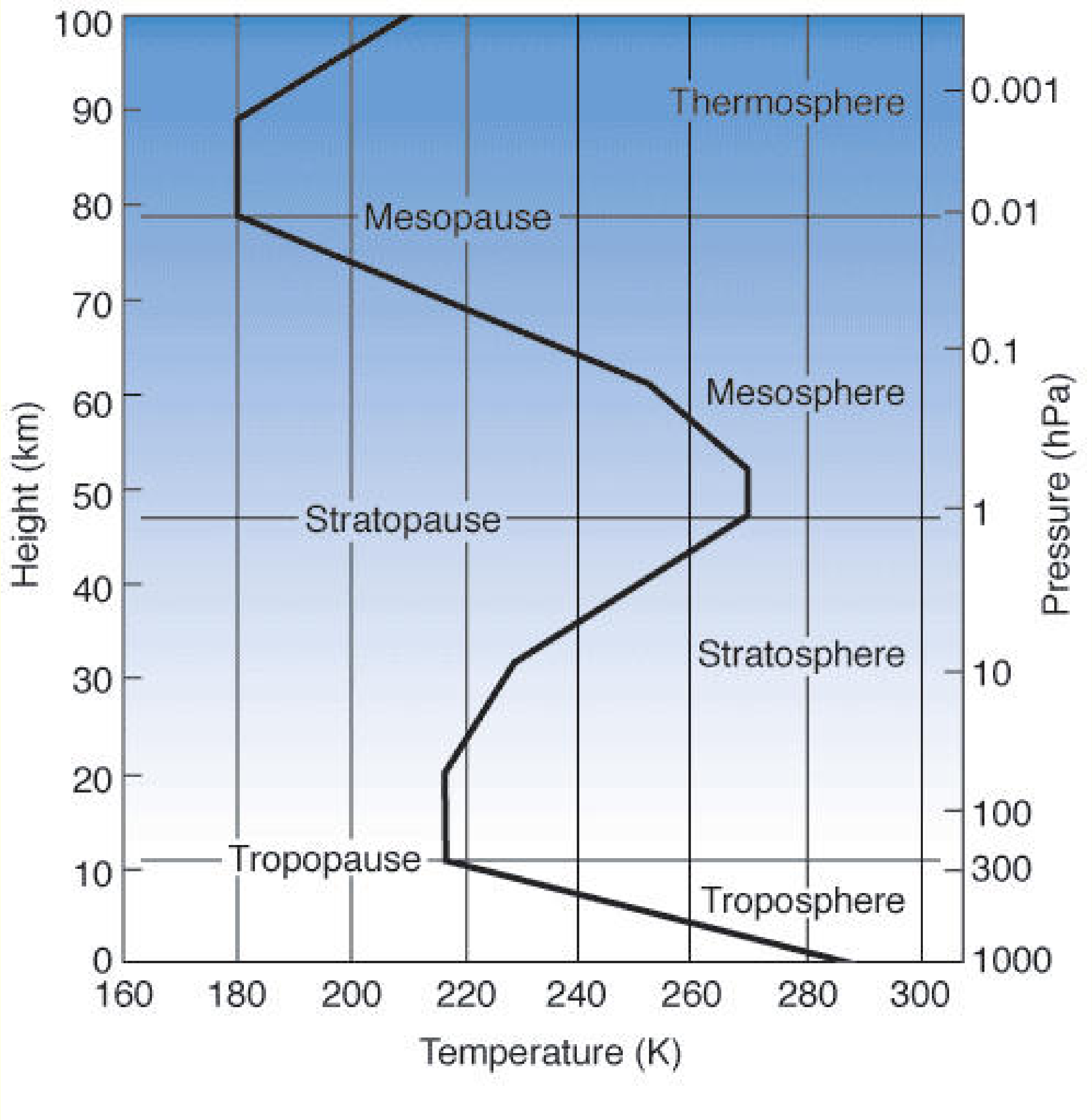
For the mean conditions, we obtain the familiar picture, with the troposphere, stratosphere, mesosphere and thermosphere.



Atmospheric stratification.

The Tephigram

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We owe to Shaw the introduction of the millibar (now replaced by the hectoPascal).

