Norwegian University of Science and Technology
Department of Physics

EXAMINATION IN FY3201 ATMOSPHERIC PHYSICS AND CLIMATE CHANGE
Faculty for Natural Sciences and Technology
1 Jun 2017
Time: 09:00-13:00

Number of pages: 5

Permitted help sources: 1 side of an A5 sheet with printed or handwritten formulas permitted
Single or Bi-lingual dictionary permitted
All calculators permitted

You may take:

Molar mass of dry air: ~29 kg/kmole
Molar mass of helium: ~4 kg/kmole
Molar mass of H_2O: ~18 kg/kmole

$N_A = 6.02\text{x}10^{23}$ molecules/mole   Boltzmann's constant $k = 1.38\text{x}10^{-23}$J/K

273.15 K = 0 °C   1 hPa = 10^2 Pa $=10^2$ N m^{-2} g=9.8 m s^{-2} and constant in z

Stefan–Boltzmann constant: $\sigma = 5.67\times10^{-8}$ $W\cdot m^{-2}\cdot K^{-4}$

Solar photospheric temperature, T_s = 5786 K   Radius of the Sun = 695800 km

Radius of the Earth = 6370 km   1 AU (Earth-Sun distance) $=150\text{x}10^6$ km

Latent heat of vaporization water: $L_v=2.5\text{x}10^6$ $J\cdot kg^{-1}$

Gas constant for water vapour: $R_v=461$ $J\cdot K^{-1}\cdot kg^{-1}$

Values for dry air: $C_p=1004$ $J\cdot K^{-1}\cdot kg^{-1}$ $C_v=718$ $J\cdot K^{-1}\cdot kg^{-1}$ $R_d=287$ $J\cdot K^{-1}\cdot kg^{-1}$

$\gamma = C_p / C_v$ $\kappa = R_d / C_p$ $R_d=C_p - C_v$ $\Gamma_{da}=9.8$ K/km

Clausius–Clapeyron relation: $e_s = 6.112\,hPa\cdot\exp\left[\frac{L_v}{R_v}\left(\frac{1}{273K}-\frac{1}{T}\right)\right]$

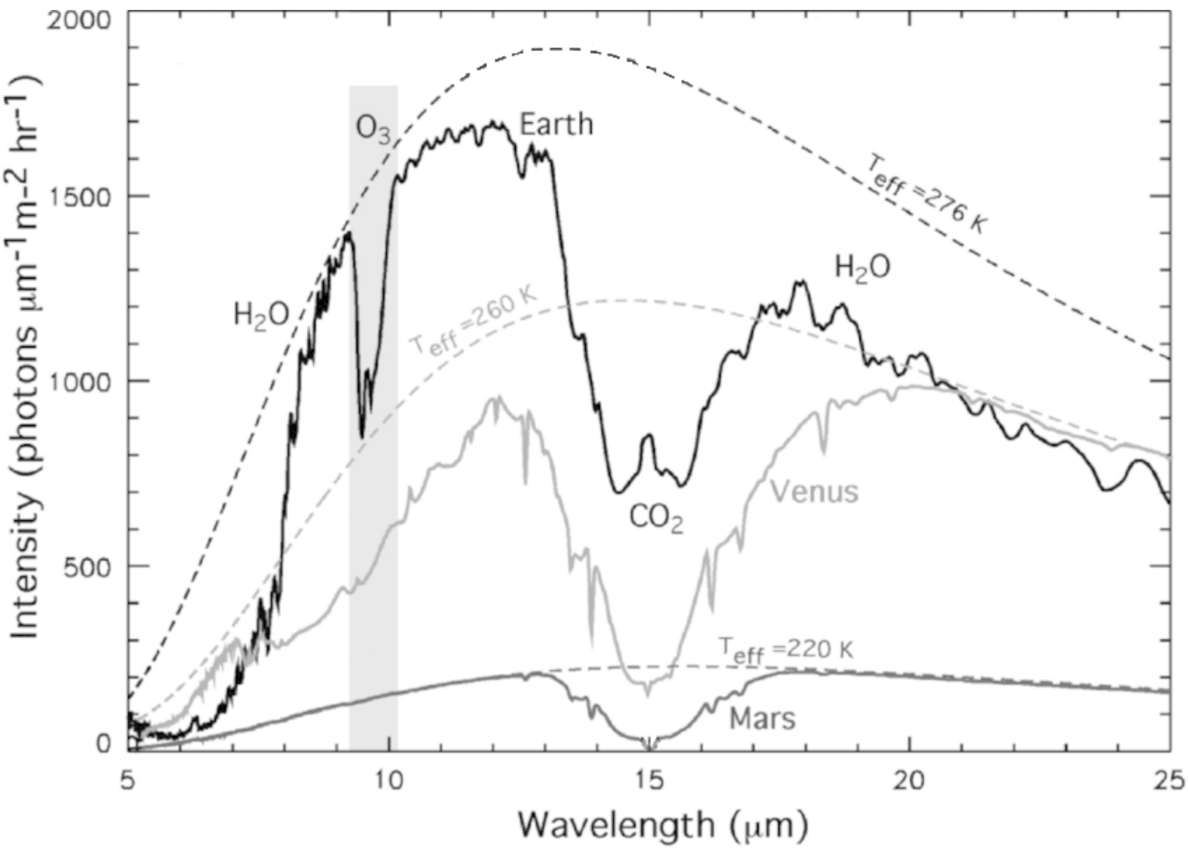
Answer all questions (English, Norwegian, or Swedish).
State all assumptions.
Good Luck!

