NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Physics

Examination paper for FY3201 Atmospheric Physics and Climate Change

Academic contact during examination: Christoph Franzen

Phone: +47 94289343

Examination date: 26.05.20016

Examination time (from-to): 9:00-13:00

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

Other information: -

Language: English

Number of pages (front page excluded): 6

Number of pages enclosed: 7

Informasjon om trykking av eksamensoppgave

Originalen er:

1-sidig ☐ **2-sidig** ☐

sort/hvit ☐ **farger** ☐

Checked by:

Date Signature

Additional Information

You may take:

Molar mass of helium: $\sim 4 \ {}^{\mathrm{kg}}/_{\mathrm{kmole}}$ Molar mass of water vapour: $\sim 18 \ {}^{\mathrm{kg}}/_{\mathrm{kmole}}$

Molar mass of dry air: $\sim 29 \ {}^{\mathrm{kg}}/_{\mathrm{kmole}}$ Molar mass of carbon dioxide: $\sim 44 \ {}^{\mathrm{kg}}/_{\mathrm{kmole}}$

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

$273.15 \ \mathrm{K} = 0 \ ^\circ\mathrm{C}$ $1 \ \mathrm{hPa} = 10^2 \ \mathrm{Pa} = 10^2 \ \mathrm{Nm^{-2}}$ $g = 9.8 \ \mathrm{ms^{-2}}$ and constant in z

Stefan–Boltzmann constant: $\sigma_B = 5.67 \times 10^{-8} \ \mathrm{Wm^{-2}K^{-4}}$

Boltzmann constant $k = 1.38 \times 10^{-23} \mathrm{JK^{-1}}$ Speed of light $c = 3 \times 10^8$ $\mathrm{ms^{-1}}$

Line broadening: approx. width for a radiative line with line centre ν_n:

Natural broadening: $\alpha_N = 3.3 \times 10^{-8} \ \mathrm{cm^{-1}} \left(\frac{\nu_n}{1000 \ \mathrm{cm^{-1}}}\right)^3$

Pressure broadening: $\gamma_L = 0.01 \ \mathrm{cm^{-1}} \left(\frac{p}{1000 \ \mathrm{hPa}}\right) \left(\frac{273 \ \mathrm{K}}{T}\right)^{1/2}$

Doppler broadening: $\gamma_D = 0.003 \ \mathrm{cm^{-1}} \left(\frac{\nu}{1000 \ \mathrm{cm^{-1}}}\right) \left(\frac{T}{300 \ \mathrm{K}}\right)^{1/2}$

Solar photospheric temperature, $T_s = 5786 \ \mathrm{K}$ Radius of the Sun = 695800 km

1 AU (Earth-Sun distance) =150×10^6 km Radius of the Earth = 6370 km

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

Gas constant for water vapour: $R_V = 461 \ \mathrm{JK^{-1}kg^{-1}}$

Values for dry air: $C_p = 1004 \ \mathrm{JK^{-1}kg^{-1}}$

$C_V = 718 \ \mathrm{JK^{-1}kg^{-1}}$

$R_d = 287 \ \mathrm{JK^{-1}kg^{-1}}$

$\gamma = {}^{C_p}/_{C_V}; \quad \kappa = {}^{R_d}/_{C_p}; \quad R_d = C_p - C_V; \ \Gamma_{DALR} = 9.8 \ {}^{\mathrm{K}}/_{\mathrm{km}}$

Clausius–Clapeyron relation: $e_S = 6.112\mathrm{hPa} \times \exp\left[\frac{L_V}{R_V}\left(\frac{1}{273\mathrm{K}} - \frac{1}{T}\right)\right]$

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

1) Multiple Choice (10%)

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 +1; incorrect answer gives -0.25.
The total score for these 10 multiple choice problems together cannot be negative.

