Atmospheric Physics

Lecture 2

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Structure of the Static Atmosphere

جو ایستا: در صورتی که در جو هیچگونه ناپایداری وجود نداشته باشد یعنی همه جو در حال سکون باشد جو را ایستا گویند.

حالت ترمودینامیکی جو در هر نقطه با مقادیر فشار- دما و چگالی (حجم ویژه) در آن نقطه تعیین می شود رابطه ای که ارتباط این کمیتها را با هم نشان می دهد معادله حالت نامیده می شود.

We can express the equation of state for dry air as:

$$P\alpha = RT$$

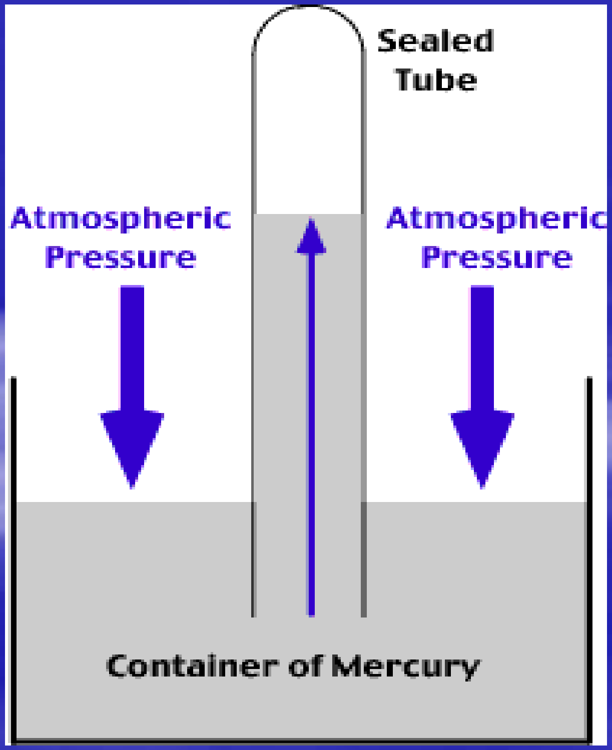
$$P = \rho RT$$

Where R is the gas constant for dry air ($R=287\ Jkg^{-1}K^{-1}$)

Pressure Measurement
Torricelli's Barometer

Weight of column of air above your head.

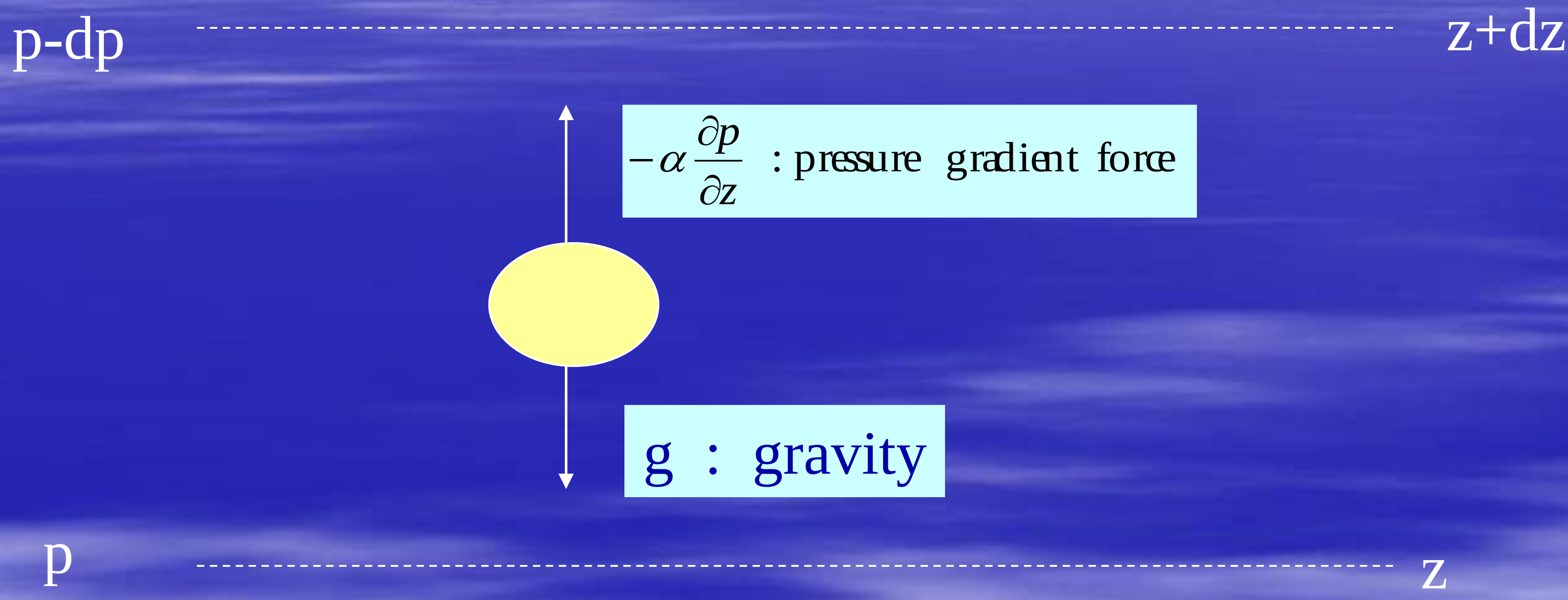
We can measure the density of the atmosphere by measuring the pressure it exerts.



