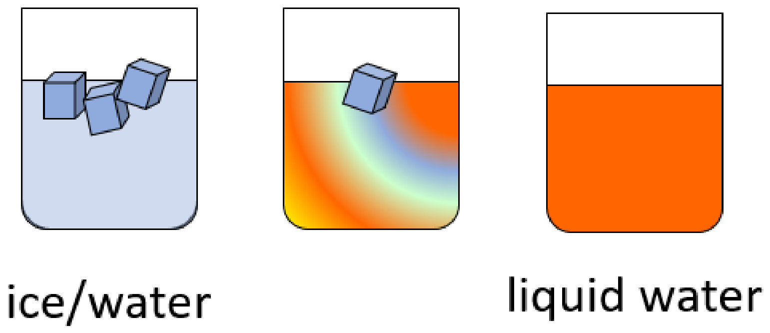
Lecture 9.
Phases of matter &
Phase transitions

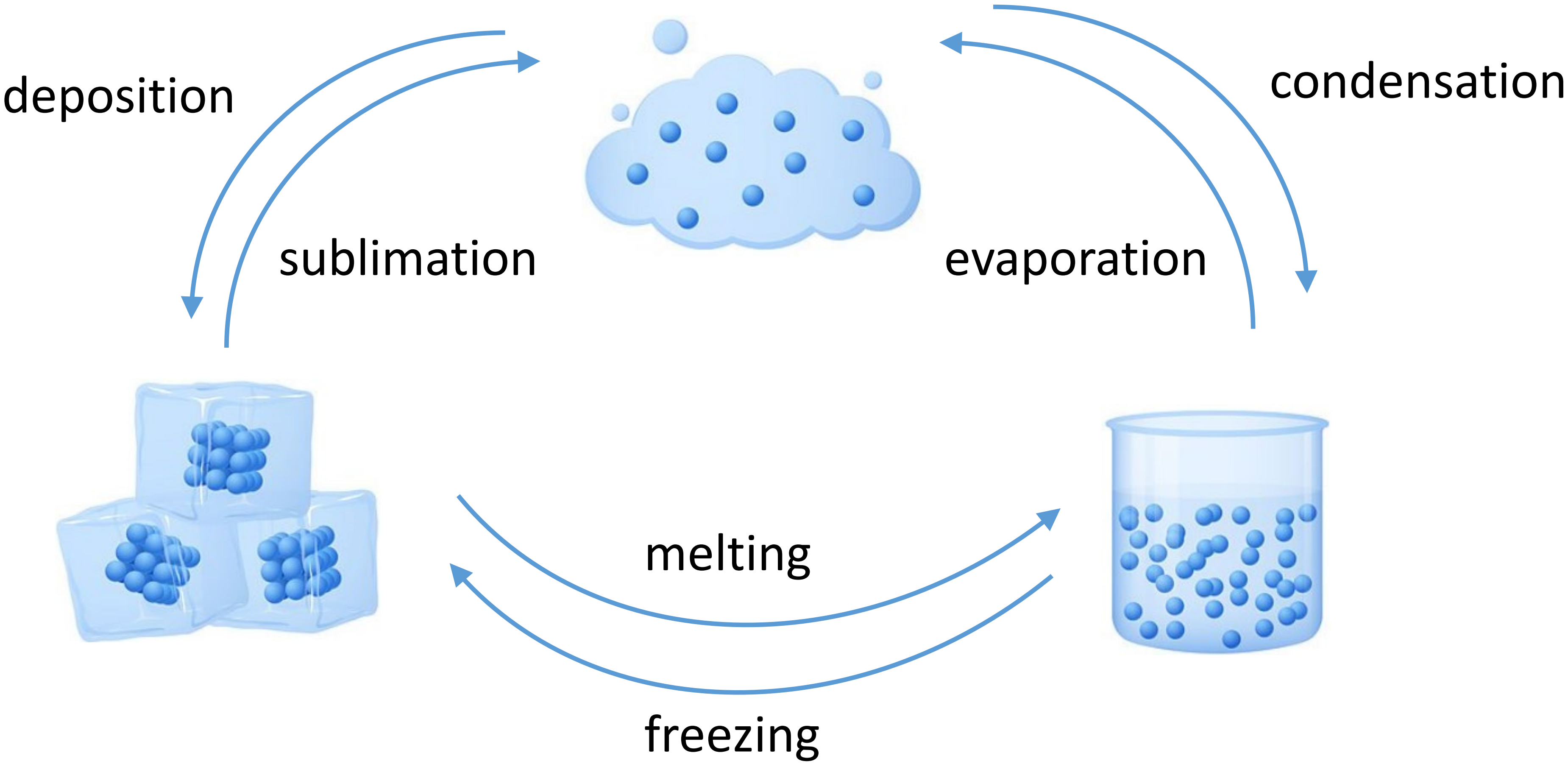


Phases of Matter

- Matter can exist in different phases (or states), corresponding to qualitatively different configurations of the molecules in the material
- The common phases are solid, liquid, and gas

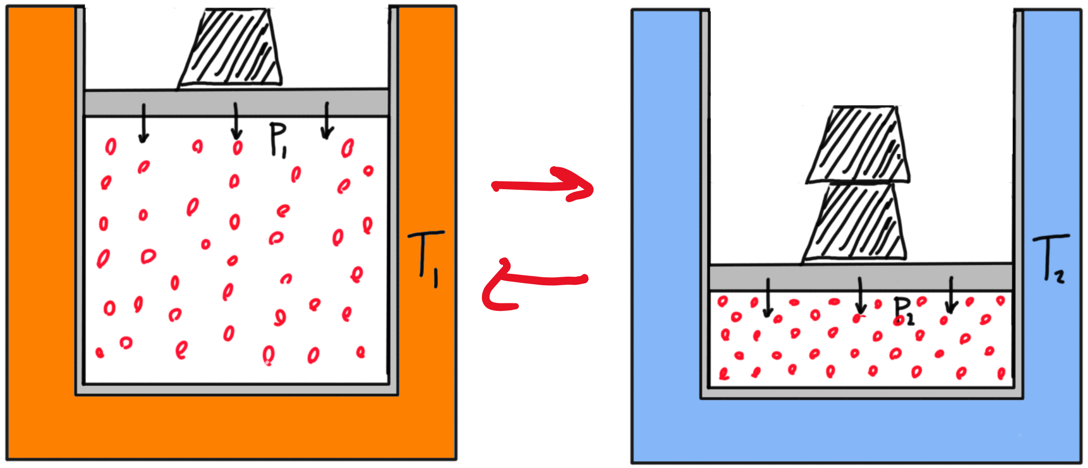
Phase Transitions

- A phase transition occurs when matter changes from one phase to another
- One way to make a material undergo phase transition: Changing the temperature

