University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER I EXAMINATION 2006/2007

MAPH 40240

Physical Meteorology

Extern examiner: Prof. Frank Hodnett

Head of School: Prof. Adrian Ottewill

Examiner: Dr. Rodrigo Caballero*

Time Allowed: 3 hours

Instructions for Candidates

Answer **four** (4) of the following six questions. Each question carries 25 marks.
A list of values of physical constants can be found on page 7.

Instructions for Invigilators

Non-programmable calculators may be used during this examination. Tephigram charts will be handed to each candidate as part of the examination material.

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Question 1

Consider the following idealized atmospheric sounding:

p (hPa)	T (°C)	T_d (°C)
1000	28.5	17.0
700	7.0	*
500	−12.0	*
350	−32.0	*
300	−32.0	*

where T is temperature and T_d is dew point temperature.

- Plot the sounding on a tephigram chart. Find the pressure at the lifting condensation level, at the level of free convection and at the level of neutral buoyancy for a parcel lifted pseudoadiabatically from the surface. Classify the stability of the sounding at 1000 hPa and 350 hPa as stable, conditionally unstable or unstable.
- What is the relative humidity at 1000 hPa? If this relative humidity is constant with height, provide the missing T_d entries indicated by asterisks in the table above.
- The air exiting an aircraft's jet engine has temperature 340 K and water vapour pressure of 150 hPa, regardless of the temperature and pressure of intake air. If this aircraft passes over the site where the above sounding was taken, estimate the *minimum* altitude (in metres) at which it will produce a contrail. This question is best answered graphically, using Figure 1 (see page 3), which shows the saturation vapour pressure of water as a function of temperature. Neglect the distinction between ice and liquid vapour pressures. Explain your reasoning, using sketches as necessary.

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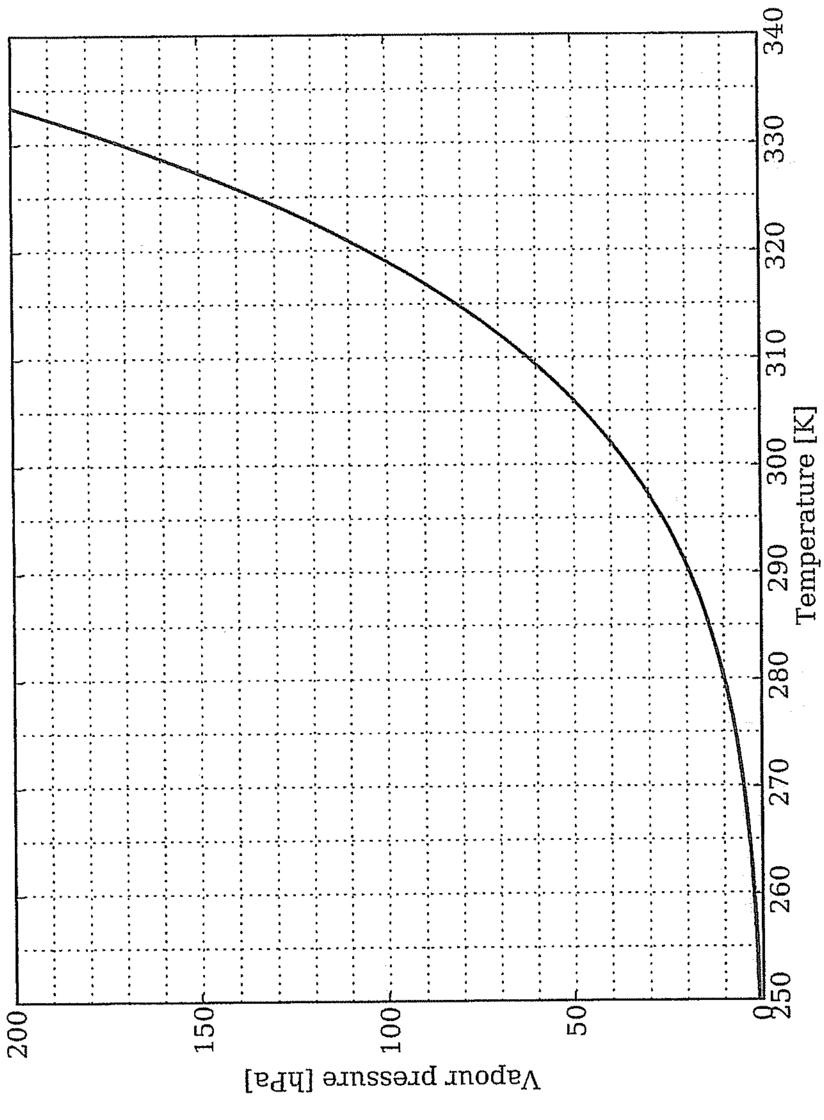
Vapour pressure [hPa]
Temperature [K]
200
150
100
50
0
250
260
270
280
290
300
310
320
330
340

