Department of Physics

Examination paper for FY3201 & FY8902 Atmospheric Physics and Climate Change

Examination date: 30 May 2024

Examination time (from-to): 15:00-19:00

Permitted examination support material: C: Specified printed and hand-written support material is allowed. A specific basic calculator is allowed.
Permitted material:

One side of A5 paper with printed or hand-written notes

Academic contact during examination:
Phone: Either Trond M. Thorseth @ 95 29 3041 or Patrick Espy @ 73 55 10 95

Academic contact present at the exam location: YES, at about 15:30

OTHER INFORMATION

Caution: do not click on any links in resource documents. This will end your test.

Get an overview of the question set before you start answering the questions.

Read the questions carefully and make your own assumptions. **NOTE: Answers to multiple choice questions are not exact and you must choose the closest answer.** If a question is unclear/vague, make your own assumptions and specify them on the exam. The academic person is only contacted in case of errors or insufficiencies in the question set. Address an invigilator if you suspect errors or insufficiencies. Write down the question in advance.

No hand drawings: This exam does not include hand drawings. If you receive hand drawing sheets, this is by mistake. **You will not be able to submit the sheets, and they will not be graded.**

Weighting: The exam consists of 5 sections.

Ungraded Information and help-sheet pages
General knowledge of the subject: 15 questions at 4 points each (60%)
Short calculations: 4 questions at 4 points each (16 %)
Longer calculations: 4 questions at 6 points (24 %)
Ungraded feedback for information I should know regarding your answers

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.

Withdrawing from the exam: If you become ill or wish to submit a blank test/withdraw from the exam for another reason, go to the menu in the top right-hand corner and click “Submit blank”. This cannot be undone, even if the test is still open.

Access to your answers: After the exam, you can find your answers in the archive in Inspera. Be aware that it may take a working day until any hand-written material is available in the archive.

Each incorrect or blank answer will score zero points. Answers have been randomized and are not exact. You must choose the best answer.
For all calculations use SI units!

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

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 c=3 x10^8 m·s^{-1}

Avagadro's number: N_A = 6.02x10^{23} molecules/mole Boltzmann's constant k = 1.38x10^{-23}J/K

Stefan–Boltzmann constant: $\sigma = 5.67\times10^{-8}$ W·m^{-2}·K^{-4} Planck Constant: h=6.63x10^{-34} J·s

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 Venus = 6051 km Venus-Sun distance = 0.72 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_{dalr}=9.8 K/km

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

Some integrals that may be of use:

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

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

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

$$\int_X^\infty e^{(-ax)}\,dx = \frac{e^{(-aX)}}{a}$$

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

PERIODIC TABLE OF ELEMENTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.008																	2 He Helium 4.0026
2	3 Li Lithium 6.94	4 Be Beryllium 9.0122											5 B Boron 10.81	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
3	11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminium 26.982	14 Si Silicon 28.085	15 P Phosphorus 30.974	16 S Sulfur 32.06	17 Cl Chlorine 35.45	18 Ar Argon 39.948
4	19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.468	38 Sr Strontium 87.62	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.60	53 I Iodine 126.90	54 Xe Xenon 131.29
6	55 Cs Caesium 132.91	56 Ba Barium 137.33	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (277)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)

Atomic # / Symbol / Name / Weight

C Solid
Hg Liquid
H Gas
Rf Unknown

Metals: Alkali metals; Alkaline earth metals; Lanthanoids (Lanthanides); Actinoids (Actinides); Transition metals; Post-transition metals

Metalloids

Nonmetals: Other nonmetals; Noble gases

Pnictogens | Chalcogens | Halogens

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

6	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97
7	89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (266)

Ptable.com

General Knowledge Questions (4 points each)

1) Matching radiometric units:

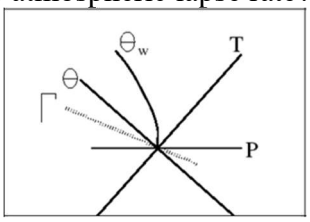
Radiance $\frac{Watts}{m^2\ sr\ nm}$

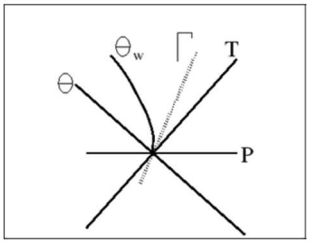
Spectral Irradiance $\frac{Watts}{m^2\ nm}$

