Physics 115
General Physics II

Session 10

Phase equilibrium, evaporation
Phase changes, latent heats

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Lecture Schedule (up to exam 1)

Date	Day	Lect.	Topic	readings in Walker
31-Mar	Mon	1	Introduction, Preview	
1-Apr	Tues	2	Density & Pressure	15.1-15.3
3-Apr	Thurs	3	Static Fluids, Buoyancy	15.4-15.5
4-Apr	Fri	4	Fluid Flow, Bernoulli	15.6-15.8
7-Apr	Mon	5	Viscosity, Flow, Capillaries	15.9
8-Apr	Tues	6	Temperature, expansion	16.1-16.3
10-Apr	Thurs	7	Heat, Conduction	16.4-16.6
11-Apr	Fri	8	Ideal gas	17.1-17.2
14-Apr	Mon	9	Heat, Evaporation	17.4-17.5
15-Apr	Tues	10	Phase change	17.6
17-Apr	Thurs	11	First Law Thermodynamics	18.1-18.3
18-Apr	Fri		**EXAM 1 Ch 15,16,17**	

Today

Just joined the class? See course home page
courses.washington.edu/phy115a/
for course info, and slides from previous sessions

4/15/14   Physics 115

2

Announcements

- Prof. Jim Reid is standing in for RJW this week
- Exam 1 **this Friday 4/18**, in class, formula sheet provided
  - YOU bring a bubble sheet , pencil, calculator (NO laptops or phones; **NO personal notes allowed**.)
  - We will post sample questions tomorrow, and go over them in class Thursday
- Clicker responses from last week are posted, so you can check if your clicker is being detected. See link on class home page, http://courses.washington.edu/phy115a

Probability Distributions

We give a 25 point quiz to N students, and plot the results as a **histogram**, showing the number n_i of students, or fraction $f_i = n_i/N$ of students, for each possible score vs. score, from 0 to 25.

Such plots represent **distributions**.

For reasonably large N, we can use $f_i = n_i/N$ to estimate the probability that a randomly selected student received a score s_i.

Peak or mode = s with max probability

$s_{av} = 14.2$

$s_{rms} = 14.9$

Score

Notice, the fractions will add to 1 for all possible scores, so that $\Sigma f_i = 1$. In that case the histogram represents a **normalized distribution function**. We have the following relations:
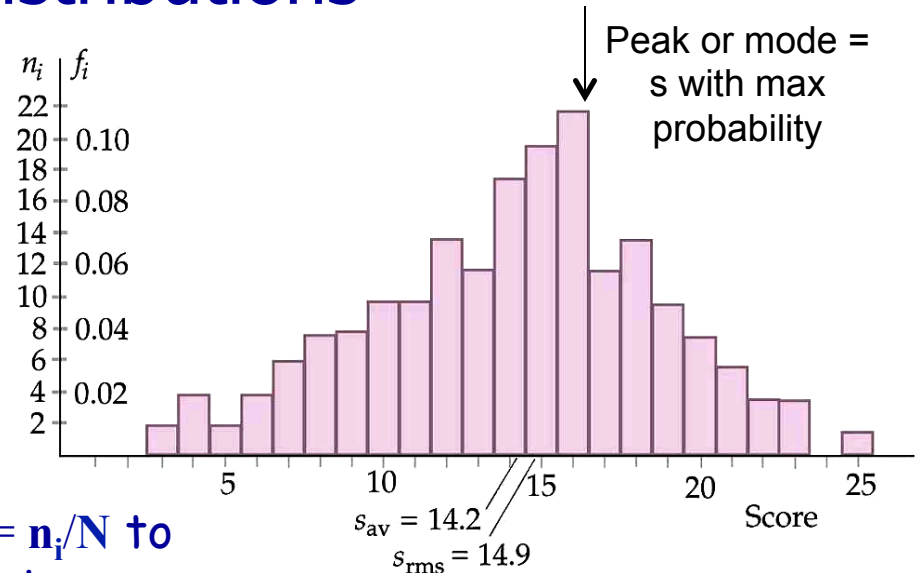
It's not useful for class grades, but we could also calculate the average **squared** score:

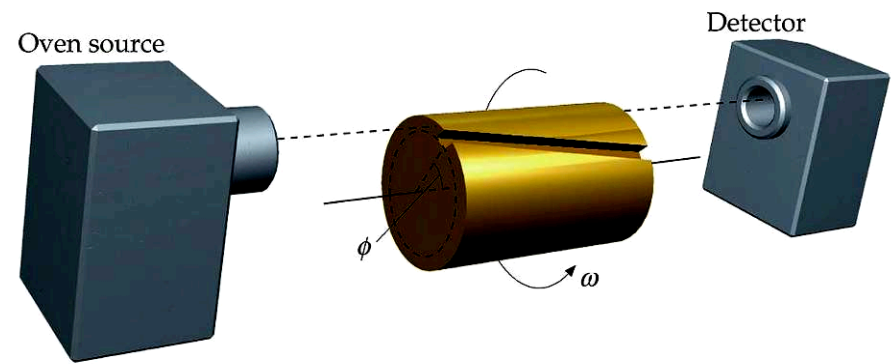$$\sum_i n_i = N \qquad \sum_i f_i = 1 \qquad s_{av} = \frac{1}{N}\sum_i n_i\, s_i = \sum_i f_i\, s_i$$

$$s_{av}^2 = \frac{1}{N}\sum_i n_i\, s_i^2 = \sum_i f_i\, s_i^2 \qquad s_{RMS} = \sqrt{s_{av}^2} = \sqrt{\sum_i f_i\, s_i^2}$$

Maxwell-Boltzmann speed distribution

One way to measure the distribution of molecular speeds of a gas: for a given speed of rotation of the cylinder, only molecules of one speed get through.

Oven source

Detector

ϕ

ω

The graph shows the speed distributions measured at temperatures T_1 and T_2 ($>T_1$).

f(v) is the Maxwell-Boltzmann speed distribution function. For N gas molecules the number of molecules between v and v+Δv is ΔN = N f(v)Δv and ΔN/N = f(v)Δv gives the fraction of molecules in that speed range. The M-B distribution gives the right RMS v, and is a useful approximation for ideal gases

$f(v)$

T_1

$T_2 > T_1$

T_2

dv v_{max} v_{av} v_{rms} v
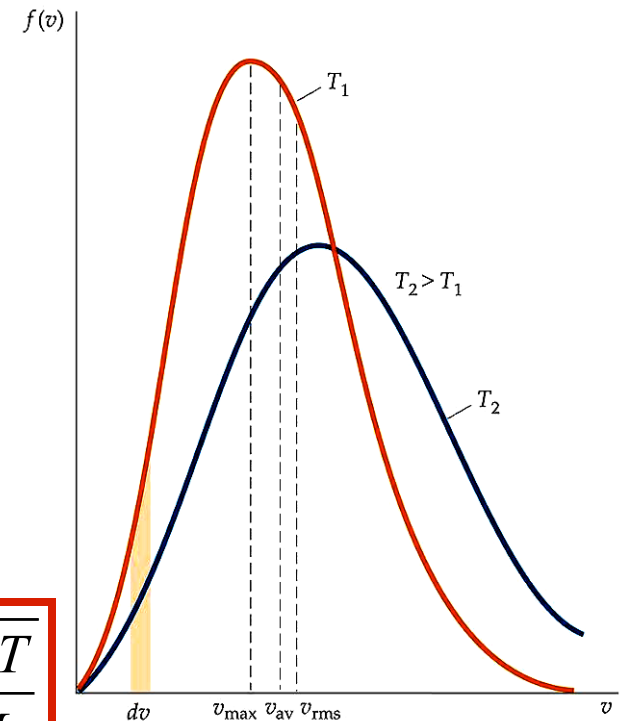
$$f(v) = \frac{4}{\sqrt{\pi}} \left(\frac{m}{2kT} \right)^{3/2} v^2 e^{-mv^2/(2kT)}$$

$$v_{RMS} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

Internal energy

Internal Energy of a gas: total energy contained in gas: U = KE+PE

Ideal gas → point particles with no interactions: So, no PE (neglecting gravitational PE), only KE due to translation (speed) of molecules

The KE of the molecules in an ideal gas is $K = (^3/_2) nRT$, where n is the number of moles of gas and R is the universal gas constant.

