ATMOS 5130
Physical Meteorology II
Thermodynamics

Dr. Gannet Hallar
University of Utah
gannet.hallar@utah.edu

Spring Semester 2016 (1.5 credits)
Monday, Wednesday, Friday
10:45 – 11:35 am
WBB - Rm. 820
January 9 to February 27, 2017

Course Website

- Lectures presented in class
- Classroom notes
- Study Guides

  http://chpc.utah.edu/~hallar/Thermo/

Course Textbook

A First Course in Atmospheric Thermodynamics

by Grant W. Petty

List price when purchased through bookstores: $51. Discounted price when ordered directly from Sundog Publishing: $36, including free shipping to U.S. addresses.
http://www.sundogpublishing.com/

Bring Calculator to Class

You will be expected to solve problems in class

Classroom Policies

- Students must take every exam and quiz with exceptions governed by University Policy.
- Plagiarizing, copying, cheating, or otherwise misrepresenting one’s work will not be tolerated.
- Missing class will not be penalized directly, but usually results in poor problem set and exam performance.
- Strongly suggest completing reading assignments.
- Homework is due at the start of class on the due date, unless otherwise noted.
- Late homework will not be accepted.
- Please respect others right to learn.

THE UNIVERSITY OF UTAH

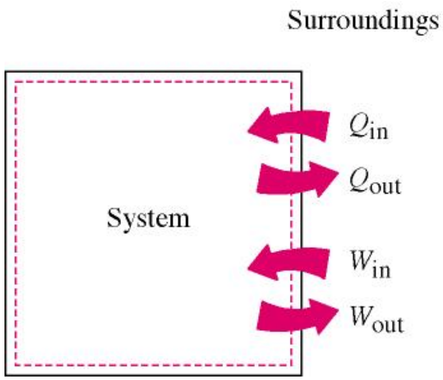
Meteorology 3510

Lecture 1: Chapter 1

- Introduction to Atmospheric Thermodynamics
  - Pressure
  - Temperature

What is Thermodynamics?

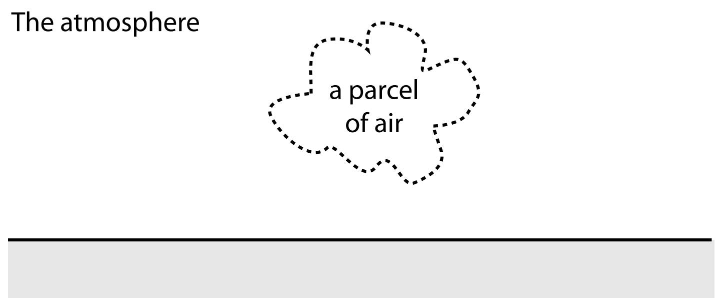
- Study of heat to work transformations (and the reverse)



Now we apply that to the atmosphere in relation to weather and climate

What is Atmospheric Thermodynamics?

Describes the physical behavior of air on local scale

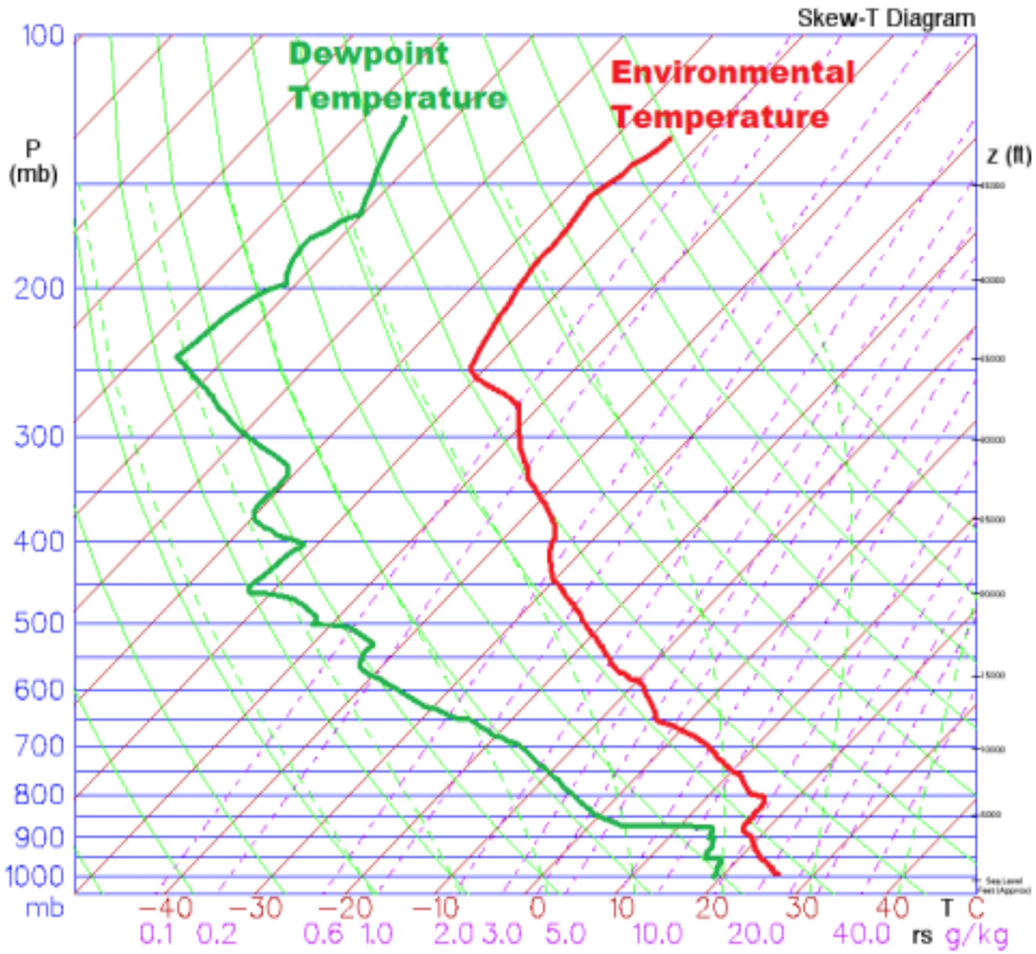


How does an isolated "parcel" of air respond to changes in <u>temperature</u> and <u>pressure</u>?

