H2 Topic 6A

Thermal Physics (I)

Content

- Temperature scales
- Specific heat capacity
- Specific latent heat

Learning Outcomes

Candidates should be able to

(a) show an understanding that regions of equal temperature are in thermal equilibrium.

(b) show an understanding that there is an absolute scale of temperature which does not depend on the property of any particular substance, i.e. the thermodynamic scale.

(c) apply the concept that, on the thermodynamic (Kelvin) scale, absolute zero is the temperature at which all substances have a minimum internal energy.

(d) convert temperatures measured in Kelvin to degrees Celsius: T / K = T / °C + 273.15.

(e) define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.

(f) define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.

6.0 Introduction

In case you have not already realised, the concept of energy is central to the study of physics. As you have just learnt in the topic of Work, Energy & Power, energy can manifest in many different forms. The topic of Thermal Physics deals with several of these manifestations, which we term “heat”, “thermal energy” or, as you will learn later, “internal energy of a substance”. This study is important because energy in these forms is responsible for a host of phenomena which include how “hot” an object is, state changes in substances, and chemical reactions. This topic is split into two different parts. This first set of notes deals with how we perceive heat at a macroscopic level. This involves temperature and a study of the thermal properties of matter.

6.1.1 Temperature & Thermometric Properties

In general, we measure the “hotness” of an object using a concept called “temperature”.

In order to construct a suitable temperature “ruler” or scale, we may rely on the thermometric properties of substances.

Intuitively, a thermometric property of a substance is a physical property that varies with hotness/temperature.

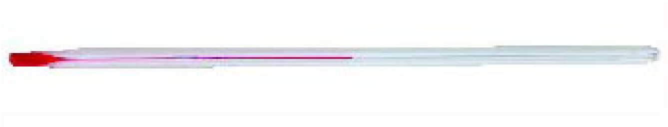
Examples include:

- Length (of a strip of metal)
- Area (of a sheet of metal)
- Volume (of a column of mercury)
- Pressure (exerted by a gas on the surface of a container)

A good thermometric property to set up a temperature scale would exhibit the following traits:

- Measurable
- Substance remains in the same state over the range of temperatures to be measured
- Property varies linearly over the range of temperatures to be measured

For the temperature scale that we are about to construct, we will use a column of mercury with a fixed cross sectional area.



If the surroundings of the bulb get warmer, the volume of the mercury will expand, causing the height of the liquid column to rise.

Conversely, if the surroundings of the bulb get colder, the volume of the mercury will contract, causing the height of the liquid column to fall.

6.1.2 The Centigrade Scale & Thermometer Calibration

In order to set up any scale, we need to define a lower and a higher reference (fixed) point. As we are going to chop up the difference between these two levels of hotness into 100 parts (degrees), we shall call this particular temperature scale the *"cent*igrade" scale

As water is so commonplace in both scientific study and everyday life, it makes sense that in the temperature scale that we are about to construct, water should be involved.

The **lower fixed point is the melting point of water**. We designate this as 0 degrees on the centigrade scale ($0°C$).

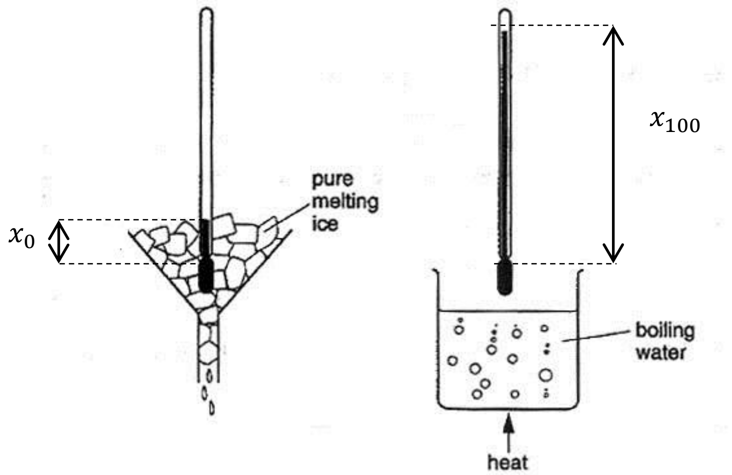
The **upper fixed point is the boiling point of water**. We designate this as 100 degrees on the centigrade scale ($100°C$)

With these two reference points and the column of mercury mentioned above, we are now ready to properly set up the temperature scale.

