# ATS620
# Thermodynamics and Cloud Physics
# Fall 2019

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User name: 620notes Password: ++++

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Office hours: Mondays and Wednesdays: 3-4pm, second floor conference room

## Course Objectives

The intent of this course is to introduce graduate students to key concepts in cloud physics and thermodynamics as applied to the atmosphere. These concepts include energy variables and energy calculations, thermodynamic diagrams, phase changes, and cloud microphysical properties and processes. A particular emphasis is placed on the formation of precipitation in warm and cold clouds.

## Course Structure, Expectations and Grading Criteria

***Course Material***:
Class material will be delivered in lecture and discussion format, meeting for two 50-minute periods each week. Lectures are posted to the class website. At least 4 hours of effort (2 hours per each hour of class time) outside of class each week are expected to complete homework assignments and any outside reading needed to support learning.

***Course Grading***:
This class is graded on a letter basis, using the +/- options. Students are expected to notify the instructors of any planned absences from class and should make arrangements to make up missed assignments. Homework will be posted online and is due to the GTA in class on the date stated on the assignment. The homework due dates, as well as exam dates are all listed on the class calendar posted online. Late homework assignments will not be accepted without prior arrangements. For every weekday that an assignment is late, 10% will be taken off that assignment. *Your course grade will be based on your performance on two midterm exams, one comprehensive final exam and a number (~9) of homework assignments. The midterm exams will be weighted 15% each, the final 30% and the homework assignments 40% of your final grade.*

***Course Texts:***
There are no required texts for this class. In addition to the class notes available online at: http://vandenheever.atmos.colostate.edu/vdhpage/ats620/ats620.php,
the following resources may be useful:

- Lohmann, Luond and Mahrt, An Introduction to Clouds from the Microscale to Climate, Cambridge University Press, 2016.
- Lamb and Verlinde, Physics and Chemistry of Clouds, Cambridge University Press, 2011.
- Cotton, Bryan and van den Heever, Storm and Cloud Dynamics, Academic Press, 2011, Second Edition.
- Pruppacher and Klett, Microphysics of Clouds and Precipitation, Kluwer Academic Publishers, 1997.
- Young, Microphysical Processes in Clouds, Oxford, 1993.
- Rogers and Yau, A Short Course in Cloud Physics, Pergamon Press, 1989, Third Edition.
- Fletcher, The Physics of Rainclouds, Cambridge University Press, 1962.
- Cotton, ATS620 past notes, available on our class website. *Please do not distribute these notes outside of CSU.*

## Academic Integrity

All students are subject to the policies regarding academic integrity found in the 2017 – 2018 General Catalog, found at http://catalog.colostate.edu/general-catalog/policies/, and the student conduct code (http://resolutioncenter.colostate.edu/conduct-code). Other information on academic integrity can be found on the Learning@CSU website (http://learning.colostate.edu/integrity/index.cfm). Examples of academic dishonesty can be found in these sources. At a minimum, violations will result in a grading penalty in this course and a report to the Office of Conflict Resolution and Student Conduct Services.

## Special Needs

Please see the instructor during the first two weeks of the semester, if you have special learning needs that should be accommodated in this class, and refer to http://rds.colostate.edu/accommodation-process for more information.

| ATS620 THERMODYNAMICS AND CLOUD PHYSICS | | | |
|---|---|---|---|
| **Topics** | **Subtopics** | **HW** | **#Class** |
| | **INTRODUCTION [1 Class]** | | |
| Introduction | • The importance of atmospheric physics | | 1 |
| | **THERMODYNAMICS [7 Classes + 1 Midterm Exam]** | | |
| The First Law | • Classical thermodynamics<br>• Thermodynamic definitions<br>• Dalton's Law of Partial Pressures<br>• Joule's Law<br>• First Law of Thermodynamics<br>• Specific Heats<br>• Potential Temperature<br>• Enthalpy<br>• Latent heating | HW1 | 1 |
| The Second and Third Laws | • Second Law of Thermodynamics<br>• Carnot Cycle<br>• Entropy<br>• Entropy calculations<br>• Third Law of Thermodynamics | HW2 | 2 |
| Free Energy Functions and Thermodynamic Potentials | • Helmholtz and Gibbs Functions<br>• Thermodynamic Potentials<br>• Maxwell Relations<br>• The Chemical Potential<br>• Stable and Unstable Equilibrium<br>• Surface Tension | | 2 |
| Thermodynamics of the Moist Atmosphere | • Phase Changes<br>• Clausius-Clapeyron equation<br>• Properties of Water<br>• Phase diagrams | HW3 | 2 |
| | **CLOUD PHYSICS [20 Classes + 1 Midterm Exam]** | | |
| Nucleation and Growth of Cloud Droplets – Homogeneous and Heterogeneous Nucleation on Soluble Surfaces | • Homogeneous nucleation<br>• Nucleation on flat insoluble surfaces<br>• Nucleation on curved insoluble surfaces<br>• Nucleation on water soluble particles | HW4 | 3 |

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| Nucleation and Growth of Cloud Droplets – Kohler Curves | • Curvature effect<br>• Water solubility | | 3 |
| Nucleation and Growth of Cloud Droplets – Condensation | • Fick's law of diffusion<br>• Energy balance at drop surface<br>• Complete diffusional growth equation<br>• Evaporation of drops<br>• Impacts on DSDs<br>• Supersaturation | HW5 | 2 |
| Nucleation and Growth of Cloud Droplets – Warm Rain Formation | • Collision-coalescence<br>• Continuous collection equation<br>• Collection kernels<br>• Stochastic collection equation<br>• Factors impacting the evolution of the droplet spectrum | HW6 | 3 |
| Ice Crystal Nucleation and Growth | • Structure of ice<br>• Homogeneous nucleation of ice by freezing and deposition<br>• Heterogeneous nucleation of ice on flat and curved surfaces | HW7 | 2 |
| Ice Particle Growth | • Growth mechanisms<br>• Deposition<br>• Capacitance<br>• Habit theory<br>• Fall speeds<br>• Aggregation<br>• Riming<br>• Ice multiplication | HW8 | 3 |
| Graupel and Hail Formation | • Energy balance at the surface<br>• Dry and wet growth regimes<br>• Hail growth models<br>• Melting | HW9 | 3 |
| Atmospheric Electricity | • Principles of atmospheric electricity<br>• Charge generation mechanisms<br>• Cloud electrification mechanism | | 1 |