So, $U = K = ^3/_2 nRT$: Internal energy depends only on the temperature of the gas, and not on its volume or pressure.

Real gas molecules may have 2 or more atoms: can have internal energy stored in vibration or rotation about center of mass, as well as translational speed of molecules

Internal energy of a real gas may include PE due to attractive forces between molecules: Work must be done to change the separation of molecules → this part of U depends on volume V.

Evaporating and boiling

- If a sealed container is partially filled with a liquid, the empty space will fill with its vapor phase
  - Fastest molecules escape from liquid surface
  - Fastest = highest speed = highest T → liquid's T drops
  - Eventually as many re-enter liquid as leave: **equilibrium**
    - Vapor pressure stabilizes

Equilibrium
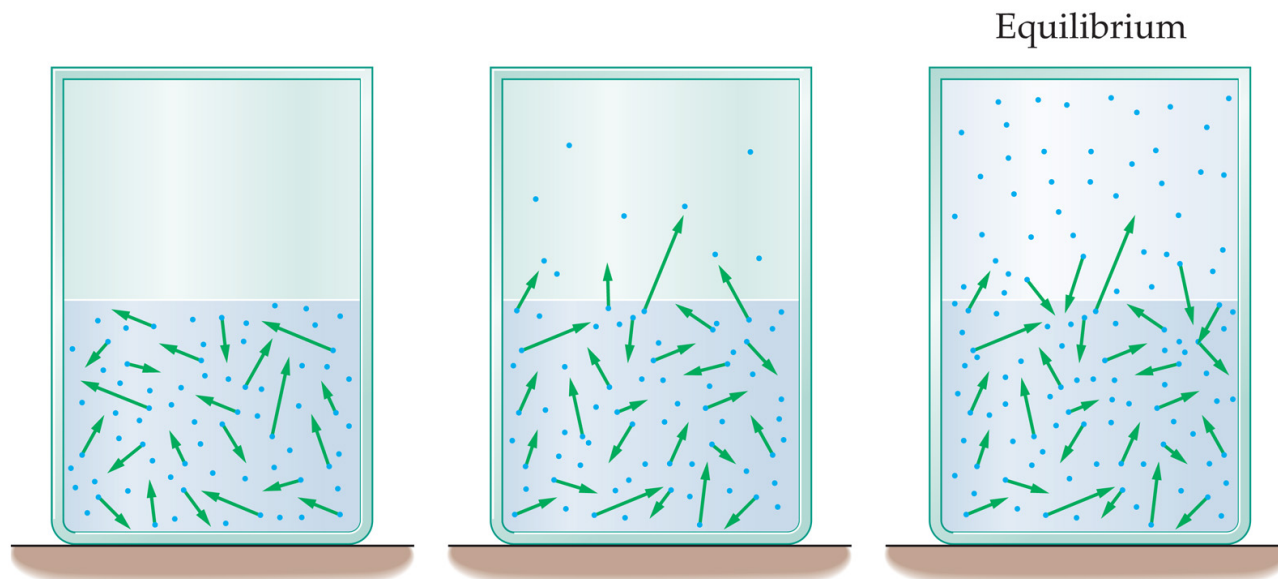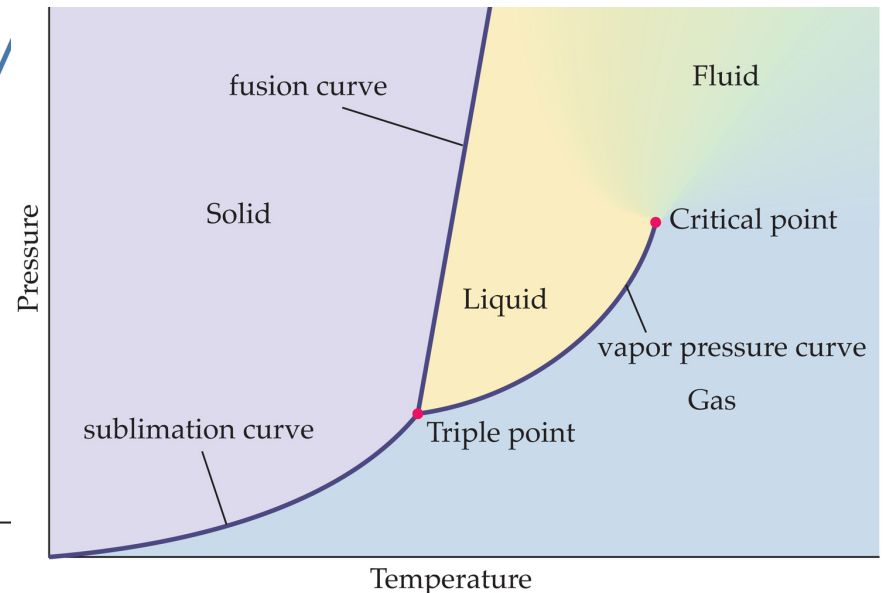
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Vapor pressures

