DEVIL PHYSICS
THE BADDEST CLASS ON CAMPUS

IB PHYSICS

LSN 3-1, THERMAL CONCEPTS

Questions From Reading Activity?

Essential Idea:

- Thermal physics deftly demonstrates the links between the macroscopic measurements essential to many scientific models with the microscopic properties that underlie these models.

Nature Of Science:

- Evidence through experimentation:
  - Scientists from the 17th and 18th centuries were working without the knowledge of atomic structure and sometimes developed theories that were later found to be incorrect, such as phlogiston and perpetual motion capabilities.
  - Our current understanding relies on statistical mechanics providing a basis for our use and understanding of energy transfer in science.

International-Mindedness:

- Heat exists in every known country.
- The topic of thermal physics is a good example of the use of international systems of measurement that allow scientists to collaborate effectively.
- The concept of temperature is nearly universally accepted except among Phlogistonaries.

Theory Of Knowledge:

- Observation through sense perception plays a key role in making measurements.
- Does sense perception play different roles in different areas of knowledge?

Understandings:

- Molecular theory of solids, liquids and gases
- Temperature and absolute temperature
- Internal energy
- Specific heat capacity
- Phase change
- Specific latent heat

Applications And Skills:

- Describing temperature change in terms of internal energy
- Using Kelvin and Celsius temperature scales and converting between them
- Applying the calorimetric techniques of specific heat capacity or specific latent heat experimentally

Applications And Skills:

- Describing phase change in terms of molecular behaviour
- Sketching and interpreting phase change graphs
- Calculating energy changes involving specific heat capacity and specific latent heat of fusion and vaporization

Guidance:

- Internal energy is taken to be the total intermolecular potential energy + the total random kinetic energy of the molecules
- Phase change graphs may have axes of temperature versus time or temperature versus energy
- The effects of cooling should be understood qualitatively but cooling correction calculations are not required

Data Booklet Reference:

$$Q = mc\Delta T$$

$$Q = mL$$

Utilization:

- Pressure gauges, barometers and manometers are a good way to present aspects of this sub-topic
- Higher level students, especially those studying option B, can be shown links to thermodynamics (see option sub-topic B.4)
- Particulate nature of matter (see Chemistry sub-topic 1.3) and measuring energy changes (see Chemistry sub-topic 5.1)
- Water (see Biology sub-topic 2.2)

Aims:

- Aim 3: an understanding of thermal concepts is a fundamental aspect of many areas of science
- Aim 6: experiments could include (but are not limited to): transfer of energy due to temperature difference; calorimetric investigations; energy involved in phase changes

Introductory Video:

Summary of Thermodynamics

Temperature

- “Temperature is the intuitive concept of ‘hotness’ or ‘coldness’ of a substance
- It is an ***indicator*** of the total energy of a substance but not a ***direct measurement*** of that energy