Figure 1:

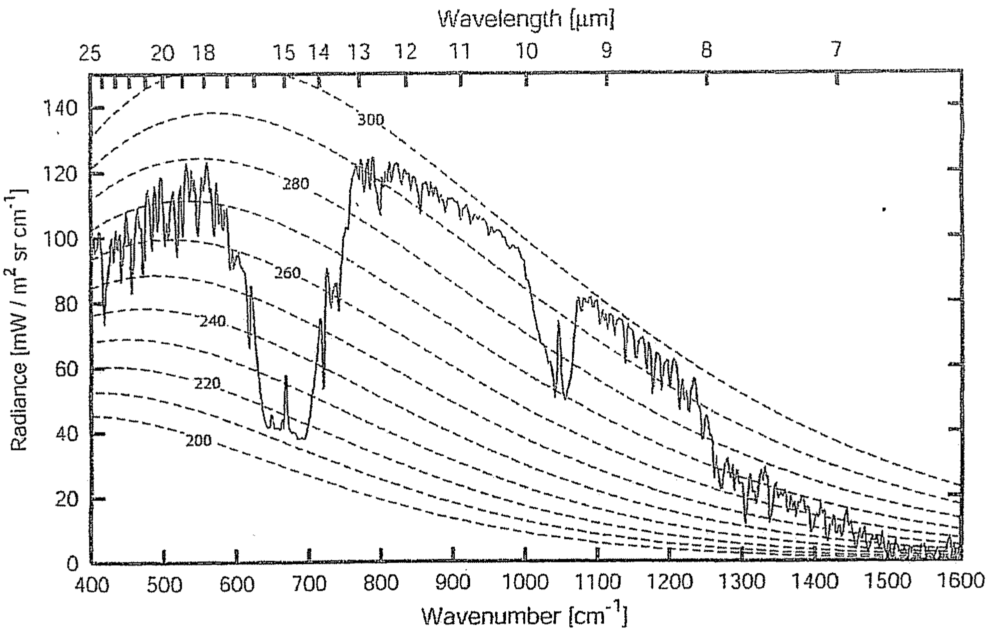

Figure 2:

Question 2

Figure 2 shows the radiance observed by a satellite looking down on Earth above the tropical Pacific ocean on a cloudless day.

- Make a sketch of this spectrum and indicate on it the atmospheric constituents responsible for each of the main absorption features.
- Define, in words, the "effective emission level". Explain the concept of "band saturation", using sketches if necessary. Estimate the temperature at the surface and at the tropopause.
- If the temperature lapse rate is 6 K km^{-1} in the troposphere and -6 K km^{-1} in the stratosphere, estimate the height above the surface of the *highest* effective emission level in the CO_2 band. Also estimate the height above which there is negligible water vapour.

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Question 3

Use of a tephigram chart will be useful in answering all parts of this question.

- State the definitions of dew-point temperature T_d and equivalent temperature T_e. Find the values of T_d and T_e for an air parcel whose temperature is 10°C, pressure is 700 hPa and specific humidity is 3 g/kg. Explain how you found these values using the tephigram.

- Consider a *well-mixed* layer of air bounded below by the ground at 1000 hPa, and above by the 790 hPa level. The layer has vertically constant potential temperature of 30°C and specific humidity of 10 g/kg. Rain is falling through this layer, and attains a steady-state temperature before reaching the ground. Find the value of this temperature. State your reasoning.