The following steps describe this process:

Liquid-in-glass Thermometer Calibration

1. Place the bulb of the mercury column in crushed, melting, pure ice. Measure the height of the mercury column, x_0
   - Ice must be crushed to ensure that maximum coverage of the bulb.
   - Ice must be melting to ensure that the temperature is at 0 degrees.
2. Immerse the bulb of the mercury column in steam. Measure the height of the mercury column x_{100}.
   - Water must be boiling to ensure that the height represents 100 degrees.



Thus, the height for each degree of temperature is given by

$$\frac{\Delta x}{\Delta T} = \frac{x_{100} - x_0}{100}$$

For an unknown temperature which causes the mercury column to have a height of $x_?$, we may thus determine the temperature by taking

$$T = \frac{x_? - x_0}{x_{100} - x_0} \times 100$$

Example 1:

At ice-point, the mercury column of an unmarked thermometer has a height of 2.0 cm. At boiling point, the mercury column has a height of 24.0 cm. What is the temperature when the mercury column reads 18.0 cm?

$$T=\frac{x_?-x_0}{x_{100}-x_0}\times 100$$

$$T=\frac{18.0-2.0}{24.0-2.0}\times 100=72.7^\circ C$$

In practice, we may calibrate using different thermometers and thermometric properties, and may even set the upper and lower fixed points at different temperatures. In which case, the formula given above may be generalised to give

$$T=\frac{x_?-x_{lower}}{x_{upper}-x_{lower}}\times\left(T_{upper}-T_{lower}\right)+T_{lower}$$

Example 2:

A resistance thermometer gives a resistance of 20 Ω when the temperature is known to be -10 ˚C. When the temperature is 110 ˚C, the resistance thermometer has a resistance of 500 Ω. What is the temperature when the resistance is 360 Ω.

$$T=\frac{x_?-x_{lower}}{x_{upper}-x_{lower}}\times\left(T_{upper}-T_{lower}\right)+T_{lower}$$

$$T=\frac{360-20}{500-20}\times[110-(-10)]+(-10)=75\ ^\circ C$$

6.1.3 Constant Volume Gas Thermometer

Learning outcomes

(c) apply the concept that, on the thermodynamic (Kelvin) scale, absolute zero is the temperature at which all substances have a minimum internal energy.

The constant volume gas thermometer makes use of the pressure of the gas contained as its thermometric property.

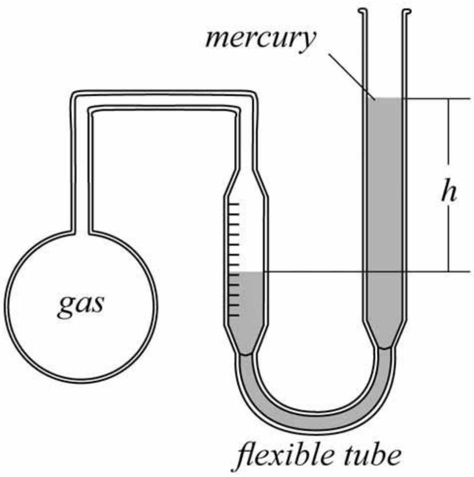


Image from http://wikipremed.com/image_science_archive_68/010301_68/125150_24801_68.jpg

At the lower fixed point, the mercury level on the left limb of the manometer is recorded. The gas pressure may be determined by

$$P_{lower} = \rho_{Hg} g h_{lower} + P_{atmosphere}$$

At the upper fixed point, the higher temperature causes the gas pressure to increase and force the mercury up the tube. The flexible tube is adjusted until the mercury in the left limb is the same level as before. The new pressure is thus calculated,

$$P_{upper} = \rho_{Hg} g h_{upper} + P_{atmosphere}$$

If ice and steam points are chosen for the lower and upper fixed points, for pressures recorded at unknown temperatures, the temperature may be determined using the calibration equation in the previous section,

$$T = \frac{P_{?}-P_0}{P_{100}-P_0} \times 100$$

When we try to plot a graph of pressure against temperature, a linear graph is formed. If the gas pressure is suitably low and the temperature much higher than the boiling point of the substance used, the type of gas used should not matter (as they all behave similar to an ideal gas, which we shall learn about later). The graphs for trials at different initial pressures are shown below.