How do these changes affect its behavior in relationship to the surrounding atmosphere?

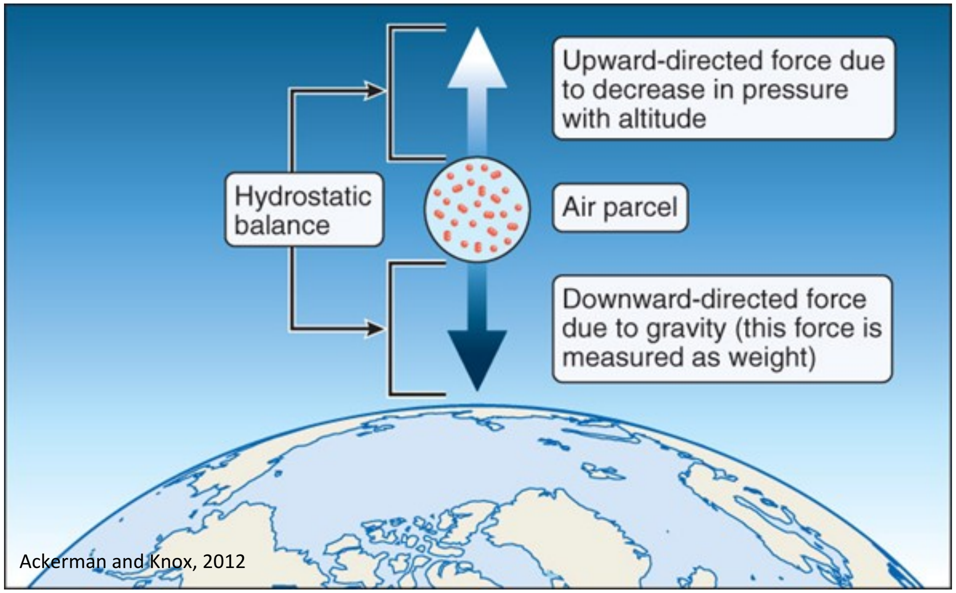
Pressure

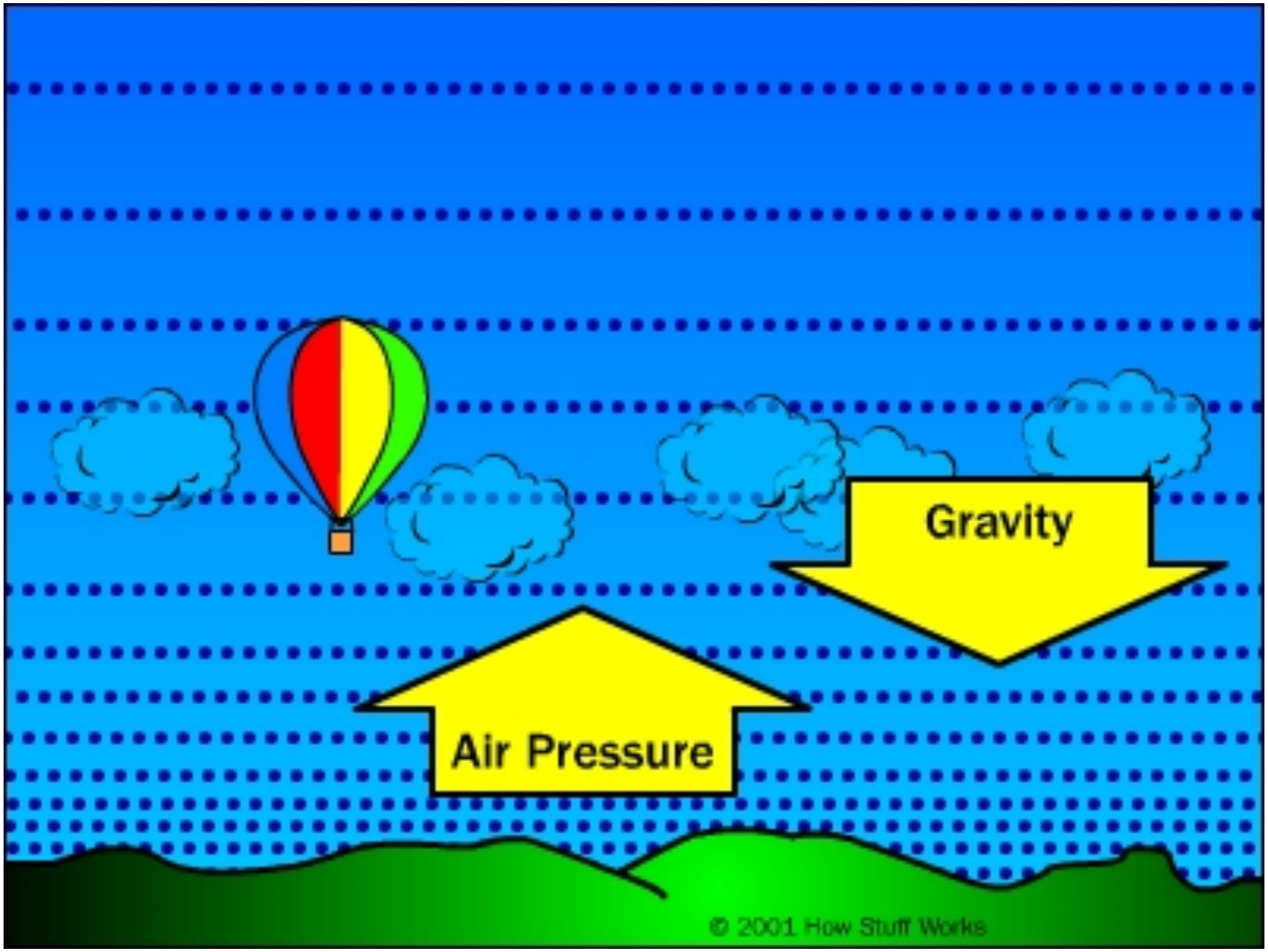
- https://www.youtube.com/watch?v=QeAp3CuGjk8 e.g. Thermodynamic Diagram = Skew-T log p chart