- P_V vs T curve gives boiling T for any pressure
  - Water boils at 100C at sea level, but 90C at high altitude
    - Pressure cooker is needed for high-altitude cooking!
  - Similar P vs T curves for freezing, sublimation (solid→gas)
    - "Phase diagram" for a specific substance
  - Critical point = liquid is indistinguishable from vapor: "fluid"
  - Triple point: solid/liquid/vapor all in equilibrium
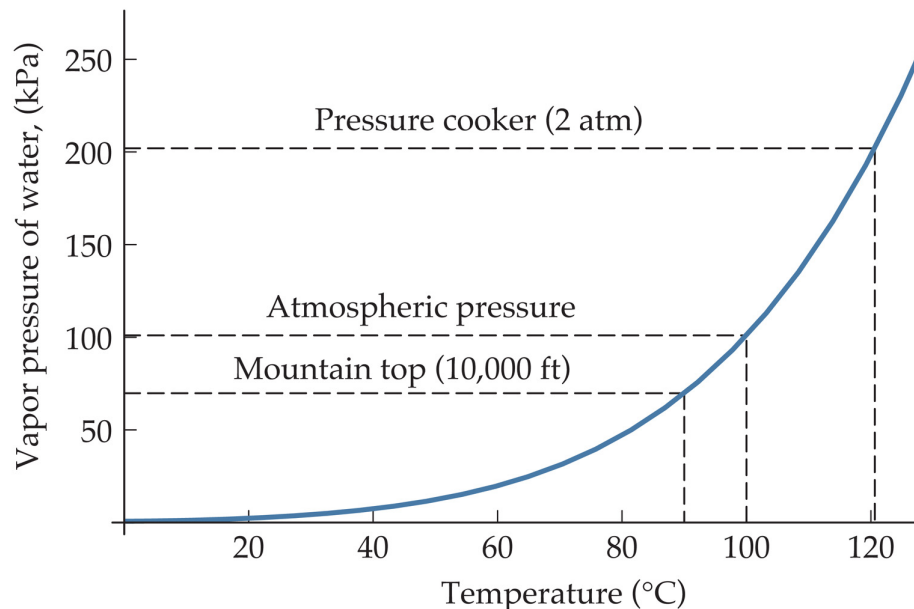
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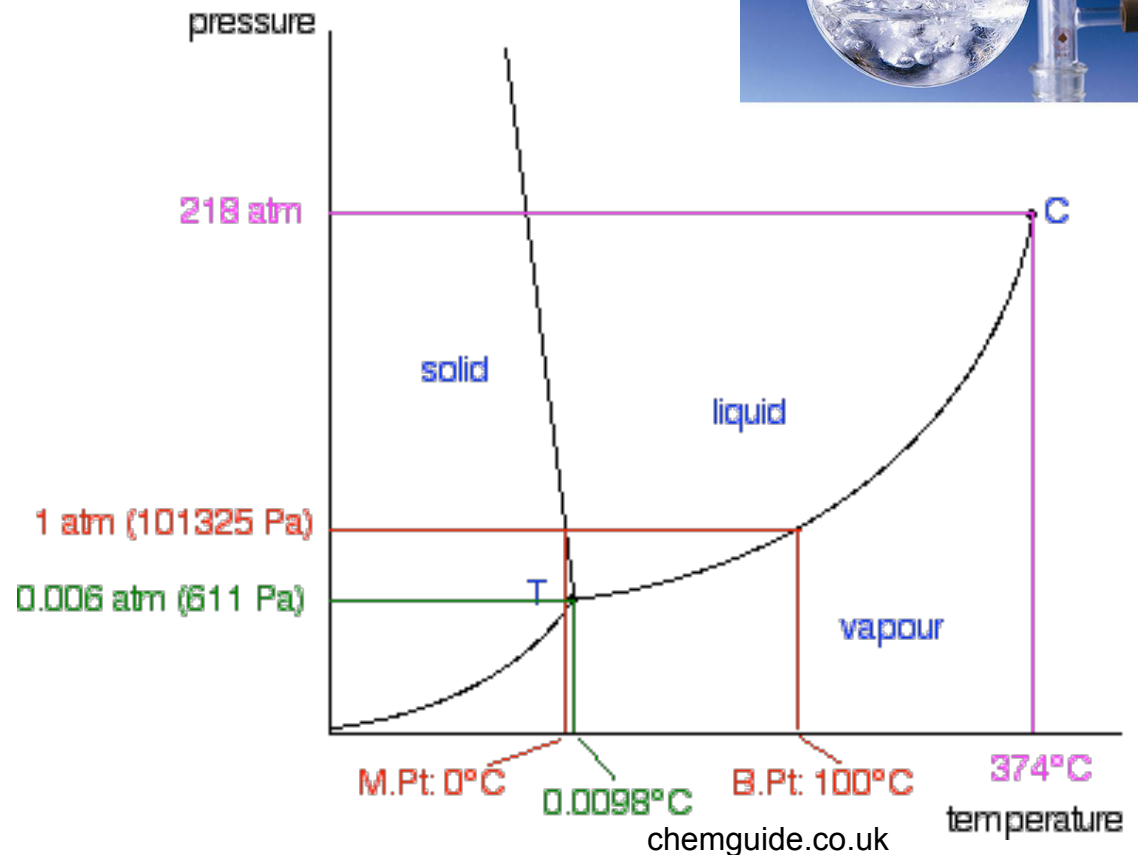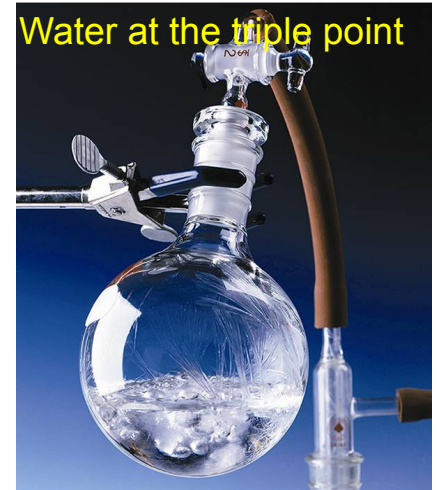
Once again: Water is special!

