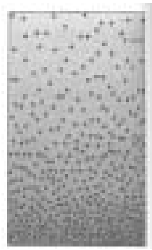
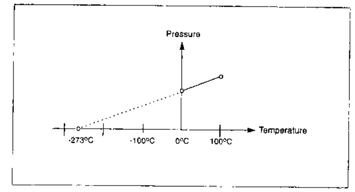
Lecture 3: Why Is Mountain Peak Cold?



- ❑ Density of the Atmosphere
- ❑ Air Pressure
- ❑ Convection
- ❑ Thermal Structure of the At[redacted]

“Absolute Zero” Temperature



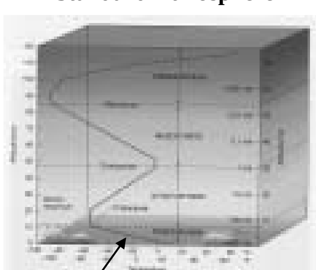
(from ***Is The Temperature Rising?***)

- ❑ The absolute zero temperature is the temperature that the molecules do not move at all.
- ❑ This temperature occurs at –273°C.
- ❑ The Kelvin Scale (°K) is a new temperature scale that has its “zero” temperature at this absolute temperature:

°K = °C + 273

Vertical Thermal Structure

Standard Atmosphere



(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

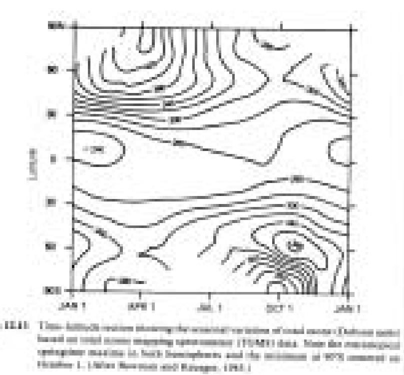
Troposphere (“overturning” sphere)
- contains 80% of the mass
- surface heated by solar radiation
- strong vertical motion
- where most weather events occur

Stratosphere (“layer” sphere)
- weak vertical motions
- dominated by radiative processes
- heated by ozone absorption of solar ultraviolet (UV) radiation
- warmest (coldest) temperatures at summer (winter) pole

Mesosphere
- heated by solar radiation at the base
- heat dispersed upward by vertical motion

Thermosphere
- very little mass

Ozone Distribution



Global Temperature Distribution

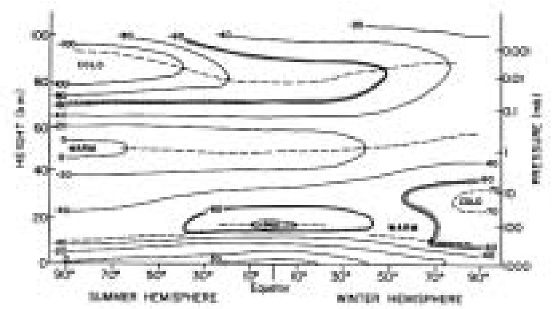
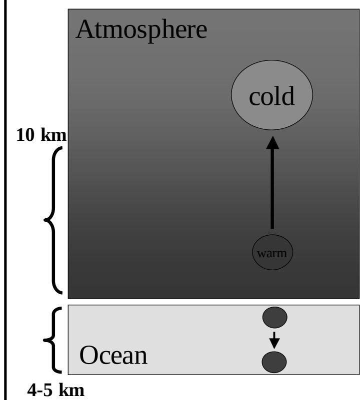


Fig. 1.3. Schematic latitude-height section of zonal mean temperatures (°C) for solstice conditions. Dashed lines indicate tropopause, stratopause, and mesopause levels. (Courtesy of R. J. Reed.)

Differences Between the Atmosphere and Ocean



- ❑ Density
  - The oceans has a constant density.
  - The density of the atmosphere decreases with height.
- ❑ Depth
  - The ocean has an average depth of about 4-5 km for the ocean.
  - The atmosphere has no fixed depth/thickness and no clear top. Most of the air is confined in the first 10 km of the atmosphere.

Three Things Need To Be Explained

(1) Why does air density decrease with height?

(2) What is air pressure?

(3) Why does air parcel expand with height?

Why Air Density Decreases with Height?