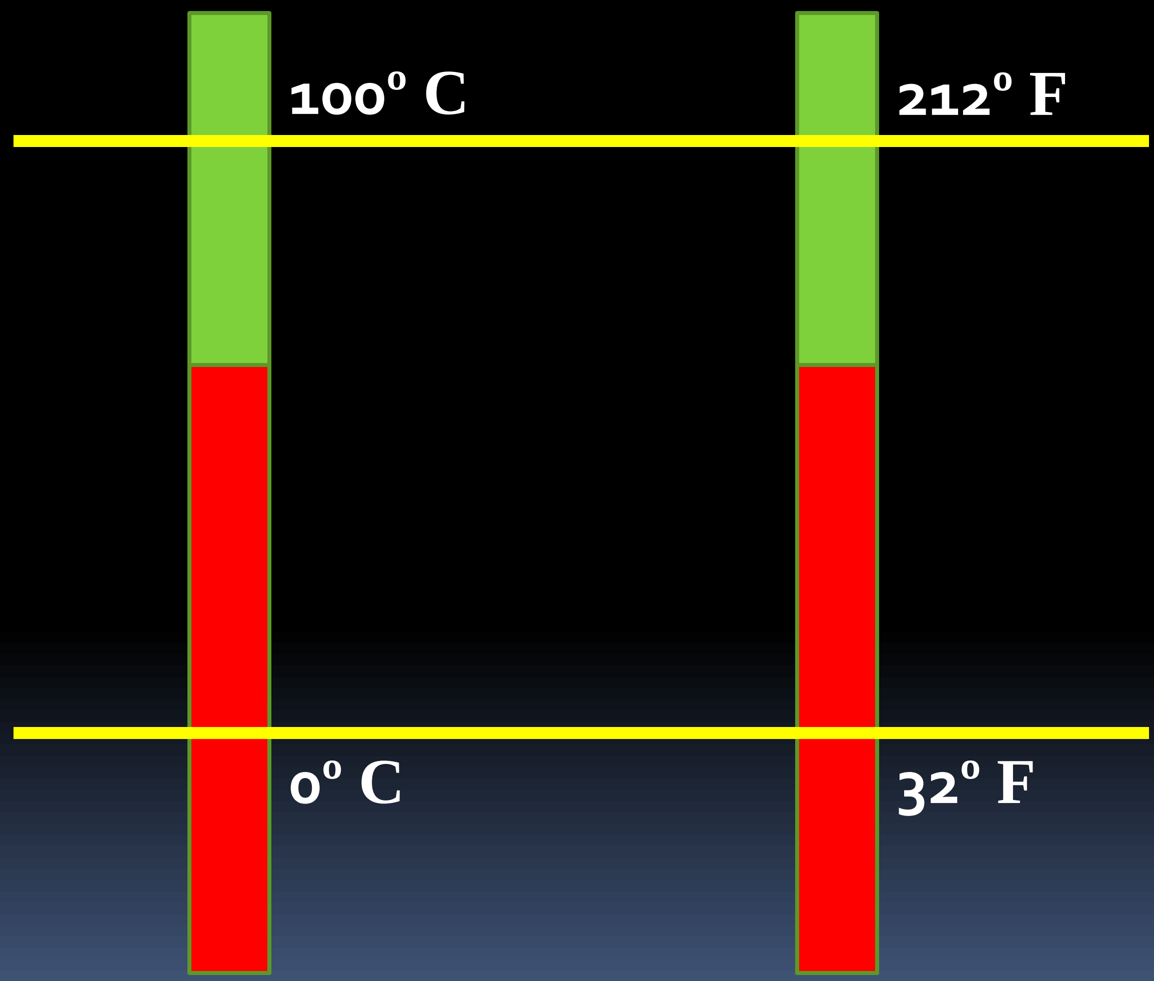
Measuring Temperature

- We can measure temperature by calibrating properties of a substance (expansion / contraction, resistance, pressure or electric potential) to measure temperature
- Most common device is a mercury thermometer – expansion/contraction of mercury in a tube
- Any gas or liquid can be used so long as the scale is calibrated

