Question 1

An air parcel has pressure 700 hPa, temperature $-4^\circ$C, and a water vapour mixing ratio of 1 g kg$^{-1}$. Assume the parcel is an ideal gas. You can use the tables in the data sheet provided.

a) Calculate the density of the parcel to two significant digits. [6]

b) If all the vapour in the parcel would condense at the same pressure level, by how much would temperature of the parcel change? [6]

c) Assume water vapour and dry air are ideal gases. Show that the vapour mixing ratio $r_v$ and the vapour pressure $e$ are approximately related as

$$ e \approx \frac{\mu_d}{\mu_v} p r_v $$

with $p$ the pressure, and $\mu_d/\mu_v = 1.61$ the ratio of the molar masses of dry air and water vapour. [10]

d) What is the relative humidity of the parcel? [8]

e) The differential of the specific enthalpy $h$ is

$$ dh = T \, ds + v \, dp. $$

(i) State what each symbol stands for. (ii) State the units of $h$. [8]

f) Explain in less than a half page the relevance of enthalpy to the study of open systems, systems that can exchange matter. [12]

(end of question 1)
Question 2

For an ideal gas, the Brunt–Vaisala frequency $N$ is given by

$$N^2 = \frac{g}{\theta} \frac{d\theta}{dz},$$

with the potential temperature given by

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

a) State the definition of potential temperature [6]

b) Using hydrostatic balance, derive the hypsometric equation

$$Z_1 - Z_0 = \int_{p_1}^{p_0} \frac{RT}{g_0p} dp$$  

[8]

The table below gives two points of a sounding:

<table>
<thead>
<tr>
<th>$p$ (hPa)</th>
<th>$T$ (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>7.0</td>
</tr>
<tr>
<td>700</td>
<td>-5.0</td>
</tr>
</tbody>
</table>

c) Calculate the geopotential thickness of the 900–700hPa layer, stating any assumptions you make. [10]
d) Using the sounding data, above, calculate the Brunt-Vaisala frequency at 800hPa, stating any assumptions you make. [10]
e) State the definition of equivalent potential temperature [6]
f) Describe the physical mechanism of potential instability. State two ways by which potential instability can be suppressed. [10]

(end of question 2)
Question 3
Answer each sub-question, below, in less than half a page, using equations or schematics where appropriate.

a) What is meant by the "activation radius" of a drop and what is its typical magnitude? [10]

b) Explain the physical mechanism by which surface tension raises the saturated vapour pressure around a curved drop? [10]

c) When breathing out in cold air (near 0°C) we can see condensation. Explain why this does not occur in warmer air (say, above 10°C.) [10]

d) State two reasons, including brief explanations, why convective available potential energy (CAPE) is an overestimate of the specific kinetic energy a parcel achieves at its level of neutral buoyancy (LNB.) [10]

e) Use Stefan's law to explain why the stratosphere cools on increasing its CO₂ content. [10]

(end of question 3)