Introduction to Hydrostatic Balance

- Pressure at any point in the atmosphere equals the weight per unit area above that point.
- Pressure = Force per unit area
- Weight of an object = Force = F_g = mg
- g = acceleration due to gravity (9.81 m s^{-2}) at sea level




Gravity
Air Pressure
© 2001 How Stuff Works

Common Units of Pressure

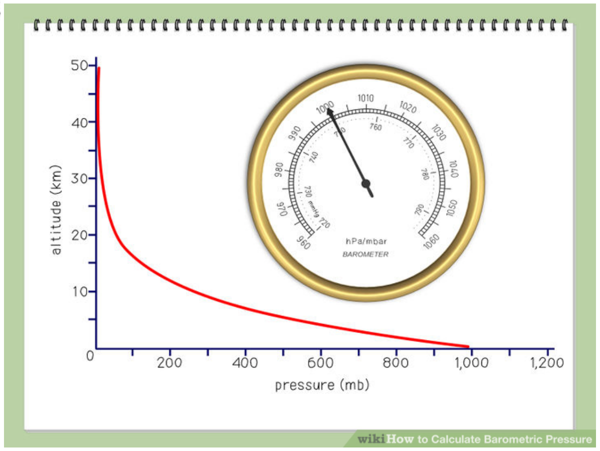
Unit	Atmospheric Pressure	Scientific Field
pascal (Pa); kilopascal(kPa)	1.01325 x 10^5 Pa 101.325 kPa	SI unit; physics, chemistry
atmosphere (atm)	1 atm*	Chemistry
millimeters of mercury (mm Hg)	760 mmHg*	Chemistry, medicine, biology
torr	760 torr*	Chemistry
pounds per square inch (psi or lb/in^2)	14.7 lb/in^2	Engineering
bar	1.01325 bar	Meteorology, chemistry, physics

