You are allowed ten minutes before the start of the examination to acquaint yourself with the instructions below and to read the question paper.

Do 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.

January 2010

Data Sheet
Answer Book
Calculators are permitted

Any bilingual English language dictionary permitted
Calculators and programmable calculators are permitted

THE UNIVERSITY OF READING

MSc/Diploma in Applied Meteorology
MSc/Diploma in Atmosphere, Oceans and Climate
MSc in Mathematics and Numerical Modelling of the Atmosphere and Oceans

MTMG02

Atmospheric Physics

Two hours

Answer any TWO questions.

The marks for the individual components of each question are given in [ ] brackets. The total mark for the paper is 100.

Values of Constants:

Avogadro's number, $N_A = 6.022 \times 10^{23}$ mol^{-1}

the specific gas constant for dry air, R_d = 287 J kg^{-1} K^{-1}

the specific gas constant for water vapour, R_v = 461 J kg^{-1} K^{-1}

Specific heat at constant pressure for dry air, c_{Pd} = 1006 J kg^{-1} K^{-1}

Specific heat at constant volume for dry air, c_{Vd} = 719 J kg^{-1} K^{-1}

Universal gas constant, R* = 8314 J kmol^{-1} K^{-1}

absolute zero temperature, 0 K = −273.15 °C

constant for dry air, $\kappa_d = (R_d/c_{Pd})$ = 0.286

Molar mass of water M_w = 18.02 kg kmol^{-1}

Molar mass of dry air M_d = 28.96 kg kmol^{-1}

Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ Wm^{-2} K^{-4}

mean Earth radius, R_E = 6370 km

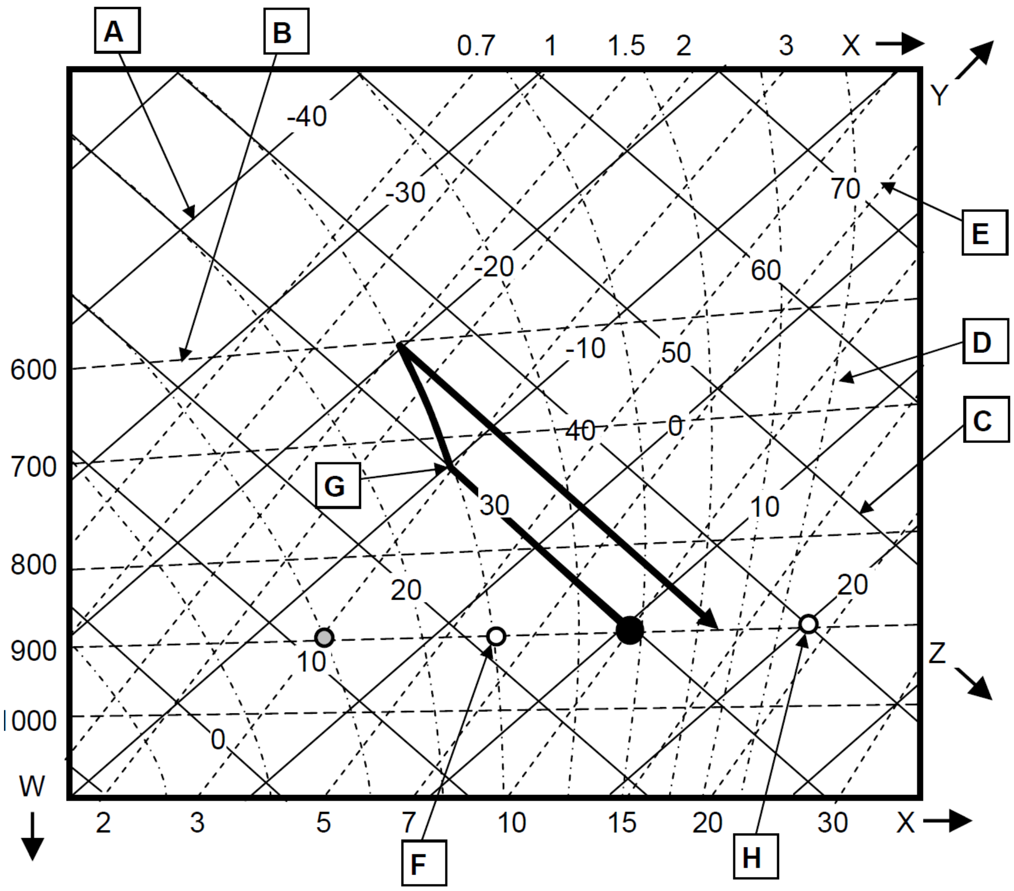
mean radius of Earth's orbit, 1AU = 1.50×10^8 km

mean solar radius $R_\odot = 6.96 \times 10^8$ m

1

a Define the dew-point temperature, T_d . [2 marks]

b In the tephigram given below, the increasing axes labels run from top to bottom for W, from left to right for X, diagonally up from bottom left for Y and diagonally down from top left for Z. Name and give the units of the axes W, X, Y, and Z. Give a definition of the parameter Y and an expression, with definitions of all parameters used, that relates it to the parameters W and Z. What feature means that a tephigram qualifies as a "thermodynamic diagram" ? [8 marks]



Question 1 continues overleaf

Question 1 continued

c A single data point of a T_d profile measured by a radiosonde is shown by the grey dot in the above tephigram and the simultaneously measured data point of the T profile is shown by the black dot. Name the lines and points labelled A-E in the figure and give a definition of each. Give the names and definitions of both the Z and Y parameters of the points F and G. [13 marks]

d The solid black arrow shows the locus on the tephigram followed by the parcel of air as it is blown over a mountain. Describe what is happening at every stage of that evolution. Estimate the relative humidity at the start and end of that evolution. [16 marks]

e If skies in the vicinity of the mountain are generally clear, what would we see over the mountain at pressures below about 700 hPa? What is the mixing ratio, mean molar mass and hence the density of the air parcel when it reaches peak altitude? What would be the percentage error introduced if it were assumed the air was dry? [11 marks]