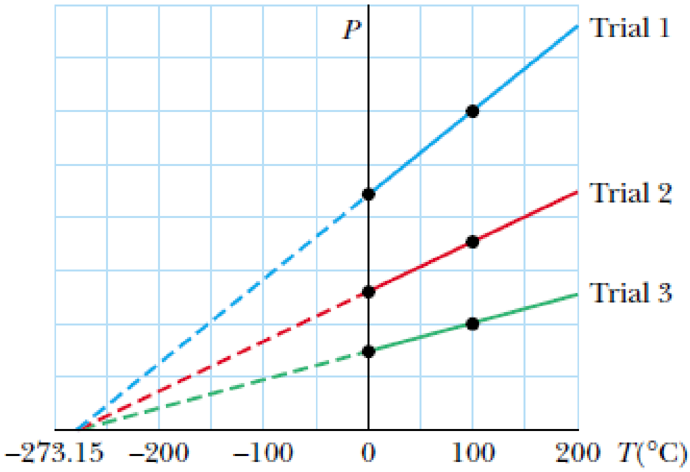


Image from *Physics for Scientists & Engineers,* Serway & Jewett

The dotted lines denote the extensions of the linear graphs obtained. It is interesting to note that they all meet at -273.15 ˚C. This very special temperature is known as **absolute zero**. Initially this was thought to be the temperature where the molecules stopped moving. However, as you will later learn in quantum physics, it is impossible for particles to do so.

Absolute zero is defined as the temperature where all substances have a <u>minimum internal energy</u>.

6.1.4 Absolute Scale

Learning outcomes

(b) show an understanding that there is an absolute scale of temperature which does not depend on the property of any particular substance, i.e. the thermodynamic scale.

(d) convert temperatures measured in Kelvin to degrees Celsius: T / K = T / °C + 273.15.

The problem with using ice and steam points of water in the practice of science is that it is far too imprecise. The exact conditions for ice and steam points are impossibly hard to duplicate in the laboratory due to impurities in water or pressure differences at different locations. Furthermore, the thermometric properties of different materials may differ in a non-linear manner, leading to differences in the temperature scale constructed. For greater precision, we must define an **absolute thermodynamic scale**.

An **absolute thermodynamic scale** is a temperature scale that does not depend on the thermometric property of any particular substance.

This is in contrast to **empirical temperature scales**, like the centigrade.

Empirical temperature scales are scales which are based on the variation with temperature of a property of a substance, assuming that the property varies linearly with temperature.

As we did in the centigrade scale, we have to choose a suitable upper and lower fixed point.

We already have a most obvious candidate for a lower fixed point, and that is absolute zero.

The lower fixed point on the absolute thermodynamic scale of temperature is absolute zero.

Choosing an upper fixed point however, is less obvious. By common agreement, this was decided to be the **triple point of water**.

The upper fixed point on the absolute thermodynamic scale of temperature is the triple point of water.

The **triple point of water** is the specific pressure and temperature at which three states of water can co-exist in equilibrium.