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From (*) and (**) it follows that

$$ds = c_p \frac{d\theta}{\theta} = c_p d\log\theta$$

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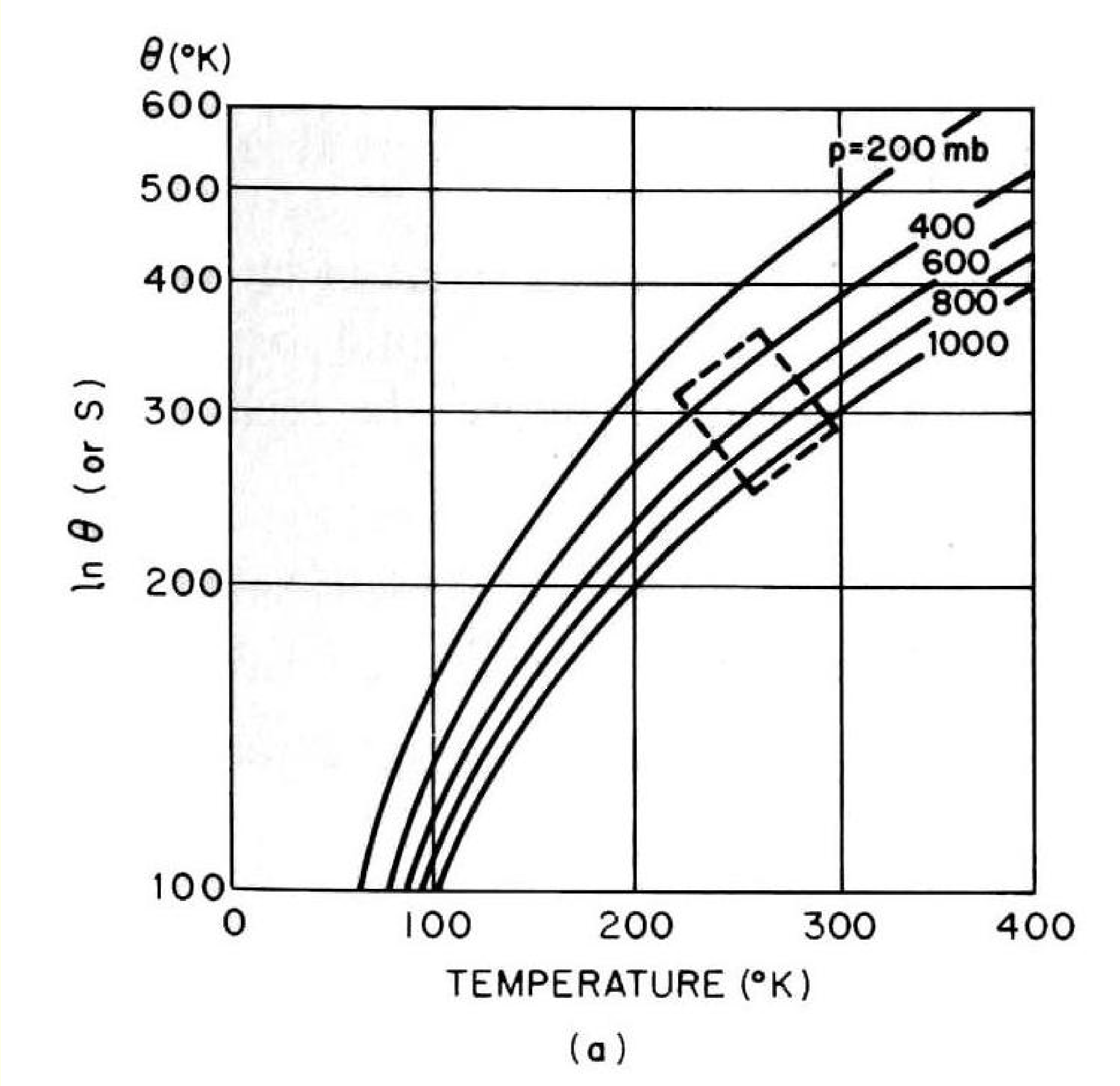
We can thus plot θ instead of s on the vertical axis, on a logarithmic scale.



The temperature-entropy diagram or tephigram. The region of primary interest is indicated by the small box.