Turn over

2

a What is the significance of the critical saturation ratio? The Köhler equation for the critical saturation in the presence of solute aerosols can be written as

$$S_C = 1 + (A/T)r^{-1} - br^{-3}$$

where r is the drop radius and A and b are positive constants. Show that there is a maximum of S_C at

$$r = r^* = (3bT/A)^{1/2}$$

which is given by $S_C = S^* = 1 + 2b/r^{*3}$ [11 marks]

b Sketch a typical Köhler curve on a saturation ratio - log(r) plot. Also sketch and label the curves for A = 0 and b = 0 and show r* and S*. What effects do these two limiting cases allow for? [6 marks]

Use your sketch to illustrate
(i) why cloud condensation nuclii are needed to initiate droplet growth. [2 marks]
(ii) why haze particles are stable at small drop sizes [5 marks]
(iii) how orographic lifting causes droplets to become activated and grow [3 marks]
(iv) why atmospheric relative humidities are restricted to one or two percent above 100. [2 marks]

c In part (a), the constant A = 3.3×10^{-7} K m. Compute the maximum haze drop size and relative humidity at a temperature of 10°C for an aerosol solute for which b = 3.8849×10^{-24} m^3 . What would be the values for an aerosol with b one quarter of that given above? [8 marks]

What is the effect on clouds of sulphate aerosols being injected into the atmosphere in diesel engine exhausts and give an example of where it has been seen? [4 marks]

Question 2 continued overleaf

Question 2 continued

d Once activated what would limit the rate of growth of cloud droplets in still air if all drops had the same size at any one time? Give a brief summary of why is this limitation not a factor in the real atmosphere.

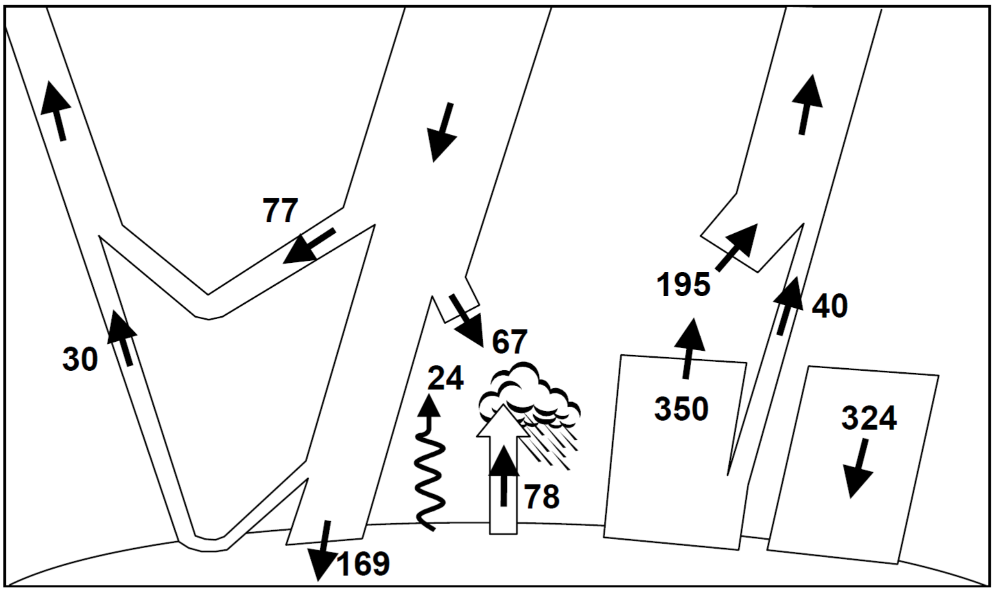
[9 marks]

Turn over

3.

a The Sun is very close to a uniform, isotropic blackbody radiator of temperature 5790 K. With the help of the constants given, compute the irradiance and radiance at the solar surface (assuming that surface is effectively flat), the solar luminosity, the mean solar irradiance at the top of Earth's atmosphere and the shortwave power input per unit area of Earth's surface. [8 marks]

b



The above figure is a version of a very famous diagram published in 1997 by Kiehl & Trenberth. Each number in this schematic diagram is a global mean power per unit area given in Wm^{-2}. For each numbered arrow give:

(i) the source of the power
(ii) the destination of the power
(iii) the type of flux (for example, shortwave radiation, sensible heat flux, etc.)
(iv) the mechanism(s) which are responsible for that energy transfer. [13 marks]

(Identify each flux in your answer with its numerical value).

Question 3 continued overleaf

Turn over

Question 3 continued

c From the numbers given in the figure in part (b), and assuming Earth's atmosphere has a mean emissivity of 0.6 and that its surface is a blackbody radiator, compute:

(i) The shortwave albedo seen from space of the Earth and its atmosphere [2 marks]

(ii) The global mean effective emission temperature of the Earth's surface [3 marks]

(iii) The global mean effective emission temperature of Earth's atmosphere as seen from space [2 marks]

(iv) The global mean effective temperature of the whole Earth as seen from space [2 marks]

(v) The total greenhouse radiative forcing, G [2 marks]

Is the Earth system in radiative equilibrium? What does this mean is happening now and what does it mean for the future? [7 marks]

d What effects do clouds have on Earth's radiation budget? What controls their net effect on the surface temperature and what is required for the global cloud response to greenhouse gas warming to be a negative feedback effect? [11 marks]

(End of Question Paper)