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Lecture 4 –STABILITY

4.1 ADIABATIC COOLING AND HEATING

- The first law of thermodynamics
  - Heat added to the air can either raise the kinetic energy of the air molecules (increase temperature), or perform work on the surrounding air by expanding
  - A process in which no heat is added or removed is called an ***adiabatic* process**
- An **air parcel** is a volume of air surrounded by an imaginary cover, such as by a very thin balloon
- ***Adiabatic cooling**: -* As an air parcel rises in the atmosphere, it encounters less pressure. It therefore expands, which does work on the surrounding air. This work is performed at the expense of the kinetic energy of the air molecules. This results in a lowering of the parcel's temperature
- ***Adiabatic heating**: -* As an air parcel sinks in the atmosphere, it encounters more pressure. It therefore contracts (shrinks), or has work done on it by the surrounding air. This work results in increased kinetic energy of the air molecules and a higher temperature

4.2 ATMOSPHERIC STABILITY

- The rate at which the temperature of an unsaturated air parcel (the relative humidity is less than **100** percent) changes due to rising or sinking is known as the ***dry adiabatic lapse rate***
- It is approximately **10**°C for every **1** km of altitude as shown in figure (**4.1**)

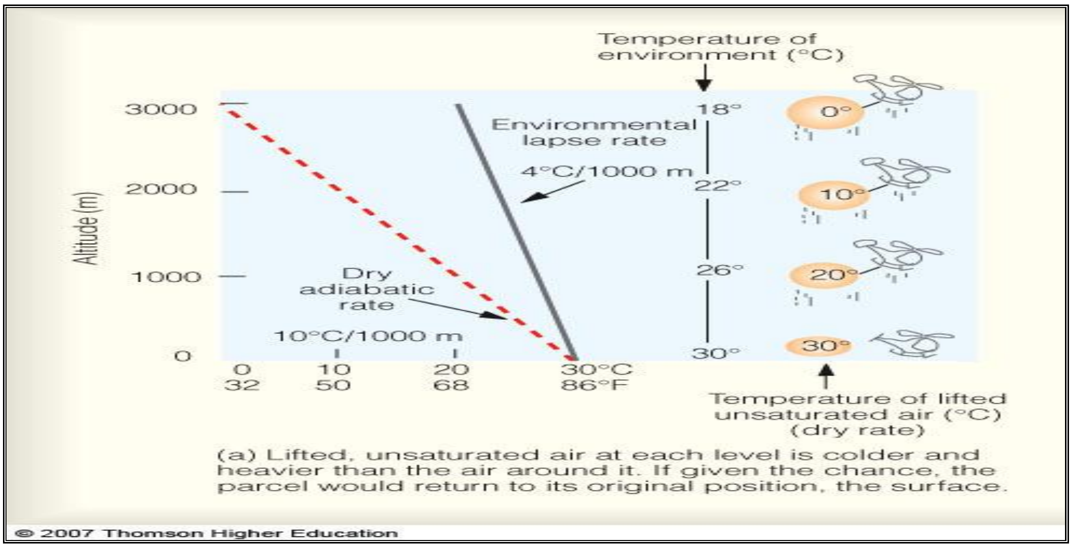


Fig. (4.1) : The dry adiabatic lapse rate of an unsaturated air parcel

- The rate at which the temperature of a saturated air parcel (the relative humidity is equal **100** percent) changes due to rising or sinking is known as the ***moist adiabatic lapse rate***
- It is approximately **6**°C for every **1** km of altitude as shown in figure (**4.2**)

