Enter your name and student ID number on the answer sheet and on this exam. Record your answers to the questions by using a No. 2 pencil to completely fill the appropriate circle on the answer sheet. The exam will be computer graded, so be sure to follow the marking instructions provided on the answer sheet. The exam is closed book, closed notes. No calculators are permitted. When you are finished, turn in both the exam and the answer sheet to the teaching assistants. Good luck!

NOTE THE USEFUL INFORMATION FOUND ON THE LAST SHEET OF THE EXAM.

1. The primary source of carbon dioxide for the earth’s atmosphere prior to the past half billion years or so appears to be:
   a. volcanic eruptions
   b. photosynthesis
   c. photodissociation
   d. exhalations of animal life
   e. transpiration

2. Earth's first atmosphere consisted primarily of:
   a. carbon dioxide and water
   b. nebular hydrogen and helium
   c. complex hydrocarbons
   d. nitrogen and oxygen

3. The atmospheres of Jovian planets consist primarily of hydrogen and helium captured from the protostellar nebula. Jovian planets are successful at nebular capture because they form beyond the _______ meaning their protoplanetary constitution is of ______________, making them more massive.
   a. asteroid belt, hydrocarbon ices
   b. 'frost line', rocks and ices combined
   c. solar system, solid iron
   d. 'frost line', heavy metals

4. The primary source of carbon dioxide for the earth’s atmosphere in the current climate appears to be:
   a. photosynthesis
   b. photodissociation
   c. decay of vegetation and exhalations of animal life
   d. fossil fuel burning
   e. b-d
5. The second most abundant gas in the earth's atmosphere by volume is:
   a. carbon dioxide
   b. nitrogen
   c. water vapor
   d. methane
   e. oxygen

6. Which of the following weather elements increases as we climb upward in the stratosphere?
   a. pressure
   b. temperature
   c. density
   d. moisture
   e. all of the above

7. Warming in the stratosphere is mainly caused by:
   a. absorption of ultraviolet radiation by ozone
   b. release of latent heat energy during condensation
   c. chemical reactions between ozone and chlorofluorocarbons
   d. frictional heating caused by meteorites

8. Cooling at the surface of Earth in Colorado during August at noon is mainly caused by:
   a. emission of longwave radiation.
   b. conduction and convection within the boundary layer.
   c. the upwards transfer of latent and sensible heat.
   d. there is no cooling of the surface at noon.
   e. a-c

9. Warming at the surface of Earth in Colorado during a cloudy night in December is mainly caused by:
   a. absorption of downwelling longwave radiation.
   b. conduction and convection from geothermal activity.
   c. the upwards transfer of latent and sensible heat.
   d. there is no warming of the surface at midnight.
   e. a-c

10. On a clear still night in Denver during December, which is most likely true in the lowest 100 meters of the atmosphere:
    a. air temperature increases with increasing height
    b. air temperature decreases with increasing height
    c. air temperature remains constant with increasing height
    d. density increases with increasing height
11. On a very windy night in Denver during December, which is most likely true in the lowest 100 meters of the atmosphere:
   a. air temperature increases with increasing height
   b. air temperature decreases with increasing height
   c. air temperature remains relatively constant with increasing height
   d. density increases with increasing height

12. The temperature of a sinking air parcel:
   a. always cools due to expansion
   b. always warms due to expansion
   c. always cools due to compression
   d. always warms due to compression
   e. remains constant

13. If the average temperature of the sun decreased, the wavelength of peak solar emission would:
   a. shift to a shorter wavelength
   b. shift to a longer wavelength
   c. remain the same
   d. impossible to tell from given information

14. Which of the following statements is not correct?
   a. calm, cloudy nights are usually warmer than calm, clear nights
   b. each year the earth's surface radiates away more energy than it receives from the sun
   c. the horizontal transport of heat by the wind is called advection
   d. good absorbers of radiation are usually good emitters of radiation