Water at the triple point

- Most substances have fusion curve with positive slope
  - Increase P at constant T and substance freezes
  - Frozen substance is denser than liquid
- Water's has negative slope
  - Ice melts if pressure is increased at constant T !

Example: ice melts under ice skate blade, due to high pressure -- liquid water on top of ice lubricates skates

Triple point for water: 0.006 atm, 0.01 C
Ice in boiling water!

Critical point: 218 atm, 374 C

Melting point at 1 atm: 0C

pressure

218 atm

solid

liquid

1 atm (101325 Pa)

0.006 atm (611 Pa)

T

vapour

C

M.Pt: 0°C   0.0098°C   B.Pt: 100°C   374°C

temperature

chemguide.co.uk

Phase changes and latent heats

- Phase = state (solid, liquid, gas)
  - Phase changes require or release heat
  - During phase change, T remains constant: "Latent heat" of change

When ice melts at 0°C, it absorbs heat with no change in temperature. When it freezes, it loses heat the same way, without change in T.
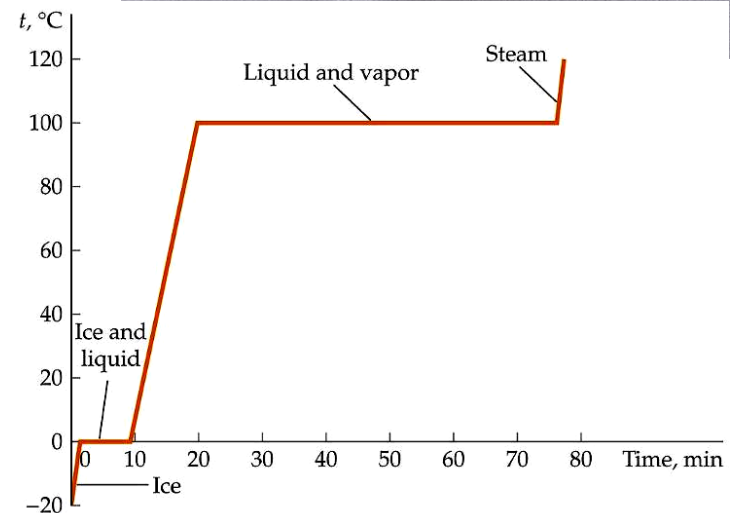
$$Q_f = mL_f, \quad L_f = \text{ latent heat of fusion}$$

$$L_f(\text{water}) = 333.5 \text{ kJ/kg} = 79.7 \text{ kcal/kg}$$

When water boils at 100°C, it absorbs heat with no change in temperature. When steam condenses, it releases heat the same way.

$$Q_v = mL_v, \quad L_v = \text{ latent heat of vaporization}$$

$$L_v(\text{water}) = 2.22 \text{ MJ/kg} = 540 \text{ kcal/kg}$$

Latent heats

Table 18-2 Melting Point (MP), Latent Heat of Fusion (L_f), Boiling Point (BP), and Latent Heat of Vaporization (L_v), all at 1 atm, for Various Substances

Substance	MP, K	L_f, kJ/kg	BP, K	L_v, kJ/kg
Alcohol, ethyl	159	109	351	879
Bromine	266	67.4	332	369
Carbon dioxide	—	—	194.6*	573*
Copper	1356	205	2839	4726
Gold	1336	62.8	3081	1701
Helium	—	—	4.2	21
Lead	600	24.7	2023	858
Mercury	234	11.3	630	296
Nitrogen	63	25.7	77.35	199
Oxygen	54.4	13.8	90.2	213
Silver	1234	105	2436	2323
Sulfur	388	38.5	717.75	287
Water (liquid)	273.15	333.5	373.15	2257
Zinc	692	102	1184	1768

* These values are for sublimation. Carbon dioxide does not have a liquid state at 1 atm.

Isolated systems

- If objects are thermally insulated from surroundings they form an isolated system

- Energy conservation → heat may be exchanged between parts of isolated system, but not created or destroyed
  - Example: if this container isolates water+ice, then final equilibrium state must have same heat energy content as initial
  - heat lost by ice = heat gained by water; $\Delta Q_{SYS}=0$