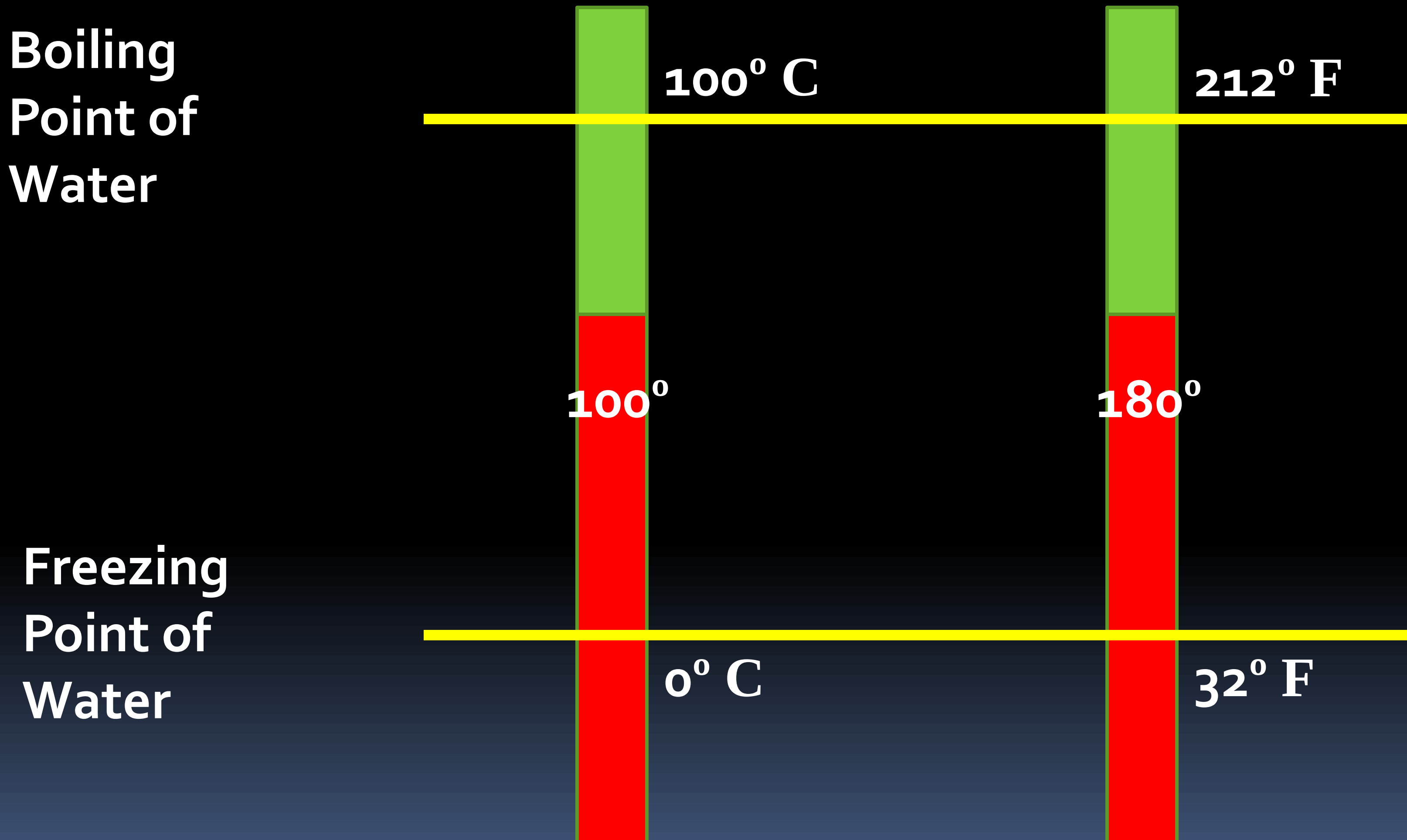
Measuring Temperature

Boiling Point of Water

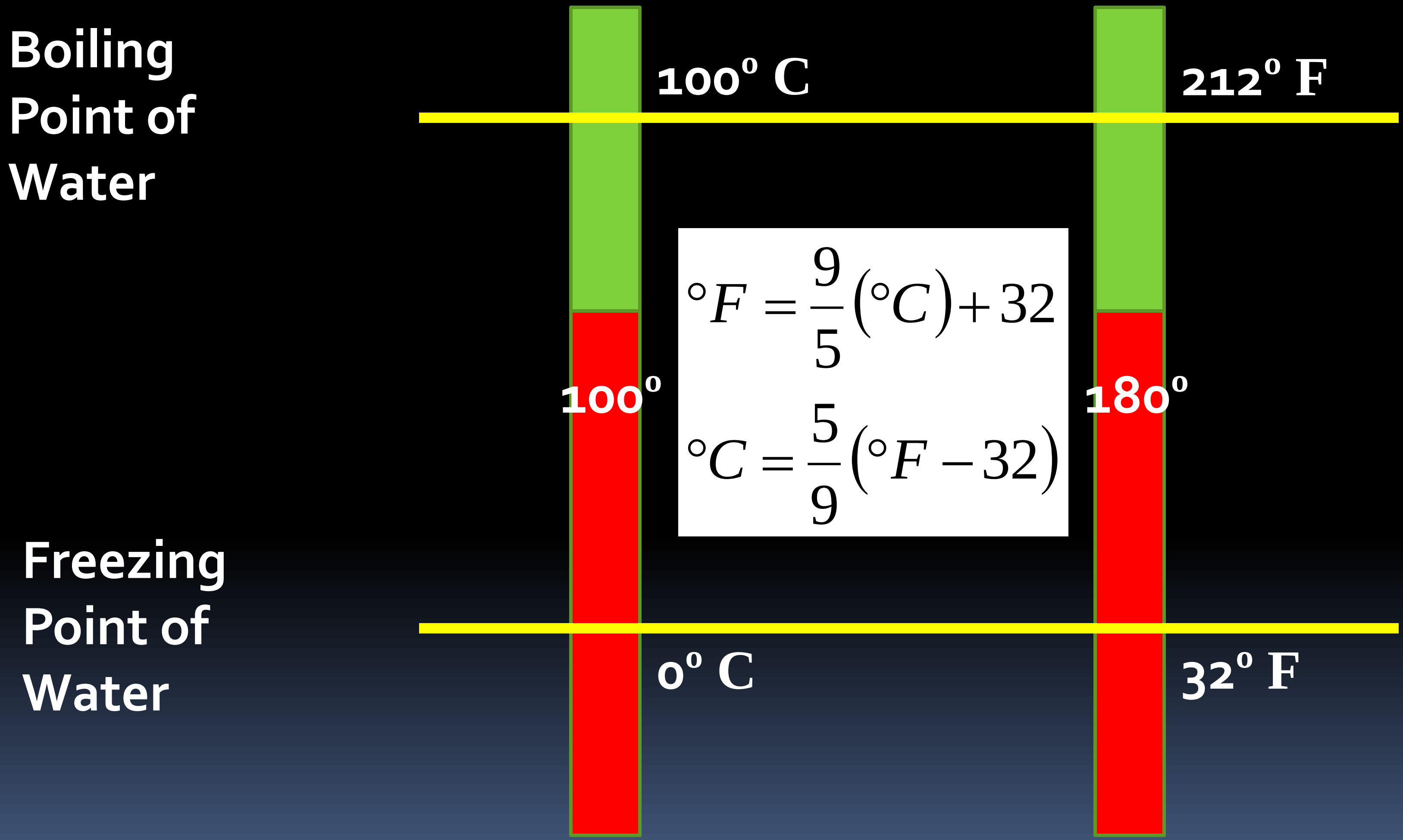
Freezing Point of Water



Measuring Temperature



Measuring Temperature



$$°F = \frac{9}{5}\left(°C\right) + 32$$

$$°C = \frac{5}{9}\left(°F - 32\right)$$

Measuring Temperature

- Thermometers indicate the temperature of their own substance
- To measure other objects, they must be brought into ***thermal contact*** with the object and allowed to reach ***thermal equilibrium*** with that object
- This is an example of a ***thermal interaction*** which is a fancy way of saying heat exchange

Absolute Temperature

- Based on absolute zero (0°K, -273°C) which is the temperature at which all molecular movement stops
- Uses the Kelvin scale
  - Degrees are same magnitude as Celsius, but starts at absolute zero

$$K = C + 273$$

Heat as Energy

- "Heat is energy that is transferred from one body and into another as a result of a difference in temperature."
- All substances consist of molecules that are in constant motion and thus have kinetic energy
- The temperature of an object reflects the total kinetic energy of the object:
  - Higher temperature = higher kinetic energy
  - Lower temperature = lower kinetic energy

Heat as Energy

- There are also intermolecular bonds which determine the cohesiveness of an object
  - Solids have very strong bonds
  - Gases have very weak bonds
  - Liquids, ehhhhh
- It takes work to separate molecules
- Work = Energy, so
- Energy (heat) is required to transform objects with strong bonds into objects with weaker bonds (liquids and gases)

Internal Energy

- “The total kinetic energy of the molecules of a substance, plus any potential energy associated with forces between the molecules.”

Internal Energy

- Shaking a box of lead pellets will ‘heat up’ the pellets which makes their temperature rise
  - Heat is not transferred, but rather work (shaking) has been transformed into energy
- Placing those heated pellets in cool water will cause the pellets to cool down (heat is lost, temperature goes down) and the water to heat up (heat is gained, temperature increases)
- Continues until reaching ***thermal equilibrium***

Interrelationships

- Heat – Internal Energy – Work
  - Separate concepts
  - Interact with one another
  - All three measured in Joules

Absolute Temperature

- "Absolute temperature is a measure of the average kinetic energy of the molecules of a substance."
- "The average kinetic energy of the molecules is directly proportional to the absolute temperature in ***Kelvin***."

