Department of Physics

Examination paper for FY3201 / 8902 Atmospheric Physics and Climate Change

Examination date: 27 May 2020

Examination time (from-to): 09:00-13:00

Permitted examination support material: All support materials are allowed

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Link: innsida.ntnu.no/wiki/-/wiki/English/Orakel+Support+Services
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OTHER INFORMATION
Only contact academic contact in case of errors or insufficiencies in the question set.

Saving: Answers written in Inspera are automatically saved every 15 seconds. If you are working in another program remember to save your answer regularly.

Cheating/Plagiarism: The exam is an individual, independent work. *Examination aids are permitted*. All submitted answers will be subject to plagiarism control. Read more about cheating ad plagiarism here: *innsida.ntnu.no/wiki/-/wiki/English/Cheating+on+exams*

Notifications: If there is a need to send a message to the candidates during the exam (e.g. if there is an error in the question set), this will be done by sending a notification in Inspera. A dialogue box will appear. You can re-read the notification by clicking the bell icon in the top right-hand corner of the screen. All candidates will also receive an SMS to ensure that nobody misses out on important information. Please keep your phone available during the exam.

Weighting: *Each correct answer is weighted 4 points. Each incorrect or blank answer is 0 points. Answers are not necessarily exact. You must choose the best or closest answer.*

ABOUT SUBMISSION

Your answers will be submitted automatically when the examination time expires and the test closes, if you have answered at least one question. This will happen even if you do not click “Submit and return to dashboard” on the last page of the question set. You can reopen and edit your answer as long as the test is open. If no questions are answered by the time the examination time expires, your answers will not be submitted.

Withdrawing from the exam: If you wish to submit a blank test/withdraw from the exam, go to the menu in the top right-hand corner and click “Submit blank”. This **can not** be undone, even if the test is still open.

Accessing your answer post-submission: You will find your answer in Archive when the examination time has expired.

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
Molar mass of CO_2: ~44 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 K = 0 ^oC 1 hPa = 10^2 Pa = 10^2 N m^{-2} 1 atm = 1013 hPa $g=9.8$ m s^{-2} constant in z

Stefan–Boltzmann constant: $\sigma = 5.67\times10^{-8}$ 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) =150x10^6 km

Radius of Mercury = 6051 km   Mercury-Sun distance = 0.387 AU

Radius of Mars = 3396 km   Mars-Sun distance = 1.52 AU

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

Latent heat of sublimation ice: $L_i=2.8\text{x}10^6$ 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: $e_s = 6.112\,hPa \cdot \exp\left[\frac{L_v}{R_v}\left(\frac{1}{273K} - \frac{1}{T}\right)\right]$

Some integrals that may be of use:

$$\int x^m e^{(a x)}\, dx = \frac{x^m e^{(a x)}}{a} - \frac{m \int x^{(m-1)} e^{(a x)}\, dx}{a}$$

$$\int x\, e^{(a x)}\, dx = \frac{e^{(a x)}(a x - 1)}{a^2}$$

$$\text{For a} > 0 \quad \int_o^{\infty} e^{(-a x)}\, dx = \frac{1}{a}$$

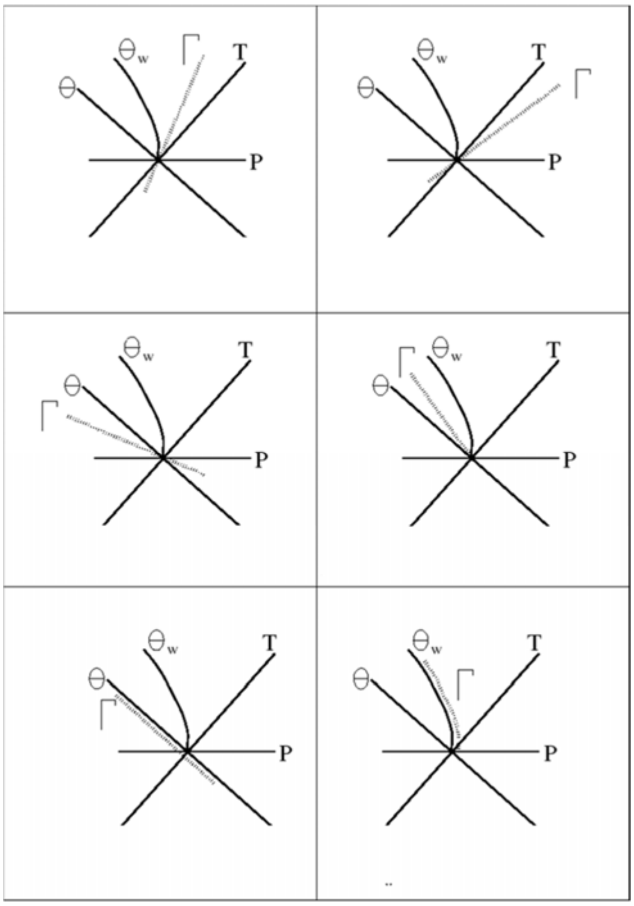
$$\int \frac{1}{a + b x}\, dx = \frac{\ln(a + b x)}{b}$$

Problem 1) Matching radiometric units:

Radiance	$\frac{Watts}{m^2\ sr\ nm}$
Spectral Irradiance	$\frac{Watts}{m^2\ nm}$
Spectral Radiance	$\frac{J}{s\ m^2\ sr}$
Irradiance	$\frac{Watts}{m^2}$

Problem 2) Atmospheric stability

Which of the following graphs depicts unstable conditions on a skew T-P diagram, where Γ is the atmospheric lapse rate?

