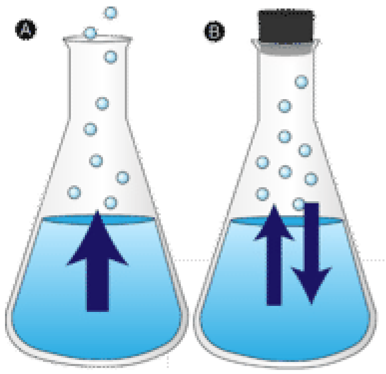
Lapse Rate. Prof. Ruiz (Doc), UNC-Asheville (1978-2021), DoctorPhys on YouTube.
Prerequisites: Chemistry, Physics I, II. Calculus I, II, III. Thermodynamics.

Chapter J. Evaporation and Condensation.



Evaporation (Up Arrow) and Condensation (Down Arrows)
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Water molecules in liquid water have a range of energies. At temperatures less than boiling, some water molecules near the water surface have enough energy to leave the liquid water. When water molecules in liquid water at a temperature less than boiling escape into the air, we have *evaporation*. The escaped water molecules form water vapor above the water. In the left figure the vapor escapes through the open top. Eventually all the water will evaporate like a water spill on your table after enough time elapses.

In the right figure the top opening is closed. After a while, enough water molecules will escape so that the vapor content in the tube is maxed out. We call this condition *saturation*. When saturation occurs, some vapor molecules return to the liquid water, which we call *condensation*. At saturation, there will be evaporation and condensation balancing each other so that conditions remain the same.

1. The Specific Enthalpy of Vaporization. Let's review a few things from earlier chapters. The first law of thermodynamics can be expressed as

$$dU = \delta Q - pdV .$$

When we divide by the mass of the gas m we arrive at $du = \delta q - pd\alpha$.

Rearranging,

$$\delta q = du + pd\alpha .$$

Introducing enthalpy $h = u + p\alpha$, we have $dh = d(u + p\alpha) = du + pd\alpha + \alpha dp$.

Solving for du ,

$$du = dh - pd\alpha - \alpha dp .$$

Set the right side of $du = \delta q - pd\alpha$ equal to the right side of $du = dh - pd\alpha - \alpha dp$.

$$\delta q - pd\alpha = dh - pd\alpha - \alpha dp$$

$$\delta q = dh - \alpha dp$$

We define l_v as the specific heat energy needed for a unit volume of liquid water to change phase into water vapor:

$$l_v = \delta q_{l \to v} .$$

The change of phase takes place at constant pressure (as well as at constant temperature). At constant pressure

$$\delta q = dh - \alpha dp \quad \text{becomes} \quad \delta q = dh$$

and we obtain $l_v = \delta q_{l \to v} = dh$,

which is called the specific enthalpy of vaporization.

We can again see the affinity between enthalpy and heat.

The change in enthalpy is equal to the final enthalpy (enthalpy for the vapor) minus the initial enthalpy (enthalpy for the liquid):

$$l_v = h_v - h_l .$$

We add this equation to our growing review list of formulas.

$$(18) \; \boxed{l_v = h_v - h_l}$$

2. Change in Specific Enthalpy of Vaporization. When liquid water evaporates, the temperature and pressure remains the same. But how does the enthalpy of vaporization change if we move slightly to a new temperature? We find out by taking the derivative of $l_v = h_v - h_l$:

$$\frac{dl_v}{dT} = \frac{dh_v}{dT} - \frac{dh_l}{dT} .$$

But we know from Equation (16) that $c_p = \dfrac{dh}{dT}$. Therefore, we arrive at the difference between the specific heat at constant pressure for the vapor and the specific heat at constant pressure for the liquid.

$$\frac{dl_v}{dT} = \frac{dh_v}{dT} - \frac{dh_l}{dT} \quad \Rightarrow \quad \frac{dl_v}{dT} = c_{pv} - c_{pl}$$

$$(19) \; \boxed{\frac{dl_v}{dT} = c_{pv} - c_{pl}}$$