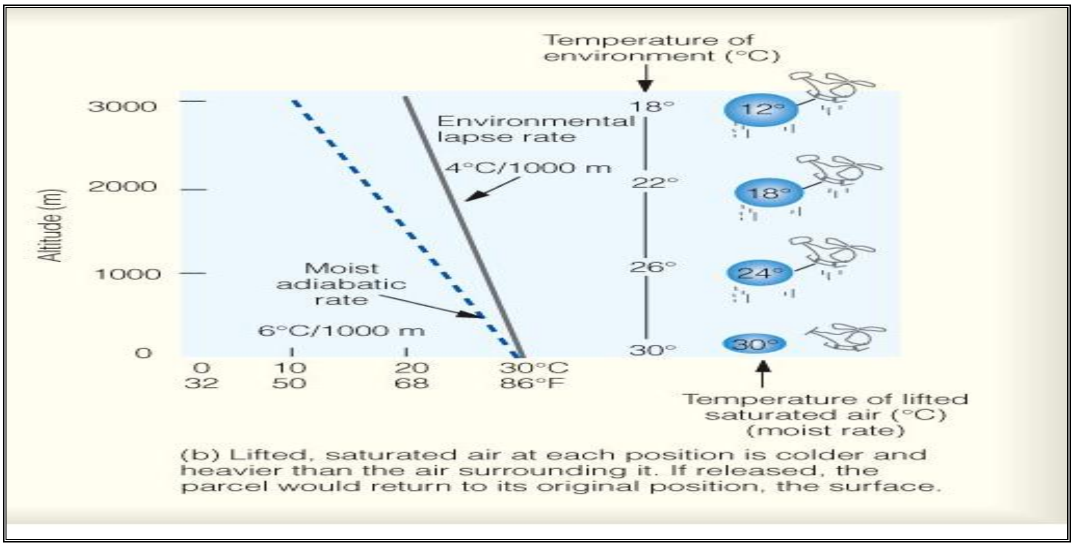


Fig. (4.2) : The moist adiabatic lapse rate of a saturated air parcel

- Stability describes the atmosphere's ability to resist vertical motion
- We determine the stability of the air by comparing the temperature of a rising parcel to that of its surroundings
- If the rising air is colder than its environment, it will be more dense (heavier) and tend to sink back to its original level
- In this case, the air is ***stable*** because it resists upward displacement
- If the rising air is warmer and, therefore, less dense (lighter) than the surrounding air, it will continue to rise until it reaches the same temperature as its environment
- This is an example of ***unstable*** air

4.3 TYPES OF STABILITY

- Stability is determined by comparing the environmental lapse rate with the dry and moist adiabatic lapse rates

4.3.1 Absolutely stable

- The environmental lapse rate is less than both the dry or moist (wet) adiabatic lapse rates as shown in figure (**4.3**)
- This means that a rising air parcel, either saturated or unsaturated, will be colder than its environment, and will sink back down if bumped upward

