1.7 Processes

The **properties** of a fluid tell us what the **state** of the fluid is. For an ideal gas, two independent properties are enough to tell us what the state of the gas is. For example, if you know what the pressure is and the volume, then you will be able to find out what the temperature is, from the ideal gas equation

$pV = mRT$

There are other thermodynamic properties, such as specific internal energy, the enthalpy and the entropy (links to other sections?). These can also be determined if any two independent properties are known. This is called the “two-property rule”.

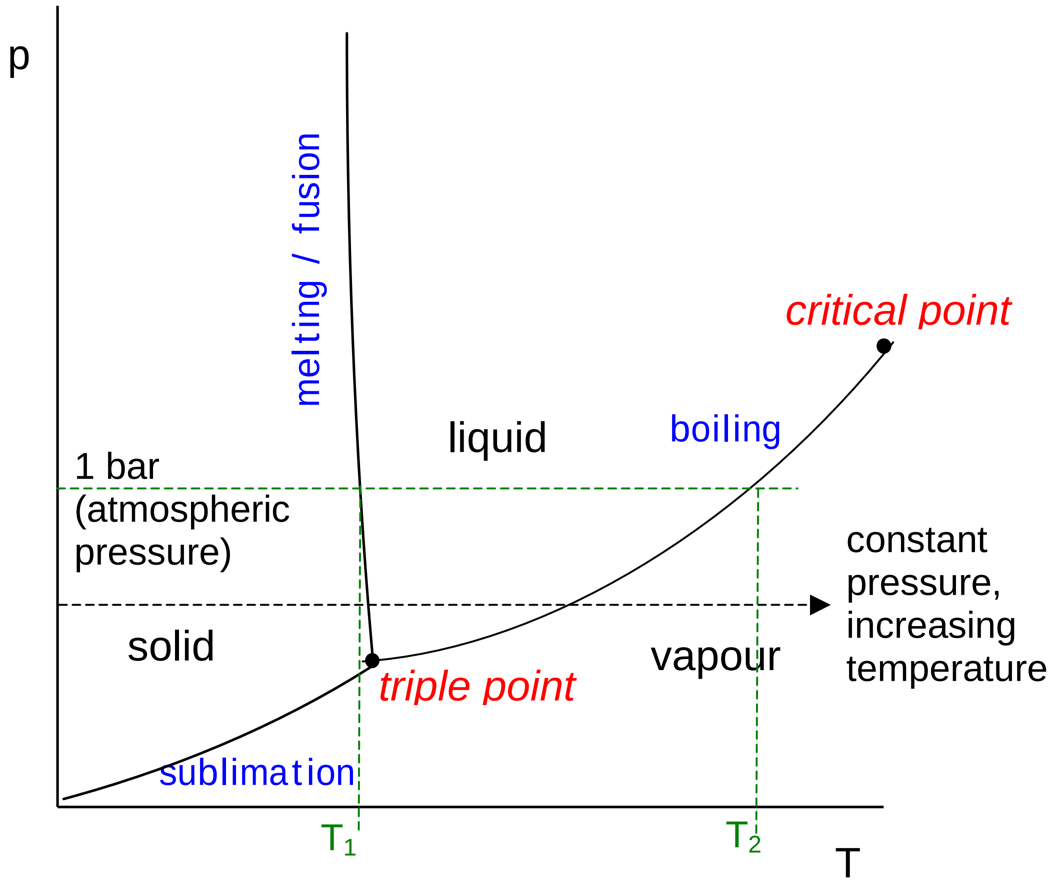
In order to change the state of a fluid, that is to change its properties, it is necessary to carry out a **process**, in which energy is transferred either to or from the system. There are two ways that energy may be transferred, either by **heating** or by **working**.

In this section we will look at what happens when a liquid is heated. How does its properties change? In particular we will look at **water**. Steam turbines are still used to generate electricity. The source of heating may vary, for example, coal may be burned, a nuclear reaction may produce heat or waste may be incinerated, but usually, the heat generated is transferred to water, which is converted to steam which drives the turbines to produce the electricity.

Can you think of reasons why steam should be used for this purpose?