- ❑ The vertical structure of the atmosphere (i.e., density decreases with height) depends on a compromise between gravity, which pulls molecules downward toward the surface of the Earth, and the tendency of the molecules to move about freely.

The Scale Height of the Atmosphere

- One way to measure how soon the air runs out in the atmosphere is to calculate the height of an atmosphere of constant density that exerts the same pressure as our atmosphere at Earth's surface.
- This height, which is about ***10 km***, is called the scale height of the atmosphere.
- Over this vertical distance, air pressure and density decrease by 37% of its surface values.
- If pressure at the surface is 1 atmosphere, then it is 0.37 atmospheres at a height of 10 km, 0.14 (0.37x0.37) at 20 km, 0.05 (0.37x0.37x0.37) at 30 km, and so on.
- Most (80%) of the mass of the atmosphere is confined in the first 10 km from the surface.

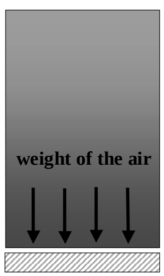
A Mathematic Formula of Scale Height

$$H = \frac{RT}{mg}$$

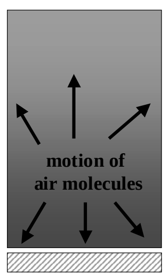
scale height (H), gas constant (R), temperature (T), molecular weight of gas (m), gravity (g)

- The higher the temperature (T) ➔ the more energetic the air molecules ➔ the larger the scale height
- The larger the gravity (g) ➔ air molecules are closer to the surface ➔ the smaller the scale height
- The heavier the gas molecules weight (m) ➔ the smaller the scale height for that particular gas
- H has a value of about 10km for the mixture of gases in the atmosphere, but H has different values for individual gases.

Air Pressure Can Be Explained As:

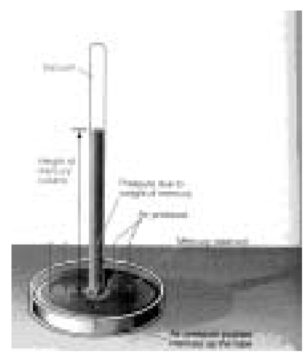


The weight of air above a surface (due to Earth's gravity)



The bombardment of air mocules on a surface (due to motion)

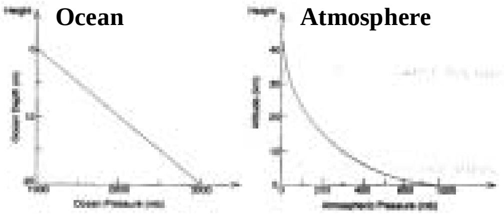
One Atmospheric Pressure



(from *The Blue Planet*)

- The average air pressure at sea level is equivalent to the pressure produced by a column of water about 10 meters (or about 76 cm of mercury column).
- This standard atmosphere pressure is often expressed as 1013 mb (millibars), which means a pressure of about 1 kilogram per square centimeter.

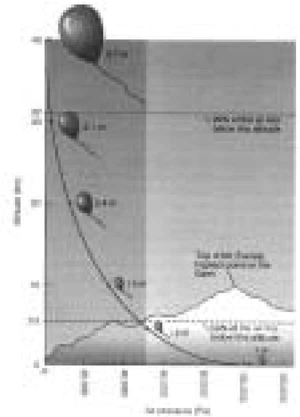
How Soon Pressure Drops With Height?



(from ***Is The Temperature Rising?***)

- In the ocean, which has an essentially constant density, pressure increases linearly with depth.
- In the atmosphere, both pressure and density decrease exponentially with elevation.

Air Parcel Expands As It Rises…



(from *The Blue Planet*)

- Air pressure decreases with elevation.
- If a helium balloon 1 m in diameter is released at sea level, it expands as it floats upward because of the pressure decrease. The balloon would be 6.7 m in diameter as a height of 40 km.

Boyle's Law

Pressure must remain proportional to density (if the temperature does not change).

➔Boyle's law would permit the gases of the atmosphere to expand indefinitely (provided their density and pressure decrease at the same rate).

What Happens to the Temperature?

- Air molecules in the parcel (or the balloon) have to use their kinetic energy to expand the parcel/balloon.
- Therefore, the molecules lost energy and slow down their motions

➔ The temperature of the air parcel (or balloon) decreases with elevation.