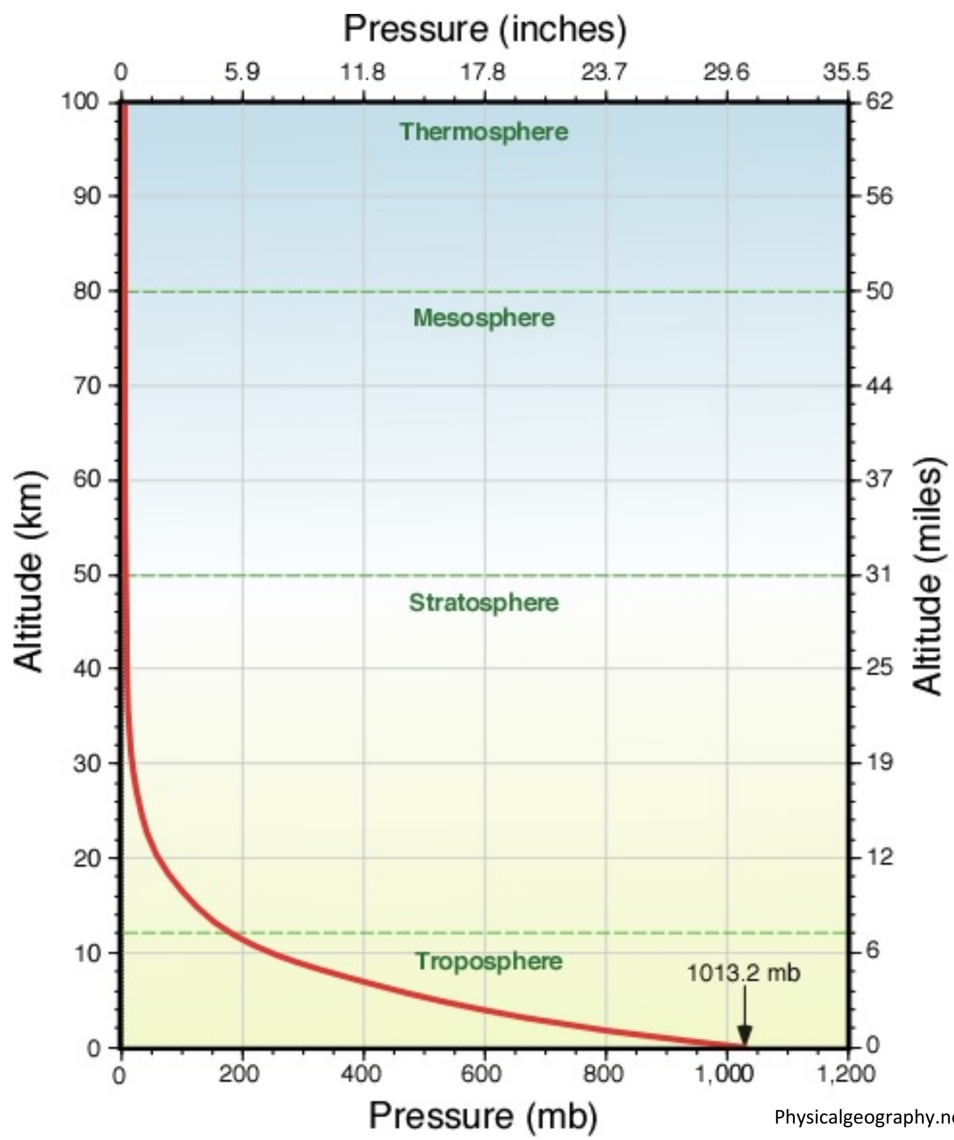
Pa = Newton/m^2

100 Pa = hPa = mbar

Work is measured in Joules (J) = Newton * m

Thus, pressure has units of J/m^3
Energy density





Physicalgeography.net

Temperature / Heat

Temperature is the quantity that determines the direction in which thermal energy (“heat”) will flow when two objects are brought into contact with one another.

Temperature of a substance is proportional to the average kinetic energy of its molecules.

Absolute Temperature

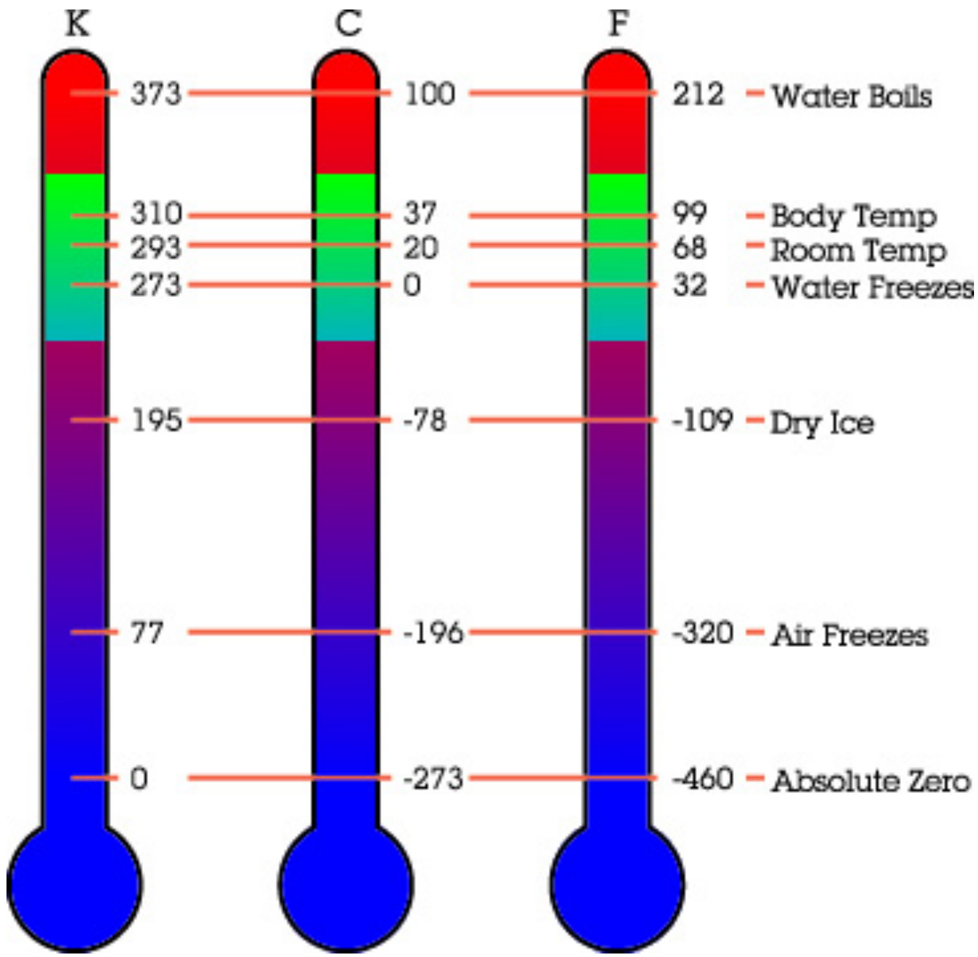
Translational Kinetic Energy $$K_E = \frac{1}{2}mv^2, \tag{1.4}$$