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or

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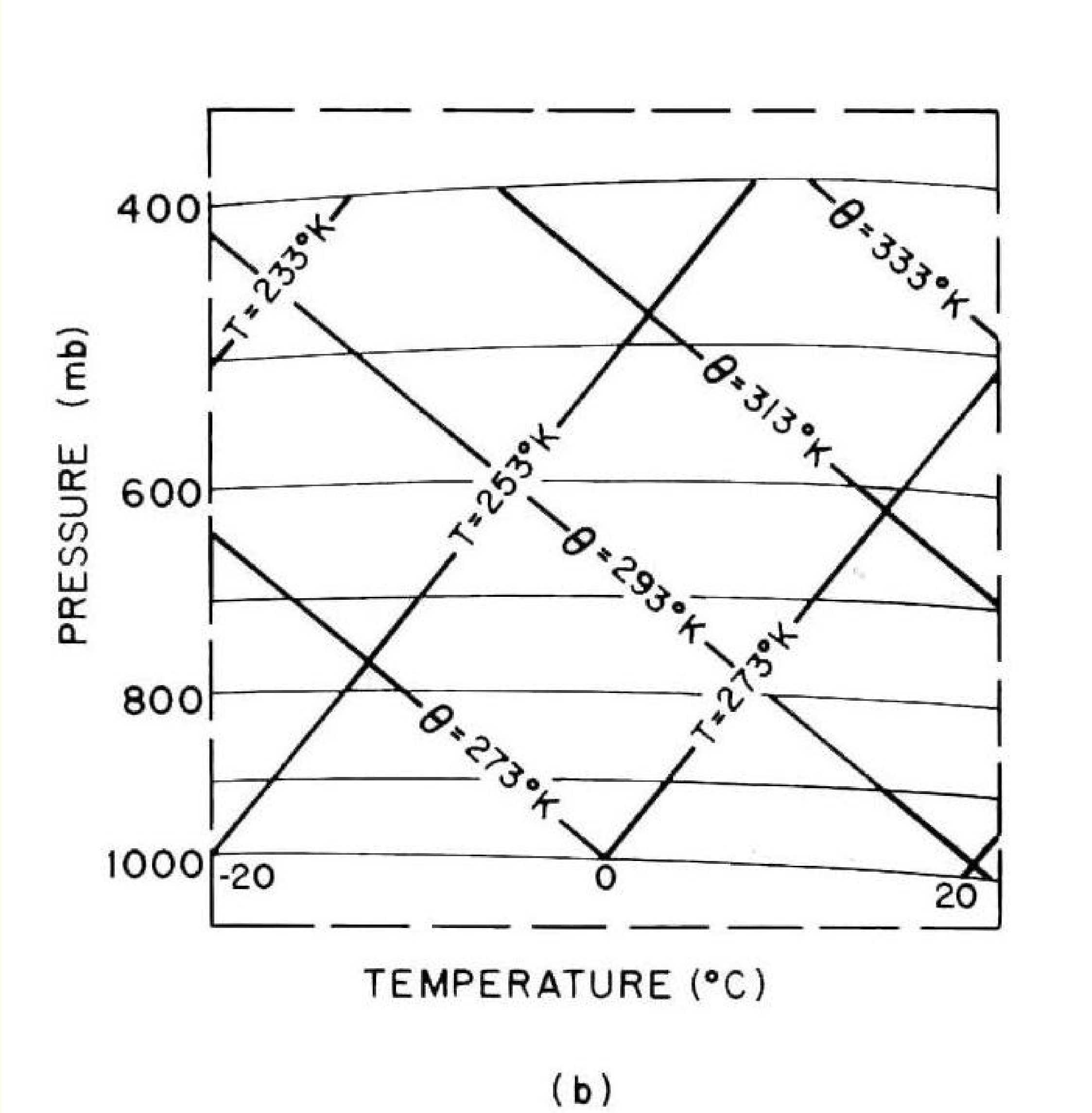
So, for a constant value of *pressure*, s is given by the logarithm of *temperature*. We can plot a series of such curves of s against T for a range of values of pressure, and get the picture shown above.

The region of interest for the lower atmopshere is indicated by a small square. This region is extracted and used in the design of the tephigram. Since surfaces of constant pressure are approximately horizontal, it is convenient to rotate the diagram through 45°.



The temperature-entropy diagram or tephigram. Zoom and rotation of area of interest (*Wallace & Hobbs*, 1st Edn, p. 96).

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Extract from the Met Éireann web-site (9 August, 2004)

A tephigram is a graphical representation of observations of pressure, temperature and humidity made in a vertical sounding of the atmosphere. Vertical soundings are made using an instrument called a radiosonde, which contains pressure, temperature and humidity sensors and which is launched into the atmosphere attached to a balloon.

