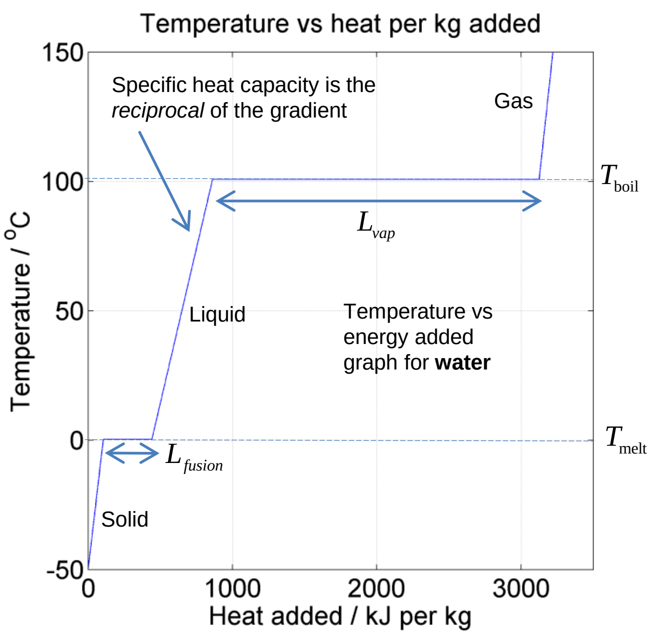
Latent heat is the amount of energy required cause a collection of molecules to **change state**. In practical terms, it is the energy required to overcome the intermolecular forces which bind solids and liquids together.

The **specific latent heat of fusion** is the energy required to convert 1kg of a substance from a **solid** to **liquid** phase.

The **specific latent heat of vaporization** is the energy required to convert 1kg of a substance from a **liquid** to **gaseous** phase.

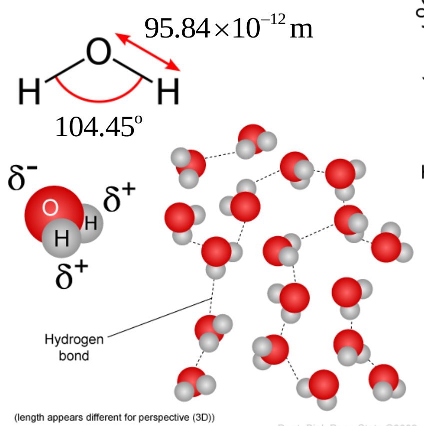
During the phase transition, all energy input is 'spent' breaking the intermolecular bonds rather than increasing the mean kinetic energy of molecules. This means there is *no rise* on a temperature vs energy input graph.

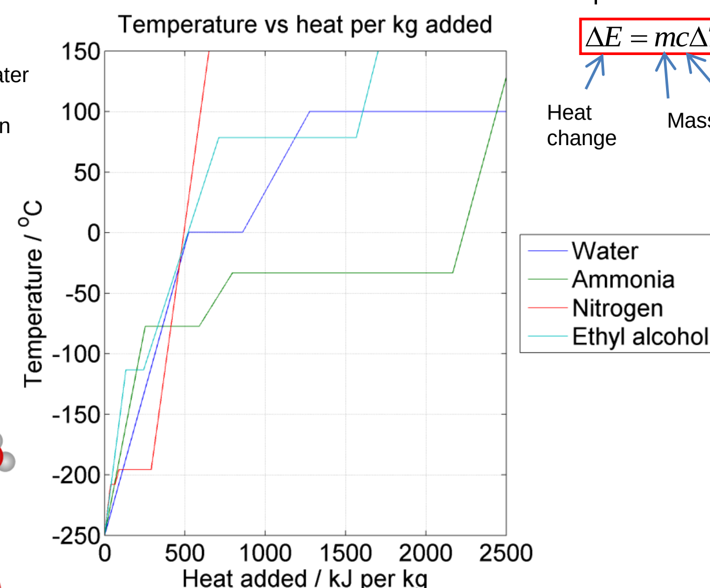
Molecule	Melting temp. / °C	Boiling temp. / °C	Latent heat of fusion / x 10^4 Jkg^{-1}	Latent heat of vaporization / x 10^5 Jkg^{-1}	Specific heat capacity (solid) / $Jkg^{-1}K^{-1}$	Specific heat capacity (liquid) / $Jkg^{-1}K^{-1}$	Specific heat capacity (gas) / $Jkg^{-1}K^{-1}$
Ammonia	-77.8	-33.4	33.3	13.7	1,465	4,700	2,060
Benzene	5.5	80.1	12.6	3.94	1,516	2,100	1,090
Copper	1,083	2,566	20.7	47.3	385	386	380
Ethyl alcohol	-114.4	78.3	10.8	8.55	970	2,440	1,900
Gold	1,063	2,808	6.28	17.2	128.9	?	?
Lead	327.3	1,750	2.32	8.59	136	117.6	?
Mercury	-38.9	356.6	1.14	2.96	124	140	?
Nitrogen	-210	-195.8	2.57	2.00	890	2,042	1,040
Oxygen	-218.8	-183.0	1.39	2.13	779	1,669	919
Water	0	100	33.5	22.6	2,090	4,186	1,930



