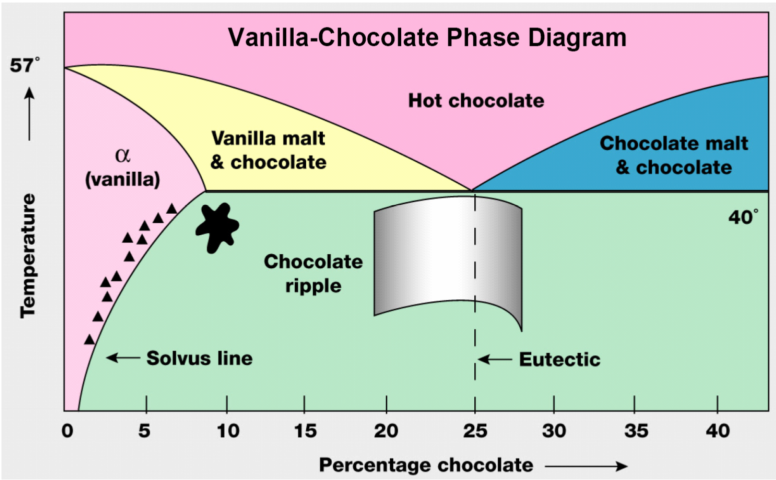
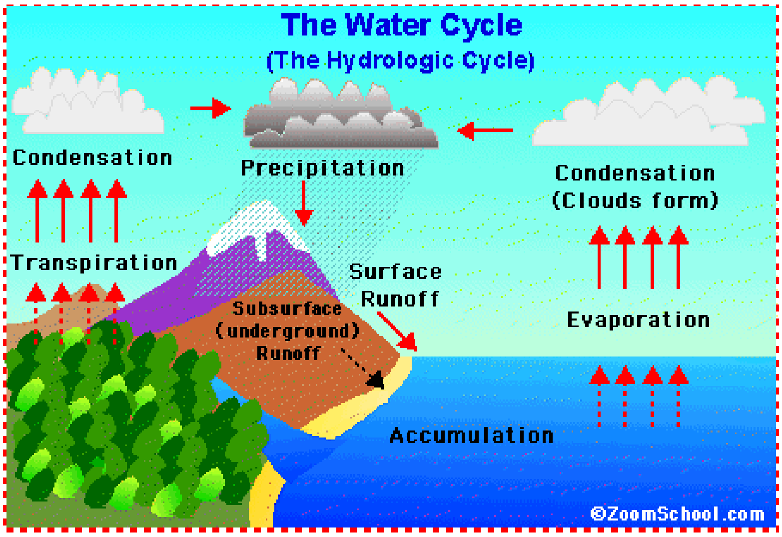
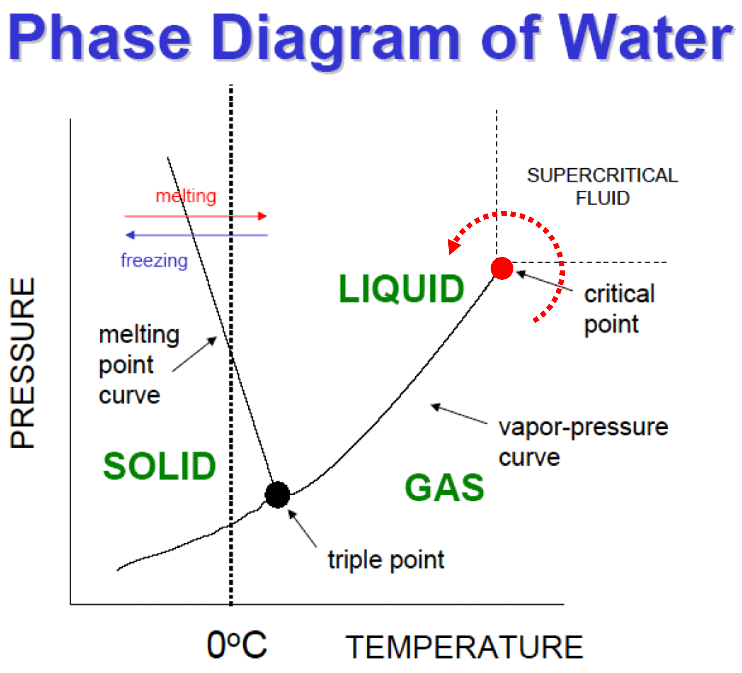
Gas-Liquid-Solid: First and Second Order Phase Transitions



Different phases of matter can be distinguished by observing various physical quantities. In standard, thermal phase transitions, these are thermodynamic quantities such as the volume, pressure, magnetization, dielectric polarization, superfluid density. Some of these quantities are familiar to everyone, and the corresponding phases can be easily distinguished just by taking a look at them. And phase transitions between these phases are familiar from everyday life!