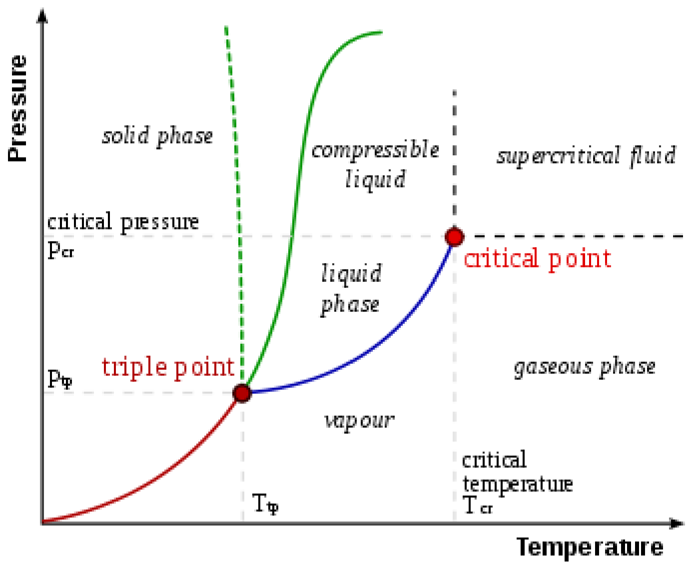


Image from http://4.bp.blogspot.com/-cN55A9IZMzQ/T81x4tqV05I/AAAAAAAAAYw/P5ebEkR3OBs/s400/Triple+point+of+water.png

The triple point of water was chosen because it is

- unique
- invariant
- experimentally easy to duplicate in the laboratory

Now that we have decided on the upper and lower fixed points, we now have to decide how many divisions to chop up the scale by. Since we are used to the centigrade, we want the divisions to be similar.

Absolute zero and the triple point of water were designated the values of -273.15 ˚C and 0.01 ˚C respectively as these are the temperatures that they are *typically* found at on the centigrade scale. Hence, by cutting up the difference in hotness between these two points into 273.16 parts and setting the start point as absolute zero, we have thus created the Kelvin scale of temperature.

1 Kelvin (1 K) is defined as 1/273.16 of the temperature difference between absolute zero and the triple point of water.

If we disguise the Kelvin scale to look like the centigrade scale and insist that the triple point occurs at 0.01 units of temperature above zero, we get what we now call the Celsius scale.

To convert temperature from Kelvin to Celsius and vice-versa, we use the formula,

$$T_K = T_C + 273.15$$

For the A-levels, we do not distinguish between Celsius and centigrade, but note that the two scales are *not* the same. **The Celsius and Kelvin scales are both absolute scales**, with lower and upper fixed points as absolute zero and the triple point of water. **The centigrade scale is an empirical scale** which sets the ice and steam points of water as the lower and upper fixed points. To highlight this difference, on the Celsius scale, the steam point of water is 99.98 ˚C (373.13 K), while on the centigrade scale, it is precisely 100 ˚C.

6.2.0 The Zeroth Law of Thermodynamics

Now that we have a proper understanding of temperature, we can begin to construct the laws of thermodynamics.

When two or more objects in thermal contact have no net heat transfer or cease to have any exchange of heat, i.e., at the same temperature, the objects are said to be in **thermal equilibrium**.

The **zeroth law of thermodynamics** states that if objects A and B are separately in thermal equilibrium with object C, then object A and B are in thermal equilibrium with each other.

This is the law upon which all other laws of thermodynamics are based upon.

6.2.1 Heat Capacities and Specific Heat Capacities

Learning outcomes

(e) define and use the concept of specific heat capacity, and identify the main principles of its determination by electrical methods.

If an object A is placed in an environment where the temperature is higher, the **energy supplied by the external hotter environment is known as thermal energy** (**or heat**). Conversely, if object A is placed in a region where the **temperature is lower**, **heat is removed from the object**. The process will continue until the **object's temperature is the same as the environment**. In physics, we say **thermal equilibrium has been reached**.

Heat is usually represented mathematically with the symbol Q.

If the object in the oven is supplied with Q amount of energy, assuming that no chemical changes have occurred, and there is no change of state, it's temperature change will be proportional to Q.

$$Q = C\Delta T$$

The constant of proportionality, C is known as the heat capacity of the object.

The **heat capacity (C)** of an object is defined as the quantity of heat required per unit temperature rise.

Units: $J.K^{-1}$, $J.^{\circ}C^{-1}$

For twice the amount of object A, twice the amount of energy is needed to illicit the same temperature rise. We modify the equation above slightly to give

$$Q = mc\Delta T$$

The constant of proportionality, c, is known as the specific heat capacity of the object.

The **specific heat capacity (c)** of an object is defined as the quantity of heat required per unit temperature rise per unit mass.

