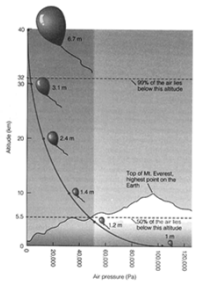
Lecture 7: Air cools when it rises



- ❑ Air expands as it rises
- ❑ Air cools as it expands
- ❑ Air pressure
- ❑ Lapse rates

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 in the atmosphere)
- ➔ Thermal energy in the parcel is used to expand the air parcel
- ➔ Air parcel becomes cold
- ➔ Temperature decreases with height in the atmosphere
- ➔ clouds, rains, snows……

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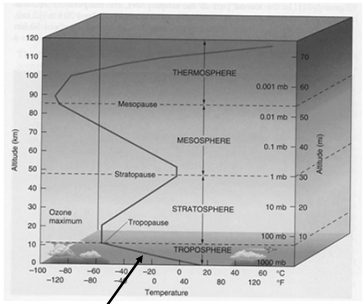
Vertical Thermal Structure

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

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Three Things Need To Be Explained

(1) Why air expands as it rises?

(2) Why air cools as it expands with height?

(3) What is air pressure?

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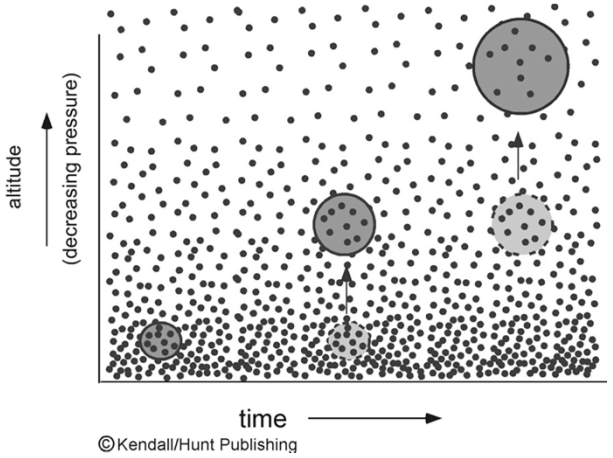
Air Parcel Expands as It Rises



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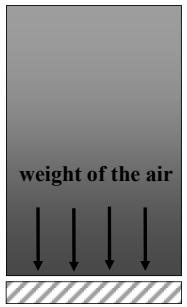
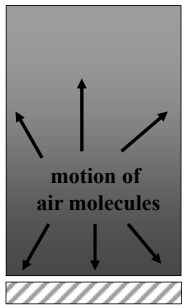
Air Pressure Can Be Explained As:



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



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

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Units of Atmospheric Pressure

- **Pascal (Pa):** a SI (Systeme Internationale) unit for air pressure.
  1 Pa = force of 1 newton acting on a surface of one square meter
  1 hectopascal (hPa) = 1 millibar (mb) [hecto = one hundred =100]
- **Bar:** a more popular unit for air pressure.
  1 bar = 1000 hPa = 1000 mb
- **One atmospheric pressure** = standard value of atmospheric pressure at lea level = 1013.25 mb = 1013.25 hPa.

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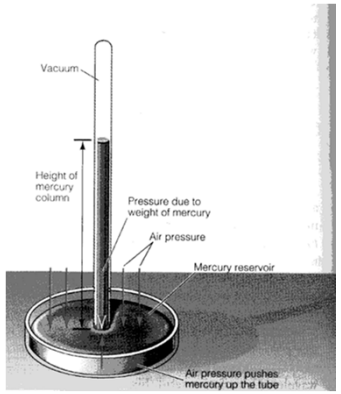
One Atmospheric Pressure



(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.

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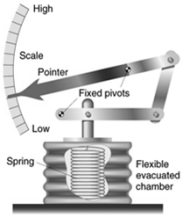
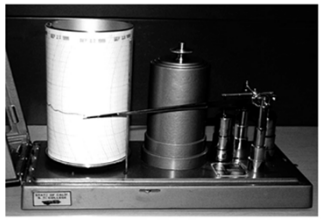
Aneroid barometer (left) and its workings (right)

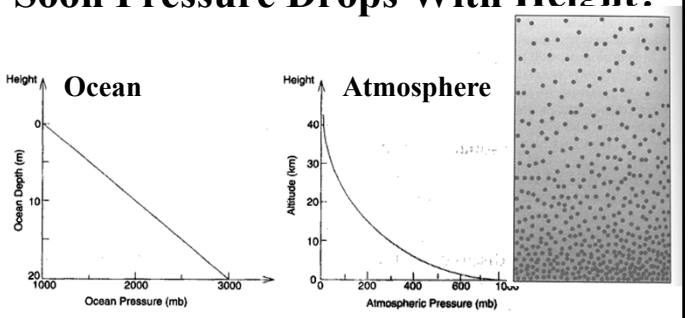




A barograph continually records air pressure through time

Why Air Pressure Decreases with Height?

