Temperature, Buoyancy, and Vertical Motion

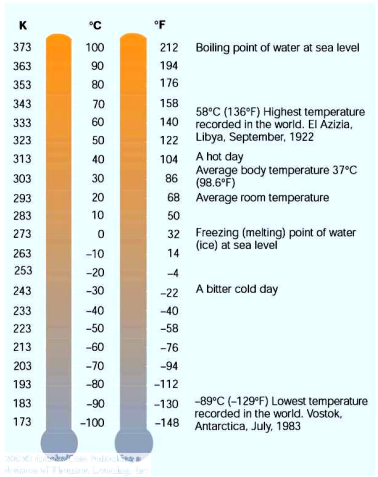
Temperature, Pressure, and Density
Buoyancy and Static Stability
Temperature "Lapse Rates"
Rising & Falling Motions in the Air

What *is* Air Temperature?

- Temperature is a measure of the kinetic energy (speed) of air molecules as they bounce around
- High temperature air is made of fast molecules that deliver a lot of energy when they hit something
- Cold air is made of slower molecules that hit things less often and deliver a weaker wallop when they do
- The sensation of warmth is created by air molecules striking and bouncing off your skin surface

Temperature Scales

- In the US, we use Fahrenheit most often
- Celsius (centigrade) is a scale based on freezing/boiling of water
- Kelvin is the "absolute" temperature scale



How Atmospehric Temperature is Measured

Helium-filled weather balloons are released from over 1000 locations around the world every 12 hours (some places more often)

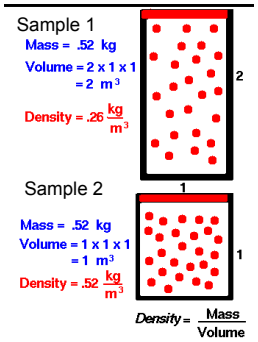
These document temperature, pressure, humidity, and winds aloft

Pressure

- Pressure is defined as a force applied per unit area
- The weight of air is a force, equal to the mass m times the acceleration due to gravity g
- Air pressure results from the weight of the entire overlying column of air!

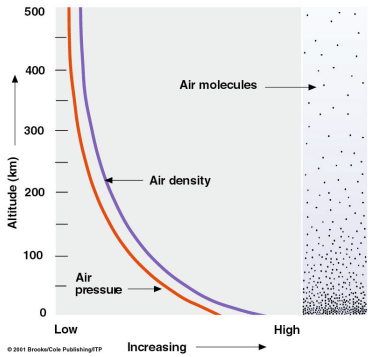
Density (mass/volume)

- Same number of molecules and mass
- Sample 1 takes up more space
- Sample 2 takes up less space
- Sample 2 is more dense than sample 1



Pressure and Density

- Gravity holds most of the air close to the ground
- The weight of the overlying air is the pressure at any point



Density is the Key to Buoyancy!

Changes in density drive vertical motion in the atmosphere and ocean.

- Less dense air rises when it is surrounded by denser air.

  -Think of a hollow plastic ball submerged under water. What happens when you release it?

The ball is less dense than the water around it …

Buoyancy and Temperature

Hot air has fast-moving molecules that spread out and occupy more space (volume) … so it is **less dense**!

Cold air has slow-moving molecules that pack more closely together and take up less space … so it is **more dense**

An air parcel rises in the atmosphere when its density is less than its surroundings

So air that is **warmer than its surroundings rises**, and air that is **colder than its surroundings sinks**

Trading Height for Heat

We can think of two *kinds* of energy in the air:

- **potential energy** (due to its height)
- **internal energy** (due to the motions of the molecules that make it up)

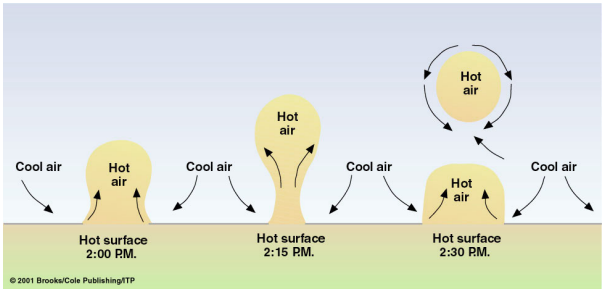
- Air can trade one kind of energy for the other, but **conserves the overall total**

When air rises, it gains height but loses heat (cools) … when it sinks it loses height but gains heat (warms)

Hot Air Ballooning

- Contain some air in the balloon envelope
- Add some serious heat energy!
- Air expands and rises (some gets out the bottom)
- Balloon accelerates upward

