

## 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 Inspira. 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 Inspira. 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:  $\sim 29 \text{ kg/kmole}$

Molar mass of helium:  $\sim 4 \text{ kg/kmole}$

Molar mass of  $\text{H}_2\text{O}$ :  $\sim 18 \text{ kg/kmole}$

Molar mass of  $\text{CO}_2$ :  $\sim 44 \text{ kg/kmole}$

$273 \text{ K} = 0^\circ\text{C}$     $1 \text{ hPa} = 10^2 \text{ Pa} = 10^2 \text{ N m}^{-2}$     $1 \text{ atm} = 1013 \text{ hPa}$     $g = 9.8 \text{ m s}^{-2}$  constant in  $z$     $c = 3 \times 10^8 \text{ m s}^{-1}$

Avagadro's number:  $N_A = 6.02 \times 10^{23} \text{ molecules/mole}$    Boltzmann's constant  $k = 1.38 \times 10^{-23} \text{ J/K}$

Stefan–Boltzmann constant:  $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \cdot \text{K}^{-4}$    Planck Constant:  $h = 6.63 \times 10^{-34} \text{ J s}$

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

Radius of the Earth =  $6370 \text{ km}$     $1 \text{ AU}$  (Earth–Sun distance) =  $150 \times 10^6 \text{ km}$

Radius of Venus =  $6051 \text{ km}$    Venus–Sun distance =  $0.72 \text{ AU}$

Radius of Mars =  $3396 \text{ km}$    Mars–Sun distance =  $1.52 \text{ AU}$

Latent heat of vaporization water:  $L_v = 2.5 \times 10^6 \text{ J kg}^{-1}$    Density of liquid water =  $1000 \text{ kg m}^{-3}$

Latent heat of sublimation ice:  $L_i = 2.8 \times 10^6 \text{ J kg}^{-1}$    Density of water vapour =  $5 \times 10^{-3} \text{ kg m}^{-3}$

Gas constant for water vapour:  $R_v = 461 \text{ J K}^{-1} \cdot \text{kg}^{-1}$    Surface tension of water droplet  $75 \times 10^{-3} \text{ N m}^{-1}$

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

$\gamma = C_p / C_v$     $\kappa = R_d / C_p$     $R_d = C_p - C_v$     $\Gamma_{\text{dalr}} = 9.8 \text{ K/km}$

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

Some integrals that may be of use:

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

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

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

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

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

# PERIODIC TABLE OF ELEMENTS

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18

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

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



**Ptable**  
com

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

## General Knowledge Questions (4 points each)

1) Matching radiometric units:

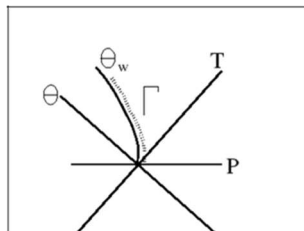
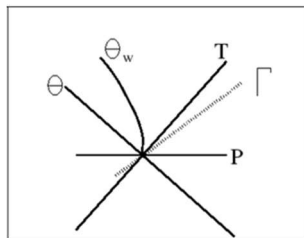
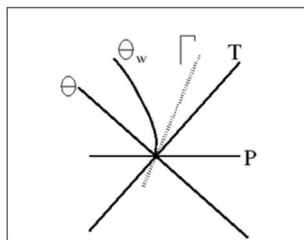
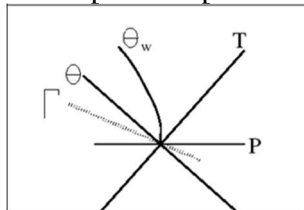
Radiance  $\frac{\text{Watts}}{m^2 \text{ sr nm}}$

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

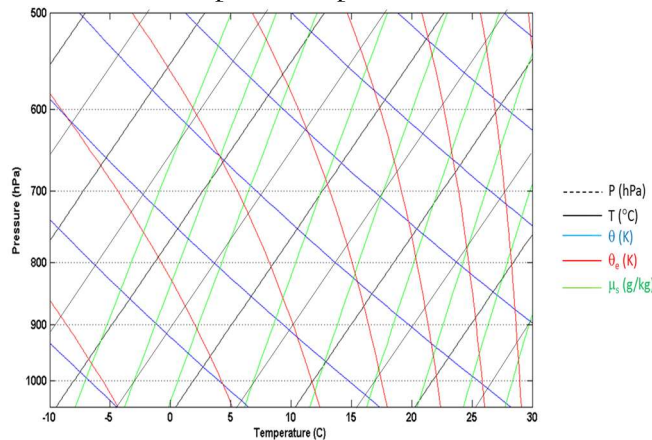
Spectral Radiance  $\frac{J}{s m^2 \text{ sr}}$

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

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



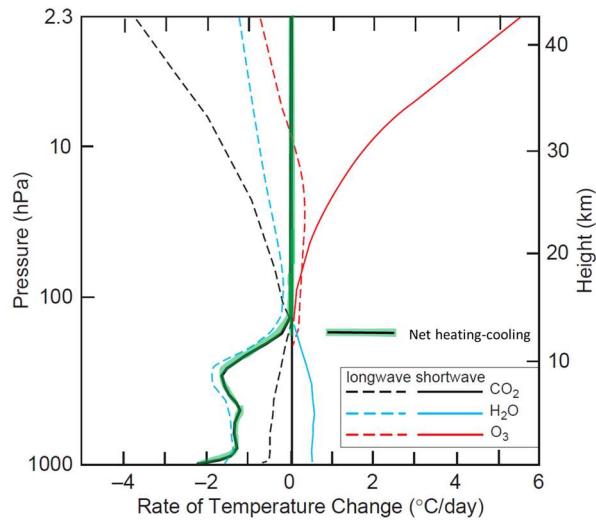
- 3) On the Skew-T log-P diagram, at a pressure of 1000 hPa an air parcel has a temperature  $T=20^\circ\text{C}$  and a dewpoint temperature of  $T_d=5^\circ\text{C}$