No one will confuse a liquid and a gas! Or will they? And what exactly is the difference between a liquid and a gas? Well...their density of course! The density of the fluid has a **jump** at the liquid-gas phase transition (evaporation). This is the best example of a **first-order phase transition,** where all the physical quantities characterizing the material undergo a sudden change. Generally, the two phases are quite different at first order transitions, and thus it takes a finite amount of energy to convert the substance from one phase to the other. This is the **latent heat.**



Unusual phase diagram- the solid/liquid equilibrium line slopes left

Liquid-gas critical Point: Critical Opalescence

It is interesting to note that the density jump at the liquid-gas transition decreases at higher pressures and temperatures. The first-order line ends at the liquid-gas **critical point**. The approach to this point is a **second-order phase transition**. In its vicinity, the fluid cannot seem to "decide" what to become: a liquid or a gas. Large density fluctuations emerge leading to a "milky" appearance of the fluid: **the critical opalescence**. It is important to note that one can smoothly go from a liquid to a gas by traveling "around" the critical point (see figure). At higher temperature and [pressure, there is no distinction between the liquid and the gas: this is **the supercritical fluid**. The fluid is very compressible in this region. The response function (isothermal compressibility) conjugate to the order parameter (density) diverges at the critical point

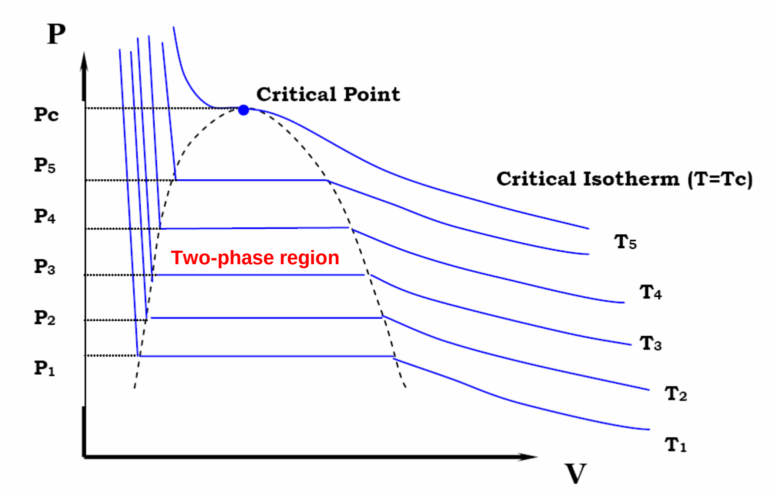
$$\kappa_T = -\left(\frac{\partial V}{\partial p}\right)_T \sim |p_c - p|^{-\gamma}.$$

Similar behavior is found also for the specific heat

$$C_V \sim |p_c - p|^{-\alpha}.$$

Physics of Clouds: Phase Separation

If the temperature and pressure are tuned precisely to the liquid-gas critical line, then the volume (density) of the system is not uniquely defined. There are two possible states possible at this point of the phase diagram: a liquid or a gas. Which one "wins"? For a container at constant pressure, and fixed number of particles, a fraction of the volume will be occupied by a liquid and the rest of the gas, depending how much heat we supply to the liquid for evaporation. Such a state is called a liquid-gas **coexistence** regime.



But what is the shape of the liquid and the gas? Normally, in equilibrium the gravity favors the gas being at the bottom of the container. But how does one reach equilibrium? We can imagine cooling a gas down to the condensation temperature at a given pressure. The gas then wants to start forming a liquid. Under random molecule motions, tiny **droplets** start to form. If they are too small they evaporate again. If a sufficiently large droplet forms (the **critical droplet**), it will continue to grow and eventually merge with other droplets.

This process of a new phase forming by the emergence of droplets is called **nucleation**. The droplets often emerge at impurity centers such as dust in the atmosphere. But this

may take time. In the meanwhile, one may get **clouds or fog** - collections of many small droplets floating in the atmosphere. Once the droplets start to grow sufficiently large, then the gravity takes over - we get rain!