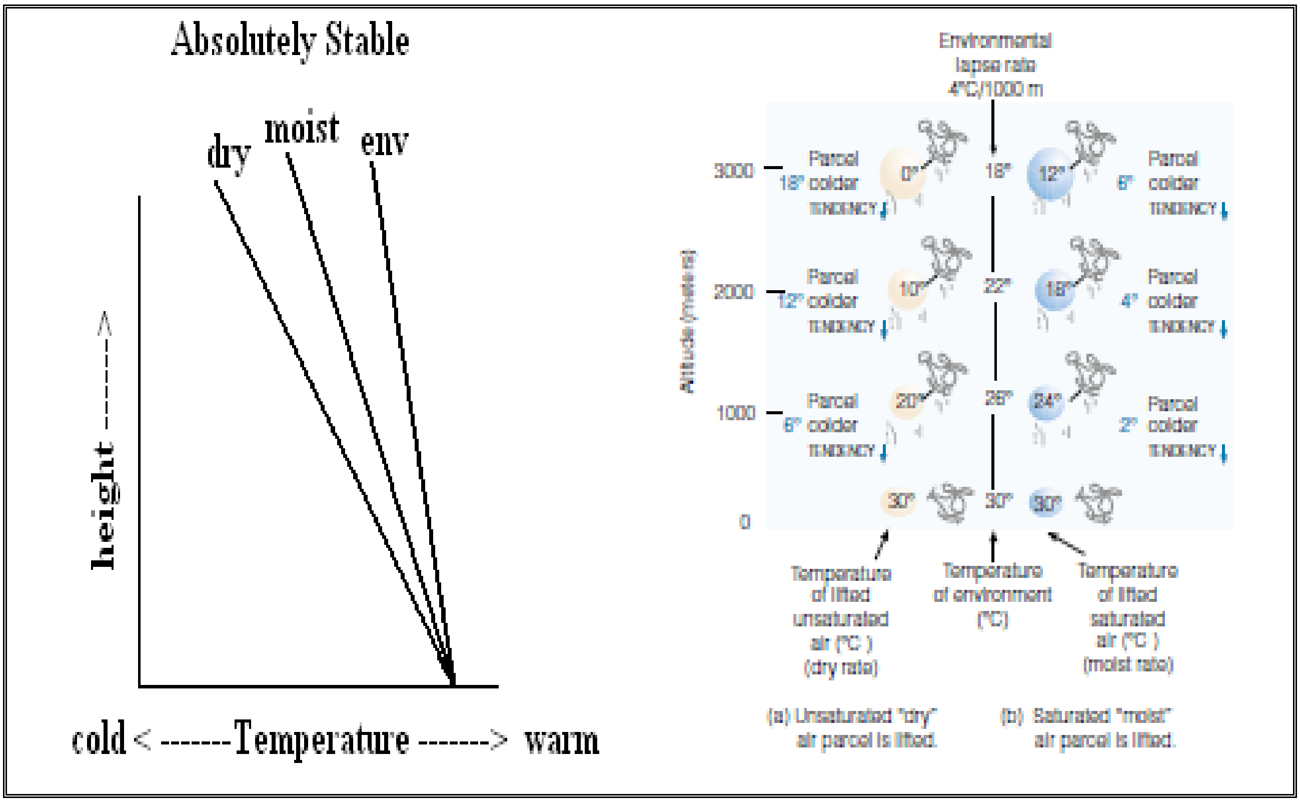


Fig.(4.3) : Absolutely stable

- The atmosphere is stable when the environmental lapse rate is small; Consequently, the atmosphere tends to become more stable—it *stabilizes*—as the surface air cools
- The *cooling* of the *surface air* may be due to: nighttime radiational cooling of the surface

4.3.2 Absolutely unstable

- The environmental lapse rate is greater than both the dry and moist adiabatic lapse rates as shown in figure (**4.4**)
- This means that a rising air parcel (either saturated or unsaturated) will be warmer than its environment and will continue to rise if bumped upward

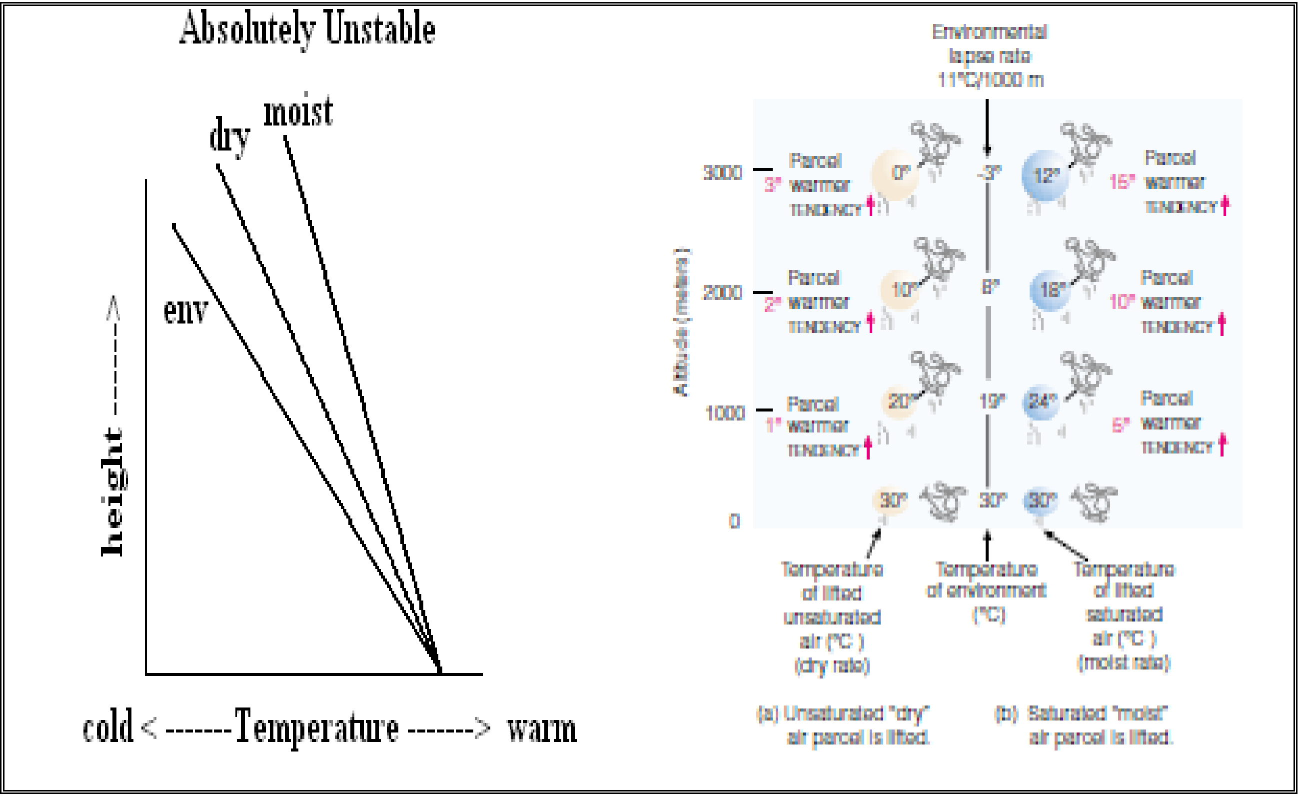


Fig.(4.4) : Absolutely unstable

- The atmosphere is unstable when the environmental lapse rate is large; Consequently, the atmosphere tends to become more unstable—it de*stabilizes*—as the surface air warms
- The *warming* of the *surface air* may be due to: daytime solar heating of the surface