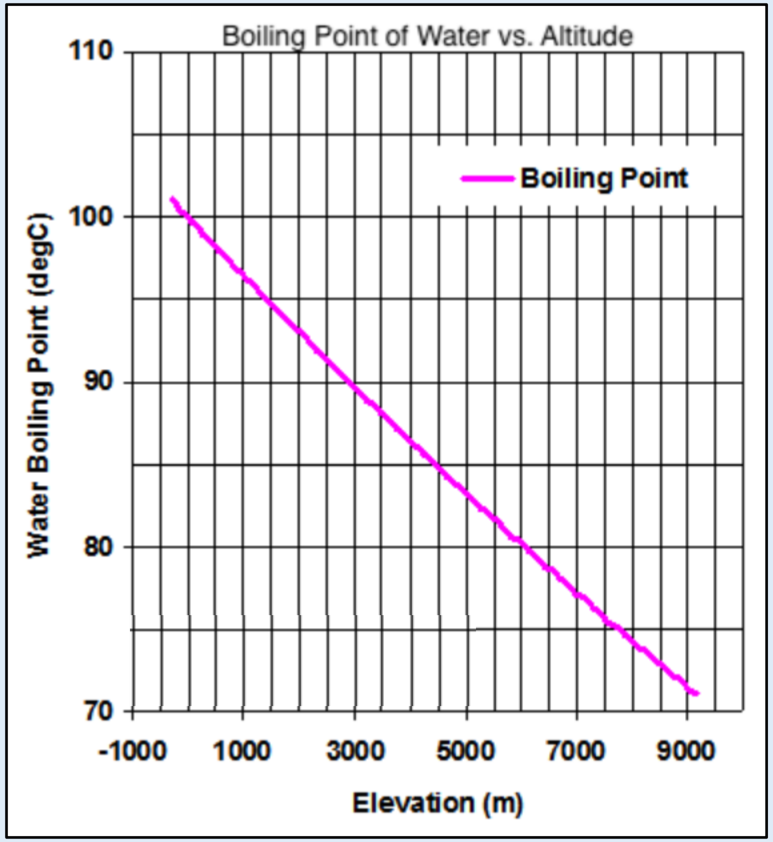


Phase Transitions

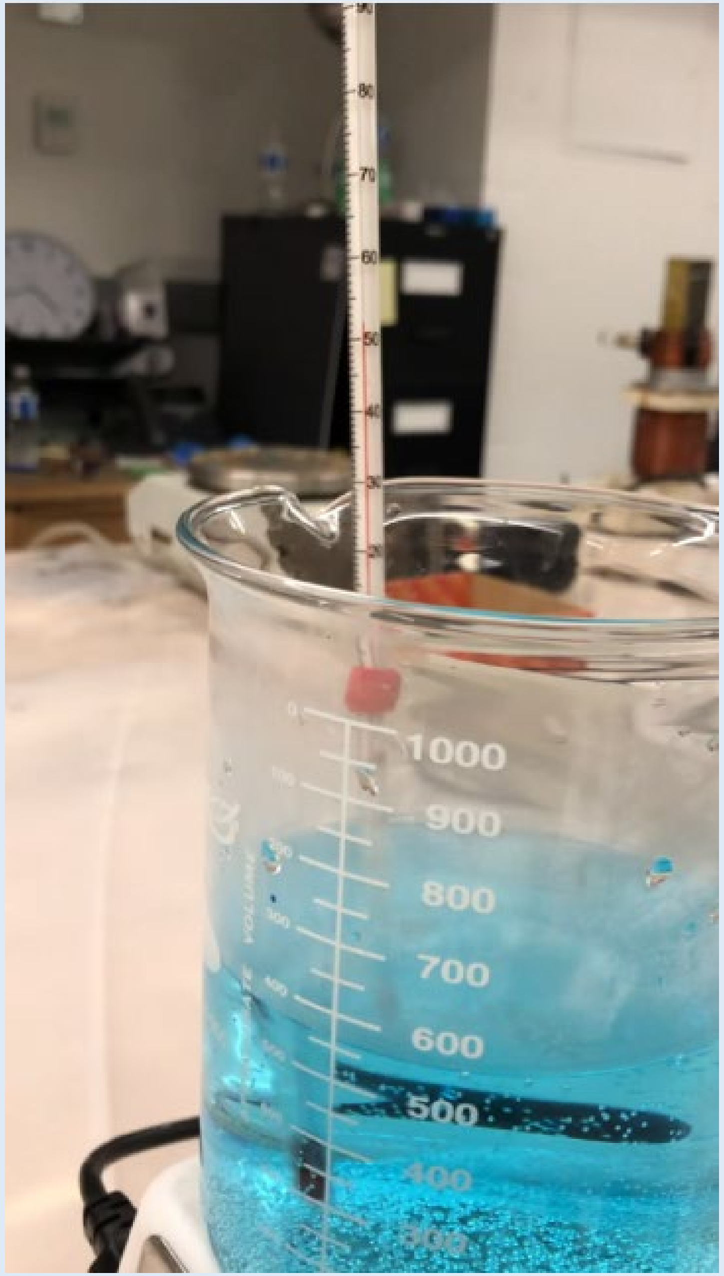
- Changing the pressure applied to a material can also induce a phase transition!
  - Take some molecules
  - Put them in a container at some temperature & vary the pressure
  - Significant changes in configuration of molecules can occur
  - For example, a gas can become a liquid as the pressure is increased, or a liquid can become a gas as the pressure is decreased.