Outside phase transitions, the temperature will typically rise linearly* with energy input i.e. we assume a *constant* heat capacity.

Water has a fairly high latent heat of vaporization due to the strength of the **hydrogen bond** intermolecular forces. This, and the angled geometry of the water molecule, also explains why ice is less dense than liquid water. Solid water is an open structure with holes rather than a densely packed molecular lattice.





Specific heat capacity c

$$\Delta E = mc\Delta T$$

Heat change (ΔE), Mass (m), Specific heat capacity (c), Temperature change (ΔT)

*The heat capacity will change as different modes of molecular vibration are excited. For a solid, three translational (x,y,z) modes are typical.

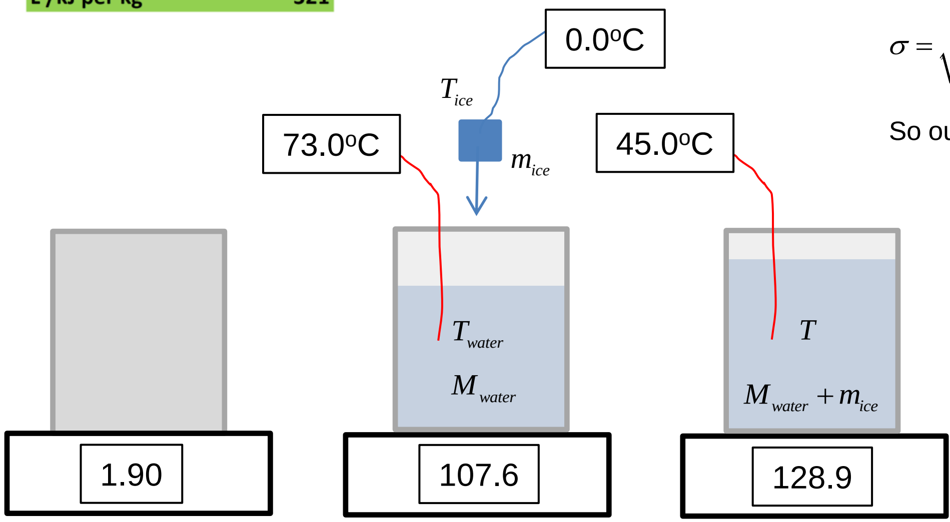
Measuring the specific latent heat of fusion L of water

The idea is to log the temperature of a small insulated beaker of warm water, before and after an ice cube is added. The beaker is mounted on a mass balance to enable the mass of (i) the beaker (ii) the beaker + warm water and (iii) the beaker + water + ice cube to be measured. A thermocouple or 'culinary spike' digital thermometer can be used to measure the ice cube temperature before it is added to the water. The idea is to use a datalogger to record the temperature of the water in the beaker from prior to adding the ice cube, till just after it has melted. The water temperature change following the addition of the ice cube can be used to determine the **latent heat of fusion.** Clearly heat will be lost continuously from the beaker, so insulating it is important. Using a datalogger with thermocouples will give a good idea of the time history of the system, and perhaps a better idea of what to take as the temperature change due to the addition of the ice cube. i.e. the step change should be in the context of a general cooling trend..

