Department of Physics

Examination paper for FY3201 / 8902 Atmospheric Physics and Climate Change

Examination date: 1 June 2021

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

Permitted examination support material: All support materials are allowed

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Technical support during examination: Orakel support services:
Link: innsida.ntnu.no/wiki/-/wiki/English/Orakel+Support+Services

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If you experience technical problems during the exam, contact Orakel support services as soon as possible before the examination time expires. If you don't get through immediately, hold the line until your call is answered.

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.

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.

Each incorrect or blank answer is 0 points. Answers have been randomized and are not exact. You must choose the closest answer!

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

$N_A = 6.02\times10^{23}$ molecules/mole　　Boltzmann's constant $k = 1.38\times10^{-23}$ J/K

273 K = 0 °C　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=2.5x10^6 J· kg^{-1}　　Density of liquid water = 1000 kg·m^{-3}

Latent heat of sublimation ice: L_i=2.8x10^6 J· kg^{-1}　　Density of water vapour = 5x10^{-3} kg·m^{-3}

Gas constant for water vapour: R_v=461 J·K^{-1}·kg^{-1}　　Surface tension of water droplet 75x10^{-3} N·m^{-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:

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

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

$$\text{For a} > 0 \quad \int_0^{\infty} e^{(-ax)}\,dx = \frac{1}{a}$$

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

1. Geostrophic flow occurs when the wind blows

(1) parallel to the isobars or contours or pressure.
(2) in the direction of the Coriolis force.
(3) in the direction of the pressure gradient force.
(4) at an angle between 10 and 30 to the contours and towards low pressure.
(5) at an angle between 10 and 30 to the contours and towards high pressure.

2. Of the gases listed below, which is NOT believed to be responsible for enhancing the earth's greenhouse
effect?
a. molecular oxygen (O_2)
b. chlorofluorocarbons (CFCs)
c. nitrous oxide (N_2O)
d. carbon dioxide (CO_2)
e. methane (CH_4)

3. The most abundant gas in the stratosphere is:

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

4. How do you find the Lifting Condensation Level (LCL) on a Skew-T diagram?

a. Find the intersection between a parcel's dry adiabat and constant $\mu_s=\mu$ of the parcel
b. Find a parcel's water vapour mixing ratio using its dew point temperature.
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.

5. 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

6. a) A spherical drop of water of radius 20 nm is stable (neither growing nor shrinking) at a temperature of 15 C. what is the relative humidity around the droplet?

b) An airplane economy cabin is pressurized to 818 hPa with a temperature 20 C and a relative humidity of 15% when flying at 11 km. What is the dew point temperature in the cabin?

c) A person perspires. How much liquid water (as a percentage of the person's mass) must evaporate to lower the temperature of the person by 5.0 C. Take the specific heat of the human body to be that of water, C_{pw} = 4200 J/kg/K.

7. An exoplanet orbits its star at a distance R_{orbit}= 0.41 AU, and has a radius R_p=1.34*R_{earth}. The planet has an albedo of 0.4 and emissivity of 1.

The star it orbits has a radius R_{st}= 0.6*R_{sun} and a photosphere blackbody temperature of T_{st}=4400 K

a. What is the planet's equilibrium temperature assuming it has no atmosphere?

b. At what wavelength does the radiance of this star with a blackbody temperature of 4400 K peak?

c. Another exoplanet in the same system has a stellar flux constant F_p of 800 W/m^2 at its orbit, The planet has an albedo of 0.4, and emissivity of 1, but there is a compound in the atmosphere that passes all infrared light but absorbs in the visible.
A probe has told us that the temperature of the surface of this planet is -85 C. What is the short wavelength transmission of the atmosphere of this planet?

8. Sunlight coming into the Earth's atmosphere can be absorbed and heat the atmosphere.
The Sun is at a solar ZENITH angle (angle of the Sun from overhead) of χ= 45 degrees. You may assume no scattering, and take the optical depth of incoming solar radiation (averaged over all wavelengths), the density of air, and the mass mixing ratio of the absorber to be defined as:

$$\tau(Z) = \int_Z^{\infty} \rho(z)\, \mu(z)\, k\, dz$$

$$\rho(z) = \rho 0\, \mathbf{e}^{\left(-\frac{z}{Hm}\right)}$$

$$\mu(z) = \mu 0\, \mathbf{e}^{\left(-\frac{z}{Hv}\right)}$$

Where $\rho(z)$ is the mass density of air, $\mu(z)$ is the mass mixing ratio of the component in the air that attenuates the radiation, and k is the mass absorption coefficient.

The air density at the surface, ρ_0= 1.2 kg/m^3 and the scale height of air is H_m=7 km. In addition, $\mu 0$=0.01 (kg of absorbing component)/(kg air), and its scale height H_v=4 km. Finally, the mass absorption coefficient, k is constant and k=0.11 m^2/(kg of absorbing compound).

a) Calculate the optical depth τ and its derivative with height $d\tau/dz$ at a height of 5 km in the atmosphere

b) If the incoming solar flux at the top of the atmosphere is 400 W/m^2, and the solar ZENITH angle, χ, is 45 degrees, calculate the NET UPWARD flux of solar radiation at 7 km if the optical depth is 0.2 at this altitude

c) Calculate the heating rate in Kelvin/day due to short wavelength radiation at 3 km if the downward solar flux at the **top** of the atmosphere is 400 W/m^2.

d) In an isothermal atmosphere of temperature 220 K, at what pressure level will the Doppler-line width be the same as the collision-line width at a wavelength of 15 microns.

9. On Venus $g=8.87\ m/s^2$, the specific gas constant for dry air is R_{dV} = 195.5 J/K/kg , and the specific heat at constant pressure, Cp = 846 J/K/kg.
The temperature profile is given by $T=T_o*exp(-a*Z)$, with T_o=783K and a=1.68e-5 m^{-1}
The surface pressure is P_o = 93320.33 hPa, and the atmosphere behaves like a dry ideal gas.

a. What is the buoyancy period at 59 km

b. Is the atmosphere stable with respect to vertical motions at 59 km?

c. Is the atmosphere stable with respect to vertical motions at the surface?

d. What is the Scale Height, H, at 59 km and at the surface?

e. What is the pressure at 59 km?

f. If a parcel of air at the surface, where the pressure is P_o=9332033 Pa, is moved adiabatically to an altitude of 700 m where the pressure is $0.96*P_o$, what is the parcel's final temperature?

10. Sulfur dioxide, (SO_2) is a pollutant released in combustion of coal and other high-sulfur fuels that can cause acid rain. Although Norway produces very little, it is transported by the prevailing winds to Norway from large industrial regions in Europe as well as from volcanic sources in Iceland. Thus, its concentration in Norway is highly variable between 1 and 25 ppbv (parts per billion by volume).

a. At 1000 hPa and 22 C, the mixing ratio of SO_2 measured one day in Bergen was 5 ppbv. What was the mass per unit volume of SO_2?

b. If a mass of 50 $\mu g/m^3$ of SO_2 is entirely converted into sulfuric acid, H_2SO_4, what is the resulting mass per volume of sulfuric acid at 1000 hPa and 22 C?

c. Originally, the Martian atmosphere was thought to consist only of 95% CO_2, 3% N_2 and 2% Ar. However, recently, it was discovered that it also contains 0.2% O_2. By how much did the initial estimate of the mean molecular weight of the Martin atmosphere change when this additional species, O_2 was taken into account.