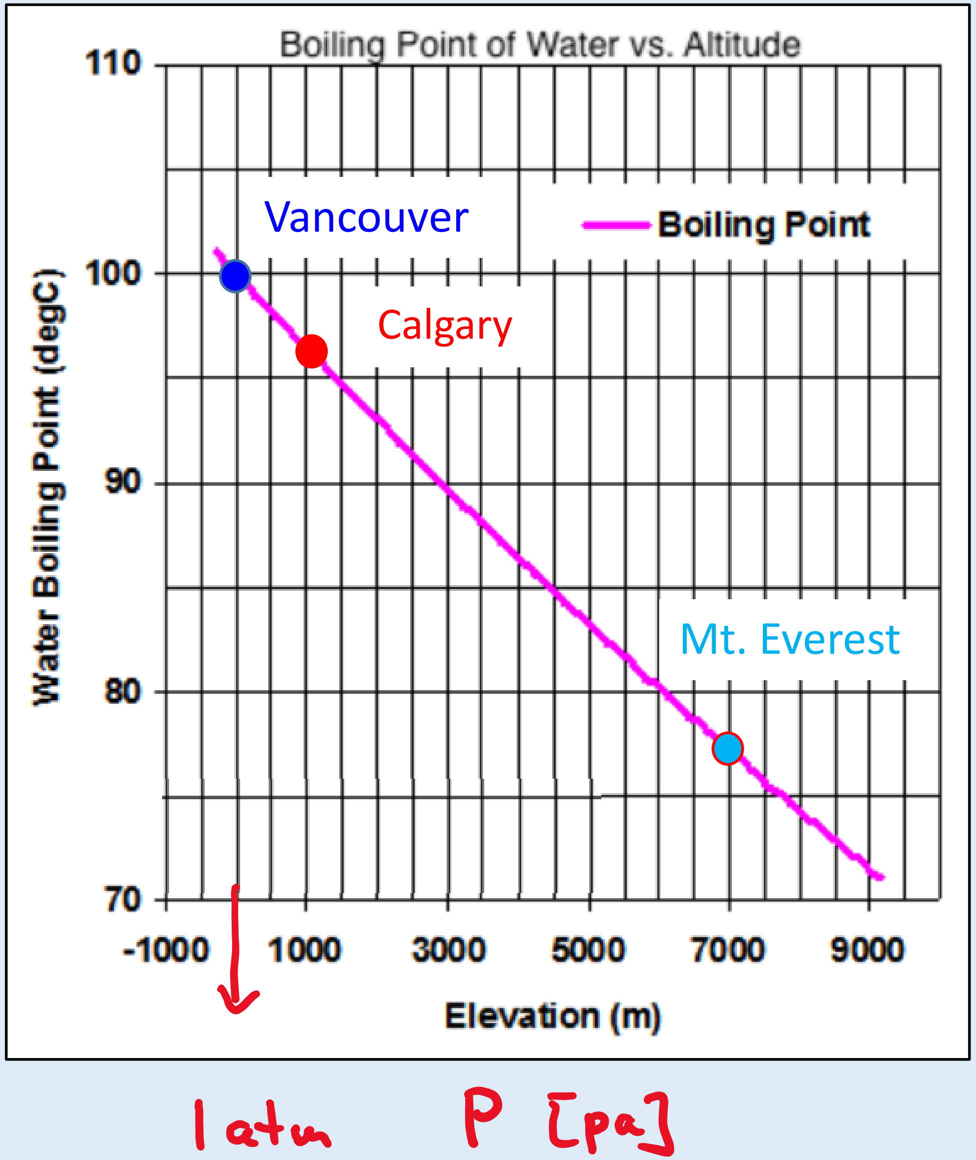


Demo: boiling water by reducing the pressure



Demo: boiling water by reducing the pressure





Mt. Everest:

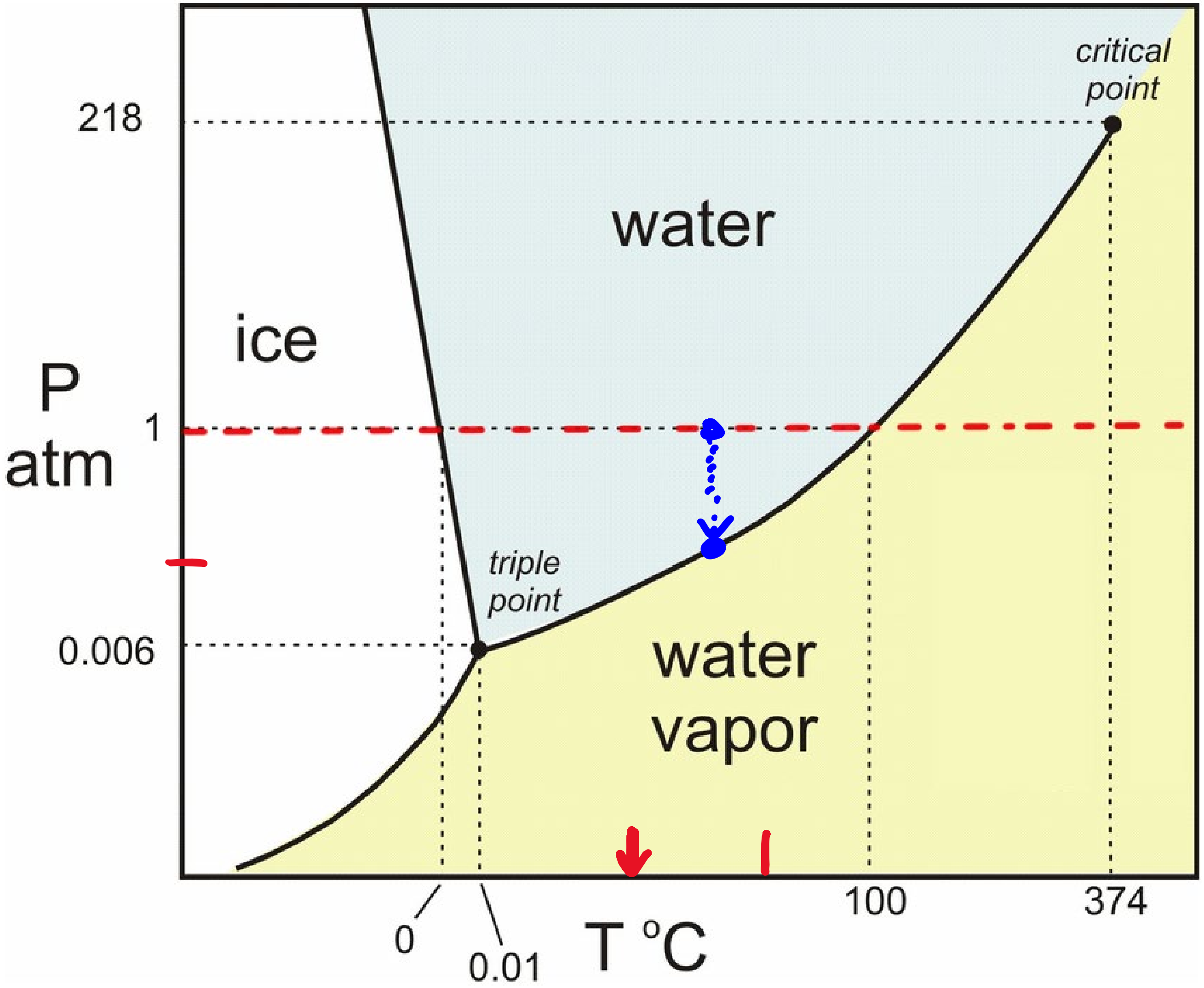
- T_{boil} = 77 °C

Boiling eggs:

- Yolk: ~65 °C
- White: ~85 °C

Phase Diagram

displays phases and phase transition curves as a function of T and P



pressure normally here

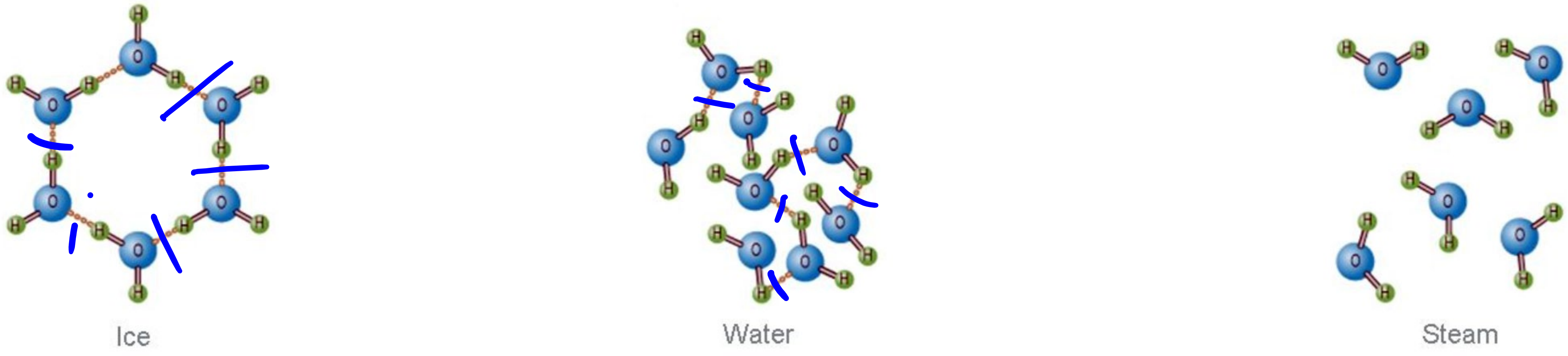
Note non-linear scale of the axes

Phase Changes: Micro and Macro.

- Macroscopic properties change dramatically across phase boundaries…

same chemistry !

- …along with the microscopic structure of the substance H_2O

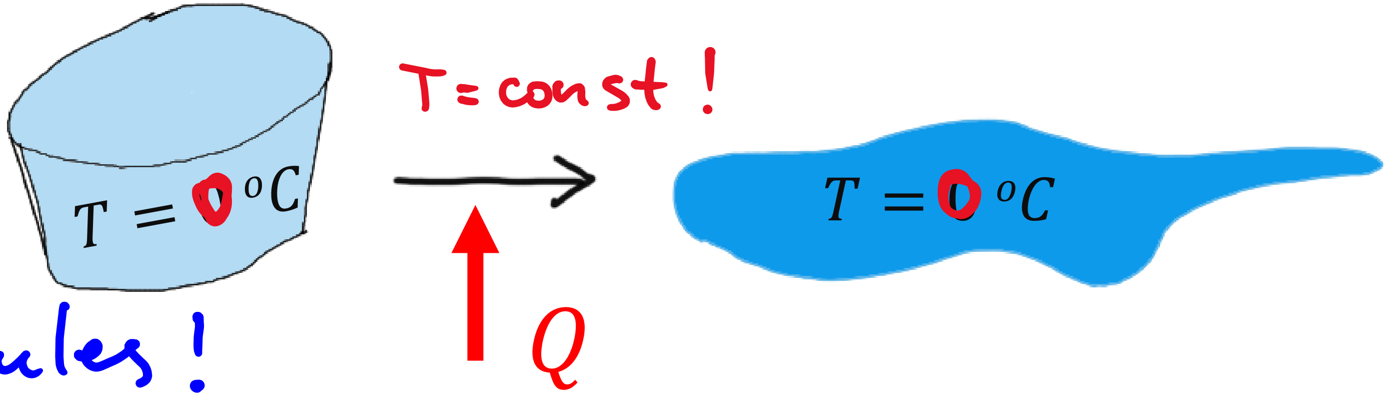


Phase Changes: Happen at a fixed temperature.

- At a transition temperature, transition occurs due to heat added / removed with no temperature change!

Q: Where does this heat go??

rearranging molecules!



- Amount of heat required for transition per mass of material is called the latent heat

Signs of Q

L_f: latent heat of fusion (freezing/melting)

releases heat   add heat

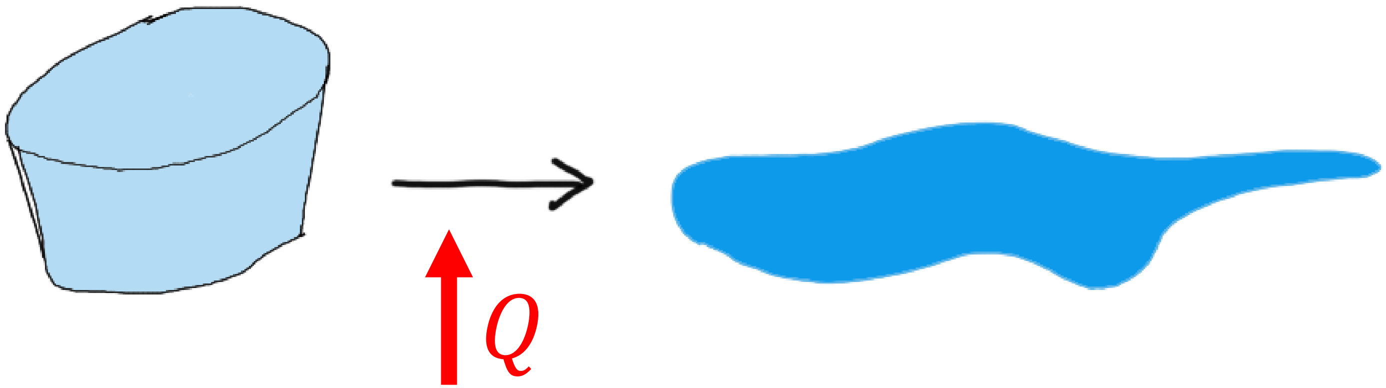
L_v: latent heat of vaporization (boiling/condensing)

add heat   releases heat

Latent heat

- Heat required to melt/boil a mass m of material (at melting/boiling T) is:

$Q = m\underline{c}\,\Delta T$ – heating



$$\boxed{Q = m\,L}$$

making a phase transition

- Hence, L is the energy required to melt/freeze 1 kg of material

- Units of L are $\frac{J}{kg}$

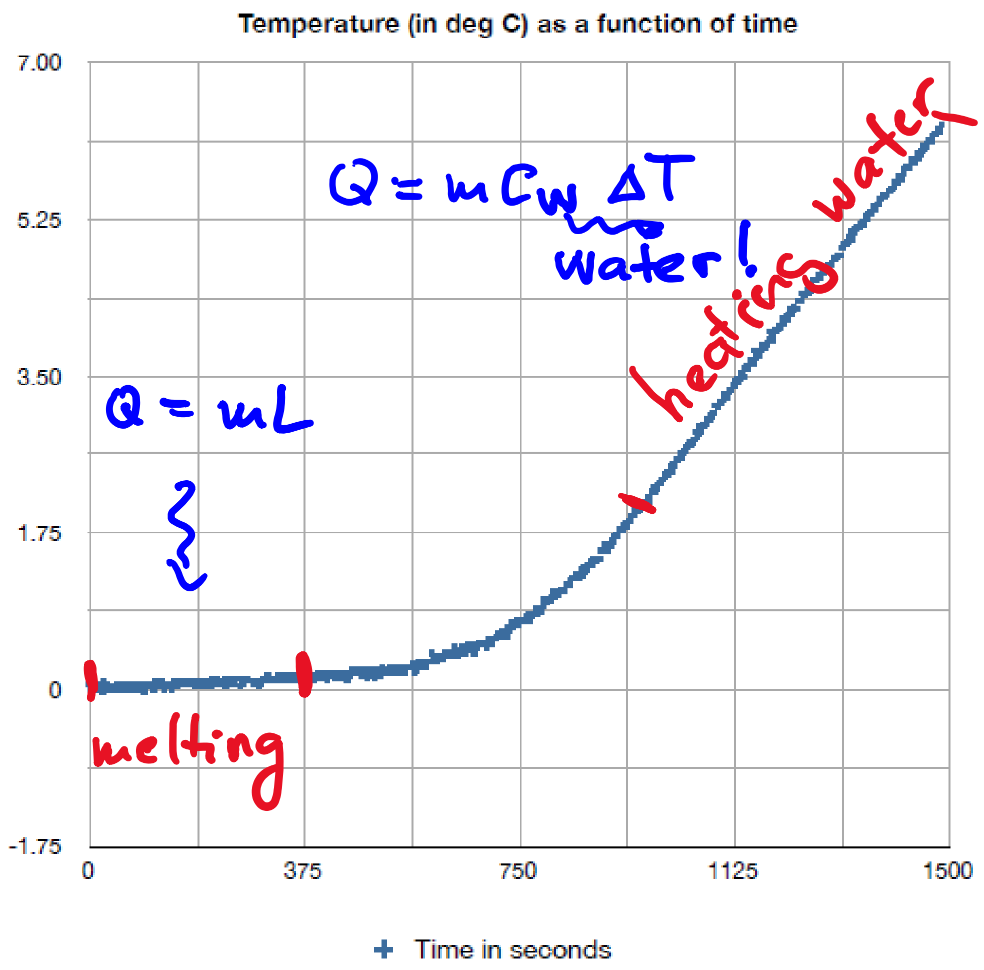
➢ Use L_f for melting (add Q)/freezing (remove Q) latent heat of fusion

➢ Use L_v for boiling (add Q)/condensing (remove Q) — " — " of vaporization

Latent Heat values (at atmospheric pressure)

TABLE 17.4 Heats of Fusion and Vaporization

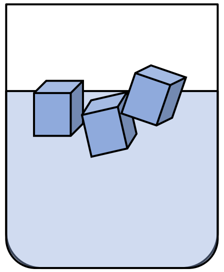
Substance	Normal Melting Point K	Normal Melting Point °C	Heat of Fusion, L_f (J/kg)	Normal Boiling Point K	Normal Boiling Point °C	Heat of Vaporization, L_v (J/kg)
Helium	*	*	*	4.216	−268.93	20.9×10^3
Hydrogen	13.84	−259.31	58.6×10^3	20.26	−252.89	452×10^3
Nitrogen	63.18	−209.97	25.5×10^3	77.34	−195.8	201×10^3
Oxygen	54.36	−218.79	13.8×10^3	90.18	−183.0	213×10^3
Ethanol	159	−114	104.2×10^3	351	78	854×10^3
Mercury	234	−39	11.8×10^3	630	357	272×10^3
Water	273.15	0.00	334×10^3	373.15	100.00	2256×10^3
Sulfur	392	119	38.1×10^3	717.75	444.60	326×10^3
Lead	600.5	327.3	24.5×10^3	2023	1750	871×10^3
Antimony	903.65	630.50	165×10^3	1713	1440	561×10^3
Silver	1233.95	960.80	88.3×10^3	2466	2193	2336×10^3
Gold	1336.15	1063.00	64.5×10^3	2933	2660	1578×10^3
Copper	1356	1083	134×10^3	1460	1187	5069×10^3



The graph shows the temperature vs time in an experiment where heat is supplied to ice water at a power of 240 W