Units: $J.(kg.K)^{-1}$, $J.(kg.^{\circ}C)^{-}$

Every material will have three specific heat capacities, one for each state.

Example 3

An electric heater supplies 1.8 kW of power in the form of heat to a tank of water. How long will it take to heat the 200 kg of water in the tank from 10 to 70 ˚C? Assume that no heat is lost to the surroundings.

Specific heat capacity of water: 4186 J.(kg.K)$^{-1}$

Solution:

Heat is supplied by the electric heater.

Therefore,

$$P\Delta t = Q$$

$$P\Delta t = mc\Delta T$$

$$1800 \times \Delta t = 200 \times 4186 \times (70\text{-}10)$$

$$\Delta t = \frac{200 \times 4186 \times 60}{1800} = 27907 \text{ s} = 7.75 \text{ h}$$

Example 4

A 2 kg copper ball at 120 ˚C is thrown into 5 kg of water at 40 ˚C. Assuming that no heat is lost to the surrounding, what is the final temperature of the mixture?

Specific heat capacity of copper: 400 $J.(kg.K)^{-1}$

Specific heat capacity of water: 4200 $J.(kg.K)^{-1}$

Solution:

By principle of conservation of energy,

$$Q_{\text{lost by Cu}} = Q_{\text{gain by water}}$$

$$m_{Cu}\, c_{Cu} \Delta T_{Cu} = m_w c_w \Delta T_w$$

Also note that the mixture must reach thermal equilibrium. Their final temperatures will be the same.

$$m_{Cu}\, c_{Cu}(T_{Cu,\,i} - T_f) = m_w c_w (T_f - T_{w,\,i})$$

$$2 \times 400 \times (120 - T_f) = 5 \times 4200 \times (T_f - 40)$$

$$T_f = 42.9\ ^{\circ}C$$

Note that heat can be supplied by conversion from other forms of energy.

Example 5

A lead bullet of mass m is fired at a tree trunk and emerges on the other side. The speed of the bullet is 500 $m.s^{-1}$ as it enters and 300 $m.s^{-1}$ as it emerges. Assuming that 40% of the loss of kinetic energy is stored as heat in the bullet, calculate the rise in temperature of the bullet.

Specific heat capacity of lead: 129.766 $J.(kg.K)^{-1}$

Solution:

$$0.4 \times \Delta KE = Q$$

$$0.4 \times (KE_{initial} - KE_{final}) = mc\Delta T$$

$$0.4 \times \frac{1}{2}m\left(v_{initial}^2 - v_{final}^2\right) = mc\Delta T$$

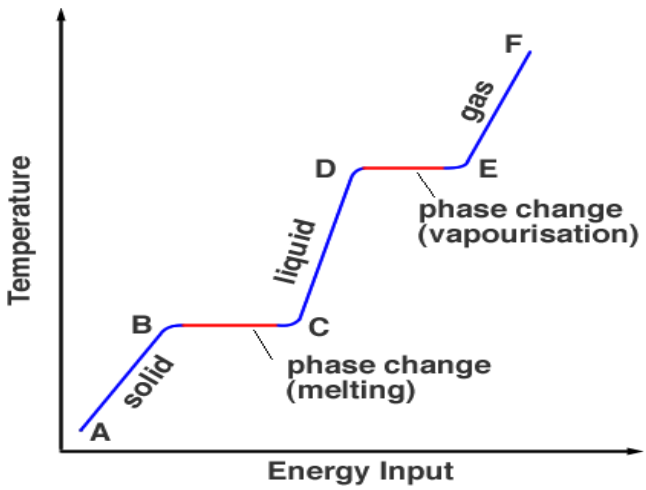
$$\Delta T = 0.4 \times \frac{\left(500^2 - 300^2\right)}{2 \times 129.766} = 246.6\ ^{\circ}C$$

6.2.3 Changes of State, Latent Heats and Specific Latent Heats

Learning outcomes

(f) define and use the concept of specific latent heat, and identify the main principles of its determination by electrical methods.

If we plot a graph of the temperature of an object against the heat energy supplied, we obtain a plot that looks like the following.



Notice that the object increases in temperature until the melting or boiling point before it is able to undergo a change in state (physicists refer to this as phase). During the change in state, there is no temperature change.