Equilibrium phase diagram for water

Water can exist in three distinct phases, as a solid (ice), as a liquid (water) and as a gas (steam). But steam does not behave like a perfect gas, so there is no convenient equation of state which we can use to find its properties. But the properties of water have been carefully measured and graphs have been drawn to show the relationships between the pressure, temperature and specific volume of water. If the pressure is plotted against the temperature then there are three distinct regions, each representing a different phase. The lines between them show at what temperature and pressure a change of phase will take place.



Heating at constant pressure can be represented by a line such as the horizontal dashed arrow. This shows that as the solid is heated and the temperature rises, a point will be reached when the “melting/fusion” line is crossed, and the solid ice will melt. As heating continues, a temperature is reached at which the liquid water will become a vapour (steam) when the horizontal line crosses the “boiling” line.

What will temperatures T_1 and T_2 be?

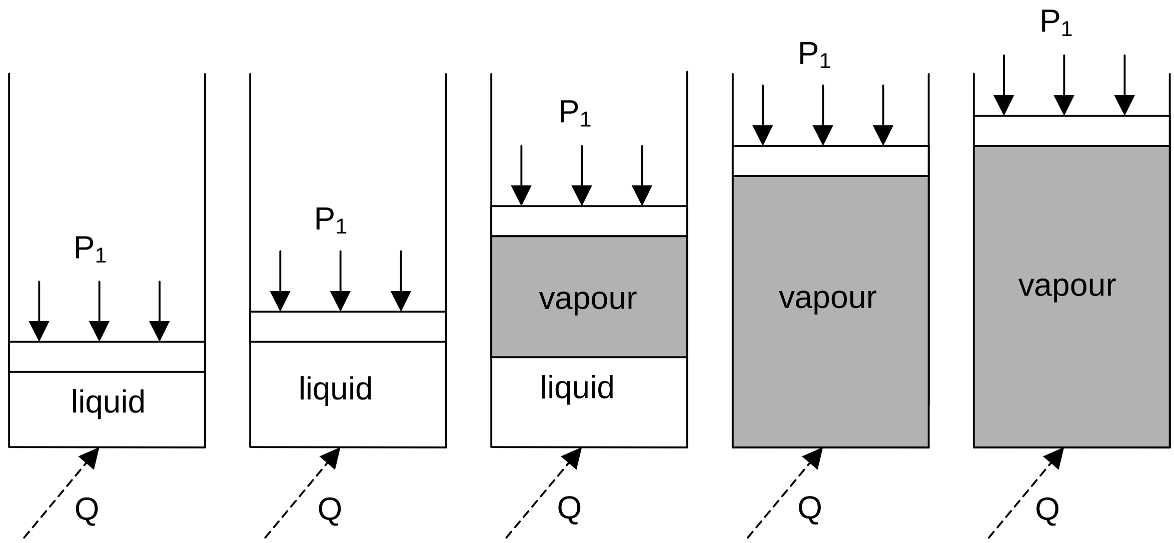
They will be 0°C and 100°C respectively, the freezing and boiling points of water at normal atmospheric pressure.

As the pressure is reduced, the freezing point of water becomes higher, but the boiling point gets less. At the **triple point** the freezing and boiling temperatures are the same. The triple point is at p = 0.006112 bar and T = 273.16K (0.01°C) and is the temperature and pressure at which all 3 phases can co-exist.

As the pressure is increased the boiling point of water increases too. But at a certain pressure, the **critical point** is reached and the liquid and vapour no longer form distinct phases. The critical point is at p_c = 221.2 bar, T_c = 647.3 K (374.15°C) and v_c = 0.00317 $m^3\ kg^{-1}$. At temperatures above T_c, steam cannot be liquefied by an increase in pressure alone.