1) (5%) Black body radiation

Sketch the relative spectral radiance as a function of wavelength or frequency for three blackbodies at temperatures $T_1 > T_2 > T_3$. Label the curves with their temperatures and give the units used for the axes.

2) (15%) Remote sensing and radiation

An inhabited planet in another solar system is excited at the prospect of finding life on other planets. They observe Earth, Venus, and Mars in the infrared and take the following spectra:



a) Estimate the surface temperatures of the three planets from their spectra (3%)

b) Using the CO_2 absorption feature, estimate the atmospheric temperatures (3%)

c) From the behaviour of the absorption near the centre of the CO_2 band, estimate whether the atmospheric temperature increases or decreases with height in the three atmospheres? (5%)

d) The surface temperature of Venus is actually 735 K. If your estimate from part a) is different, can you explain why? (4%)

3) Multiple Choice (20%):

There is only **one** correct answer so you must **choose the best answer**.
Answer A, B, C… (Capital letters).
Correct answer gives +2; incorrect or blank answers give 0.

Write the answers for the multiple choice questions **on the answer sheet you turn in** using a table similar to the following:

Question	a	b	c	d	e	f	g	h	i	j
Answer										

a. If the atmospheric pressure at the surface of the Earth is 1000 hPa, what is the weight of the atmosphere in kg?

A) $5x10^{15}$ B) $5x10^{16}$ C) $5x10^{17}$ D) $5x10^{18}$ E) $5x10^{19}$

b. The dry adiabatic ***lapse rate*** is ___________ than the moist adiabatic lapse rate.
A) Always greater
B) Always smaller
C) Never greater
D) Sometimes greater
E) Sometimes smaller

c. A small cloud droplet will evaporate _______ a large cloud droplet?
A) At the same rate as
B) More slowly than
C) Faster than
D) It will not evaporate

d. Which two atmospheric layers would the mean temperature profiles be stable against convection?
A) Mesosphere and Stratosphere.
B) Mesosphere and Thermosphere.
C) Mesosphere and Troposphere.
D) Stratosphere and Thermosphere.
E) Stratosphere and Troposphere.
F) None of the above.

e. In which layer of the atmosphere is ozone the major species?
A) Stratosphere
B) Mesosphere.
C) Troposphere.
D) Thermosphere.
E) Exosphere.
F) None of the above.

f. If the greenhouse effect produces a temperature warming in the troposphere, why do we find a net 2 K/day radiative cooling there?

A) The greenhouse heating is offset by this cooling, resulting in a steady temperature.
B) It is offsetting non-radiative processes that heat the atmosphere in this region
C) That cooling is only affecting the radiation and not the temperature.
D) There is, in fact, a net cooling of the troposphere
E) None of the above

g. At sunset, in which direction would you look to find a rainbow?