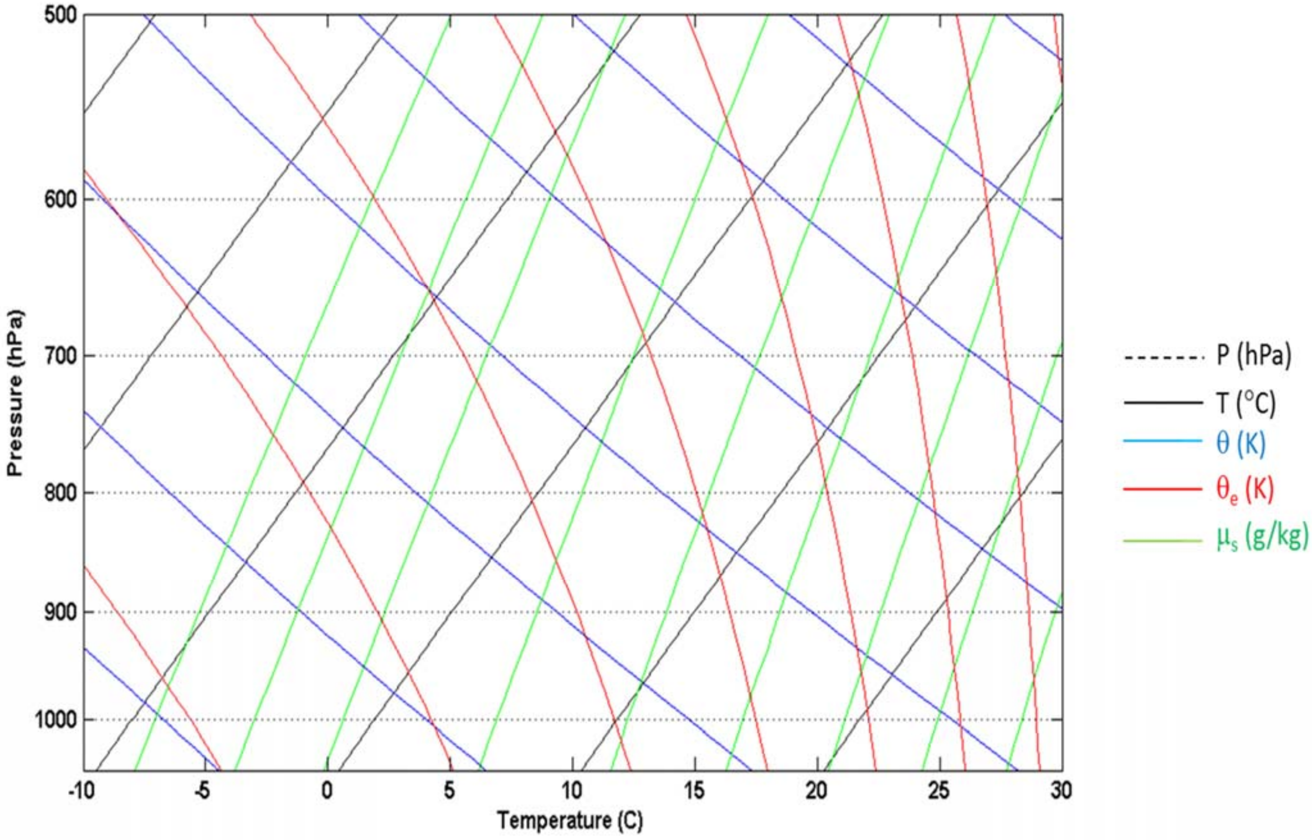


3) Meteorology Graphs

In the Skew-T log-P diagram, at a pressure of 1000 hPa an air parcel has a temperature T=20 °C and a dew-point temperature of T_d=10 °C.

a) At what pressure is the Lifting Condensation Level (LCL)?

b) If the parcel contains no water, what is the air parcel's temperature when it is lifted to 600 hPa.



Problem 4) CO_2 radiation

At what altitude does the CO_2 molecule radiate to space with little chance of of the radiation being absorbed?
Assume an isothermal atmosphere at 20 °C, with a constant mixing ratio of CO_2 = 400 ppmv and a surface pressure of 1000 hPa. Take the mass of dry air to be 29 g/mole, the mass of CO_2 to be 44 g/mole, and the absorption coefficient, k= 0.4 m^2/kg.