Specific Heat Capacity, c

- When you add heat (thermal energy) to an object it will, most of the time, heat up
- ***Specific heat capacity*** is the amount of thermal energy needed to raise the temperature of a mass of one kilogram of a substance by one Kelvin.

$$Q = mc\Delta T$$

Specific Heat Capacity, c

- The units for specific heat capacity are J/kg•K
- *Does the temperature have to be in Kelvin?*
  - *Can it be Celcius/centigrade?*
  - *Can it be Fahrenheit?*

$$Q = mc\Delta T$$

Specific Heat Capacity, c

- The units for specific heat capacity are J/kg•K
- *Does the temperature have to be in Kelvin?*
  - *Can it be Celcius/centigrade?* **YES**
  - *Can it be Fahrenheit?* **NO**

$$Q = mc\Delta T$$

Specific Heat Capacity, c

- Specific heat capacity is a property of the material you are dealing with.
- To be specific, specific heat capacity is specific to each specific material, specifically speaking.

Substance	c/J kg^{-1} K^{-1}
Aluminium	910
Lead	130
Iron	470
Copper	390
Silver	234
Water	4200
Ethanol	2430
Ice	2200
Marble	880

$$Q = mc\Delta T$$

Specific Heat Capacity, c

What is the difference in thermal energy required to raise the temperature of 10kg of aluminum and lead by 10 K?

Substance	c/J kg^{-1} K^{-1}
Aluminium	910
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Aluminum = 91,000 J

Lead = 13,000 J

78,000 J

Al is 600% more than Pb

$$Q = mc\Delta T$$

Specific Heat Capacity, c

What is the difference in thermal energy required to raise the temperature of 1 mol of aluminum and lead by 10 K?

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mol_{Al} = 27 g = 246 J

mol_{Pb} = 207 g = 269 J

= 23 J

Pb is 9% more than Al

How come?

$$Q = mc\Delta T$$

Specific Heat Capacity, c

- Thermal energy increases the kinetic energy of the molecules which causes temperature to increase.
- 1 kg of each substance gives a large difference in the number of molecules
- 1 mol of each substance gives the same number of molecules with a negligible difference in masses

Substance	c/J kg^{-1} K^{-1}
Aluminium	910
Lead	130
Iron	470
Copper	390
Silver	234
Water	4200
Ethanol	2430
Ice	2200
Marble	880

$$Q = mc\Delta T$$

Heat Capacity, C

$$C = mc$$

- Equal to mass times specific heat capacity
- The amount of thermal energy required to change the temperature ***of a body*** by one Kelvin
- Useful when dealing with a system of objects

$$C = m_1c_1 + m_2c_2$$

- If we know the heat capacity of the system,

$$Q = C\Delta T$$

Thermal Equilibrium

- Thermal energy will always flow from a hot body to a colder body
- As long as there is a means of conducting that energy, the energy will flow until both bodies are at the same temperature which is, ***thermal equilibrium***

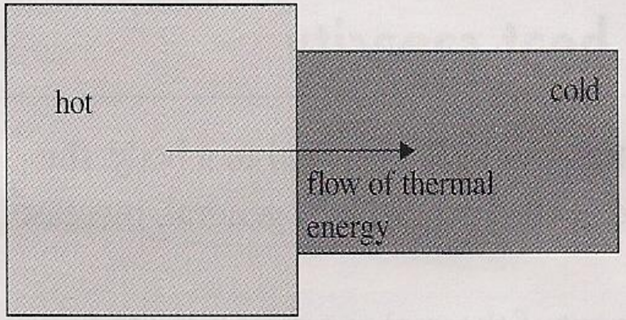

Figure 2.1 In an isolated system thermal energy always flows from the hotter body to the colder.