standard sea-level pressure from Torricelli's experiment is 76.0 cm or 29.92 inches or 1013 millibars

The Hydrostatic Equilibrium

In the absence of atmospheric motions the gravity force must be exactly balanced by the vertical component of the pressure gradient force.



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

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

(one of the best approximations in meteorology)

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

$$dp = -\rho g\, dz$$

$$p(z) = \int_z^{\infty} \rho g\, dz$$

Pressure at any point is the weight per square meter of the atmospheric column overlying that point.

For average conditions,

$$p_0 = \int_0^{\infty} \rho g\, dz = 1013.25\, hpa$$

This is the mean sea-level pressure.

Barometric Equation for isothermal atmosphere

$$p\alpha = RT$$

$$\rho = 1/\alpha$$

$$p = p_0 e^{-\frac{g(z-z_0)}{RT_0}}$$

$$dp/dz = -\rho g$$

P_0 the pressure of the gas at sea-level (z=0)
g the acceleration due to gravity at the surface of the planet (on earth, g=9.81 m/s^2)
z the height above sea-level in meters
T the temperature in K
the gas constant (if the units given above are used, R=8.3145 J/molK is appropriate)

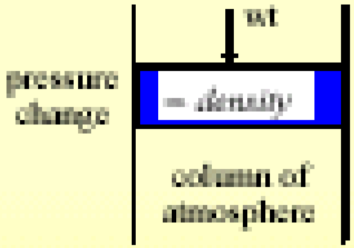
For an isothermal atmosphere g/RT_0 is a constant.

$$H = T_0 R / g \qquad P = P_0 \exp(-Z/H)$$

Atmospheric pressure falls almost exponentially with Height.
For each 8 km of altitude the pressure is down by e^{-1} or one "e-fold."

If H= 8 km and ground level pressure is 1010 mb what is Pressure at a height of 11 km? 255 mb

Why does pressure fall exponentially?



- There are 2 lines to the argument
  - *hydrostatic equilibrium* requires:

    $\boxed{\textit{change in pressure} \propto \textit{density}}$

  - *gas law* requires:

    $\boxed{\textit{density} \propto \textit{pressure}}$

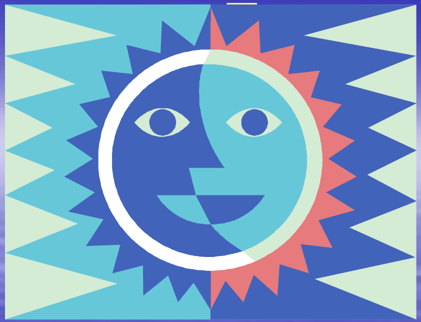
  - combining these two gives:

    $\boxed{\textit{change in pressure} \propto \textit{pressure}}$

  which is the fundamental rule underlying exponential change

Edmund Halley in 1686 appreciated the exponential decrease of pressure with height

Homogeneous Atmosphere



A hypothetical atmosphere in which the density is constant with height.

$$dp / dz = -\rho_0 g$$

$$\int_{z_0}^{z} dz = -\int_{p_0}^{p} \frac{dp}{\rho_0 g}$$

$$z - z_0 = -\frac{p - p_0}{\rho_0 g}$$

$$z = \frac{p_0}{\rho_0 g} = \frac{RT_0}{g} = \frac{287 \times 288}{9.8} = 8.4\,\mathrm{km}$$