Problem 5) Water vapour

An air parcel at 300 K and a total pressure of 1000 hPa .

a) What is the water vapour pressure, e, of the air parcel if it has a relative humidity of 40 %?

b) What is the dew point temperature of the air parcel if the partial pressure of water vapour is 6 hPa?

c) What is the mean molecular weight of the air with 3 hPa water?

d) If the air parcel had a water vapour mass mixing ratio of 1 g/kg, what would its relative humidity be after lifting it adiabatically to 900 hPa?

Problem 6) Atmospheric composition

At the surface of the Earth, there are 2.3×10^{25} molecules/m^3. If the temperature is a constant 20 °C with altitude:

a) How many molecules are there in the Earth's atmosphere?

b) What is the surface pressure if the molar mass of dry air is taken as 27.9 g/mole?

Problem 7) Ozone

In Antarctica, the winter ozone density is 250 DU (Dobson Units). In Spring, this drops to 100 DU in the ozone hole. What is the ozone column density loss (in molecules/m^2) from Winter to Spring? Take 1 atm = 1013 hPa

Problem 8) Radiative Equilibrium

a) Given the black-body temperature of the Sun, what is the equilibrium temperature of Mercury. Mercury has an albedo of 0.068 and no atmosphere to absorb radiation.

b) Given the solar flux at Mars is 586.2 W/m^2, and the surface temperature is 242 K, what is the long wavelength transmission of the Martian atmosphere. The Martian atmosphere is transparent to short wavelengths, and the planetary albedo is 0.25.

Problem 9) Vertical Structure

In a dry atmosphere with a surface pressure of 1000 hPa

a) With a temperature profile given by: T(z in metres)= =263K+30K·exp(-0.0004), what is the buoyancy period in minutes at 8 km.
b) Approximating the temperature with T(z) = 293-0.01215·z, what is the pressure at 8 km?

c) Using the approximation of an average temperature of 220 K, what is the height in km above the surface of the 200 hPa level?

Problem 10) General Stratosphere

The most abundant gas in the stratosphere is:

a. oxygen (O_2).
b. nitrogen (N_2).
c. carbon dioxide (CO_2).
d. ozone (O_3).
e. chlorofluorocarbons (CFCs).

Problem 11) General stratosphere

In the stratosphere, the air temperature normally:

a. decreases with increasing height.
b. increases with increasing height.
c. both increases and decreases depending on the season.
d. cannot be measured.

Problem 12) General Thermodynamics

The processes of condensation and freezing:

a. both release sensible heat into the environment.
b. both absorb sensible heat from the environment.
c. do not affect the temperature of their surroundings.
d. do not involve energy transport.

Problem 13) General radiation

If the Earth's average surface temperature were to increase, the amount of radiation emitted from the Earth's surface would ____, and the wavelength of peak emission would shift toward ____ wavelengths.

a. increase; shorter b. increase; longer c. decrease; shorter d. decrease; longer

Problem 14) General structure

Which is not the case in baroclinic stratification?

a. is the lowest energy state of the atmosphere
b. isentropes are not parallel to isobars
c. potential energy can be converted to kinetic energy
d. can be caused by horizontal temperature gradients

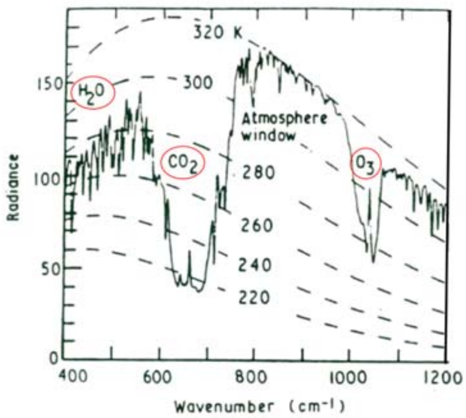
14) General dynamics

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.

Problem 16) General radiation

A downward looking satellite takes the following spectrum of the outgoing long-wavelength radiation from the Earth.



Why does the CO2 radiate at a blackbody temperature of 220 K while water vapour and ozone radiate at a temperature of 280 K?

a) CO_2 radiate in a region with a negative lapse rate above H_2O while O_3 radiates above them in a region of positive lapse rate.
b) H_2O and O_3 radiate from the same region of the atmosphere that is warmer than where the CO_2 radiates.
c) CO_2 absorbs more radiation than H_2O and O_3 and so has a deeper minimum.
d) The O_3 and H_2O absorptions are from smog pollution near the surface while the CO_2 absorbs higher in the troposphere.

Problem 17) General structure

The rate at which temperature decreases with increasing altitude is known as the:

a. temperature slope.
b. lapse rate.
c. sounding.
d. thermocline.