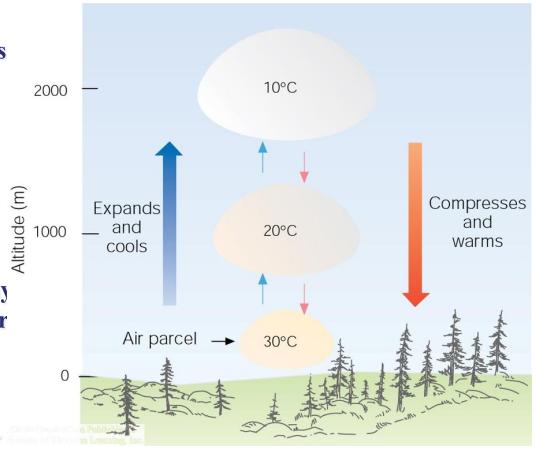
Vertical Motion and Temperature

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

A parcel of air may be forced to rise or sink, and change temperature relative to environmental air



"Lapse Rate"

- The lapse rate is the change of temperature with height in the atmosphere
- Environmental Lapse Rate
  - The actual vertical profile of temperature (e.g., would be measured with a weather 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

Trading Height for Heat

Define two kinds of "static" energy in the air:

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

$$\Delta S = c_p \Delta T + g \Delta z$$

Change in static energy — *Change in enthalpy* — *Change in gravitational potential energy*

Trading Height for Heat (cont'd)

Suppose a parcel exchanges no energy with its surroundings …
we call this state *adiabatic*, meaning, "not gaining or losing energy"

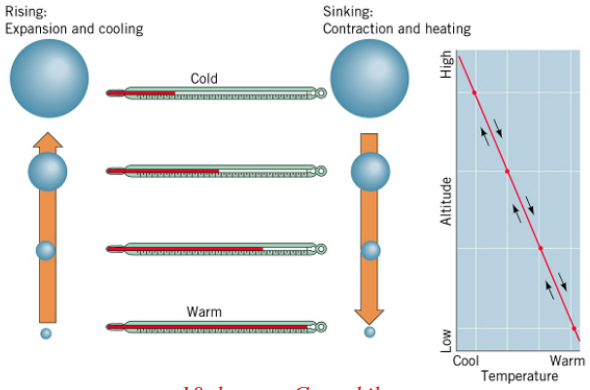
$$0 = c_p \Delta T + g \Delta z$$

$$c_p \Delta T = -g \Delta z$$

$$\frac{\Delta T}{\Delta z} = -\frac{g}{c_p} = -\frac{(9.81 m s^{-2})}{(1004 J K^{-1} kg^{-1})} = -9.8 K km^{-1}$$

"Dry lapse rate"

Dry Lapse Rate

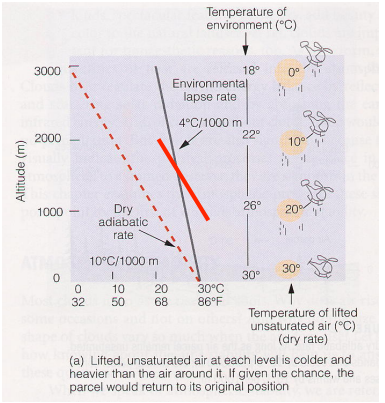


10 degrees C per kilometer

Warming and Cooling due to changing pressure

Stability and the Dry Lapse Rate

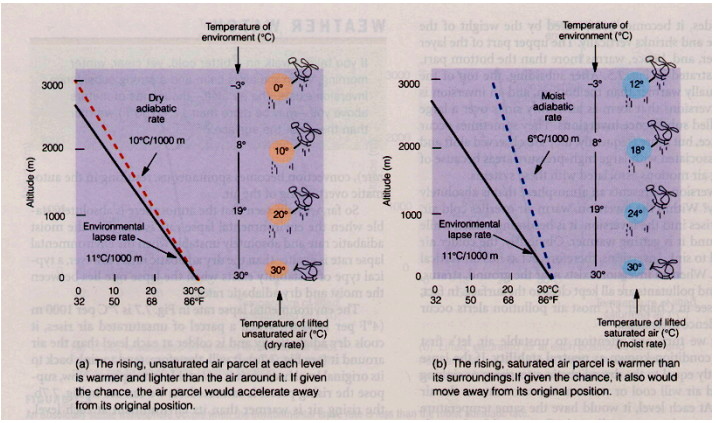
- A rising air parcel cools according to the dry lapse rate
- If this air parcel is
  - warmer than surrounding air it is less dense and buoyancy accelerates the parcel upward
  - colder than surrounding air it is more dense and buoyancy forces oppose the rising motion



Absolute Instability

- The atmosphere is absolutely unstable if the actual lapse rate exceeds the dry lapse rate
- 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

Absolute instability (examples)



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

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., snow)
- Warming of the air due to compression from subsidence (sinking)