Norwegian University of Science and Technology
Department of Physics

EXAMINATION IN FY3201 ATMOSPHERIC PHYSICS AND CLIMATE CHANGE
Faculty for Natural Sciences and Technology
26 May 2015
Time: 09:00-13:00

Number of pages: 4

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 water vapour: ~18 kg/kmole Molar mass of dry air: ~29 kg/kmole

$N_A = 6.02 \times 10^{23}$ molecules/mole

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: $\sigma = 5.67 \times 10^{-8}$ W·m^{-2}·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) = 150×10^6 km

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

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

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

$\gamma = C_p / C_v$ $\kappa = R_d / C_p$ $R_d = C_p - C_v$ Γ_{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 or Norwegian).
State all assumptions.
Good Luck!

1) (5%) Black body radiation

Sketch the relative spectral radiance as a function of wavelength for three blackbodies at temperatures $T_1 > T_2 > T_3$. Label the curves with their temperatures and put units on the axes, but you do not need to put numerical values on the axes.

2) Multiple Choice (20%):

There is only **one** correct answer so you must **choose the best answer**.
Answer A, B, C… (Capital letters), or leave the answer blank.
Correct answer gives +2; incorrect 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. What is the correct order of earth's atmospheric layers from bottom to top?
A) Stratosphere, Mesosphere, Troposphere, Thermosphere, Exosphere.
B) Stratosphere, Troposphere, Mesosphere, Thermosphere, Exosphere.
C) Stratosphere, Troposphere, Thermosphere, Mesosphere, Exosphere.
D) Troposphere, Mesosphere, Stratosphere, Thermosphere, Exosphere.
E) Troposphere, Stratosphere, Mesosphere, Thermosphere, Exosphere.

b. Which two atmospheric layers have temperature profiles that allow 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.

c. 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.

d. If the amount of energy lost by the earth to space each year were not approximately equal to that received,
A) The atmosphere's average temperature would change.
B) The length of the year would change.
C) The sun's output would change.
D) The mass of the atmosphere would change.
E) None of the above.

e. From what phenomenon does the Coriolis effect arise?
   A) Curvature of the Earth's surface.
   B) Rotation of the spherical Earth around its axis.
   C) Rotation of the spherical Earth around the sun.
   D) Effect of winds high in the atmosphere.
   E) Motion of the oceans in their basins.
   F) None of the above

f. Relative to the Earth's surface, what does the Coriolis effect have on masses of air or water that are changing latitude?
   A) The results are unpredictable; currents can veer right or left in either hemisphere.
   B) They turn to the left in the northern hemisphere and to the right in the southern hemisphere.
   C) They turn to the right in the northern hemisphere and to the left in the southern hemisphere.
   D) They turn to the right in both hemispheres.
   E) They turn to the left in both hemispheres.

g. How can we describe the scattering of sunlight by clouds?
   A) Mie scattering theory.
   B) Rayleigh scattering theory.
   C) Tyndall scattering theory.
   D) Geometric scattering theory.
   E) None of the above.

h. What wavelengths of sunlight are absorbed by molecular nitrogen in the troposphere?
   A) Infrared.
   B) Ultraviolet.
   C) Radio waves.
   D) Microwaves.
   E) Visible.
   F) None of the above.

i. In an isothermal atmosphere, two air parcels, one wet and one dry, are continuously displaced upward. What happens to the parcel temperatures?
   A) They remain constant since the atmosphere is isothermal.
   B) Both parcels heat at the same rate as they get nearer to the Sun.
   C) The wet air parcel cools faster than the dry one due to its thermal conductivity.
   D) The dry air parcel cools faster than the wet one due to latent heat effects.
   E) Both parcels cool at the same rate as the pressure drops.
   F) None of the above.

j. The geostrophic wind results from a balance between?
   A) Coriolis force and centripetal force.
   B) Centripetal force, pressure gradient force, and Coriolis force.
   C) Pressure gradient force and Coriolis force.
   D) Pressure gradient force, Coriolis force, and friction.
   E) None of the above.

3) (25 %) Atmospheric thermodynamics, water vapour and structure

a. A commercial airliner suffers a sudden de-pressurization due to the loss of a cargo door. If the internal and external air pressures were 850 and 350 hPa respectively, and the internal temperature was 19°C before de-pressurization, determine the final internal temperature (assume it is an adiabatic process). (5%)

b. In practice, a fog formed in the airplane after it de-pressurized. What effect would this have on the final temperature? If the relative humidity in the cabin before it de-pressurized was 22%, how much would the final temperature change? (5%)

c. In the winter hemisphere, the 500 hPa level is usually at a height of about 6000 m at a latitude of 30°, and at a height of 5600 m at a latitude of 70°. What is the mean temperature of the layer of atmosphere between 1000 hPa and 500 hPa in each case? (5%)

d. Calculate the number density of CO_2 (365 ppmv) in the atmosphere at ground level (P = 984 hPa, T = +18° C). (5%)

e. An air mass of temperature +10° C and pressure 1013 hPa contains 10 g/kg water vapour. Calculate the relative humidity. (5%)

4) (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. Derive general expressions for the solar constant, S, and the effective temperature, T_e, of a planet with an albedo, α, a distance R from the sun. (6%)

b. Calculate the solar constant and effective temperature for Earth. Earth is still 1 AU from the sun, and has an albedo $\alpha = 0.3$ (6%)

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

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

5) (30%) Greenhouse effect

The Earth's atmosphere can be modelled as an isothermal layer with temperature T_a, above the ground, which has a temperature T_g. Under normal conditions the planetary albedo, $\alpha = 0.3$, the short wavelength absorptivity of the atmosphere is $A_a = 0.21$ and the longwave atmospheric emissivity (or absorptivity) is $\varepsilon_a = 0.95$.

A large volcano erupts, creating a 2 km thick ash layer on top of the atmospheric layer, increasing the planetary albedo to $\alpha = 0.35$. The density of the ash is a constant 0.03 $kg \cdot m^{-3}$, and the attenuation coefficient of the volcanic ash is 0.01 $m^2 \cdot kg^{-1}$ at all wavelengths.

a. Sketch a diagram showing the energy exchanges between the Earth and the atmosphere. (5%)

b. Set up the energy balance equations (9%)
   i. at the top of the ash layer,
   ii. at the top of the atmospheric layer,
   iii. at the ground.

c. Calculate the transmission of the volcanic layer (6%)

d. Solve the energy balance equations to find the temperatures of the ash layer, T_v, the atmospheric layer, T_a, and the surface, T_g, after the eruption. (10%)