The tephigram contains a set of fundamental lines which are used to describe various processes in the atmosphere. These lines include:

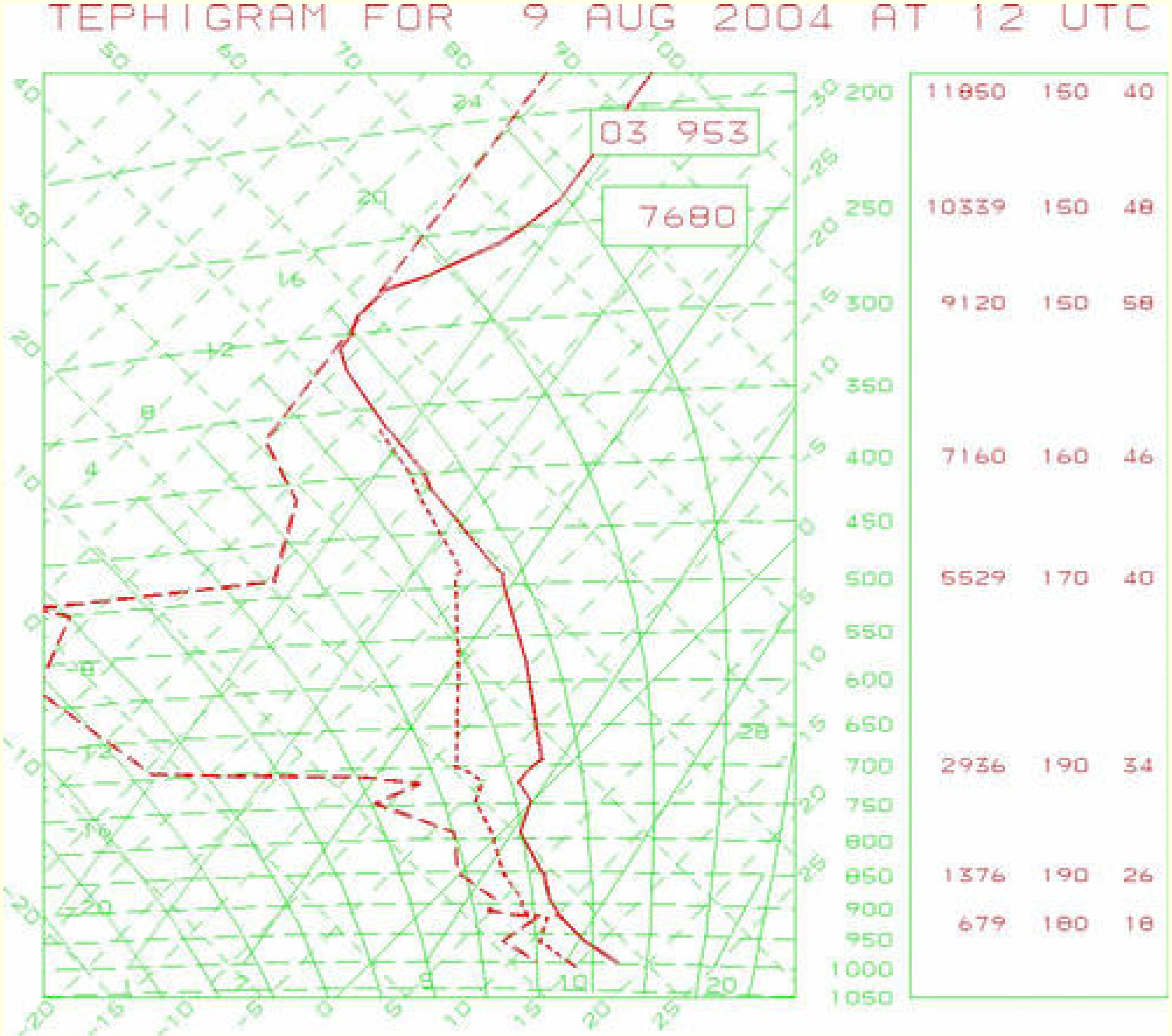
- Isobars — lines of constant pressure
- Isotherms — lines of constant temperature
- Dry adiabats — related to dry adiabatic processes (potential temperature constant)
- Saturated adiabats — related to saturated adiabatic processes (wet bulb potential temperature constant)

On the tephigram there are two kinds of information represented

- The environment curves (red) which describes the structure of the atmosphere
- The process curves (green) which describes what happens to a parcel of air undergoing a particular type of process (e.g. adiabatic process)

In addition, the right hand panel displays height, wind direction and speed at a selection of pressure levels.
Tephigrams can be used by the forecaster for the following purposes

- to determine moisture levels in the atmosphere
- to determine cloud heights
- to predict levels of convective activity in the atmosphere
- forecast maximum and minimum temperatures
- forecast fog formation and fog clearance



Sample Tephigram based on radiosode ascent from Valential Observatory for 1200 UTC, 9 August, 2004.