where v is its speed. Thus, the absolute temperature

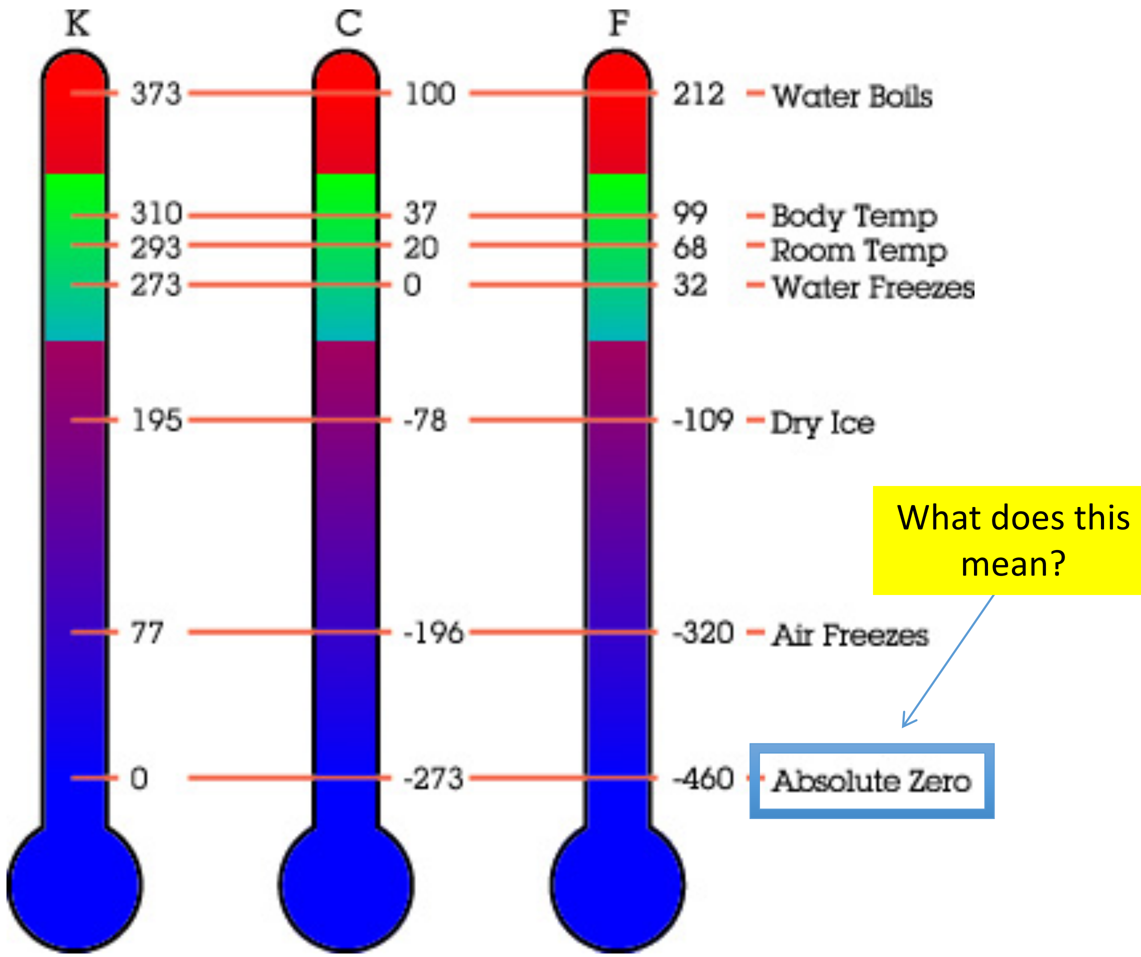
$$T \propto m\overline{v^2}, \tag{1.5}$$

where the bar over v^2 indicates the average of that quantity for all atoms in the sample.