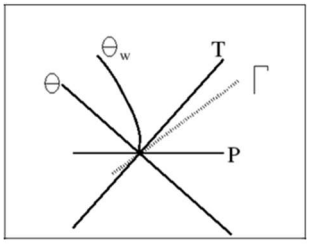
Spectral Radiance $\frac{J}{s\ m^2\ sr}$

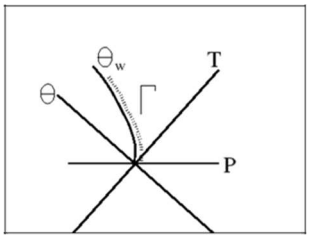
Irradiance $\frac{Watts}{m^2}$

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

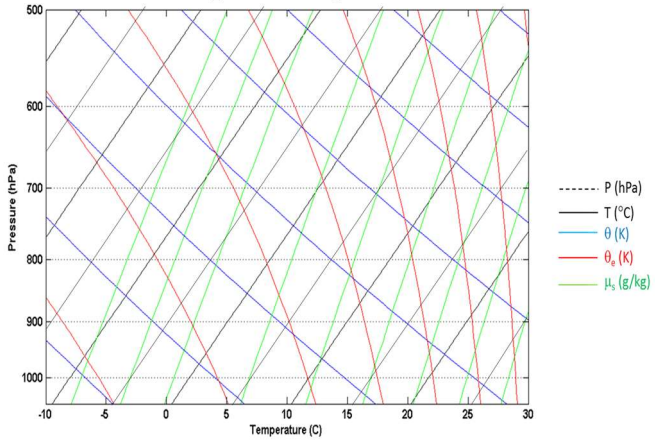








3) On the Skew-T log-P diagram, at a pressure of 1000 hPa an air parcel has a temperature T=20 C and a dewpoint temperature of Td=5 C



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a) At what pressure would the parcel's Lifting Condensation Level (LCL) be?
850 hPa 550 hPa 750 hPa 800 hPa 900 hPa

b) If the parcel at 1000 hPa had a dew point temperature of 20 C and a temperature of 20 C, what is the air parcel's temperature when it is lifted to 600 hPa?
0 C -20 C -10C -5C 5 C

4) 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

5) 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)

6) 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).

7) Which two atmospheric layers have temperature profiles that allow convection?
    a. Mesosphere and Troposphere.
    b. Mesosphere and Stratosphere.
    c. Mesosphere and Thermosphere.
    d. Stratosphere and Thermosphere.
    e. Stratosphere and Troposphere.
    f. The correct answer is not shown.

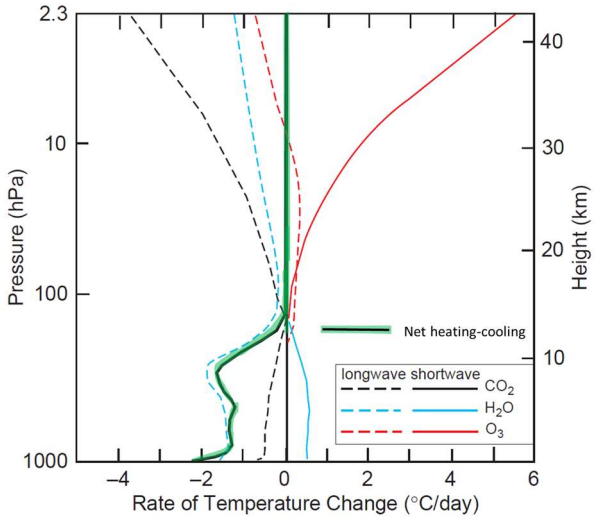
8) Relative to the Earth's surface, what does the Coriolis effect have on masses of air or water that are displaced northward or southward?
    a) Relative to the direction of travel, they turn to the right in the northern hemisphere and to the left in the southern hemisphere.
    b) Relative to the direction of travel, they turn to the left in the northern hemisphere and to the right in the southern hemisphere.
    c) The results are unpredictable; currents can veer right or left relative to the direction of travel in either hemisphere.
    d) Relative to the direction of travel, they turn to the right in both hemispheres.
    e) Relative to the direction of travel, they turn to the left in both hemispheres

9) Molecular nitrogen (N_2) does not absorb infrared dipole radiation to make vibrational transitions because:
    a. N_2 has no permanent dipole moment.
    b. N_2 only makes rotational transitions at longer wavelengths.
    c. False, N_2 does absorb infrared dipole radiation to make vibrational transitions.
    d. The dipole moment of N_2 is perpendicular to dipole radiation.
    e. The correct answer is not shown.

