Physical Meteorology
ATMS 455 – Spring 2025
Study Guide for Final Exam

Since the second exam, we've studied cold and warm cloud microphysics, drop size distributions, elementary radar principles, atmospheric electricity, and acoustics. The vast majority, but not necessarily all, of the questions on the final exam will cover the latest course material. Once again, I will create questions by perusing the class notes and handouts to pick out some important concepts, so that would be a great way to study. The following list is not exhaustive, but should give you an idea of the topics that the exam will cover. The questions again will be in short-answer and fill-in-the-blank format. You should memorize or be able to derive simple relationships. It would be a very good idea to review the homework assignments, handouts, and class notes. Your goal (and my goal for you) is to understand the *concepts* from the course. The exam will take place in the regular classroom on **Friday, 2 May 2025 at 11:30 a.m.** As always, ask questions and good luck!

1. You should have the following handouts (if not, please ask me for them): *Problem Set Tips and Expectations, Atmospheric Composition, Vertical Structure of the Atmosphere to 100 km, Atmospheric Properties, Atmospheric Structure, Lapse Rates, Traveling Waves, Terrestrial Refraction, The Inverted Inferior Mirage, Astronomical Refraction, Rainbow Geometry, Rainbow Intensity, Halo Phenomena, Table 3-1, Refraction of Light by Ice Crystals, Diffraction Phenomena, Scattering Processes in the Atmosphere, Spectral Distribution of Blackbody Radiation, The Sun and the Solar Spectrum, Absorption Spectra, Earth- Sun Geometry, Daily Solar Insolation at the Top of the Atmosphere, The Global Energy Balance, Vertical Distribution of Ions in the Atmosphere, The Global Electrical Circuit, Cloud Electrification,* and *Lightning.*

Topics from the first third of the course

2. What are the major atmospheric gas constituents and what are their concentrations?
3. Name several trace constituents of the atmosphere. What are some gases with variable concentrations? What else is up there?
4. What are the layers of the atmosphere? How are they defined?
5. Why are ozone and water vapor important?
6. What and where is the ionosphere, where are its layers located, and what is each layer called?
7. How does the concentration of ozone vary with height?
8. What is the difference between molecular and kinetic temperature?
9. What is the molecular weight of dry air at sea level?
10. What two components contribute to the measured acceleration of gravity at sea level?
11. How does the height of a pressure surface depend on the temperature of an atmospheric layer?
12. What is the scale height and how is it defined?
13. What are the homogeneous and dry adiabatic lapse rates and how are they defined?
14. Understand how pressure, temperature, and density vary with height in a layer with a constant lapse rate.
15. What two accelerations are in balance when an object is in orbit?
16. What is a geosynchronous orbit?
17. What is primarily responsible for atmospheric tides?
18. What are the types of electromagnetic radiation? What are some representative frequencies and wavelengths for each type? How are these related to the propagation speed of the wave?
19. What is the angular wave number? What does it mean?
20. How is the index of refraction defined? How does light change direction when moving from one medium to another? What about through multiple media? What happens to the frequency of the wave? What happens to the wavelength?
21. What is Snell's law? You might want to memorize it and know how to apply it.
22. Why is the index of refraction for microwaves a function of temperature?
23. What happens to the speed of light as a function of height under normal lapse conditions?
24. How is the curvature of a light ray related to the lapse rate? You might want to memorize the meat and potatoes of this general relationship.

25. How does refraction extend the distance to the apparent horizon?
26. Understand how the following phenomena occur: superior and inferior mirages, looming, sinking, stooping, towering, and multi-part mirages. Be able to identify the type of mirage associated with a particular temperature profile and vice versa.
27. What is astronomical refraction and how does it influence astronomical observations, sunrises and sunsets?
28. How does the refractive index change with the wavelength of light?
29. What is the minimum deviation angle and how does it influence optical phenomena? What is special about this angle?
30. Describe the physical processes involved in the production of rainbows.
31. What is Alexander's dark band? What are supernumerary rainbows?
32. Why are primary rainbows brighter than secondary rainbows? Why is it difficult to see tertiary rainbows?
33. Derive the rotation rate of the Earth (i.e., Ω).

Topics from the middle third of the course

34. What is the value of the Stefan-Boltzmann constant? What are the units?
35. Describe the physical processes involved in the production of rainbows, ice crystal phenomena, and diffraction phenomena.
36. Exactly why is the sky blue? What is the *full* name of the phenomenon responsible?
37. How does the prism angle influence ice crystal phenomena? Which types of crystals and which orientations produce which phenomena?
38. Why are sundogs next to the Sun? Why are they not exactly on the 22° halo?
39. What is diffraction? What is the difference between Fraunhofer and Fresnel diffraction?
40. What does Huygen's principle say?
41. What does Babinet's principle say? What does this have to do with atmospheric optics?
42. What is the significance of the first-order Bessel function in diffraction phenomena?
43. How do droplet sizes influence the angular radii of rings in a corona?
44. List some ice crystal (refraction), diffraction, and reflection phenomena. Describe each phenomenon that we studied in class.
45. How does the size of an atmospheric particle affect light scattering? What size particles are responsible for Lorenz-Mie scattering? Do these particles have common names?
46. Why isn't the sky violet?
47. What is the difference between flux, irradiance, radiance, flux density, intensity, and luminosity? What are the units of each?
48. What does *monochromatic* mean? Why do we care?
49. What is a solid angle and what are its units?
50. What are reflectivity, absorptivity, and transmissivity and how are they related?
51. What is a blackbody?
52. What does Kirchhoff's law say?
53. What is the energy of a photon?
54. What is Planck's function and what can we use it for? How does it change with temperature?
55. What is the Stefan-Boltzmann law and how can we apply it? What does it mean physically?
56. What is Wien's displacement law and how can we apply it? How does it relate to Planck's function?
57. What is emissivity?
58. What is the solar constant (both numerically and physically)? How constant is it?
59. Understand how to calculate the solar flux (a constant), the solar irradiance, the effective blackbody temperature of an object, and the intercepted flux of a planetary object.
60. What is the Earth's average albedo and how is it defined? What is the albedo for certain objects (e.g., clouds, snow/ice, water, land, etc.)?
61. *Derive* an equation for the Earth's radiative equilibrium temperature based on the Earth's budget of incoming shortwave and outgoing longwave radiation. Derive a similar relationship for any object, regardless of its shape.
62. What are the major selective absorbers in the Earth's atmosphere?