- The layer of air described above is forced to pass over a mountain. Clouds and precipitation are observed high up the mountain. After the air has passed over the mountain and descended to 1000 hPa, its temperature is measured and found to be 40°C. Assuming that only 50% of the condensate rains out of cloudy air, estimate the height (in metres) of the mountain.

Question 4

- State the definition (in words) of absorptivity a, transmissivity t, emissivity e and reflectivity r. Give 2 mathematical relations between these quantities.

- Derive the mathematical relationship between a and the optical depth

$$\tau = \int_0^x \rho\, k\, dx,$$

  where ρ is the density of the absorbing species and k is the mass absorptivity.

- A sample of moist air contained in a transparent cube of side 1 m is kept at a pressure of 1000 hPa, a temperature of 30°C and specific humidity of 10 g/kg. When a beam of infrared radiation is passed through the cube, 50% is absorbed within the cube. Treating water vapour as a gray gas, and assuming water vapour is the only radiatively active gas present, estimate the mass absorption coefficient k and the radiative flux *emitted* by the cube. Also, estimate the emitted flux if the air in the cube were saturated.

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Question 5

Consider the following idealised atmospheric sounding:

p (hPa)	T (°C)	q (g/kg)
1000	30	12
700	6	4
600	-1	3
500	-9	1.5
400	-21	*
300	-38	*
200	-38	*

- Using a tephigram chart, find the values of the Showalter index $T_{500} - T'_{850}$ and the lifted index $T_{500} - T'_{1000}$, where T'_x indicates the temperature of a parcel adiabatically lifted from level x. Is there likely to be fog in a mountain pass at an elevation of 1000 m nearby the sounding station?

- Recalling that
$$\text{CAPE} \simeq R_d \int_{p_{LNB}}^{p_{LFC}} (T_p - T_s)\, d\ln p,$$
where T_p is the temperature of a parcel adiabatically lifted from the surface, T_s is the sounding temperature and p_{LFC}, p_{LNB} are the pressures at the level of free convection and level of neutral buoyancy, estimate the CAPE and the typical speed of cloud updrafts in the convecting region. Simplify the calculation by neglecting virtual temperature effects and assuming that the distance between adjacent moist adiabats is constant with height.

- Recalling that
$$f_v = \frac{q}{\epsilon - (\epsilon - 1)q},$$
where f_v is the number fraction of water vapor in air, $\epsilon = R_d/R_v$ and q is specific humidity, show that virtual temperature is given by $T_v = (1 + 0.608q)T$. For the sounding above, estimate p_{LFC} and the lifted index if virtual temperature effects are taken into account. Explain your reasoning, using a sketch if necessary.

Question 6

Consider a rigid balloon of *fixed* volume V containing a fixed mass M of hydrogen gas. Take V=3000 m^3, M=240 kg and m=1000 kg, where m is the of the mass of the balloon's rigid skin.

- The balloon is initially at sea level, where the ambient air pressure is 1000 hPa and temperature is 300 K. Compute the *net* force on the balloon. If the atmosphere is isothermal (zero lapse rate), calculate the height (in metres) at which the balloon is neutrally buoyant (zero net force).
- If the balloon is released from its initial position at sea level and allowed to rise freely, estimate its vertical velocity when it arrives at its level of neutral buoyancy.
- The buoyancy of the balloon can be controlled using a "ballonet", an inflatable balloon contained *inside* the rigid skin of the main balloon. The ballonet can be inflated by pumping ambient air into it, changing the overall density of the balloon. Compute the volume of the ballonet required to keep the balloon neutrally buoyant in its initial, sea-level position. For simplicity, assume that the temperatures of the air in the ballonet and the hydrogen are the same.

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Values of physical constants

Gravitational acceleration g = 9.8 m s^{-1}
Gas constant for dry air R_d = 287 J K^{-1} kg^{-1}
Gas constant for water vapour R_v = 462 J K^{-1} kg^{-1}
Gas constant for hydrogen gas R_{H_2} = 4157 J K^{-1} kg^{-1}
Stefan-Boltzmann constant $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}

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