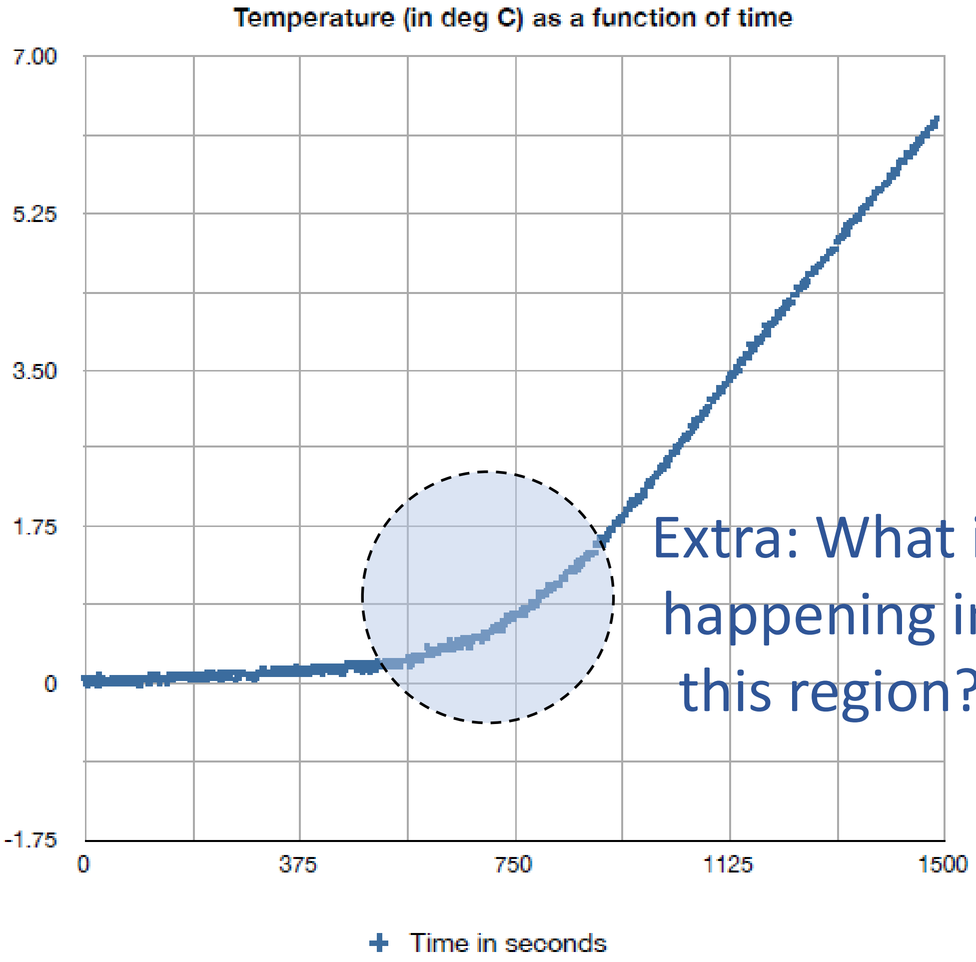
(1 Watt = 1 Joule / second)

Q: Why does the graph look like this?

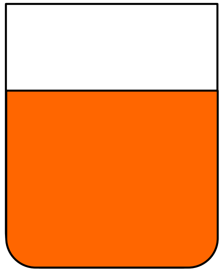


ice/water

0°C

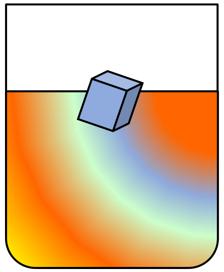


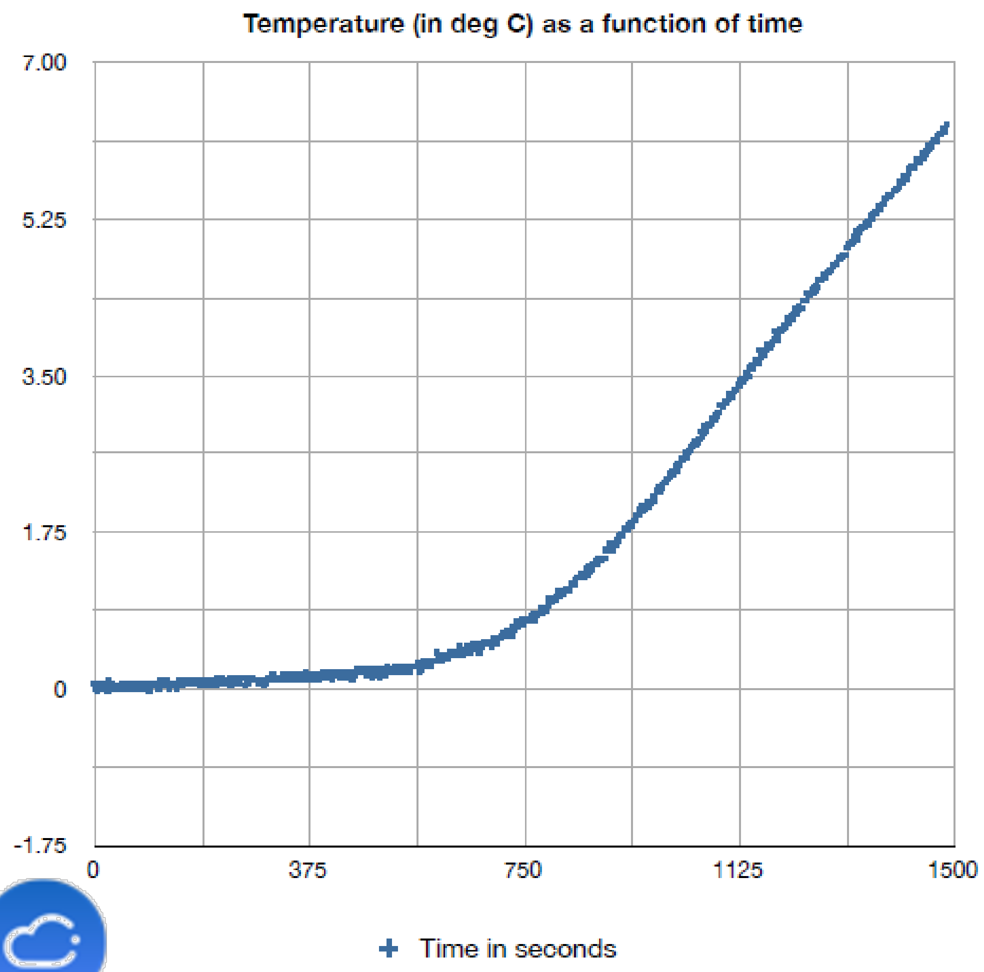
Extra: What is happening in this region?