Temperature, Density, and Convection

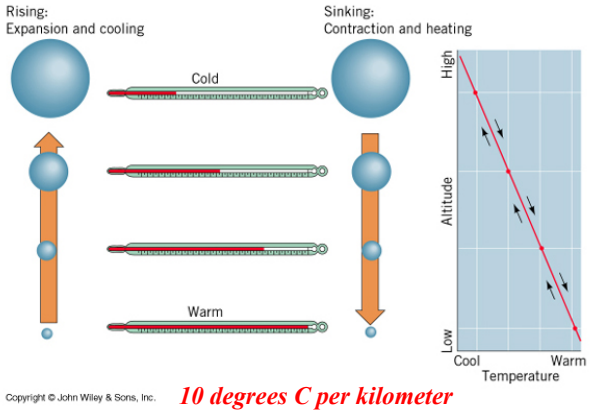


Heating of the Earth's surface during daytime causes the air to vertically mix

"Lapse Rate"

- The lapse rate is the change of temperature with height in the atmosphere
- Environmental Lapse Rate
  - The actual vertical profile of temperature (as measured on a tower or airplane or balloon)
- Dry Lapse Rate
  - The change of temperature that an air parcel would experience if it were displaced vertically with no condensation or heat exchange

Dry Lapse Rate



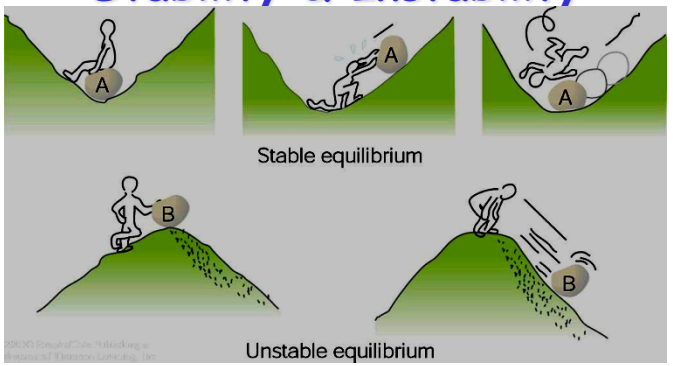
10 degrees C per kilometer

Warming and Cooling due to changing pressure

Hiking Long's Peak

- Fort Collins is 5000 feet above sea level
- Longs Peak is 14255 feet above sea level
- Climbing 9255 feet is almost 3000 m
- Dry lapse rate 10 °C / km, so should be 30 °C colder (=54 F)
- Suppose it's 95 °F in FC today, 95 – 54 = **41 °F** on Long's!

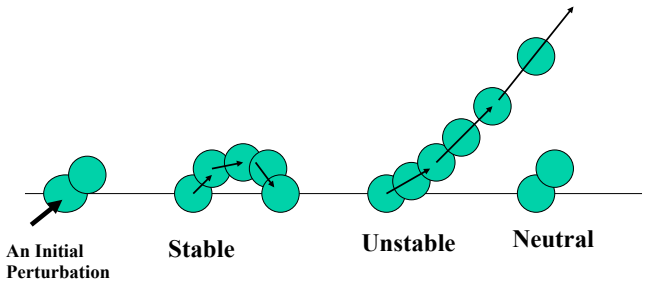
Stability & Instability



A rock, like a parcel of air, that is in **stable** equilibrium will return to its original position when pushed.

A rock or parcel of air in **unstable** equilibrium will rush **away from its initial position** when pushed a little

Stability in the atmosphere



If an air parcel is displaced from its original height it can:

Return to its original height - Stable
Accelerate upward because it is buoyant - Unstable
Stay at the place to which it was displaced - Neutral

Why is stability important?

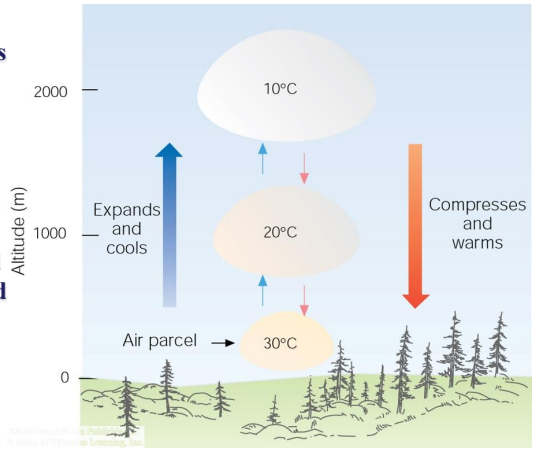
Vertical motions in the atmosphere are a critical part of energy transport and strongly influence the hydrologic cycle