- 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  $20^\circ\text{C}$  and a temperature of  $20^\circ\text{C}$ , what is the air parcel's temperature when it is lifted to 600 hPa?  
 $0^\circ\text{C}$        $-20^\circ\text{C}$        $-10^\circ\text{C}$        $-5^\circ\text{C}$        $5^\circ\text{C}$
- 4) Which is not the case in baroclinic stratification?
- is the lowest energy state of the atmosphere
  - isentropes are not parallel to isobars
  - potential energy can be converted to kinetic energy
  - 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?
- molecular oxygen ( $\text{O}_2$ )
  - chlorofluorocarbons (CFCs)
  - nitrous oxide ( $\text{N}_2\text{O}$ )
  - carbon dioxide ( $\text{CO}_2$ )
  - methane ( $\text{CH}_4$ )
- 6) The most abundant gas in the stratosphere is:
- nitrogen ( $\text{N}_2$ ).
  - oxygen ( $\text{O}_2$ ).
  - carbon dioxide ( $\text{CO}_2$ ).
  - ozone ( $\text{O}_3$ ).
  - chlorofluorocarbons (CFCs).

- 7) Which two atmospheric layers have temperature profiles that allow convection?
- Mesosphere and Troposphere.
  - Mesosphere and Stratosphere.
  - Mesosphere and Thermosphere.
  - Stratosphere and Thermosphere.
  - Stratosphere and Troposphere.
  - 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?
- Relative to the direction of travel, they turn to the right in the northern hemisphere and to the left in the southern hemisphere.
  - Relative to the direction of travel, they turn to the left in the northern hemisphere and to the right in the southern hemisphere.
  - The results are unpredictable; currents can veer right or left relative to the direction of travel in either hemisphere.
  - Relative to the direction of travel, they turn to the right in both hemispheres.
  - 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:
- $N_2$  has no permanent dipole moment.
  - $N_2$  only makes rotational transitions at longer wavelengths.
  - False,  $N_2$  does absorb infrared dipole radiation to make vibrational transitions.
  - The dipole moment of  $N_2$  is perpendicular to dipole radiation.
  - The correct answer is not shown.
- 10) A small cloud droplet will evaporate \_\_\_\_\_ a large cloud droplet?
- faster than.
  - at the same rate as.
  - more slowly than.
  - it will not evaporate.
  - the correct answer is not shown.
- 11) If the atmospheric absorption of carbon dioxide at  $15\text{ }\mu\text{m}$  becomes saturated, what happens if carbon dioxide levels continue to increase?
- Total absorption increases as lines farther from the band centre begin to saturate.
  - Total absorption stays the same because it is saturated.
  - Total absorption begins to decrease near the band centre after it saturates.
  - 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?



- The cooling offsets non-radiative processes that heat the atmosphere in this region
  - The greenhouse heating is offset by this cooling, resulting in a steady temperature.
  - That cooling is only affecting the radiation and not the temperature.
  - There is, in fact, a net cooling of the troposphere
  - 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?
- 53 and 127 degrees
  - 24 and 156 degrees
  - 35 and 145 degrees
  - 42 and 138 degrees
  - 60 and 120 degrees
  - The correct answer is not shown
- 14) At a wavelength of 500 nm, the scatter from a 50 nm radius particle is approximately:
- Rayleigh
  - Mie
  - Geometric
  - In the forward direction
  - Able to create a rainbow
  - 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?
- 2070 K
  - 1712 K
  - 13 K
  - 3.5 K
  - 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,  $C_{pw} = 4200 \text{ J/kg/K}$
- 1%
  - 3%
  - 5%
  - 9%
- 17) If the atmospheric pressure at the surface of the Earth is 1000 hPa, what is the mass of the atmosphere in kg?
- $5 \times 10^{18}$
  - $5 \times 10^{15}$
  - $5 \times 10^{16}$
  - $5 \times 10^{17}$
  - $5 \times 10^{19}$
- 18) An air mass of temperature  $+10^\circ \text{C}$  and pressure 1013 hPa contains 7 g/kg water vapour. Calculate the relative humidity.
- 90%
  - 60 %
  - 0.1 %
  - 135 %



## Long Calculations 6 Points each

- 19) For an isothermal atmosphere at 20 °C and a surface pressure of 1000 hPa, how many molecules are there in the Earth's atmosphere?
- $10^{44}$
  - $10^{42}$
  - $10^{38}$
  - $10^{29}$
  - $10^{27}$
- 20) An exoplanet orbits its star at a distance  $R_{\text{orbit}} = 0.41 \text{ AU}$ , and has a radius  $R_p = 1.34 R_{\text{earth}}$ . The planet has an albedo of 0.4 and emissivity of 1. The star it orbits has a radius  $R_{\text{st}} = 0.6 R_{\text{sun}}$  and a photosphere blackbody temperature of  $T_{\text{st}} = 4400 \text{ K}$ . What is the planet's equilibrium temperature assuming it has no atmosphere?
- 50 °C
  - 15 °C
  - 273 K
  - 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?
- 9 m
  - 40 m
  - 6 m
  - 30 m
- 22) An incoming downward flux of short-wavelength radiation of  $400 \text{ W/m}^2$  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 °C 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  $k = 0.02 \text{ m}^2$  per kg of absorber. How much power, in Watts/ $\text{m}^2$ , is absorbed between 2 and 7 km.
- 50
  - 3
  - 1800
  - 0.7
  - The correct answer is not shown