63. What types of energy transitions are responsible for absorption lines in various parts of the electromagnetic spectrum? Which three energy transitions are possible? Which types of molecules are responsible for this absorption?
64. What is the atmosphere's optical depth and what does it have to do with the atmosphere's absorptivity? How is absorptivity different from scattering?
65. What geometric factors influence the distribution of undepleted solar radiation at the top of the atmosphere?
66. What are Bohr's postulates?
67. What is an energy budget?
68. What are aphelion and perihelion and when do they occur?
69. What is the declination angle?
70. Completely explain why Earth has seasons.
71. How does the distribution of undepleted solar radiation at the top of the atmosphere vary through the day or the year?
72. How much energy does the Earth receive from the Sun at a particular location on a particular day of the year?
73. In what ways could a slab of soil gain or lose energy?
74. What are the components of the surface energy balance? What is the sum of these components at the top of the atmosphere?
75. Where are there net gains and losses of energy at the Earth's surface?
76. Why do meteorological disturbances even exist?
77. What are Milankovitch cycles?
78. Why is the work of Johannes Kepler important to us?

Topics from the last third of the course

79. Define nucleation, supersaturation, homogeneous and heterogeneous nucleation, hygroscopic and hydrophobic aerosols, haze, liquid water content, droplet concentration, droplet spectrum, drop size distribution, supercooled, glaciated, mixed cloud, and ice multiplication (splintering).
80. What is Kelvin's formula and what are its implications for cloud droplets?
81. What is the Köhler solute effect? Understand Köhler curves and how to interpret them.
82. Understand the role of cloud condensation nuclei and ice nuclei in precipitation formation.
83. How do the concentrations of CCN differ between maritime and continental air?
84. What are some sources of CCN?
85. What are two ways for droplets to grow in warm clouds? Upon what factors do these mechanisms depend?
86. How do terminal velocities depend on drop size?
87. What are collision efficiency, coalescence efficiency, and collection efficiency and how do they differ?
88. How does the growth rate of droplets vary with increasing radii?
89. What is the stochastic collision model?
90. What are some possible mechanisms for ice nucleation?
91. Explain the physics behind the Bergeron-Findeisen process.
92. What are some ice crystal habits? Why do ice crystals differ and how are they all alike?
93. What are some mechanisms for ice crystal growth?
94. What is the bright band and why is it significant?
95. What shape are raindrops?
96. Where did the Marshall-Palmer distribution come from and what does it describe?
97. Do all observed drop size distributions actually conform to the Marshall-Palmer distribution?
98. How is radar reflectivity related to the size of raindrops in a drop size distribution?
99. What are some typical R–Z relations? Memorize them.
100. What is the equation for the speed of sound in dry air? Memorize it.
101. How does temperature affect the speed of sound? How does moisture affect the speed of sound? Which is most influential?
102. How do sound waves refract in the atmosphere under normal lapse conditions and in inversion layers? How might a steeper lapse rate change the curvature?

103. Explain how an observer might hear thunder, even though it might be inaudible for someone between the observer and the lightning bolt.
104. How does wind shear affect sound propagation?
105. How might you determine the temperature in the stratosphere by using sound?
106. What are Aeolian tones? Memorize the relationship between wind speed, obstruction diameter, and the frequency of the sound that is produced by Aeolian tones. Seriously, memorize it.
107. In reference to atmospheric electricity, define electrostatic potential, Coulomb's Law, an electric field, current and current density, Ohm's Law, conductivity, and mobility.
108. What is an ion and what are the two different types of atmospheric ions? What mechanisms produce atmospheric ions and how are they destroyed? Where are ions most abundant and where is the greatest production rate of ions? Under what conditions are ions more efficiently removed by different removal processes?
109. What determines the drift velocity of ions?
110. What happens to the conductivity of the atmosphere from the surface to 30 km?
111. Understand the properties of the atmospheric electric field in fair weather (i.e., where does the electric field vector point, what is the direction of the potential gradient, what are some typical values of the fair weather current, potential, resistance, etc.).
112. How long would it take for the average current density to neutralize the charge on the Earth and in the atmosphere? What prevents this from happening?
113. What are some characteristics of water that make it an especially suitable molecule for charge separation in clouds?
114. How does the thermoelectric effect lead to charge separation in clouds?
115. What is inductive charging? What is non-inductive charging?
116. What are the steps involved in a lightning discharge?
117. What are the three primary types of lightning?
118. Define return stroke, dart leader, stepped leader, and upward streamer.
119. What is the difference between a negative and positive lightning discharge?
120. What is thunder?
121. Where is cloud-to-ground lightning most active in the U.S.? In the world?