15. The atmospheric greenhouse effect is produced mainly by the:
   a. absorption and re-emission of visible light by the atmosphere
   b. absorption and re-emission of ultraviolet radiation by the atmosphere
   c. absorption and re-emission of infrared radiation by the atmosphere
   d. absorption and re-emission of visible light by clouds
   e. absorption and re-emission of visible light by the ground

16. Which of the following is a selective absorber of longwave radiation?
   a. carbon dioxide
   b. ozone
   c. water vapor
   d. clouds
   e. all of the above
17. Low clouds retard surface cooling at night better than clear skies because:
   a. the clouds absorb and radiate infrared energy back to earth
   b. the water droplets in the clouds reflect infrared energy back to earth
   c. the clouds start convection currents between them
   d. the clouds are better conductors of heat than is the clear night air
   e. the formation of the clouds releases latent heat energy

18. If the present concentration of carbon dioxide were to decrease, what other gas would likely decrease as well?
   a. nitrogen
   b. oxygen
   c. methane
   d. water vapor

   a. absorb, absorb
   b. absorb, reflect
   c. reflect, reflect
   d. reflect, absorb

   a. absorb, absorb
   b. absorb, reflect
   c. reflect, reflect
   d. reflect, absorb

21. The sun is directly overhead at 21 degrees North:
   a. once a year
   b. twice a year
   c. four times a year
   d. never

22. A ski resort in Colorado should be placed on what side of a mountain to minimize the amount of sunshine incident on the ski runs:
   a. north
   b. south
   c. east
   d. west

23. If the tilt of the Earth was increased to 60°, a ski resort in Colorado should be placed on what side of a mountain to minimize the amount of sunshine incident on the ski runs:
   a. north
   b. south
   c. east
   d. west
24. The earth is currently tilted at an angle of 23.5° with respect to the plane of its orbit around the sun. If the amount of tilt were increased to 90°, we would expect in middle latitudes:
   a. hotter summers and colder winters than at present
   b. cooler summers and milder winters than at present
   c. hotter summers and milder winters than at present
   d. cooler summers and colder winters than at present
   e. no appreciable change from present conditions

25. If the amount of tilt were decreased to 0°, we would expect in middle latitudes:
   a. hotter summers and colder winters than at present
   b. cooler summers and milder winters than at present
   c. hotter summers and milder winters than at present
   d. cooler summers and colder winters than at present
   e. no appreciable change from present conditions

26. The surface temperature of the earth will most likely decrease under which of the following scenarios:
   a. we add a gas to the atmosphere that preferentially absorbs longwave radiation
   b. we add a gas to the atmosphere that preferentially scatters shortwave radiation
   c. the albedo of the earth-atmosphere system increases.
   d. the distance of the earth from the sun decreases.
   e. b and c.

27. Why doesn't air constantly move downward due to the force of gravity?
   a. temperature advection
   b. absorption by ozone
   c. emission of longwave radiation moves air upward
   d. the pressure decreases with height

28. In this case, at what latitude would we find the Arctic Circle:
   a. at the Equator
   b. 90 degrees North
   c. 90 degrees South
   d. there would be no Arctic circle

29. At what latitude would the sun be overhead at noon on June 21?
   a. at the Equator
   b. 90 degrees North
   c. 90 degrees South
   d. there would be no summer solstice

*For the following 3 questions, imagine that the tilt of the earth relative to the axis of rotation increases from 23.5 degrees to 90 degrees.*
30. How many times per year would the sun be overhead at 45 degrees North?
   a. 1
   b. 2
   c. 3
   d. none

For the questions 31-38, use the figure above.
31. Imagine you suddenly increase the concentration of a gas that preferentially absorbs shortwave radiation. If all other things are held equal, what number(s) in the figure above will be the first to change?
   a. +111 will increase.
   b. +19 will increase only.
   c. +19 will increase and +51 will decrease.
   d. -96 and -64 will increase (become less negative).
   e. +7 will increase.

32. Based on your answer in 31, what number(s) will change next?
   a. +111 will decrease.
   b. +7 will decrease.
   c. +23 will increase and -64 will decrease.
   d. -96 and -64 will decrease (become more negative) and -117 will increase (become less negative).
   e. +7 will increase.

