On admission to the examination room, you should acquaint yourself with the instructions below. You must listen carefully to all instructions given by the invigilators. You may read the question paper, but must not write anything until the invigilator informs you that you may start the examination.

You will be given five minutes at the end of the examination to complete the front of any answer books used.

DO NOT REMOVE EXAM PAPER FROM THE EXAM ROOM

January 2016 **MTMG02/ 2015/16 A001**

Answer book
Data sheet
Tephigram
Any bilingual English language dictionary permitted
Any non-programmable calculator permitted

UNIVERSITY OF READING

Atmospheric Physics (MTMG02)

Three hours

Answer **ANY TWO QUESTIONS**.

The marks for the individual components of each question are given in [] brackets.

1. (a) Give definitions (using equations where appropriate) of:

   (i) the wetbulb temperature,

   (ii) the specific humidity,

   (iii) the latent heat of melting.

[10 marks]

The saturation vapour pressure e_s (in hPa) can be calculated from the temperature T (in °C) with the following empirical formula:

$$e_s = 6.112 \exp\left(\frac{17.67\,T}{243.5 + T}\right)$$

(b) A parcel at 750 hPa has a temperature of -1°C and a dewpoint temperature of -5°C. Without using the tephigram at any point, use the above equation to calculate:

   (i) its relative humidity,

   (ii) its vapour mixing ratio.

[7 marks]

(c) The parcel is moved down to 800 hPa. Without using the tephigram at any point, calculate:

   (i) its temperature,

   (ii) its vapour mixing ratio,

   (iii) its vapour (partial) pressure,

   (iv) its relative humidity.

[13 marks]

(d) A cylinder with piston is filled with 5 g of liquid water and is completely compressed, so there is only water in it. The temperature of the cylinder, piston, and water is initially 5°C.

   (i) To what value do we need to isothermally expand the volume in the cylinder to completely evaporate the liquid water?

(ii) The cylinder has a circular cross section of 10 cm diameter and the external atmospheric pressure is 997.0 hPa. With what force do I need to pull at the cylinder to expand it isothermally?

[10 marks]

(e) Assume there is still liquid left in the cylinder when we have expanded the volume isothermally to 2 litre.

(i) How much work do we put into the system to *compress* the volume isothermally to 1 litre?

(ii) If the compression was performed adiabatically a different amount of work would be found. Give a physical explanation why the two values are different.

[10 marks]

[Total: 50 marks]

2. Use the attached tephigram. Please write all your answers in your answer book. **Hand in the named tephigram with your answer book.**

   (a) For the given sounding determine:

      (i) the top of the boundary layer (in hPa),

      (ii) the tropopause (in hPa).

      In both cases, explain why you chose your particular value.

[8 marks]

   (b) For the surface parcel in the given sounding determine:

      (i) the LCL (in hPa),

      (ii) the LFC (in hPa),

      (iii) the LNB (in hPa).

[10 marks]

   (c) CAPE is given by the equation

$$\text{CAPE} = R \int_{\text{LNB}}^{\text{LFC}} (T_p - T_e) \frac{\mathrm{d}p}{p}.$$

      (i) What is the physical meaning of CAPE?

      (ii) Calculate the value of CAPE for the surface parcel in the given sounding.

      (iii) How are CAPE and the updraught velocity in convective clouds related?

[15 marks]

   (d) The buoyancy frequency N is given by the following equation:

$$N^2 = \frac{g}{\theta} \frac{\mathrm{d}\theta}{\mathrm{d}z}$$

      (i) What is the physical meaning of the buoyancy frequency?

[4 marks]

(ii) Use a finite difference approximation (replace $(\mathrm{d}\theta/\mathrm{d}z)$ by $(\Delta\theta/\Delta z)$) to calculate the average buoyancy frequency for the given sounding in the layer between 500 and 450 hPa.

[8 marks]

(iii) How are convective instability and buoyancy frequency related?

[5 marks]

[Total: 50 marks]

3. (a) (i) Give the definition of specific heat capacity and state its units.

   (ii) Which system has a larger heat capacity: a closed cylinder with just vapour in it, or the same closed cylinder with vapour and a small amount of its liquid in it? Give the physical reason for your answer.

   (iii) What is the effective heat capacity per unit area of a surface slab in a fixed SST (Sea Surface Temperature) model of the climate? Explain your answer.

[14 marks]

(b) Consider an atmosphere made up of a single slab of uniform temperature with a total long-wave optical depth of $\delta = 3.0$, above a surface slab (assumed a black body) held at a fixed uniform SST of 25°C.

   (i) Calculate the long-wave absorptivity of the atmospheric slab.

[4 marks]

   (ii) Draw a schematic of the relevant radiative energy fluxes in our model of a single atmospheric slab over the fixed SST surface.

[5 marks]

   (iii) Calculate the temperature of the atmosphere in the given model. (If you found no answer in the first part of this subquestion, then assume a long wave absorptivity of $\epsilon = 0.9$.)

[5 marks]

   (iv) Calculate the peak wavelength and the corresponding angular frequency of the long wave radiation emitted by the atmospheric slab. (If you found no answer in the previous part of this subquestion, then assume an atmosphere temperature of $T_A = 5$°C.)

[4 marks]

(c) The stratosphere cools down when its long-wave absorptivity increases. Explain why this happens.

[7 marks]

(d) (i) A rainfall rate of $2\,\mathrm{mm\,hr^{-1}}$ is measured during a shower. How many drops of 2 mm diameter fall per second per square metre?

[6 marks]

(ii) Explain why surface tension at a drop surface prevents drops from forming in very clean environments.

[5 marks]

[Total: 50 marks]

[End of Question Paper]