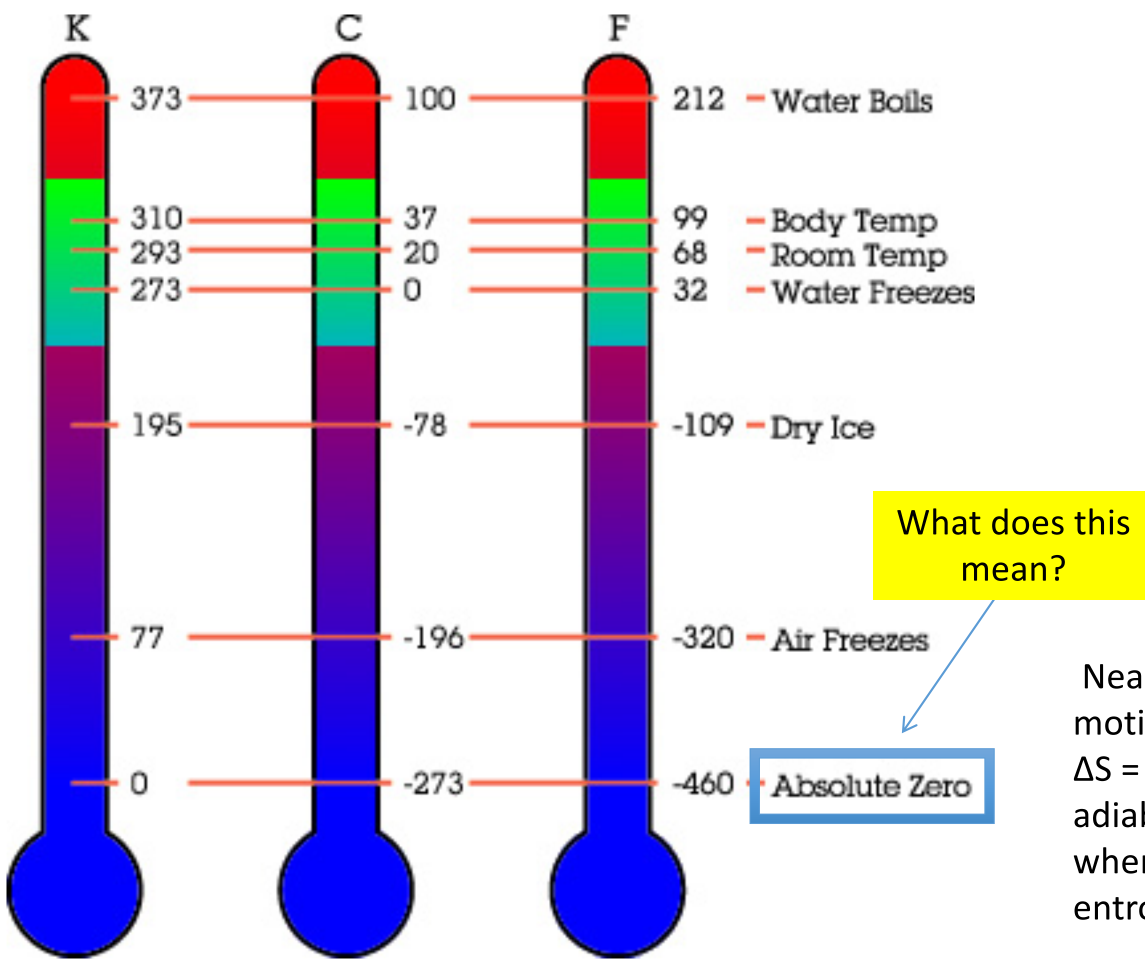
Temperature Scales



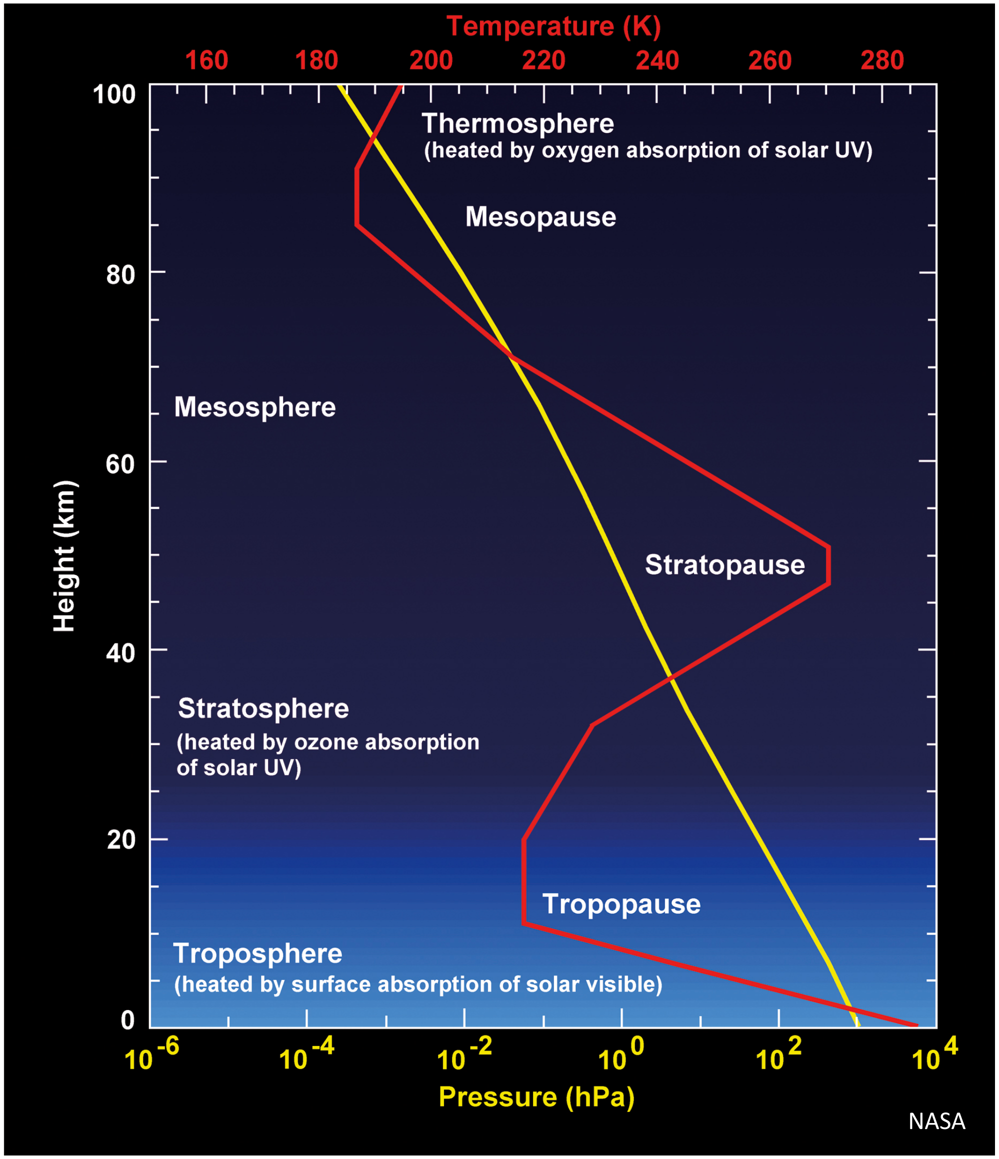
Temperature Scales



Temperature Scales



Nearly all molecular motion ceases and $\Delta S = 0$ for any adiabatic process, where S is the entropy.



