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 THE QUESTION PAPER FROM THE EXAM ROOM.

January 2015 **MTMG02/ 2014/15 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. The psychrometric equation is used to calculate the vapour mixing ratio r_v if the dry bub temperature T and wetbulb temperature T_w are given. The equation reads

$$r_v = r_{vs}(T_w) - \frac{c_p}{L}(T - T_w)$$

(a) (i) State the meaning of $r_{vs}(T_w)$, give its definition in terms of density ratios, and state its units.

(ii) Using the ideal gas law, derive an expression for r_{vs} in terms of the saturated vapour pressure.

(iii) Give a typical value for r_{vs} at the surface in the midlatitudes.

[10 marks]

(b) In an experiment, a whirling psychrometer was taken up to a pressure of 800hPa. A dry bulb temperature of 4°C and a wetbulb temperature of -0.5°C was measured.

(i) Use the psychrometric equation, above, to find the vapour mixing ratio of this air.

(ii) Calculate the relative humidity of the air.

(iii) Using the tephigram, provided, verify the above answers. (Hand in the tephigram with your answer book.)

[10 marks]

(c) (i) Give a *physical* explanation of how the latent heat of evaporation L is related to the enthalpy exchange between the liquid and vapour state.

(ii) Explain why this implies that the specific Gibbs functions for the vapour (g_v) and liquid (g_l) have to be equal at equilibrium.

[10 marks]

(d) The annual and global mean latent heat flux is estimated to be $80\,\mathrm{W\,m^{-2}}$.

(i) Calculate the monthly mean accumulation of rain, in mm, that this latent heat flux corresponds to.

(ii) Briefly indicate where on the globe you expect relatively high values of the latent heat flux.

[10 marks]

(e) Outside we measure a dry bulb temperature of -2°C, inside we measure a dry bulb temperature of 18°C. Estimate the relative humidity inside. State any assumption you make (and explain why you are allowed to make these assumptions).

[10 marks]

2. (a) The buoyancy b of an ideal gas air parcel is given by

$$b = \frac{T_p - T_e}{T_e} g$$

The buoyancy represents the net upward force per unit mass on the parcel in a given environment.

(i) Derive the equation, above, using Archimedes' principle ("upward force equals the weight of the displaced fluid")

(ii) Explain why the temperatures in the above equation should really be the *virtual* temperatures.

(iii) According to Newton's first law the upward force per unit mass should equal the upward acceleration. Give two reasons why this is not true for an air parcel.

[10 marks]

(b) When a parcel is displaced vertically in a stable environment, it will oscillate with a natural frequency equal to

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

(i) Use this equation to show that the atmosphere is unstable if $\mathrm{d}\theta/\mathrm{d}z < 0$.

(ii) In the midlatitudes, the potential temperature of the tropopause is about 320K. Use this fact and the above equation to estimate the buoyancy frequency in the midlatitudes.

[10 marks]

(c) Diffusional growth of droplets satisfies the equation

$$r_d(t) = \sqrt{r_d^2(0) + 2At} \quad \text{with} \quad A = D\frac{\rho_{vs}}{\rho_l}(\text{RH} - 1)$$

Assume a fixed temperature of 2°C and a relative humidity of 102%.

(i) State the meaning of the constant D in the above equation. What physical process does it represent?

(ii) To what size will a drop of $5\,\mu$m initial radius grow in 2 minutes assuming a fixed relative humidity?

[10 marks]

(d) The diffusional growth of drops will feed on the water vapour in the environment. Assume that we have 100 drops per cubic centimetre, at a size of $5\,\mu$m initial radius. We start off with a 102% relative humidity.

(i) How much water per unit volume (in kg m^{-3}) is initially in the form of droplets.

(ii) What is the vapour density (kg m^{-3}) at the initial stage of the the growth process.

[10 marks]

(e) (i) How large can the drops grow when the diffusional growth reduces the relative humidity from 102% to 100%.

(ii) In light of this result, comment on the vapour availability for drops to grow from activation to cloud drop size.

[10 marks]

3. Consider an atmosphere that is made up of two slabs, the troposphere and the stratosphere. The troposphere has a long-wave optical depth of $\delta = 2.5$, and the stratosphere has a long-wave optical depth of $\delta = 0.1$. (We do not consider any further wavelength dependency of the long-wave optical depth.)

   (a) (i) State the relationship between optical depth δ and transmittance τ.

   (ii) Calculate the total long-wave transmittance of the above atmosphere.

   (iii) Calculate the long-wave absorptivity of each atmospheric layer.

   [10 marks]

   (b) The atmosphere is overlying a solid black-body surface at a *fixed* temperature of 15°C.

   (i) Calculate the total radiative flux emitted by the surface.

   (ii) Calculate the peak wavelength of this flux.

   (iii) How does this wavelength compare to the wavelength of visible radiation?

   [10 marks]

   (c) The surface exchanges latent and sensible heat fluxes with the troposphere as well as radiative heat fluxes. Give a *physical* explanation whether such convective heat fluxes will increase or decrease the lapse rate in the troposphere compared to the situation with only radiative heat fluxes.

   [10 marks]

(d) The radiative balance in the stratosphere is dominated by a balance between long-wave emission to space and short-wave (mostly UV-radiation) absorption due to ozone. For this part of the question, assume the troposphere is a blackbody radiating at a fixed temperature of 250K, and the stratosphere is an isothermal layer of longwave optical thickness $\delta = 0.1$, and that it absorbs $15\,\mathrm{W\,m^{-2}}$ of ultraviolet radiation.

(i) Draw a schematic of the radiative fluxes in this model.

(ii) Write down the radiation budget for the stratosphere.

(iii) Calculate the equilibrium temperature of the stratosphere.

(iv) Using the above model explain what happens to the stratospheric temperature when the greenhouse gas concentration in the stratosphere increases.

[12 marks]

(e) The “water vapour” channel on a weather satellite observes wavelengths that are in the middle of a strong water vapour absorption band. Explain what such a satellite image shows, and how such an image can be used to locate stratospheric intrusions in weather systems.

[8 marks]

[End of Question Paper]