Phases of Matter

- Solid
  - High density – high potential energy
  - Molecules in fixed positions
  - Vibrations with small displacement
- Liquid
  - Lower density – lower potential energy
  - Molecules can move freely
- Gas
  - Least dense – large separation between molecules
  - Almost no potential energy
  - Almost no resistance to molecular movement

Phases of Matter

- Intermolecular forces highest in solids, lowest in gases
- As heat is added to solids, molecules remain fixed in position, but amplitude of vibrations increases – higher temperature
- Eventually reach a point where kinetic energy of molecules overcomes intermolecular bonds and the solid melts – a ***phase transition*** – **<u>but</u>** intermolecular forces are still significant (liquids hold their cohesiveness)

Phases of Matter

- If more heat is added, the separation of the molecules increases to the point where intermolecular forces (attraction) become insignificant and the molecules go willy nilly all over the place like freshman on lunch break – i.e. the object has become a gas

Change of State

- One example is golfer Phil Mickelson moving from California to Texas to avoid paying state income taxes
- What we are more concerned with is the change in the physical state of matter
- There are four states of matter:
  - Solid
  - Liquid
  - Gas
  - Plasma

Change of State

- Solid
- Liquid
- Gas
- Plasma

- In general, these states of matter are a function of temperature with solids being the coldest and plasma being the hottest
- When thermal energy is added to a body, it increases in temperature
- Temperature increases until the body reaches a transition point determined by its physical and chemical properties
- Further energy added will cause a change of state

- **Solid**
- **Liquid**
- **Gas**
- **Plasma**

Change of State

- Melting point
  - Point at which a substance transitions from a solid to a liquid or vice versa if thermal energy is being extracted
  - Once the melting point is reached, further energy is required to provide the work needed to overcome the intermolecular bonds which hold the solid together
  - Temperature will remain constant during this transition
  - Once melting is complete, additional energy added will increase the temperature of the liquid

Change of State

- Solid
- Liquid
- Gas
- Plasma

- Melting point
  - The thermal energy required to melt a given substance is called the specific latent heat of fusion, L_f

$$Q = mL_f$$

  - The units for specific latent heat of fusion are, J/kg

Substance	Specific latent heat of fusion/kJ kg^{-1}	Melting temperature/°C	Specific latent heat of vaporization/kJ kg^{-1}	Boiling temperature/°C
Water	334.4	0	2257	100
Ethanol	108.9	−114	840	78.3
Aluminium	395	660	10548	2467
Lead	23	327	849.7	1740
Copper	205	1078	2567	5190
Iron	275	1540	6285	2800

Change of State

- Solid
- Liquid
- Gas
- Plasma

- Boiling point
  - Point at which a substance transitions from a liquid to a gas or vice versa if thermal energy is being extracted
  - Once the boiling point is reached, further energy is required to provide the work needed to overcome the intermolecular forces which hold the liquid together, i.e. to further separate them
  - Temperature will remain constant during this transition
  - Once boiling is complete, additional energy added will increase the temperature of the gas

Change of State

- Solid
- Liquid
- Gas
- Plasma

- Boiling point
  - The thermal energy required to turn a given liquid into a gas is called the specific latent heat of vaporization, L_v

$$Q = mL_v$$

Substance	Specific latent heat of fusion/kJ kg^{-1}	Melting temperature/°C	Specific latent heat of vaporization/kJ kg^{-1}	Boiling temperature/°C
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Change of State