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

Question	1)	2)	3)	4)	5)	6)	7)	8)	9)	10)
Answer										

1) You measure an atmospheric lapse rate of $6\,{}^{\mathrm{K}}/_{\mathrm{km}}$. Which of the statements below is true?
   - A) The temperature falls with altitude and the atmosphere is absolutely unstable.
   - B) The temperature falls with altitude and the atmosphere is conditionally unstable
   - C) The temperature rises with altitude and the atmosphere is conditionally stable
   - D) The temperature rises with altitude and the atmosphere is conditionally unstable
   - E) The temperature rises with altitude and the atmosphere is absolutely stable

2) Which of the statements below about El Niño is wrong?
   - A) El Niño is an interaction between the sea-surface and the atmosphere.
   - B) El Niño has the opposite effect on sea-surface temperature as La Niña.
   - C) The main effect of an El Niño is a warmer Atlantic sea-surface temperature.
   - D) During a typical El Niño year, air temperatures in Alaska are warmer.
   - E) The net integrated effect of El Niño is a slightly warmer global temperature.

3) At which wavelength does a solar blackbody radiation curve peak?
   - A) $\sim 100\mathrm{nm}$
   - B) $\sim 500\mathrm{nm}$
   - C) $\sim 1000\mathrm{nm}$
   - D) $\sim 2000\mathrm{nm}$
   - E) $\sim 3000\mathrm{nm}$

4) In which layer of the atmosphere is ozone the major species?
   - A) Troposphere
   - B) Stratosphere
   - C) Mesosphere
   - D) Thermosphere
   - E) None of the above

5) In the two-stream approximation, the integral over wavelength and angle can be approximated as two streams at which angles to the vertical?

- A) $\theta = \pm 24°$
- B) $\theta = \pm 35°$
- C) $\theta = \pm 42°$
- D) $\theta = \pm 53°$
- E) None of the above

6) Which of the statements below is wrong for a neutrally stable atmosphere?

- A) The atmospheric lapse rate equals the dry adiabatic lapse rate.
- B) A displaced parcel will not be forced from its new altitude.
- C) The Brunt Väisälä frequency is an imaginary number.
- D) The temperature of the parcel equals the atmospheric temperature at every pressure level.
- E) The parcel's temperature change with altitude is constant.

7) How much will the global mean temperature change given a solar cycle variation of the solar constant by $\pm 1\%$ if no feedbacks are included?

- A) $1.5\ \mathrm{K}$
- B) $0.75\ °\mathrm{C}$
- C) Negligibly small.
- D) $-1\ °\mathrm{C}$
- E) On average 0, since it is a sinusoidal cycle.

8) What does Kirchoff's law say?

- A) The short wavelength heating chapman function peaks where the atmosphere becomes optically thick.
- B) Long wavelength radiative transfer only cools the atmosphere.
- C) The scattering from clouds can be described with Mie scattering.
- D) A blackbody with a constant emissivity is a grey body.
- E) A good absorber is a good emitter.

9) Describe the change of the earth's visible albedo if the polar ice caps melt.

- A) It will go up.
- B) It will first go up, then go down.
- C) It will not change.
- D) It will first go down, then go up.
- E) It will go down.

10) How do you find the Lifting condensation level on a Skew-T diagram?

- A) Find the water vapour mixing ratio of the dew point temperature.
- B) Find the intersection between the dry adiabat and the line of constant $\mu_S = \mu$.
- C) Find the region where the temperature starts to rise with altitude.
- D) Find where the atmospheric lapse rate is equal to the dry adiabatic lapse rate.
- E) Find where the atmospheric temperature equals the dew point temperature.

2) Vertical movements (20%)

a) You stand on a cold winter day $(-13°C)$ on top of the Scandic Lerkendal hotel. The weather station there tells you that the pressure difference to the ground is 8hPa. Estimate how high the building is. (4%)

b) Later on the same day, you fly on a plane. The instruments tell you that you are at an altitude of 10 km and that the pressure is 190 hPa. The thermometer tells you the atmosphere temperature is 156 K. Are your instruments working correctly? (6%)

c) Start from the general definition of the lapse rate. Derive an expression for the dry adiabatic lapse rate in terms of only approximated constants for the well-mixed atmosphere, as done in class and calculate an approximate value. (6%)

d) Starting from the Poisson relations, derive and define the potential temperature θ. (4%)

3) Radiation Absorption (20%)

