The behavior of gasses in the atmosphere (atmospheric thermodynamics)

Thermodynamics is the study of the relationship between mechanical work and the internal energy of a gas (its heat content)

The state variables

State: The condition of the system (or part of the system) at an instant of time measured by its properties.

The thermodynamic properties of a gas are specified by the three state variables:

1. Pressure p
2. Temperature T
3. Density ρ
   (or its inverse, specific volume α)

Pressure

is force per unit area exerted by the molecular motions of a gas.

Units: a) the unit of force in the MKS system (SI) is the Newton (N) $\equiv$ kg m s^{-2}
(F=ma, mass x acceleration)

A force of 1 N will cause an acceleration of 1 m s^{-2} in a mass of 1 kg

b) the unit of pressure is Newtons per square meter, which is called the Pascal (Pa).

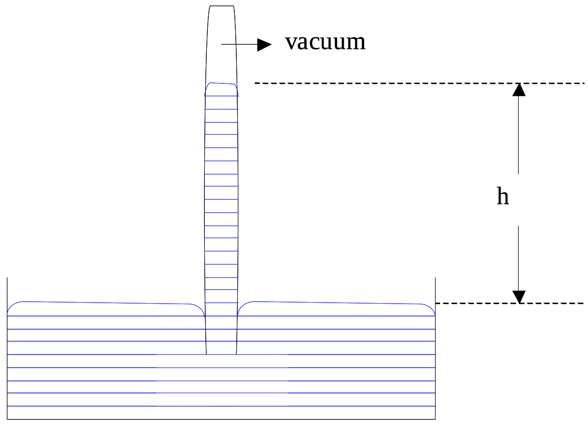
$$1 \text{ Pa} \equiv 1 \text{ N m}^{-2} \equiv \text{kg m}^{-1} \text{ s}^{-2}$$

c) the common meteorological unit of pressure is the millibar (1 bar/1000). The conversion to Pa is as follows:

$$1 \text{ mb} \equiv 100 \text{ Pa}$$

So, $1000 \text{ mb} \equiv 100 \text{ k Pa}$ (kilopascals)

d) other units in common usage are inches or cm of mercury (the height of a column of mercury in a barometer)



A "standard atmosphere" pressure is the globally averaged MSL atmospheric pressure and is numerically equal to

A standard atmosphere
= 1013.25 mb
= 1013.25 h Pa (hecto Pascal)
= 101.325 k Pa
= 76.0 cm of Hg
= 29.92 inches of Hg
= 14.7 lb/sq inch

Temperature T

The degree of hotness, which determines the direction of heat transfer (hot to cold). It is related to the internal energy of a body or mass of material.

(Units: ^oC, ^oF, K)

Density ρ

is mass per unit volume (kg m^{-3})

$\alpha = 1/\rho$ is volume per unit mass (m^3 kg^{-1})

The gas laws and the equation of state

We need to know that happens to a gas when it is subjected to a change in pressure (air spirally in towards a low pressure center, or being forced upwards over a mountain range, or being lifted by the action of thermal convection). A relationship is needed between the state variables. This is provided by the equation of state which is derived from two empirically laws:

1. Boyle's law: at constant T

$p_1 V_1 = p_2 V_2$ (for a fixed mass of gas)

where V is the volume.

2. Charles' law: at constant pressure

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$ (for a fixed mass of gas)

as long as T is expressed in Kelvin ($K = {}^{o}C + 273.15$)

Combing the gas laws and taking a fixed mass of gas from one state to another. i.e.

$p_1, V_1, T_1 \Rightarrow p_2, V_2, T_2$

We obtain the equation of state

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

From Avogadro's hypothesis, gases containing the same number of molecules occupy the same volumes at the same temperature and pressure. Therefore,

$$pV = nR^{*}T$$

where R^{*} is the universal gas constant (= 8314.3 J/K/kmol) and n the number of kilomoles of a gas.

$$n = \frac{m}{M}$$

m: mass of the gas
M: molecular weight (one kilomore of a gas) in kilograms

$$pV = \frac{m}{M} R^* T = mRT, \quad \text{where } R = \frac{R^*}{M}$$

R: (specific) gas constant for 1 kg of a gas

$$pV = mRT$$

Equation of state

$$p = \rho RT, \quad \text{where } \rho = \frac{m}{V}, \quad \text{or}$$

$$p\alpha = RT, \quad \text{where } \alpha = \frac{1}{\rho}$$

α : specific volume of the gas, volume per unit mass

Isothermal process:

T is constant, pressure increased density increases

Isobaric process:

p is constant, T increased density decreases

Dry air

For example, for dry air with a molecular weight of 29

$$R_d = \frac{R^*}{M_d} = \frac{8314.3 \text{ J/K/kmol}}{29 \text{ kg/kmol}} \approx 287 \text{ J/K/kg}$$

R_d : gas constant for 1 kg of dry air

Water vapor

For water vapor with a molecular weight of 18

$$R_v = \frac{R^*}{M_v} = \frac{8314.3 \text{ J/K/kmol}}{18 \text{ kg/kmol}} \approx 416.5 \text{ J/K/kg}$$

R_v : gas constant for 1 kg of water vapor

☺ Is the gas constant for moist air larger or smaller than for dry air? (Larger!)