- Solid
- Liquid
- Gas
- Plasma

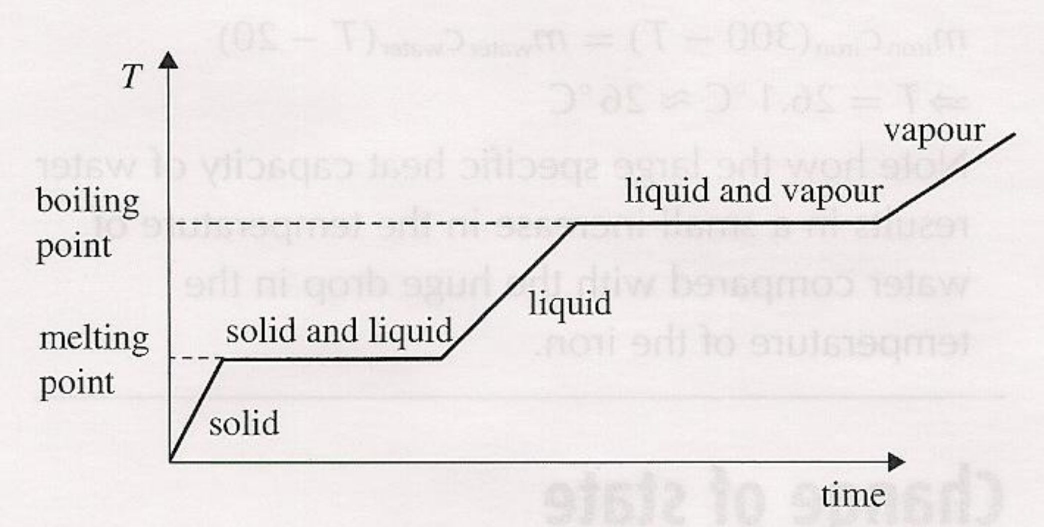
- Gas to Plasma
  - Not assessed by IB or discussed in Tsokos
  - At extremely high temperatures, electrons have so much energy that it overcomes the electromagnetic attraction of the nucleus
  - Electrons separate from the nucleus and we are left with a mixture of electrons and nuclei

Change of State

- **Solid**
- **Liquid**
- **Gas**

- Sample Problem

How much heat is required to completely vaporize 10 kg of lead at 25° C?



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Change of State

- Solid
- Liquid
- Gas
- Plasma

- Specific Latent Heats
  - Amount of heat needed to change the state of a unit mass of a material at its specific melting / boiling point
- Latent Heats (Not Specific)
  - The amount of heat needed to change the state of a material irrespective of mass

Measuring Specific Heat – Method of Mixtures

- In order to determine the specific heat of a substance, we need to measure
  - The amount of heat added
  - Mass of the substance
  - The change in temperature

Calorimetry

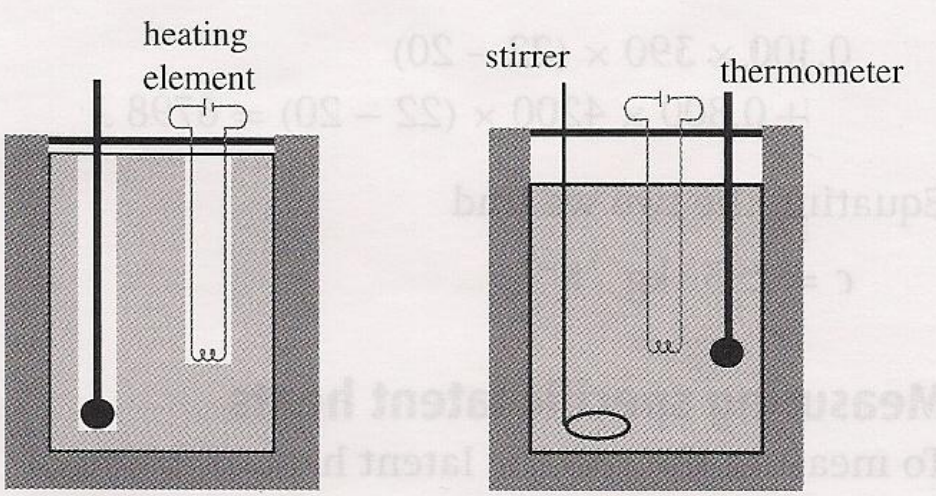

Figure 2.4 Apparatus for measuring the specific heat capacity of a solid (left) and a liquid (right).

$$Q = mc\Delta T$$

$$c = \frac{Q}{m\Delta T}$$

Measuring Specific Heat – Method of Mixtures

- A second method is to drop a hot substance into a cold liquid whose specific heat is known
- By obtaining an equilibrium temperature we can calculate the unknown specific heat