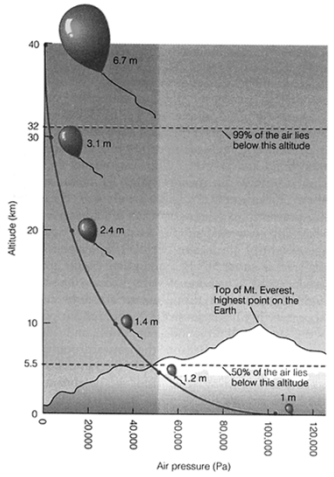
How Soon Pressure Drops With Height?



(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.

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***.

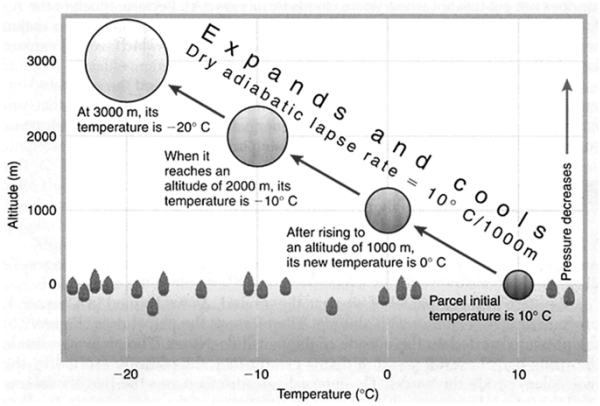
How to Change Air Temperature?

- **Add (remove) heat to (from) the air parcel (diabatic processes)**
  - (1) Conduction: requires touching
  - (2) Convection: Hot air rises
  - (2) Advection: horizontal movement of air
  - (3) Radiation: exchanging heat with space
  - (4) Latent heating: changing the phase of water
- **Without adding (removing) heat to (from) the air parcel**
  - (1) Adiabatic Process: Expanding and compressing air

Adiabatic Lapse Rate

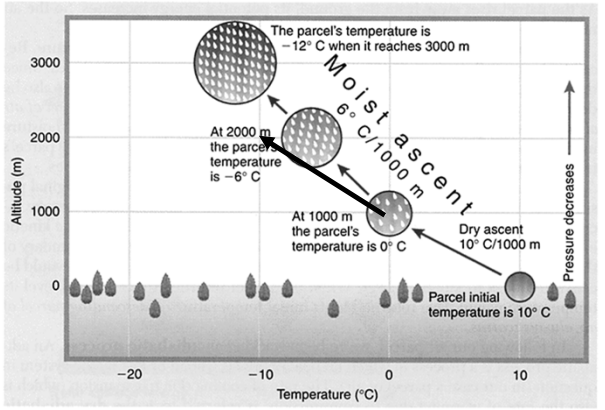
- By considering the Boyle's law (about random motion of air molecules), the barometric law (about the gravitational pull of air molecules), and the first law of thermodynamics (about the energy conversion), it can be shown that air temperature decrease linearly with height.
- This linear decreasing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

Dry Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

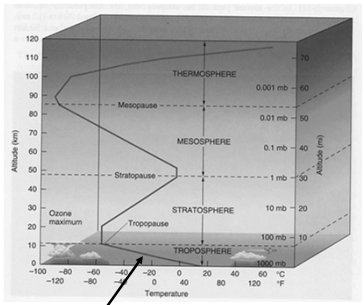
Moist Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

Air Temperature

Standard Atmosphere

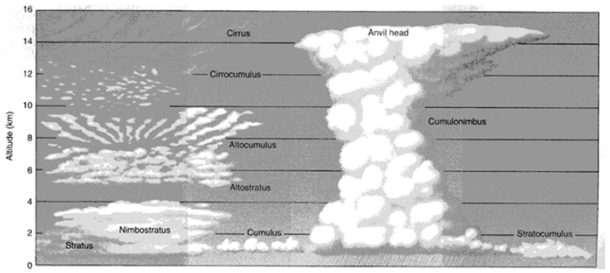


(from *Understanding Weather & Climate*)

lapse rate = 6.5 C/km

- ❑ The reasons for the inversion in the stratosphere is due to the ozone absorption of ultraviolet solar energy.
- ❑ Although maximum ozone concentration occurs at 25km, much solar energy is absorbed in the upper stratosphere and can not reach the level of ozone maximum.
- ❑ Also, the lower air density at 50km allows solar energy to heat up temperature there at a much greater degree.