N_2 =6.2 km

O_2 =1.7 km

Ar =74 m

O_3 =3 mm

Lapse Rate for Homogeneous Atmosphere

$$\gamma = -\frac{dT}{dz}$$

$$\gamma = \frac{\rho_0 g T_0}{p_0} = \frac{g}{R_d} =$$

$$dp / dz = -\rho_0 g$$

$$\frac{9.8 \text{ N/kg}}{287.05 \text{ J/kg K}} = 34\ ^{\text{o}}\text{c/km}$$

$$\frac{dp}{dz} dT = -\rho_0 g dT$$

$$\gamma(p - p_0) = \rho_0 g (T - T_0)$$

تقریب دوم: معادله بارومتریک برای جو با لپس ریت ثابت

$$\gamma = -\frac{dT}{dz}$$

$$T = T_0 - \gamma z$$

$$dp = -\rho g dz$$

$$p = \rho RT \rightarrow \rho$$

$$\int_{p_0}^{p} \frac{dp}{p} = -\int_{z_0}^{z} \frac{g dz}{R(T_0 - \gamma z)}$$

$$\ln \frac{p}{p_0} = \frac{g}{R\gamma} \ln \frac{T_0 - \gamma z}{T_0 - \gamma z_0}$$

$$p = p_0 \left(\frac{T_0 - \gamma z}{T_0}\right)^{g/R\gamma}$$

$$z = \frac{T_0}{\gamma}\left[1 - \left(\frac{p_0}{p}\right)^{-R\gamma/g}\right]$$

TEMPERATURE LAPSE RATE

Going to the mountains in Shenandoah National Park the summer is a nice way to escape Washington's heat. Why? Consider a parcel of air. If it rises it will expand and cool. If we assume it exchanges no heat with the surroundings (a pretty good assumption, because air is a very poor conductor of heat) it will cool "adiabatically."

CALCULATE: ADIABATIC LAPSE RATE

First Law Thermodynamics:

$$dU = DQ + DW$$

U = Energy of system (also written E)

Q = Heat across boundaries

W = Work done by the system on the surroundings

H = Internal heat or *Enthalpy*

ASSUME:

a) Adiabatic ($dH = 0$)

b) All work PdV work

c) (remember $\alpha = 1/\rho$)

$$dH = Cp\, dT - \alpha\, dP$$

$$CpdT = \alpha\, dP$$

$$dT = (\alpha/Cp)\, dP$$

Remember the Hydrostatic Equation

$$dP = -(g\rho)dZ$$

$$dP = -(gP/RT)dZ$$

Ideal Gas Law

$$\alpha = RT / P$$

Result: $$dT / dZ = -g / C_p$$

This quantity, $-g/C_p$, is a constant in a dry atmosphere. It is called the dry adiabatic lapse rate and is given the symbol γ_0, defined as $-dT/dZ$.

$$\gamma_0 = 9.8K / km$$

For a parcel of air moving adiabatically in the atmosphere:

$$T_2 = T_1 - \gamma_0 (Z_2 - Z_1)$$

Where Z_2 is higher than Z_1, but this presupposes that no heat is added to or lost from the parcel, and condensation, evaporation, and radiative heating can all produce a non-adiabatic system.

The dry adiabatic lapse rate is a general, thermodynamic property of the atmosphere and expresses the way a parcel of air will cool on rising or warm on falling, provided there is no exchange of heat with the surroundings and no water condensing or evaporating. The **environmental** lapse rate is seldom equal to exactly the dry adiabatic lapse rate because radiative processes and phase changes constantly redistribute heat. The mean lapse rate is about –6.5 K/km.

