5.8 VAPOR PRESSURE OF WATER AND HUMIDITY

The vapor pressure of water plays an important role in atmospheric physics. Humidity or dampness of air is a measure of the presence of water molecules in air. Air is mostly made up of the Nitrogen gas (approx. 78% by volume) and the Oxygen gas (approx. 21% by volume). The remaining 1% by volume consists of many other gases, Argon (0.93%), Carbon dioxide (0.03%), Neon (0.008%), Helium (0.0005%), Hydrogen (0.00005%), varying amounts of water and trace amounts of other gases, where all numbers are given as percentages by volume.

When the temperature of air increases more water is boiled off from oceans and lakes into the vapor phase which changes the ratio of water to other gases in air. Since water molecules are lighter than diatomic nitrogen and oxygen molecules, the density of air decreases when the humidity in the air increases. The **humidity** or relative humidity of air is defined in terms of partial pressure of water in the air compared to the saturated vapor pressure for the corresponding temperature and pressure.

Partial pressure is a useful concept for mixture of gases. If you go back to the beginning of this chapter and think about how pressure in a gas is related to the motion of molecules, you would find that total pressure of a mixture of gases will be equal to the pressure that each gas will exert if it alone occupied the entire volume at the given temperature. The net pressure of air would be equal to the sum of the partial pressures of the component gases.

$$p_{\text{atm}} = p_{N_2} + p_{O_2} + p_{H_2O} + \cdots \tag{5.28}$$

Relative humidity is defined as the ratio of partial pressure p_{H_2O} of water actually present in air and the saturated vapor pressure $p^{sat}_{H_2O}$ of water expected at that temperature from the coexistence curve of water.

$$\text{Relative Humidity} = \frac{p_{H_2O}}{p^{sat}_{H_2O}} \times 100\%. \tag{5.29}$$

Thus, if the humidity is close to 100% then air holds the maximum amount of water it can under the equilibrium condition. Table 5.1 shows the saturated water vapor pressure and the corresponding densities at various temperatures.

If the relative humidity is more than 100%, then we would have more water vapor pressure than the value of the saturated vapor pressure for that condition. We say that the air is supersaturated with

water. When the air is supersaturated with water, water will precipitate out of air. This is what happens at night when temperature drops but water vapor content remains the same as in the evening.

Suppose there is 50% humidity at $77°F$, which corresponds to a partial pressure of $0.5 \times 23.76 = 11.88$ mmHg from Table 5.1. Now, if the temperature overnight drops to $50°F$ without any change in partial pressure of water molecules in the air. At $50°F$, saturated vapor pressure is 9.21 mmHg. That means that when the temperature drops to $50°F$, the air will be supersaturated. The water vapor will then condense to liquid. This is the process behind dew formation at night. The **dew point** is the temperature at which the partial pressure of water in a given atmospheric condition will correspond to the saturated vapor pressure for that condition. In our example of 50% humidity at $77°F$, the dew point will be the temperature at which the saturated vapor pressure is 11.8 mmH, which is between $55.4°F$ and $57.2°F$ as extrapolated from the data in Table 5.1.

Table 5.1: Saturated vapor pressure and saturated vapor densities of water (Ref: http://hyperphysics.phy-astr.gsu.edu/hbase/kinetic/watvap.html#c1)

Temp (C)	Temp (F)	Saturated Vapor Pressure (mmHg)	Saturated Vapor Density (g/m^3)	Temp (C)	Temp (F)	Saturated Vapor Pressure (mmHg)	Saturated Vapor Density (g/m^3)
-10	14	2.15	2.36	60	140	55.3	51.1
0	32	4.58	4.85	80	176	355.1	293.8
5	41	6.54	6.8	95	203	634	505
10	50	9.21	9.4	98	208	707	560
15	59	12.79	12.83	100	212	760	598
20	68	17.54	17.3	101	214	788	618
25	77	23.76	23	110	230	1074.6	...
30	86	31.8	30.4	120	248	1489	...
40	104	55.3	51.1	200	392	11659	7840