- You can get an idea of atmospheric stability by just looking at the sky
  - A **stable atmosphere** will either have no clouds, or clouds that are spread out horizontally and not very deep (**stratiform** clouds)
  - If stable air is forced aloft, then the weather will likely be overcast and drizzly
  - Clouds in an unstable atmosphere will have more vertical development (**cumuliform** clouds)
  - *Thunderstorms are a sure sign of instability!*
  - Precipitation will usually be more showery, rather than continuous

4.3.3 Conditionally unstable (also called conditionally stable)

- The environmental lapse rate is between the moist and dry adiabatic lapse rates as shown in figure (**4.5**)
- This means that a rising, unsaturated air parcel will be colder than its environment and sink back down if bumped upward, but a saturated, rising air parcel will be warmer than the environment and continue to rise if bumped upward

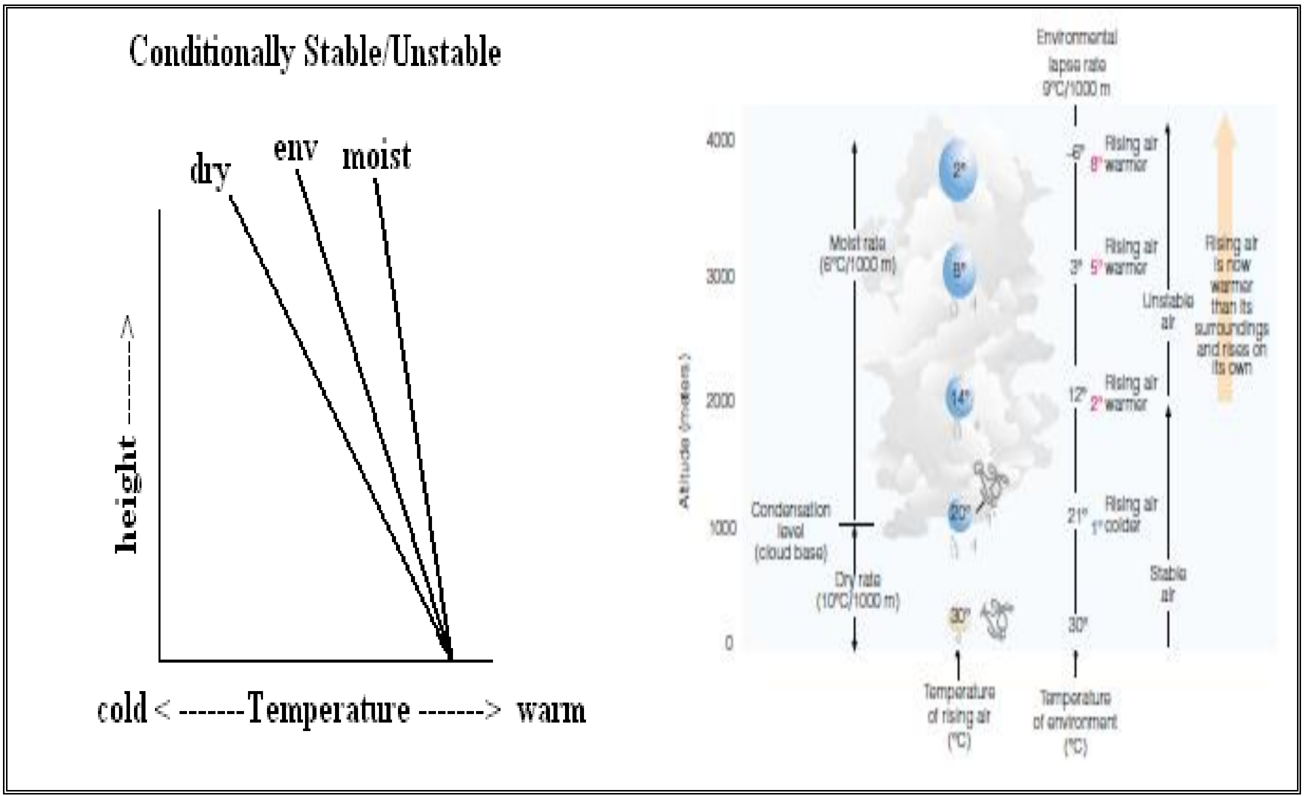
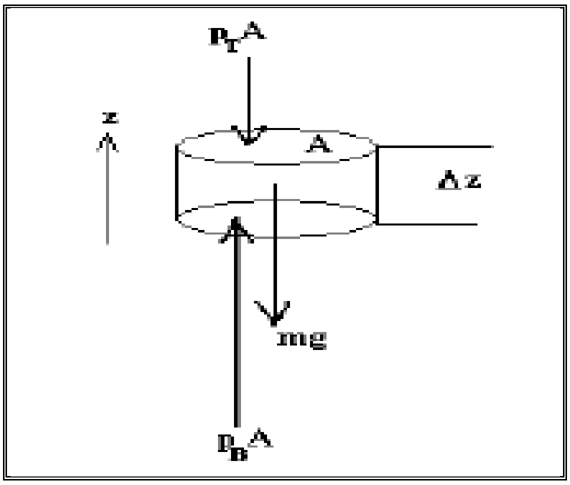