Worked (albeit somewhat crude) example, with three repeats.

	1	2	3
Cup mass in g	1.9	1.9	1.9
Cup + water	110	107.6	100.6
M /g	108.1	105.7	98.7
Cup + water + ice	130.6	128.9	114.6
m /kg	22.5	23.2	15.9
T0 /degC	64.5	73	72
T1 /degC	45.5	45	48
L (kJ/kg)	**192**	**347**	**424**

L /kJ per kg	**321**



Measure insulated beaker mass

Add warm water, log temperatures, add ice cube

Record water temperature once ice has melted

Calculation is based upon an energy balance, and assuming no loss of heat to the surroundings. The idea is that the energy to enable state change from solid to liquid of the ice, and then a rise of temperature from T_{ice} to T, is accounted for by the loss of heat of the water, which cools from T_{water} to T. The **specific heat capacity** of liquid water is assumed to be c = **4200 Jkg^{-1}K^{-1}.**

$$m_{ice}L + cm_{ice}\left(T - T_{ice}\right) = cM_{water}\left(T_{water} - T\right)$$

$$\therefore L = \frac{cM_{water}\left(T_{water} - T\right) - cm_{ice}\left(T - T_{ice}\right)}{m_{ice}}$$

In our case the mean L is:

$$\bar{L} = \tfrac{1}{3}\left(192 + 347 + 424\right)\text{kJkg}^{-1} = 321\text{kJkg}^{-1}$$

and the *unbiased estimator** of the standard deviation in L is:

$$\sigma = \sqrt{\frac{1}{3-1}\sum_{i=1}^{3}\left(L_i - \bar{L}\right)^2} = \sqrt{\tfrac{1}{2}} \times \left(\left(192-321\right)^2 + \left(347-321\right)^2 + \left(424-321\right)^2\right) = 118\,\text{kJkg}^{-1}$$

So our result is: $L = \left(321 \pm 118\right)\ \text{kJkg}^{-1}$

The 'official' answer is **335 kJkg^{-1}**

*Assumes that each measurement is **independent** and subject to **random error**. The idea is repeat measurements form a **sample**, and from that sample we would like to estimate the mean and standard deviation of the **population** that we are sampling.

$$L = \frac{cM_{water}\left(T_{water} - T\right) - cm_{ice}\left(T - T_{ice}\right)}{m_{ice}}$$

Measuring the specific latent heat of vaporization L_{vap} of water

The idea is to place a (half filled) electric kettle with the lid open on a mass balance, and record the mass lost after the water has started boiling vs time. An electrical meter is used to determine the power input to the system, and therefore a graph of energy input vs mass lost can be plotted. The gradient of this graph (which is particularly linear) yields the latent heat of vaporization of water.

The problem with this method is that the efficiency of conversion of electrical energy to the kettle heating element to the energy used in vaporizing the (boiling) water may not be 100%. There will certainly be heating of the kettle. The data below (measured at Winchester College in 2018) predicts a specific latent heat of vaporization of about **2480 kJkg^{-1}**. The 'official' value is **2260 kJkg^{-1}**. The fact that we overestimate the true result is consistent with the hypothesis that the process of electrical to thermal energy conversion is less than 100%.

I /A	4.5
V /volts	230
Power /kW	**1.04**

t /s	Energy added /kJ	mass lost /g	mass lost in kg
0	0.0	0	0
30	31.1	10.4	0.0104
60	62.1	21.1	0.0211
90	93.2	35.2	0.0352
120	124.2	48.6	0.0486
150	155.3	60.2	0.0602
180	186.3	74.8	0.0748
210	217.4	85.4	0.0854
240	248.4	98.5	0.0985
270	279.5	111.2	0.1112
300	310.5	125	0.125
330	341.6	138.1	0.1381
360	372.6	148.8	0.1488
390	403.7	162.9	0.1629
420	434.7	174.8	0.1748
450	465.8	188.5	0.1885
480	496.8	201.4	0.2014
510	527.9	212.3	0.2123
540	558.9	226.2	0.2262
570	590.0	237.6	0.2376
600	621.0	250.8	0.2508