$-10\,°C \longrightarrow 0\,°C$

$-10\,°C$

$0\,°C$

Q

$0\,°C$

$0\,°C$

$0\,°C$

$0\,°C$

(a) Initial

(b)
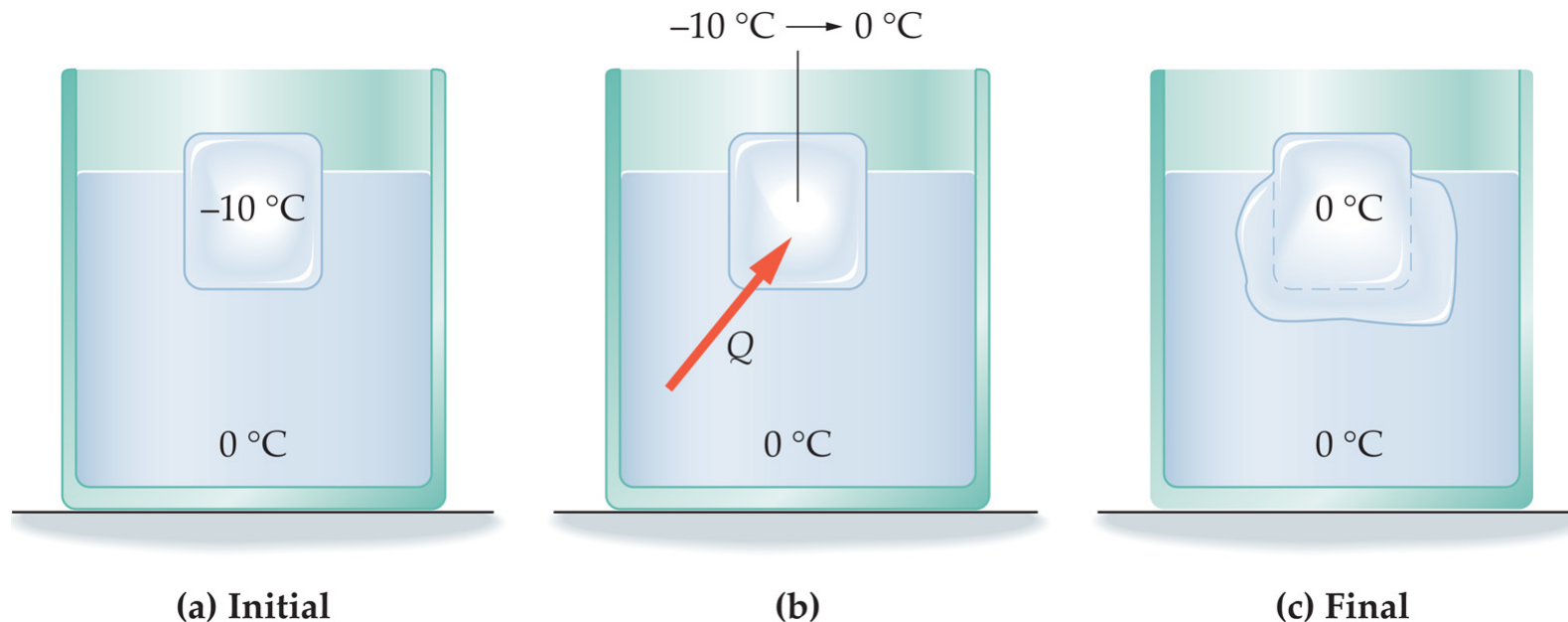
(c) Final

Example: melting ice

A 2.0 L pitcher of water has T = 33°C. You pour 0.24 kg into a Styrofoam cup and add two cubes of ice (each 0.025 kg at 0.0°C).

a) Assuming no heat is lost to the surroundings, what is the final temperature of the water ?

$$\Delta Q_{SYSTEM} = 0 \qquad Q_{\text{out of liquid}} = m_L c \Delta T = m_L c \left(T_f - T_{\text{Liq-i}} \right)$$

$$Q_{\text{into ice}} = m_{ice} L_{ice} + m_{ice} c \Delta T_W = m_{ice} L_{ice} + m_{ice} c \left(T_f - T_{\text{W-i}} \right)$$

$$Q_{\text{out of liquid}} + Q_{\text{into ice}} = 0 \rightarrow Q_{\text{out of liquid}} = -Q_{\text{into ice}}$$

$$m_L c \left(T_{Li} - T_f \right) = m_{ice} L_f + m_{ice} c \left(T_f - T_{Wi} \right)$$

$$T_f = \frac{\left(m_{ice} T_{Wi} + m_L T_{Li} \right) c - m_{ice} L_f}{\left(m_L + m_{ice} \right) c}$$

$$= \frac{[(0.050)(273.15) + (0.24)(306.15)](4.18) - (0.050)(333.5)}{(0.29)(4.18)} = 286.7K = 13.7°C$$