Problem left to the students: Derive a new expression for the change in pressure with height for an atmosphere with a constant lapse rate,

$$T_Z = T_0 - \gamma Z$$

دمای پتانسیل

$$T = cons \times P^k$$

$$k = R / c_p$$

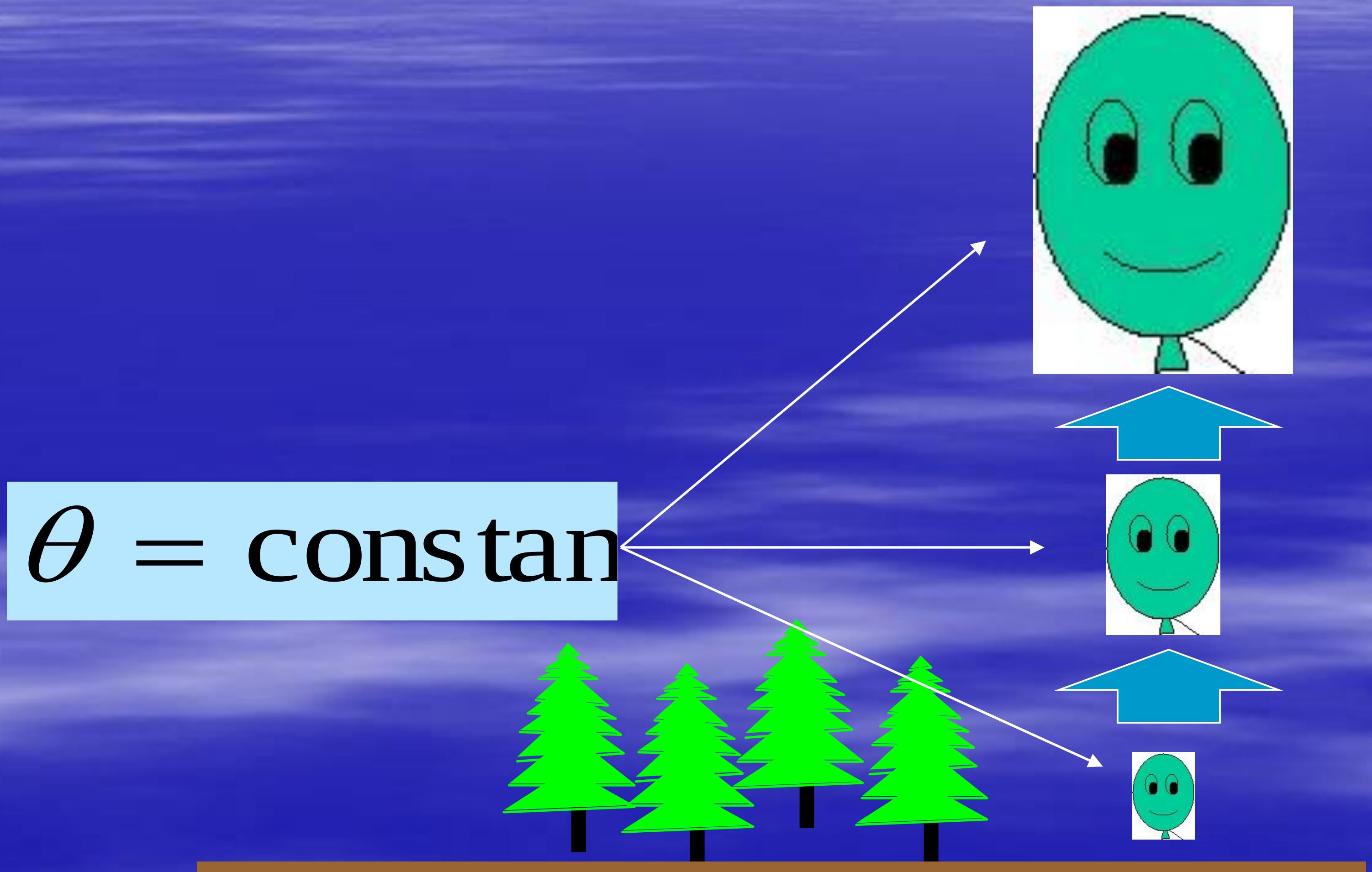
$$\frac{\theta}{1000^k} = \frac{T}{p^k} = cons$$

$$\theta = T\left(\frac{1000}{p}\right)^k$$

Potential temperature, θ, is a conserved quantity in an adiabatic process.

the temperature a parcel would have if moved to the 1000 hPa level in a dry adiabatic process.

- Potential temperature can act as a *tag* or air *tracer*



DFN: **Potential temperature**, : The temperature that a parcel of air would have if it were brought to the 1000 hPa level (near the surface) in a dry adiabatic process.

$$\theta_z \approx T_Z + Z\gamma_0$$

از توجه شما متشکرم