33. Based on the above, if all other things are held equal, how will the increased absorption of shortwave radiation by the atmosphere change surface temperature?
   a. it will increase.
   b. it will decrease.
   c. it will not change.
   d. can not tell from the information given.

34. Now consider the effect of increased absorption of longwave radiation. If all other things are held equal, what number(s) in the figure above will be the first to change?
   a. +111 will increase.
   b. -117 will decrease (become more negative).
   c. +19 will increase.
   d. +51 will increase.
   e. +7 will increase.

35. Based on your answer in 30, what number(s) will change next?
   a. +111 will decrease.
   b. +7 will decrease.
   c. +23 will increase and -64 will decrease (become more negative).
   d. -96 and -64 will decrease (become more negative).
   e. -117 will decrease.
36. In the net, how will the increased absorption of longwave radiation by the atmosphere change surface temperature?
   a. it will increase.
   b. it will decrease.
   c. it will not change: the increase longwave at the surface balances the decreased shortwave from the atmosphere.
   d. can not tell from the information given.

37. Now imagine the atmosphere is suddenly whisked away from Earth. All others things being equal, what will be the net shortwave at the surface?
   a. 70
   b. 90
   c. 51
   d. 96
   e. none of the above

38. When radiative equilibrium is reached, what will be the net longwave from the surface?
   a. 70
   b. 90
   c. 51
   d. 96
   e. none of the above
The figures at the end of the previous page show the hypothetical seasonal cycle in temperature at two different cities. Assume that radiation plays the dominant role in driving the observed seasonal cycle at both locations. You do not need to know the units on the temperature axis.

39. At city A, during what months is the amount of incoming shortwave radiation likely increasing from one day to the next?
   a. Roughly January-June
   b. Roughly July and August
   c. Roughly August-December
   d. Roughly September and March
   e. none of the above

40. At city A, during what months is the amount of outgoing longwave radiation likely increasing from one day to the next?
   a. Roughly August-September
   b. Roughly July and December
   c. Roughly January-June
   d. Roughly September and March
   e. none of the above

41. At city B, during what months is the amount of outgoing longwave radiation increasing?
   a. Roughly January-March and June-September
   b. March and September
   c. June and October
   d. January and August
   e. Can't tell from the information given.

42. City A is most likely located at what latitude?
   a. 0
   b. 23 N
   c. 60 S
   d. 90 S
   e. none of the above

43. City B is most likely located at what latitude?
   a. 0
   b. 23 N
   c. 45 S
   d. 60 N
   e. none of the above
44. Often before sunrise on a clear, calm, cold morning, ice (frost) can be seen on the tops of parked cars, even when the air temperature is above freezing. This condition happens because the tops of the cars are cooling by:
   a. conduction
   b. convection
   c. latent heat
   d. solar cooling
   e. radiation

45. If the absolute temperature of an object halves, the maximum energy emitted changes by a factor of:
   a. 2
   b. 4
   c. 16
   d. 1/4
   e. 1/16

46. The atmosphere near the earth’s surface is “heated from below.” Which of the following is not responsible for the heating?
   a. conduction of heat upward from a hot surface
   b. convection from a hot surface
   c. absorption of infrared energy that has been radiated from the surface
   d. heat energy from the earth’s interior

47. An important reason for the large daily temperature range over deserts is:
   a. there is little water vapor in the air to absorb and re-radiate infrared radiation
   b. the light-colored sand radiates heat very rapidly at night
   c. dry air is a very poor heat conductor
   d. free convection cells are unable to form above the hot desert ground
   e. the ozone content of desert air is very low

48. The temperature of the tropopause:
   a. is close to the temperature at the earth’s surface
   b. is much colder than the temperature at the earth’s surface
   c. has never been measured
   d. is much warmer than the temperature at the earth’s surface
   e. is nearly the same as the sun’s temperature

49. The earth emits radiation with greatest intensity at
   a. Infrared wavelengths
   b. Radio wavelengths
   c. Visible wavelength
   d. Ultraviolet wavelengths