Cloud Types Based On Height



If based on cloud base height, the ten principal cloud types can then grouped into four cloud types:

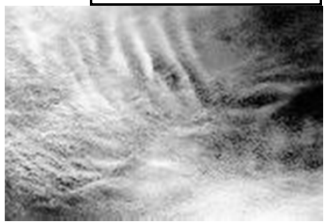
- ✓ High clouds -- cirrus, cirrostratus, cirroscumulus.
- ✓ Middle clouds – altostratus and altocumulus
- ✓ Low clouds – stratus, stratocumulus, and nimbostartus
- ✓ Clouds with extensive vertical development – cumulus and cumulonimbus.

(from "*The Blue Planet*")

High Clouds

1. Cirrus Clouds

3. Cirrocumulus Clouds



(from Australian Weather Service)

2. Cirrostratus Clouds

- High clouds have low cloud temperature and low water content and consist most of ice crystal.

Middle Clouds

4. Altostratus Clouds

5. Altocumulus Clouds

(from Australian Weather Service)

- Middle clouds are usually composite of liquid droplets.
- They block more sunlight to the surface than the high clouds.

Low Clouds

6. Stratus Clouds

8. Nimbostratus Clouds

(from Australian Weather Service)

7. Stratocumulus Clouds

- Low, thick, layered clouds with large horizontal extends, which can exceed that of several states.

Clouds With Vertical Development

9. Cumulus Clouds

10. Cumulonimbus Clouds

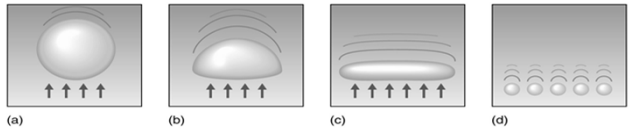
(from Australian Weather Service)

- They are clouds with substantial vertical development and occur when the air is absolute or conditionally unstable.

Forms of Precipitation

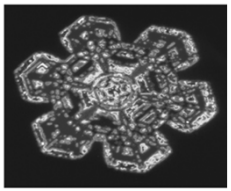
- ***Rain***
- ***Snow***
- ***Graupel and Hail***
- ***Sleet***
- ***Freezing Rain***

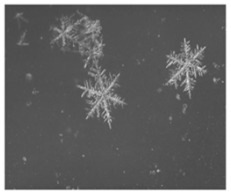
Rain



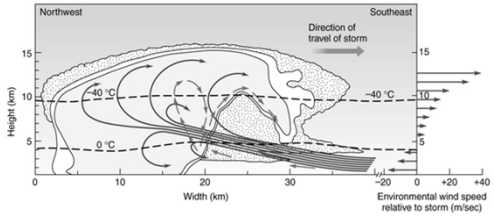
- ***Rain*** is associated with warm clouds exclusively and cool clouds when surface temperatures are above freezing
- ***Rainshowers*** are episodic precipitation events associated with convective activity and cumulus clouds
  - Drops tend to be large and widely spaced to begin, then smaller drops become more prolific
- ***Raindrop Shape*** begins as spherical
  - As frictional drag increases, changes to a mushroom shape
  - Drops eventually flatten
  - Drops split when frictional drag overcomes the surface tension of water
  - Splitting ensures a maximum drop size of about 5 mm and the continuation of the collision-coalescence process

Snow





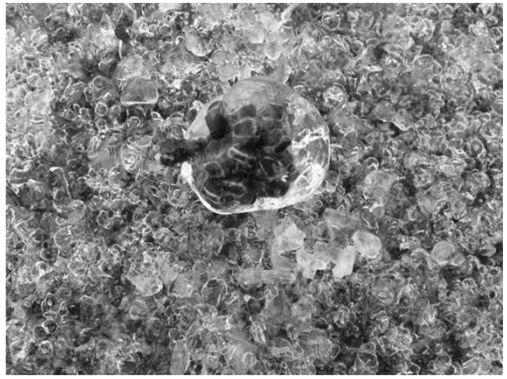
- Snowflakes have a wide assortment of shapes and sizes depending on moisture content and temperature of the air.
- Snowfall distribution in North America is related to north-south alignment of mountain ranges and the presence of the Great Lakes.
- Lake effect: snows develop as the warm lake waters evaporate into cold air.



Hail Formation

Concentric layers of ice in hail indicate the cyclical hailstone formation process

Freezing Rain and Sleet



(Photographer: Lee Anne Willson)