All liquid water, well mixed

Poor mixing as ice melts, non-uniform temperature





A. 0.05 kg

B. 0.5 kg

C. 5 kg

D. 50 kg

The graph shows the temperature vs time in an experiment where heat is supplied to ice water at a power of 240 W

(1 Watt = 1 Joule / second)

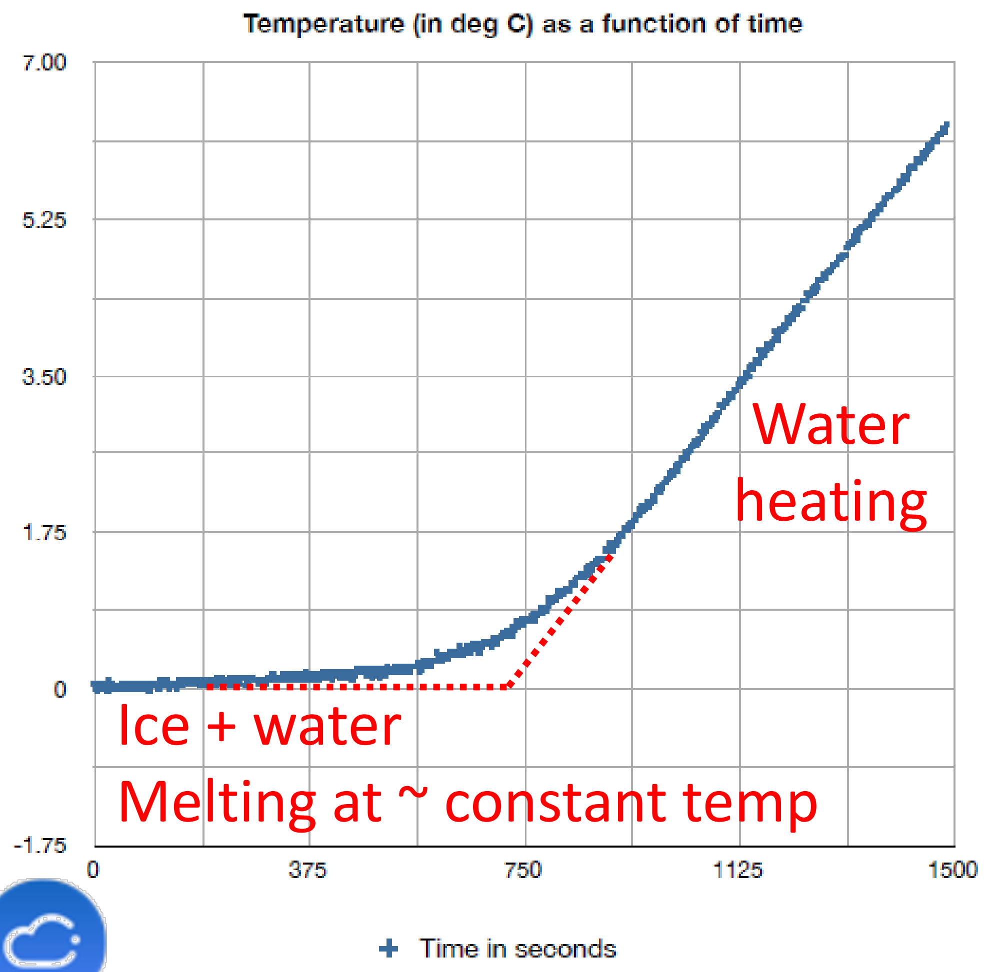
Q: Roughly how much ice was present initially?

- $L_f = 334 \times 10^3$ J/kg

$Q = mL$

$m = \frac{Q}{L}$

?



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Q: Roughly how much ice was present initially?

- $L_f = 334 \times 10^3$ J/kg

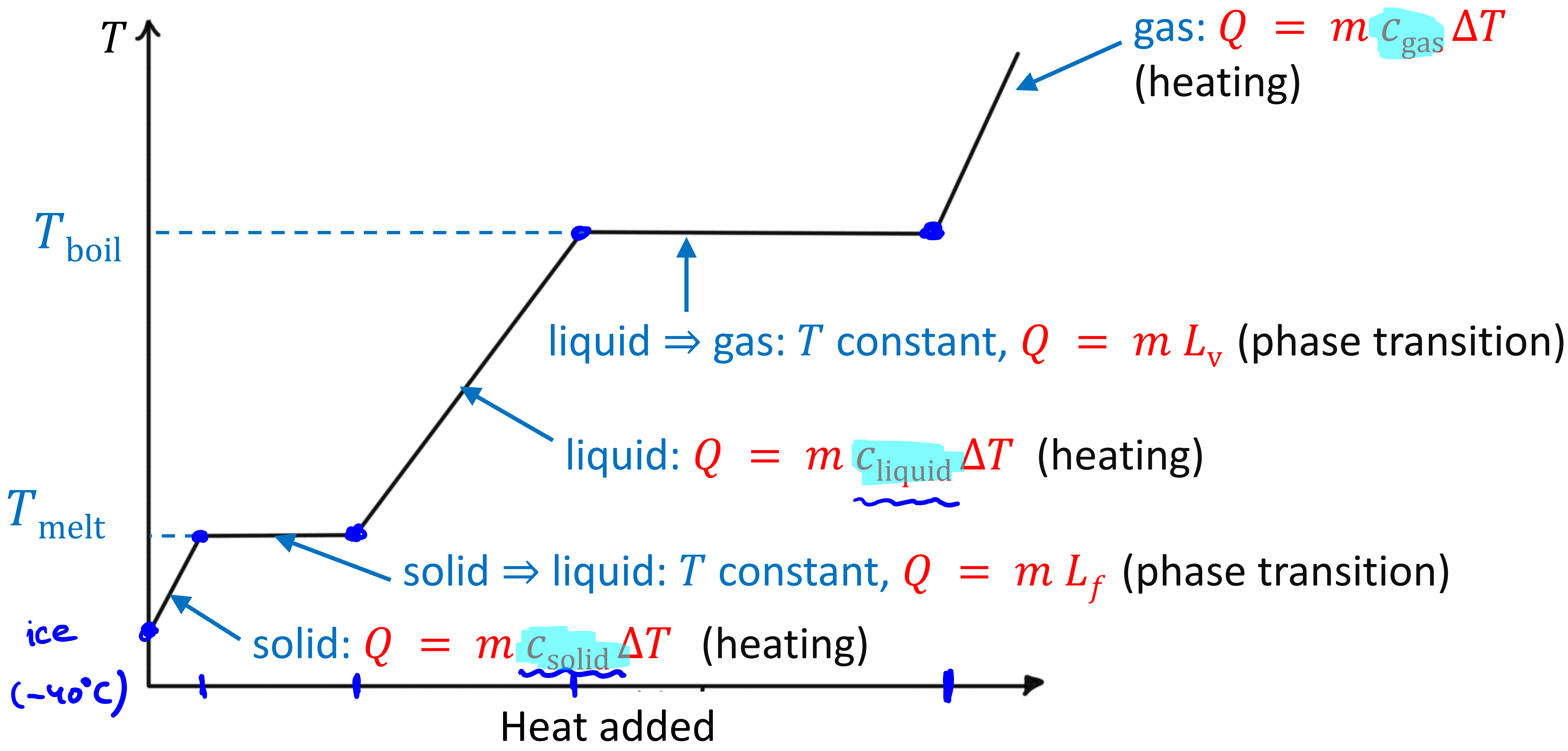
$$\text{Power} = \frac{\text{energy}}{\Delta t}$$