Fig.(4.5) : Conditionally unstable (also called conditionally stable)

4.4 BUOYANCY

- If we write Newton's second law for the vertical force balance on an air parcel of volume $V = A\Delta z$ (see diagram) we have

$$F_z = p_B A - p_T A - \rho' V g \ldots(1)$$



- Defining $p_T - p_B = \Delta p$ the force balance equations becomes

$$F_z = -\frac{\Delta p}{\Delta z} V - \rho' g V$$

or, as $\Delta z \rightarrow 0$,

$$F_z = -\frac{dp}{dz} V - \rho' g V \ldots(2)$$

- From the hydrostatic equation we know that

$$\frac{dp}{dz} = -\rho g$$

so the force balance equation becomes

$$F_z = \rho g V - \rho' g V \ldots(3)$$

- The force balance equation shows that there are two forces acting on the air parcel…a downward force due to the weight of the air parcel itself (**ρ'*Vg***), and an upward force equal to the weight of the environmental air displaced by the air parcel (**ρ*Vg***)
- This is Archimedes's principle…there is a buoyant force on an object equal to the weight of any fluid it displaces
   - This is the reason why ships and balloons can float.
- From Newton's second law we know that $F_z = ma_z = \rho' V a_z$
- Therefore, the vertical acceleration of the air parcel will be

$$a_z = \frac{(\rho - \rho')}{\rho'} g \ldots (4)$$

   - If the parcel is denser than the environment, the acceleration will be downward. If it is lighter than the environment, the acceleration will be upward
   - Substituting for density from the ideal gas law, and assuming the pressure of the air parcel is the same as the pressure of the environment ($p = p'$), we can write the acceleration in terms of temperature

$$a_z = \frac{(T' - T)}{T} g \ldots (5)$$

   - This shows us that warm air rises and cold air sinks

4.5 STABILITY IN A DRY ATMOSPHERE

- Stability refers to whether an air parcel, one moved vertically, will continue to accelerate in the direction that it was pushed (**unstable**), or return in the direction from which it came (**stable**)
- We've already established that to determine the acceleration on the air parcel we need to compare its temperature with that of its surroundings
- Imagine an air parcel that is in equilibrium with the environment, so that

$$T' = T = T_o$$

- There will be no acceleration of the air parcel, so the air parcel will remain at rest

- If the air parcel is initially at the origin, and is displaced a distance ***z***, ***T'*** will change according to the adiabatic lapse rate so that

$$T'_{(z)} = T_o - \gamma_d z$$

where γ_d is the **dry adiabatic lapse rate**

- At altitude ***z***, the environmental temperature is

$$T_{(z)} = T_o - \gamma_e z$$

where γ_e is the **environmental lapse rate**

- The acceleration at altitude ***z*** is [from Eqn. (**5**)]

$$a_z = \frac{\gamma_e - \gamma_d}{T_o - \gamma_e z} gz \ldots (6)$$

- Whether the parcel has an upward, downward, or no acceleration depends on how the environmental lapse rate compares with the dry-adiabatic lapse rate

- If $\gamma_d < \gamma_e$, then:
  - The parcel will continue to accelerate upward after it was displaced upward
  - The atmosphere is **unstable**

- If $\gamma_d = \gamma_e$, then:
  - The parcel will remain where it is after it was displaced upward
  - The atmosphere is **neutral**

- If $\gamma_d > \gamma_e$, then:
  - The parcel will accelerate downward after it was displaced upward
  - The atmosphere is **stable**