10) A small cloud droplet will evaporate _____ a large cloud droplet?
    a. faster than.
    b. at the same rate as.
    c. more slowly than.
    d. it will not evaporate.
    e. the correct answer is not shown.

11) If the atmospheric absorption of carbon dioxide at 15 μm becomes saturated, what happens if carbon dioxide levels continue to increase?
    a. Total absorption increases as lines farther from the band centre begin to saturate.
    b. Total absorption stays the same because it is saturated.
    c. Total absorption begins to decrease near the band centre after it saturates.
    d. The absorption continues to increase but only near the band centre.

12) If the greenhouse effect produces a temperature warming in the troposphere, why do we find a net 2 K/day radiative cooling there as shown in the figure?



a. The cooling offsets non-radiative processes that heat the atmosphere in this region
b. The greenhouse heating is offset by this cooling, resulting in a steady temperature.
c. That cooling is only affecting the radiation and not the temperature.
d. There is, in fact, a net cooling of the troposphere
e. The correct answer is not shown

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

a. 53 and 127 degrees
b. 24 and 156 degrees
c. 35 and 145 degrees
d. 42 and 138 degrees
e. 60 and 120 degrees
f. The correct answer is not shown

14) At a wavelength of 500 nm, the scatter from a 50 nm radius particle is approximately:

a) Rayleigh
b) Mie
c) Geometric
d) In the forward direction
e) Able to create a rainbow
f) The correct answer is not shown

Short Calculations (4 points each)

15) In the movie The Day After Tomorrow, the premise was that cold air in the mesosphere would descend to the surface, normally at 1000 hPa and 288 K, and freeze everything. Apparently, an atmospheric scientist pointed out their mistake, and in later versions you can see they dubbed in "stratosphere" instead of "mesosphere". If stratospheric air with a temperature of 270 K at 50 km, where the pressure is 0.8 hPa, were to descend adiabatically to the surface, what would its temperature be?
    a. 2070 K
    b. 1712 K
    c. 13 K
    d. 3.5 K
    e. 6385 K

16) 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, Cpw = 4200 J/kg/K
    a. 1%
    b. 3%
    c. 5%
    d. 9%

17) If the atmospheric pressure at the surface of the Earth is 1000 hPa, what is the mass of the atmosphere in kg?
    a. $5x10^{18}$
    b. $5x10^{15}$
    c. $5x10^{16}$
    d. $5x10^{17}$
    e. $5x10^{19}$

18) An air mass of temperature +10° C and pressure 1013 hPa contains 7 g/kg water vapour. Calculate the relative humidity.
    a. 90%
    b. 60 %
    c. 0.1 %
    d. 135 %

Long Calculations 6 Points each

19) For an isothermal atmosphere at 20 ºC and a surface pressure of 1000 hPa, how many molecules are there in the Earth's atmosphere?
    a. 10^{44}
    b. 10^{42}
    c. 10^{38}
    d. 10^{29}
    e. 10^{27}

20) 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. What is the planet's equilibrium temperature assuming it has no atmosphere?
    a. -50 C
    b. -15 C
    c. 273 K
    d. 295 K

21) an instrument of 100 kg. In a dry atmosphere it floats at an altitude of 40 hPa where the temperature is 230 K. Assuming the temperature of the helium inside the balloon has equilibrated with the temperature of the air outside of the balloon, what is the radius of the balloon?
    a. 9 m
    b. 40 m
    c. 6 m
    d. 30 m

22) An incoming downward flux of short-wavelength radiation of 400 W/m^2 is incident at the top of the atmosphere at a 45-degree **zenith** angle (there is no upward flux). The dry atmosphere is isothermal with a temperature of 17 ºC and a surface pressure of 1000 hPa. There is a well-mixed absorber of mass mixing ratio 10 g/kg and a constant attenuation coefficient k = 0.02 m^2 per kg of absorber.
    How much power, in Watts/m^2, is absorbed between 2 and 7 km.
    a. 50
    b. 3
    c. 1800
    d. 0.7
    e. The correct answer is not shown