The **latent heat** of a substance is defined as the amount of thermal energy required to bring about a complete change of state, without any change in temperature.

Units: J

The **specific latent heat (l)** of a substance is defined as the amount of thermal energy required per unit mass to bring about a complete change of state without any change in temperature.

Units: $J.kg^{-1}$

The formula relating the latent heat to the specific latent heat is given by,

$$Q = ml$$

Every substance has two latent heats, one for melting (or fusion) and the other for vapourisation (or condensation). The definitions above thus change slightly.

The **latent heat of fusion** a substance is defined as the amount of thermal energy required to bring about a complete change of state from solid to liquid, without any change in temperature.

The **specific latent heat of fusion, (l_f)** of a substance is defined as the amount of thermal energy required per unit mass to bring about a complete change of state from solid to liquid without any change in temperature.

The **latent heat of vaporisation** a substance is defined as the amount of thermal energy required to bring about a complete change of state from liquid to gas, without any change in temperature.

The **specific latent heat of vaporisation, (l_v)** of a substance is defined as the amount of thermal energy required per unit mass to bring about a complete change of state from liquid to gas without any change in temperature.

Example 6

How much steam at 120 ˚C is needed to heat 800 g of aluminium from 20 to 70 ˚C?

Specific heat capacity of aluminium: 920.92 J.(kg.K)$^{-1}$

Specific heat capacity of steam: 1925.56 J.(kg.K)$^{-1}$

Specific latent heat of vaporisation for water: 2,260,440 J.kg^{-1}.

Specific heat capacity of water: 4186 J.(kg.K)$^{-1}$

Solution:

Remember that steam has to cool to 100 ˚C first, before changing state. Once the process is complete, the water has to cool to 70 ˚C.

By conservation of energy,

$$Q_{st,\,\Delta T} + Q_{st\rightarrow w} + Q_{w,\,\Delta T} = Q_{gain\ in\ Al}$$

$$m_{st}c_{st}\Delta T_{st} + m_{st}l_v + m_{st}c_w\Delta T_w = m_{Al}c_{Al}\Delta T_{Al}$$

$$m_{st}(c_{st}\Delta T_{st} + l_v + c_w\Delta T_w) = m_{Al}c_{Al}\Delta T_{Al}$$

$$m_{st} = \frac{m_{Al}c_{Al}\Delta T_{Al}}{c_{st}\Delta T_{st} + l_v + c_w\Delta T_w} = \frac{0.8 \times 920.92 \times 50}{1925.56 \times 20 + 2{,}260{,}440 + 4186 \times 30} = 0.0152\ \text{kg}$$

Example 7:

What is the mass of unmelted ice when 200 g of ice at -20 ˚C is dropped into 350 g of water at 40 ˚C contained in a container whose heat capacity is 209.3 $J.K^{-1}$.

Specific heat capacity of water: 4186 $J.(kg.K)^{-1}$
Specific heat capacity of ice: 2108 $J.(kg.K)^{-1}$
Specific latent heat of fusion of water: 334,000 $J.kg^{-1}$

Solution:

We note that the question asks for unmelted ice, implying that the system is at thermal equilibrium at 0 ˚C.

Taking the same approach as the previous example,

$$\text{Total heat gained} = \text{Total heat lost}$$

$$Q_{w,\,\Delta T} + Q_{con,\,\Delta T} = Q_{all\ ice,\Delta T} + Q_{some\ ice \rightarrow water}$$

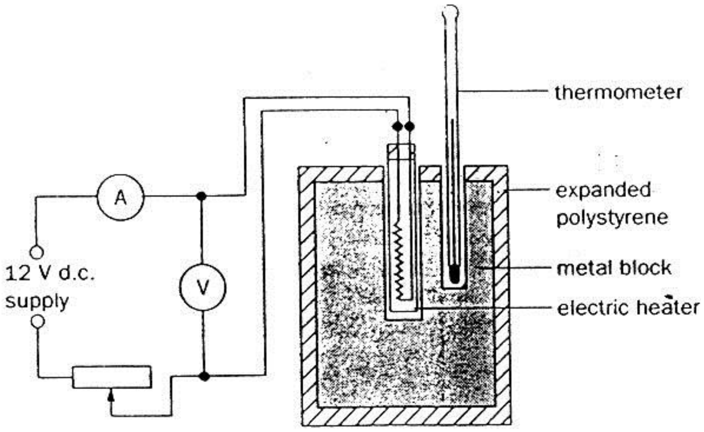
$$m_w c_w \Delta T_w + C_{con} \Delta T_{con} = m_{all\ ice} c_{ice} \Delta T_{ice} + m_{some\ ice} l_f$$