Temperature (K)
160
180
200
220
240
260
280
100
80
60
40
20
0
Height (km)
Thermosphere
(heated by oxygen absorption of solar UV)
Mesopause
Mesosphere
Stratopause
Stratosphere
(heated by ozone absorption
of solar UV)
Tropopause
Troposphere
(heated by surface absorption of solar visible)
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
Pressure (hPa)
NASA

Environmental Lapse Rate

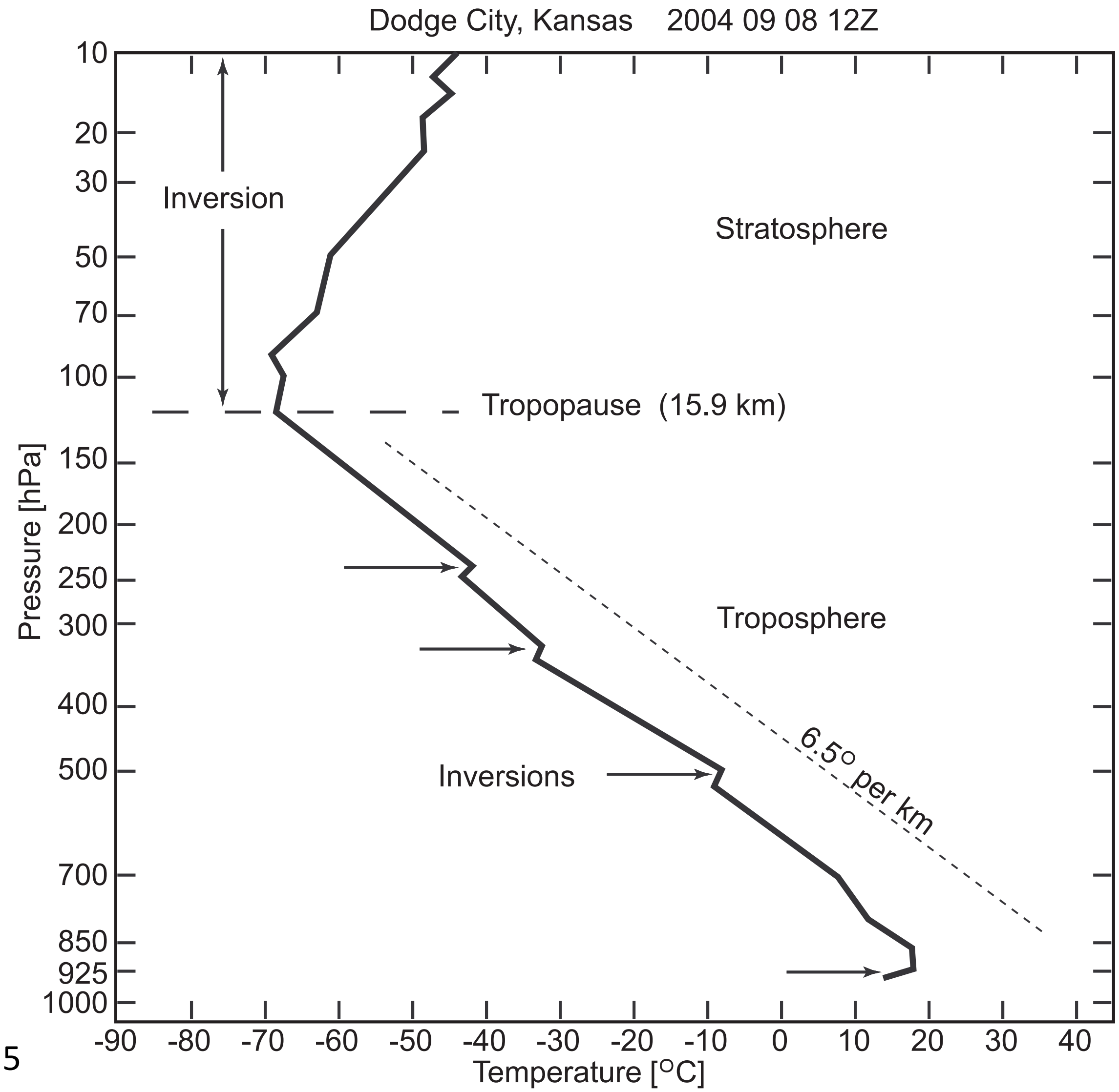
$$\boxed{\Gamma = -\frac{\partial T}{\partial z}.} \qquad (1.6)$$

$$\Gamma \simeq -\frac{T_2 - T_1}{z_2 - z_1}. \qquad (1.7)$$

Typically positive in the Troposphere

When Negative = Inversion

Standard Lapse Rate = 6.5 C/km



Dodge City, Kansas 2004 09 08 12Z
Inversion
Stratosphere
Tropopause (15.9 km)
Troposphere
Inversions
6.5° per km
Pressure [hPa]
10
20
30
50
70
100
150
200
250
300
400
500
700
850
925
1000
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40
Temperature [°C]

Fig. 1.5

Inversions

Jude Tibway took this photo of the Salt Lake Valley from near Snowbird in February 2010