- **Without vertical motion, there would be no precipitation, no mixing of pollutants away from ground level - weather would be totally boring!**
- There are two types of vertical motion:
  - **forced motion** such as forcing air up over a hill, over colder air, or from horizontal convergence
  - **buoyant motion** in which the air rises because it is less dense than its surroundings

Vertical Motion and Temperature

Rising air expands using energy to push outward against its environment, cooling the air

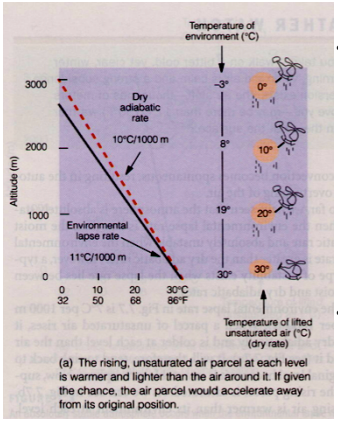
Air may be forced to rise or sink, and change its temperature relative to the air around it



Stability and the Dry Lapse Rate

- A rising air parcel cools according to the dry lapse rate (10 C per km)
- If rising, cooling air is:
  - warmer than surrounding air it is less dense and buoyancy accelerates the parcel upward … **UNSTABLE!**
  - colder than surrounding air it is more dense and buoyancy opposes (slows) the rising motion … **STABLE!**

Unstable Atmosphere



(a) The rising, unsaturated air parcel at each level is warmer and lighter than the air around it. If given the chance, the air parcel would accelerate away from its original position.

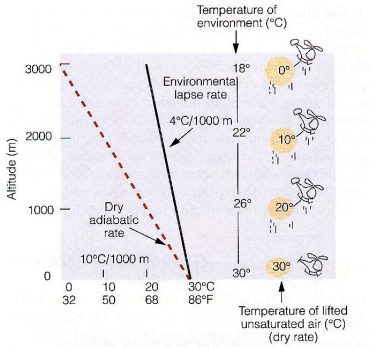
- The atmosphere is unstable if the actual lapse rate exceeds the dry lapse rate (air cools more than 10 C/km)
- This situation is rare in nature (not long-lived)
  - Usually results from surface heating and is confined to a shallow layer near the surface
  - Vertical mixing eliminates it
- Mixing results in a dry lapse rate in the mixed layer, unless condensation (cloud formation) occurs

What conditions make the air unstable?

- Warming of surface air
  - Solar heating of ground
  - Warm "advection" near surface
  - Air moving over a warm surface (e.g., a warm body of water)
- Cooling of air aloft
  - Cold "advection" aloft (thunder-snow!)
  - Radiative cooling of air/clouds aloft

- The atmosphere is stable if the actual lapse rate is less than the dry lapse rate (air cools less than 10 C/km)
- This situation is common in nature (happens most calm nights, esp in winter)
  - Usually results from surface cooling and is confined to a shallow layer near the surface
  - Vertical mixing or surface heating eliminates it

Stable Atmosphere



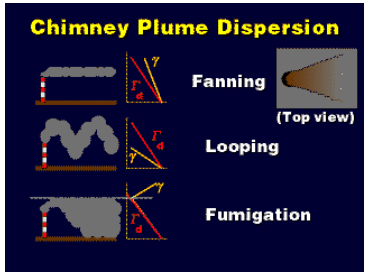
(a) Lifted, unsaturated air at each level is colder and heavier than the air around it. If given the chance, the parcel would return to its original position

What conditions make the air stable?

- Radiative cooling of surface at night
- Advection of cold air near the surface
- Air moving over a cold surface (e.g., snowy ground, cold water, ice,)
- Warming of the air due to compression from subsidence (sinking)

Air Stability and Pollution

- When air is stable (cold near ground), pollution pools like water (cough cough)
- Unstable air (warm near surface) mixes pollution up up and away



Stability and Clouds

- Stable air (cold surface, warm aloft) resists vertical motion

- Unstable air (warm surface, cold aloft) amplifies vertical motion

Stability and Turbulence

- Daytime heating of the ground by the sun produces instability
- Strong vertical motion near ground is turbulent

Vertical Motion and Weather

- Sinking motion warms and dries the air, produces sunny weather
- Rising motion usually required for clouds, rain, and snow