Calorimetry

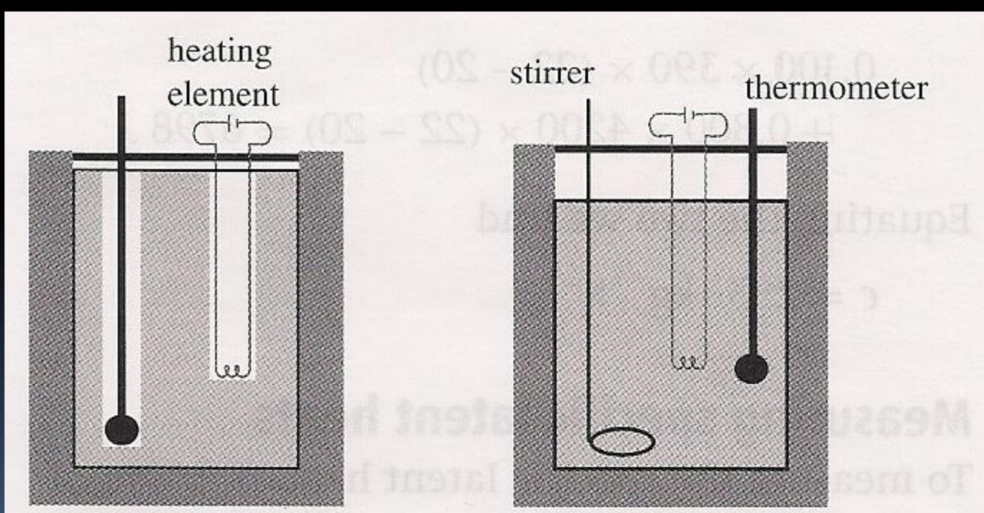

Figure 2.4 Apparatus for measuring the specific heat capacity of a solid (left) and a liquid (right).

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Measuring Specific Latent Heats

- A similar method can be used to determine the latent heat of fusion
- Drop a cold solid substance at its melting temperature into a warm liquid mixture of the same substance
- By measuring the temperature change of the liquid we can calculate the energy given up by the liquid that was used to melt the solid

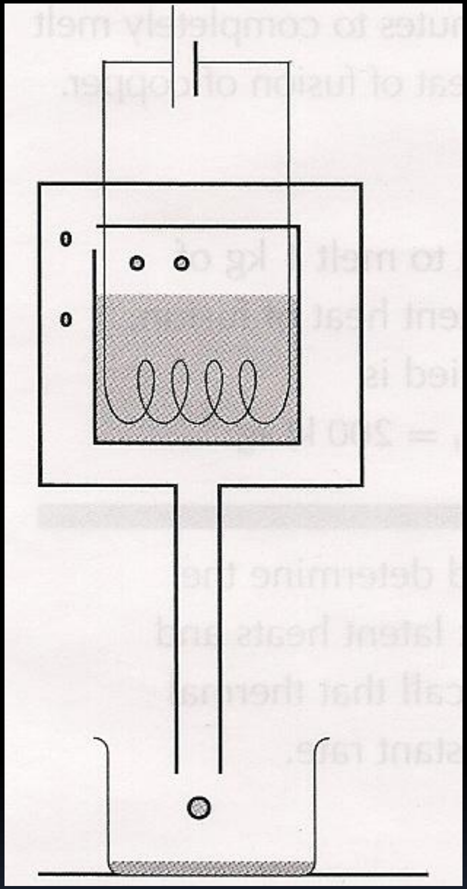
$$Q_l = m_l c \Delta T$$

$$Q_s = mL$$

$$Q_l = Q_s$$

Measuring Specific Latent Heats

- Specific heat of vaporization can be measured using the device shown at right
- Measure the amount of heat added to a liquid in a double container
- As the liquid vaporizes, it leaves the inner container, condenses on the outer container, and then drips down and is collected in a beaker at the bottom



$$Q = mL$$

Evaporation

- The molecules of a liquid are constantly moving at various speeds
- At the surface of the liquid, the fastest of these molecules may contain enough energy to break free and enter the atmosphere as vapour (vapor)
- When that molecule has left, the total kinetic energy of the liquid has decreased which means its temperature will drop

Evaporation

- Rate of evaporation increases with surface area and temperature of the liquid
- In an enclosed system, the escaping vapour creates vapour pressure above the surface of the liquid causing some of the molecules to re-enter the liquid
- Evaporation continues until equilibrium is reached where as many molecules leave the liquid as those that return
- The air is then considered saturated

Understandings:

- Molecular theory of solids, liquids and gases
- Temperature and absolute temperature
- Internal energy
- Specific heat capacity
- Phase change
- Specific latent heat

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QUESTIONS?

Homework

#1-12