The First Law of Thermodynamics

- This law states that (1) heat is a form of energy that (2) its conversion into other forms of energy is such that total energy is conserved.
- A parcel of air expands and pushes its surroundings back loses energy in the process.
- That energy comes from the random motion of the air molecules in the parcel.
- After the expansion, the molecules move less energetically ➔ ***the expansion causes the temperature of the air to decrease***.

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Why Air Parcels Move Upward?

- The atmosphere is heated from below by sunlight.
- The heat is moved upward in the atmosphere in three ways:

(1) **Conduction**: requires physical contact between the objects that exchange heat. Very slow for gases.

(2) **Convection**: possible only in fluid and gases in which the flow of heat from one region to another involves the movement of matter from one region to the other. Very efficient.

(3) **Radiation**: is possible across empty space

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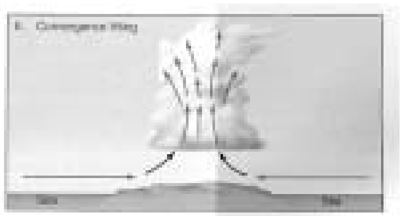
Convection Brings Heat Upward..



(from *The Blue Planet*)

- Warm, low-density air rises convectively and displace cooler, dense air.
- In this way, the convection process redistribute heat from the surface to the rest part of the atmosphere.

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How Strong Can the Convections be?

- In a thunderstorm that has intense convection, parcels of air can rise from Earth's surface to heights ***in excess of 10 km in a matter of minutes!***

➔ Very dangerous to airplanes.

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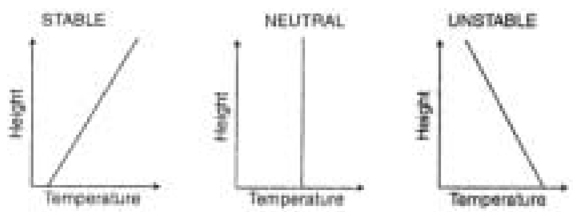
Unstable, Neutral, and Stable Atmosphere



(from ***Is The Temperature Rising?***)

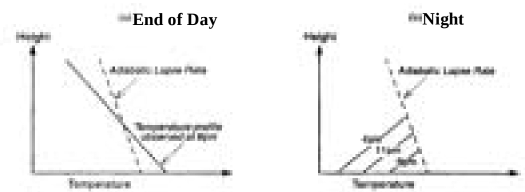
Why Is the Mountain Peak Cold?

- ❑ Sunlight heats the atmosphere from below
- ➔ Convection occurs and brings heat upward
- ➔ Air parcels expands as they move upward (because air pressure decreases with height)
- ➔ Thermal energy in the parcel is used to expand the air parcel
- ➔ Air parcel becomes cold
- ➔ Temperature decreases with height in the atmosphere

Adiabatic Lapse Rate

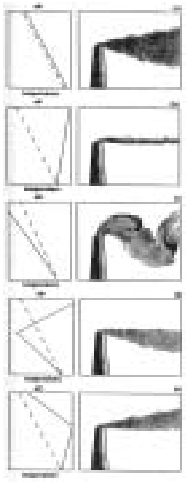
- ❑ By considering the Boyle's law (about random motion of air molecules), the barometric law (about the gravitational pull of air molecules), and the first law of thermodynamics (about the energy conversion), it can be shown that air temperature decrease linearly with height.
- ❑ This linear decreasing rate is called the "adiabatic lapse rate", which is about ***10°C per kilometer***.
- ❑ "Adiabatic" means no heat is added or subtracted from a parcel as it rises, expands, and cools.

Day/Night Changes of Air Temperature



- ❑ At the end of a sunny day, warm air near the surface, cold air aloft.
- ❑ In the early morning, cold air near the surface, warm air aloft.
- ❑ The later condition is called "inversion", which inhibits convection and can cause sever pollution in the morning.

Stability and Air Pollution



Neutral Atmosphere (Coning)

Stable Atmosphere (Fanning)

Unstable Atmosphere (Looping)

Stable Aloft; Unstable Below (Fumigation)

Unstable Aloft; Stable Below (Lofting)

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