A) North.
B) South.
C) East.
D) West.

h. At sunset, which type of scattering causes the Sun to appear orange?

A) Rayleigh scattering.
B) geometric scattering.
C) Mie scattering.
D) total internal reflection.
E) refraction

i. If the atmospheric absorption of ozone at 9.6μm becomes saturated, what happens if the concentration of ozone continues to increase?

A) The absorption remains the same because it is saturated.
B) The absorption begins to decrease near the band centre.
C) The absorption continues to increase near the band centre.
D) The absorption increases as lines farther from the band centre begin to saturate.

j. What two sets of conditions, working together, will make the atmosphere the most unstable?

A) Warm the surface and warm the air above.
B) Warm the surface and cool the air above.
C) Cool the surface and cool the air above.
D) Cool the surface and warm the air above.
E) None of the above.

k. Under geostrophic conditions, in which direction will the wind blow?

A) In the direction of the Coriolis force.
B) In the direction of the pressure gradient force.
C) Parallel to the isobars or contours of pressure.
D) At an angle between 10^o and 30^o to the contours and toward the low pressure.
E) At an angle between 10^o and 30^o to the contours and toward the high pressure
F) None of the above.

4) (20%) Atmospheric thermodynamics and structure

A helium balloon, weighing 50 kg when empty, must carry an instrument payload weighing 100 kg to an altitude where the pressure is 40 hPa and the temperature is 230 K.

a) Assuming this spherical balloon has been floating at this altitude, and the temperature of the helium has equilibrated to the surrounding air temperature, what is the approximate radius of the balloon? (6%)

b) A similar balloon and payload is launched from a ground station where the pressure was 1000 hPa and the temperature was 300 K. If it ascended quickly to 40 hPa such that the helium in the balloon behaved adiabatically and did not have time to equilibrate with the surrounding air, what would the temperature of the helium inside the balloon be when it reached 40 hPa? The specific heat for helium is $C_p = 5190\ J{\cdot}K^{-1}{\cdot}kg^{-1}$. (6%)

c) In the case of the adiabatic ascent of part (b), what is the approximate radius of the balloon when it reaches 40 hPa? (6%)

d) What happens to the balloon that has adiabatically ascended to 40 hPa when the helium inside begins to equilibrate with the surrounding air? (2%)

5) (20%) Atmospheric water vapour and thermodynamics

Our now infamous air parcel starts at a pressure of 950 hPa and a temperature of 17 ^{o}C.

a. How do you define the Lifting Condensation Level (LCL)? If our parcel is lifted to the LCL at a pressure level of 800 hPa, what would its temperature be? (5%)

b. What was the dew point temperature and relative humidity of the parcel before it was lifted? (5%)

c. What mass mixing ratio of water must condense during its ascent in order to change the parcel air temperature by 10 K? (Assume the atmospheric mass is the mass of dry air.) (5%)

d. If the environmental (atmospheric) temperature decreased adiabatically with height, where would the atmosphere be unstable with respect to vertical motion? Why? (3%)

e. On the bus, an air-filled balloon is hanging from the ceiling by a string. A helium-filled balloon floats while tied to the floor by a string. Assuming the string and balloon material itself has negligible mass, how do the balloons move as the bus accelerates forward, and why? (2%)

6) (20%) Radiation

In another 5 x10^9 years or so, our Sun will probably become a red giant with its photospheric temperature dropping to 4000 K and its radius swelling to 3.5 x 10^6 km. Under these conditions:

a. Construct a general expressions for the solar constant, S, and the effective temperature, T_e, of a planet with no atmosphere but with an albedo, α, a distance R from the sun. (6%)

b. Calculate the solar constant and effective temperature for Venus under these conditions. Venus is 0.72 AU from the sun, has a radius of 6052 km, and has an albedo $\alpha = 0.71$ (6%)

c. What fraction of the Sun's total power output does the Venus intercept? (4%)

d. Calculate the wavelength of maximum emission for both the Sun and Venus. (4%)