Pressure-specific volume diagram for water

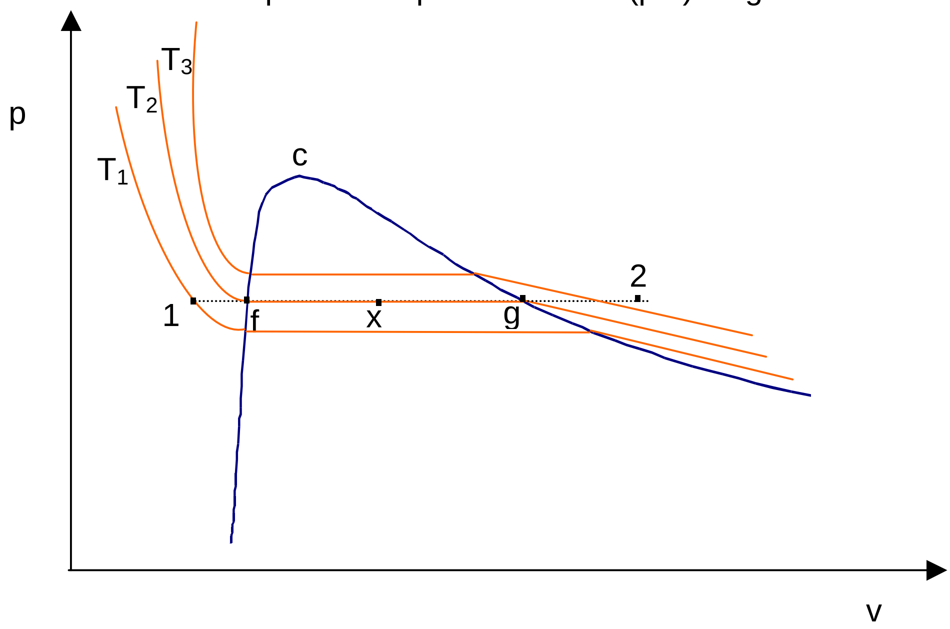
Imagine again, heating water at a constant pressure. Suppose the water is enclosed in a piston-cylinder arrangement as shown below, so that as it is heated it can expand at constant pressure.



State:	1	f	x	g	2
Temp	T_1	T_2	T_2	T_2	T_3
	subcooled liquid	saturated liquid	liquid-vapour mixture	saturated vapour	superheated vapour

As the liquid is heated from state 1 to state f, the temperature rises from T_1 to T_2 and the liquid expands. At state f it begins to boil. The temperature remains constant at T_2, but the liquid changes into a vapour. At state x the cylinder contains a mixture of liquid and vapour. At state g all the liquid has just evaporated but the temperature is still T_2. At state 2, the vapour temperature has risen to T_3 and the vapour has expanded.

This process can be shown on a pressure-specific volume (p-v) diagram:



The orange lines are isotherms, lines of constant temperature. The blue line is called the **saturation curve**. On this curve, on the left hand side, the water is said to be a **saturated liquid**, while on the right it is known as a **saturated vapour**. The point c represents the **critical point**. Above this temperature and pressure, the steam will not condense and behaves more like a perfect gas. To the right of the saturation curve the water is **superheated vapour**, while to the left of it, it is a **sub-cooled liquid**.

Many experiments have been carried out on water and steam and the properties can be found listed in tables (e.g. Rogers and Mayhew)

What is the correct term in the following statements?

(a) A vapour is a gas below its ________________ temperature. (saturation/critical)

(b) The critical temperature of a gas is the temperature _________________ which the gas cannot be liquefied by pressure alone. (above/below)

(c) In the above example, the saturation temperature of the water corresponding to a pressure of P1 is ____________ (T_1/T_2/T_3)

(d) A superheated vapour is a vapour ___________ its saturation _____________ (above/below; temperature/pressure).

Note that as the water changes from liquid to vapour between states f and g, the temperature stays constant, although energy is still being supplied as heating. This energy, the heat required to change 1kg of liquid to 1 kg of vapour with no change in temperature is called the latent heat of vaporisation, or the specific enthalpy of vaporisation.

Further reading:

Bacon and Stephens, Mechanical Technology   Chapter 22

Rogers and Mayhew, Engineering Thermodynamics   8.2-8.3

Rogers and Mayhew, Thermodynamic and Transport Properties of Fluids (steam tables)

Next page: http://www.tech.plym.ac.uk/sme/mech225/continuity.pdf

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