$Q = m\,L$ gives $m = {}^{Q}/_{L}$

Q = 240 J/s x 700 s ≈ 168,000 J

$$m = {}^{Q}/_{L} \approx 0.5\ kg$$

T vs heat added (e.g., water at atmospheric pressure)



Q: A mass M of ice at temperature $T_1 < 0$ is heated until we have water at temperature $T_2 > 0$. How much heat has been added?

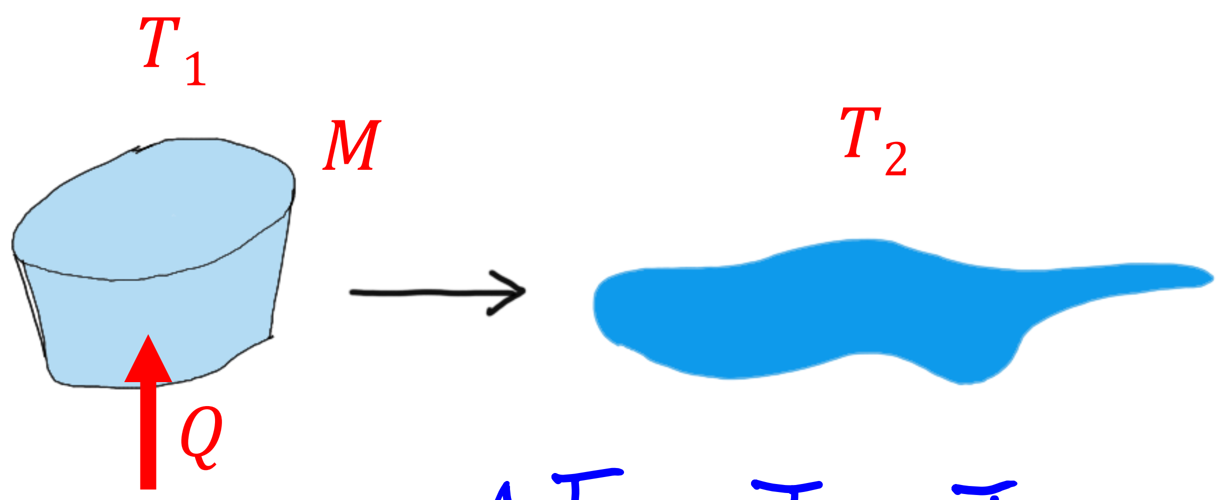
A. $M\, c_{\text{ice}}\,(T_2 - T_1)$

B. $M\, c_{\text{water}}\,(T_2 - T_1)$

C. $M\, L_f$

D. $M\, c_{\text{ice}}\,(-T_1) + M\, c_{\text{water}}\,(T_2)$

E. $M\, c_{ice}\,(-T_1) + M\, L_f + M\, c_{\text{water}}\,(T_2)$



$$\Delta T = T_f - T_i$$

$$Q = Q_{\text{heat ice}} + Q_{\substack{\text{melt ice}\\ \text{or}\\ \text{water}}} + Q_{\substack{\text{heat}\\ \text{water}}}$$

Q: A mass M of ice at temperature $T_1 < 0$ is heated until we have water at temperature $T_2 > 0$. How much heat has been added?

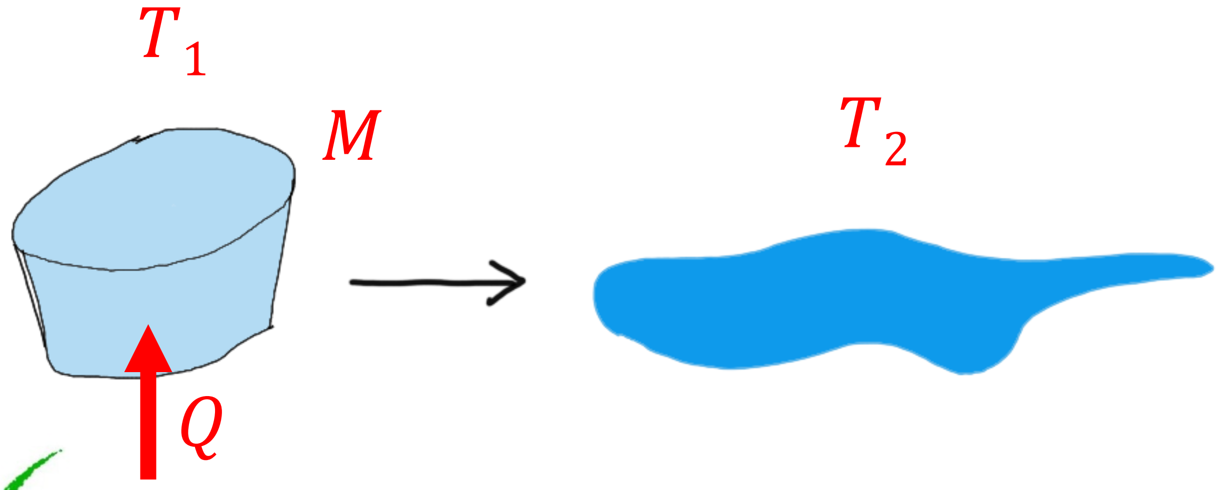
A. $M\, c_{\text{ice}}\, (T_2 - T_1)$

B. $M\, c_{\text{water}}\, (T_2 - T_1)$

C. $M\, L_f$

D. $M\, c_{\text{ice}}\, (-T_1) + M\, c_{\text{water}}\, (T_2)$

E. $M\, c_{ice}\, (-T_1) + M\, L_f + M\, c_{\text{water}}\, (T_2)$



Q to heat ice from T_1 to 0 °C

Q to melt

Q to heat water from 0 °C to T_2