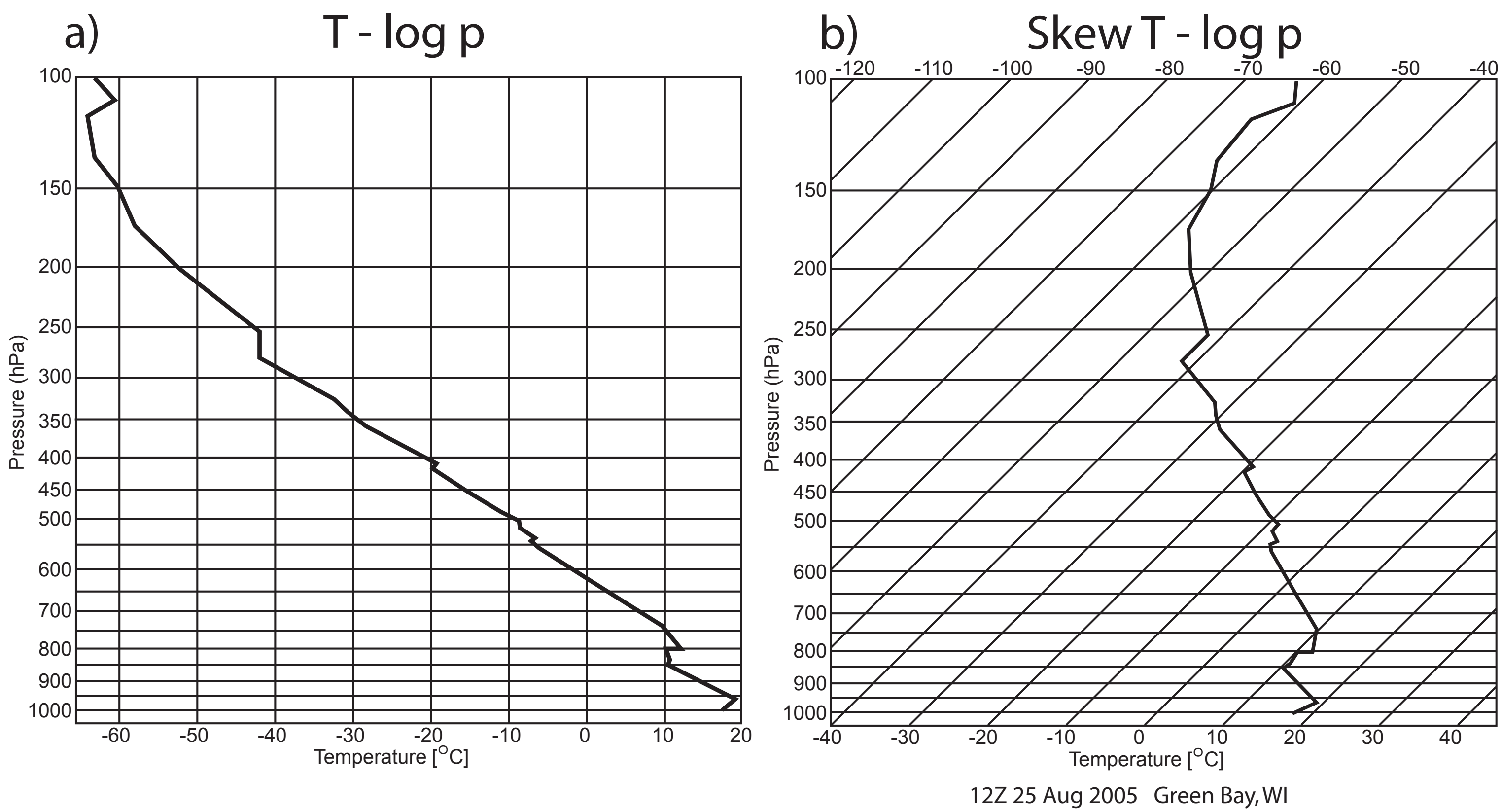
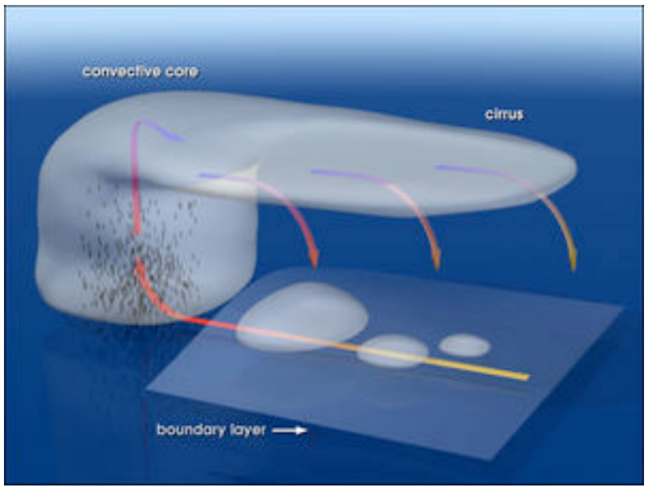

a)
T - log p
Pressure (hPa)
100
150
200
250
300
350
400
450
500
600
700
800
900
1000
-60 -50 -40 -30 -20 -10 0 10 20
Temperature [°C]
b)
Skew T - log p
-120 -110 -100 -90 -80 -70 -60 -50 -40
Pressure (hPa)
100
150
200
250
300
350
400
450
500
600
700
800
900
1000
-40 -30 -20 -10 0 10 20 30 40
Temperature [°C]
12Z 25 Aug 2005 Green Bay, WI

Fig. 1.19

Atmospheric thermodynamic principles form foundation of:

- atmospheric dynamics (the study of the fluid motions of the atmosphere)
- cloud and precipitation physics
- weather forecasting (especially the forecasting of severe weather)



(Image provided by Robert Simmon)

As the air travels toward convective system, it gains moisture. Ascending motion in a deep convective core produces air expansion, cooling, and condensation. Upper level outflow visible as an anvil cloud is eventually descending.

(Image provided by UK Met Office)