Example: melting ice

b) What is the final temperature if you add 6 instead of 2 ice cubes?

$$T_{f6} = \frac{\left(m_{ice}T_{Wi} + m_L T_{Li}\right)c - m_{ice}L_f}{\left(m_L + m_{ice}\right)c}$$

$$= \frac{[(0.150)(273.15) + (0.24)(306.15)](4.18) - (0.150)(333.5)}{(0.39)(4.18)}$$

$$= 262.8K = \boxed{-10.4°C} \quad !$$

Wrong! Water does not freeze when you put ice cubes in it!

Evidently: all 6 ice cubes do not melt. $T_{f6} = 0.00°C$

exercise for you: calculate the mass of ice remaining when T reaches 0°C

Example: changing ice into steam

- How much heat is needed to change 1.5 kg of ice at -20°C and 1.0 atm into steam at 100°C?

Q to bring to 0°C $\quad Q_1 = mc\Delta T = (1.5 \text{ kg})(2.05 \text{ kJ/kg}\cdot\text{K})(20 \text{ K}) = 0.0615 \text{ MJ}$

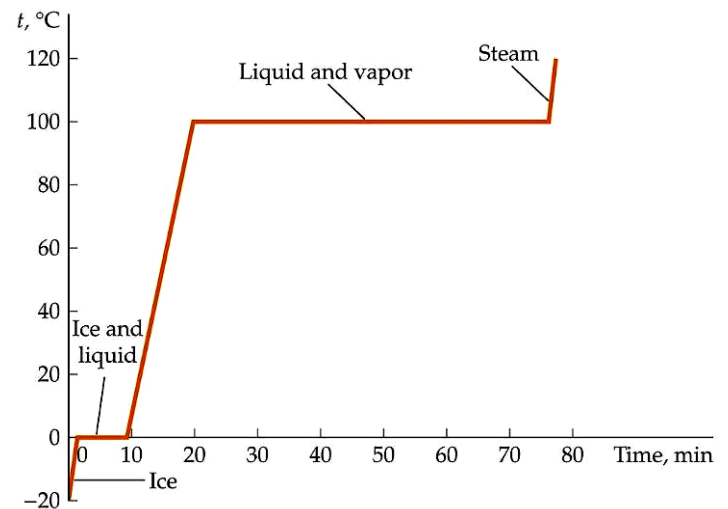Q to melt at 0°C $\quad Q_2 = mL_f = (1.5 \text{ kg})(333.5 \text{ kJ/kg}) = 0.500 \text{ MJ}$

Q to bring up to 100°C:

$$Q_3 = mc\Delta T = (1.5 \text{ kg})(4.15 \text{ kJ/kg}\cdot\text{K})(100 \text{ K}) = 0.627 \text{ MJ}$$

Q to evaporate at 100°C:

$$Q_4 = mL_v = (1.5 \text{ kg})(2.26 \text{ MJ/kg}) = 3.39 \text{ MJ}$$

$$Q = \sum Q_i = 4.58 \text{ MJ}$$

Quiz 6

You pour water at 100°C and ice cubes at 0°C into an insulated container. When thermal equilibrium is reached, you notice that some ice remains and floats in the liquid water. The final temperature of the mixture is:

(a) above 0°C

(b) 0°C

(c) less than 0°C

(d) can't say without knowing masses of ice and water used.

Quiz 6

You pour water at 100°C and ice cubes at 0°C into an insulated container. When thermal equilibrium is reached, you notice that some ice remains and floats in the liquid water. The final temperature of the mixture is:

(a) above 0°C

(b) 0°C   ice+water in equilibrium at 0°C

(c) less than 0°C

(d) can't say without knowing masses of ice and water used.