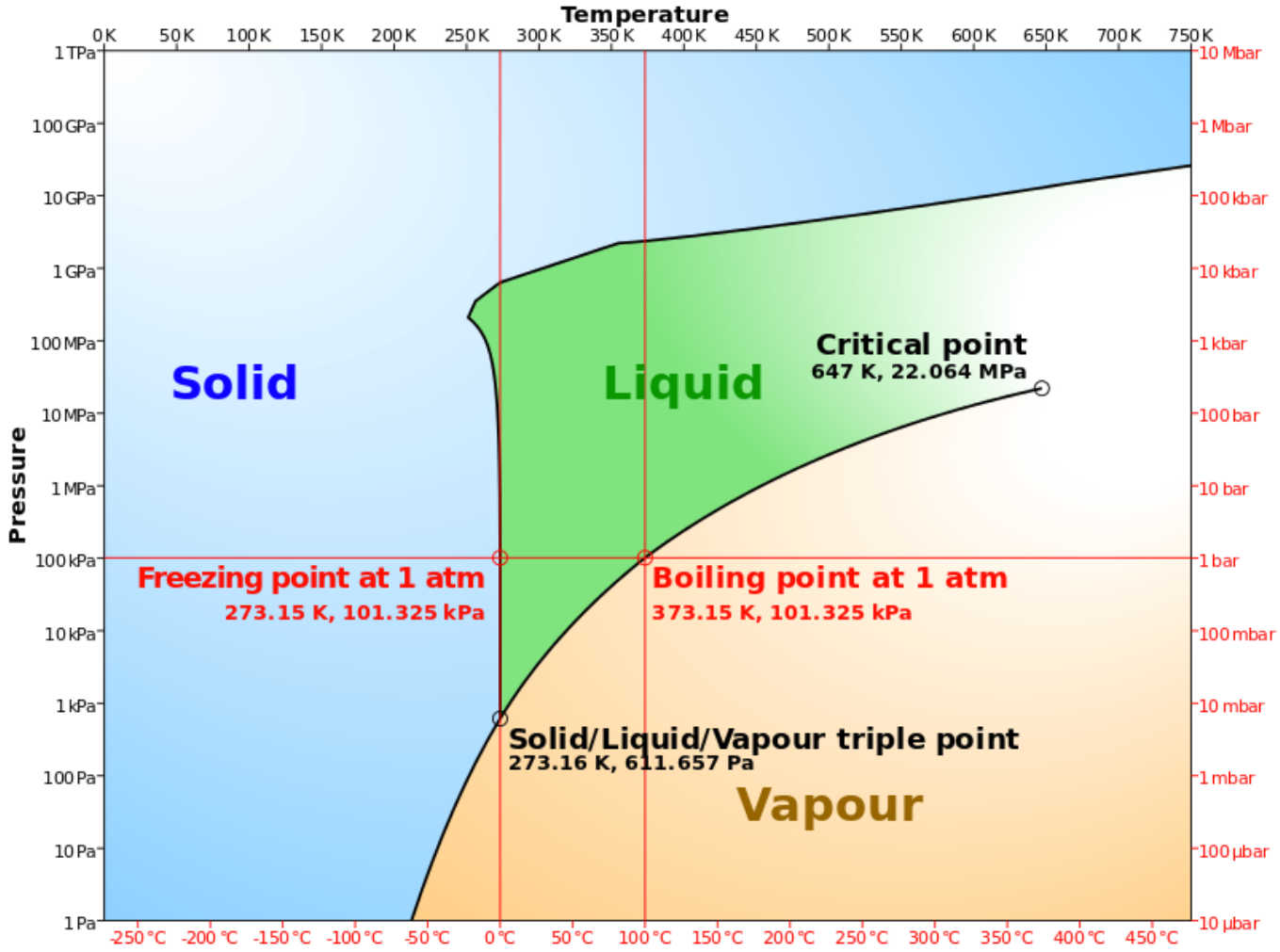
Phase transitions in cell biology

We are familiar with first order phase transitions from our daily life. We boil or freeze water. The phase behavior of a system is typically summarized in a so called phase diagram that maps the qualitative state of the systems as a function of variables such as temperature or pressure.



Simplified phase diagram of water.

The black lines in the above sketch mark first order phase transition with a latent heat. This latent heat is energy that needs to be put into the system to move it from one phase to another, for example the energy expended when boiling water: turning 100C water into 100C vapor at constant pressure requires energy.

In addition, there is a critical point at which the distinction between vapor and liquid disappears. The behavior at the critical point is nicely shown in this video (https://youtu.be/-AXJISFdC2E).

Multicomponent systems and Gibbs' phase rule

From thermodynamics, you should be familiar with Gibb's phase rule

$$f = c - p + 2$$

Here:

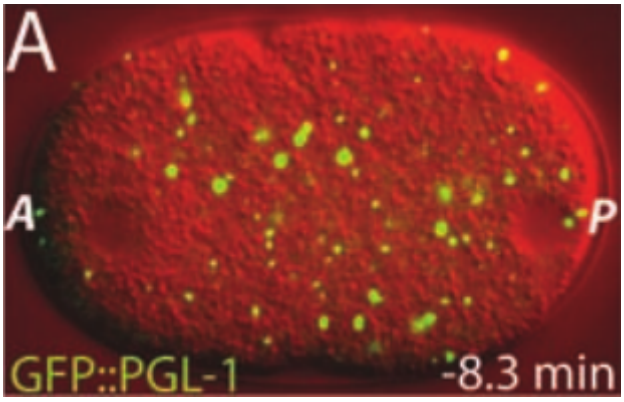
- f is the number of degrees of freedom (external variables you can vary -- pressure, temperature etc)
- c is the number of distinct molecular species
- p is the number of co-existing phases

In the above phase diagram of water (a single component $c = 1$) we therefore have

- at the triple point: $f = 0$, $c = 1$, hence $p = 3$
- on a phase boundary: $f = 1$, $c = 1$, hence $p = 2$
- elsewhere: $f = 2$ and $p = 1$ (a single phase)

In a single component system, coexistence is a **special condition** that only happens at isolated points. But if $c > 1$, there is much more potential for phase co-existence.

Phase coexistence in biology



"Droplets" (p-granules) in C.elegans embryos. Brangwynne et al., 2009 (https://science.sciencemag.org/content/324/5935/1729)

Examples of membrane-less organelles

- nucleoli: nuclear structures in which ribosomal RNAs are produced
- Cajal bodies: associated with nucleoli -- possibly RNA processing centers
- stress granules, p-granules, P bodies: form in particular developmental stages or specific environmental conditions.

These structures are mixtures of RNA and protein with a markedly different composition than the surrounding cytosol.

For more background, consult this video by Ciff Brangwynne (https://www.youtube.com/watch?v=AP47mIkd-h0)