If there is no scattering, a parallel beam from the sun at zenith angle ϕ
is absorbed in the atmosphere according to the equation:

$$-\frac{\mathrm{d}I_\lambda}{I_\lambda} = -k_\lambda \rho(z) \sec(\phi)\mathrm{d}z$$

a) Given an isothermal atmosphere, what is the optical depth τ_λ, at height z? (8%)

b) Take the sun directly overhead ($\phi = 0$), the surface density $\rho_0 = 1 \text{ kg m}^{-3}$, the scale height $H = 10 \text{ km}$ and the absorption coefficient $k_\lambda = 0.001 \text{ m}^2\text{kg}^{-1}$. Calculate the optical depth at height levels of 35, 25, 15 and 5 km. (4%)

c) Calculate the transmission and absorption of the atmosphere at the height levels 35, 25, 15 and 5 km. (4%)

d) Between which two neighbouring height levels, 35, 25, 15 and 5 km does the absorption change the most? How is this maximum change related to the optical depth? (4%)

4) Observation of a highly simplified planet (30%)

You observe a highly simplified planet “p”, which orbits our sun at 1.5 times the distance of the earth from the sun. You measure a visible albedo of 20%. This planet only emits pure black body radiation.

a) Create a simple no-atmosphere model and calculate the radiative equilibrium temperature of this highly simplified planet “p”. (6%)

b) More measurements with a crashing satellite show that the planet's surface temperature is actually 273 K on average. You can also determine that the atmosphere absorbs on average only 15% of the incoming visible light.
Create a single layer atmosphere model to calculate the temperature for the planet's atmosphere. Calculate the transmission coefficient for long wavelengths of this atmosphere. (6%)
Tip: Drawing a diagram may help you account for all beams.

A spectroscopic measurement from an orbiting satellite shows strong CO_2 lines, which were neglected until now. As the crashing satellite passed through the atmosphere, it observed a CO_2 layer in this planet's atmosphere that is narrowly centred at a pressure level of 1 hPa.

c) You observe an unsaturated CO_2 absorption line centred on $\nu_n = 2360\ \mathrm{cm}^{-1}$. For this line, find the natural, pressure and Doppler broadening line widths. First, assume the atmosphere at this pressure level has the same temperature as calculated in part b). Which type of broadening has the largest line width? Which broadening process would be the largest on earth at this same pressure level? (2%)

d) Which mechanism would produce the greatest line-width at a pressure level of 1000 hPa? Explain the difference. (2%)

e) The actual line width is 0.005 cm^{-1}. Assuming only the dominant broadening for the CO_2 in this atmosphere at 1 hPa, calculate the temperature of the CO_2 layer. (1%)

f) (If you could not find an answer to the previous part, use 140 K for the temperature of the CO_2 layer)
Now assume a two-layer atmosphere, with one normal atmosphere layer and the CO_2 layer from above, at higher altitudes. You can assume that the absorption for visible light of the CO_2 layer is 0. The long wavelength absorption may (and will) be different from the absorption from the first layer.
Find the transmission coefficients for short wavelengths for both layers and the temperature of the lower atmosphere layer. (13%)

5) Balloon sounding (20%)

A light helium balloon is released at ground level $p_0 = 1000$ hPa, where the temperature was 0°C. It rises quickly stops rising at a pressure level of $p = 0.1$ hPa in dry air. You may assume the weight of the balloon is only the weight of the gas inside. The specific heat constant for helium is $C_{p_{He}} = 5190\ \mathrm{JK}^{-1}\mathrm{kg}^{-1}$.

a) Calculate the temperature of the atmosphere at the altitude, where the balloon stops rising. (8%)

The balloon's instrument measure a different temperature of the atmosphere of $T_1 = 200$ K.

b) You assume the balloon could be leaking, such that a part of the Helium left the balloon. What percentage of the helium mass is still left in the balloon, if the atmosphere really is $T_1 = 200$ K at $p = 0.1$ hPa? (4%)

c) Assume again a non-leaking balloon. Another explanation would be that there was water vapour in the helium. The condensing water vapour would change the helium's temperature and the result from part a) was due to a wrong value of the temperature this gas.
Calculate how much water vapour condensed in the balloon. State your answer in grams water vapour condensed per kg helium in the balloon. You may assume for this that the condensation is the only change in heat. (8%)