$$m_{some\ ice} = \frac{0.35 \times 4186 \times 40 + 209.3 \times 40 - 0.2 \times 2108 \times 20}{334{,}000} = 0.175 \text{ kg}$$

$$m_{ice\ left} = 200 - 175 = 25 \text{ g}$$

Annex A: Determination of Specific Heat Capacity of Solid Metal

This method is suitable for metals such as copper and aluminum that are good thermal conductors.



Set-up

- The solid is in the form of a thick cylindrical block with two deep holes.
- The heating coil is inside one hole, the thermometer is inside the other hole.
- Both the thermometer and heater must make good thermal contact with the material of the block. This is obtained by putting some oil in the holes.
- The block is lagged with expanded polystyrene to reduce heat loss to the surroundings.

Procedure

1. Measure the initial temperature T_1 and mass m_1 of the block.
2. Heat the block for a known time t_1.
3. Measure the final temperature T_2 of the block.
4. Record

I	=	current in the heater (from ammeter)
V	=	potential difference across heater (from voltmeter)
t	=	heating time
m	=	mass of block

T_1 = initial temperature

T_2 = final temperature

5. Calculations:

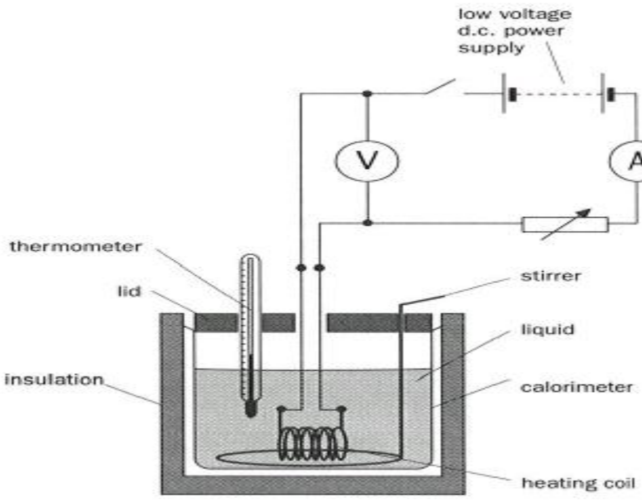
Ignoring heat loss to surrounding,

$$P = \frac{Q}{t} = \frac{mc\Delta T}{t}$$

$$IV = \frac{mc(T_2 - T_1)}{t}$$

$$c = \frac{VIt}{m(T_2 - T_1)}$$

Annex B: Determination of Specific Heat Capacity of Liquids (Calorimeter)



Set-up

- The liquid is in a calorimeter.
- The calorimeter is lagged with an insulating jacket (e.g. felt) to reduce heat loss to the surroundings.

Procedure

1. Measure the initial temperature T_1 of the liquid.
2. Heat the liquid with the heater for a known time t, stirring the liquid slowly to evenly distribute the heat.
3. Measure the final temperature T_2 of the liquid.
4. Record

I	=	current in the heater (from ammeter)
V	=	potential difference across heater (from voltmeter)
t	=	heating time
m	=	mass of liquid
T_1	=	initial temperature
T_2	=	final temperature
m_c	=	mass of calorimeter + stirrer
c_c	=	specific heat capacity of calorimeter + stirrer

5. Calculations:

By conservation of energy (assume no heat loss),

$$Pt = Q_{\text{gain by liquid}} + Q_{\text{gain by calorimeter + stirrer}}$$

$$IVt = mc(T_2 - T_1) + m_c c_c (T_2 - T_1)$$

$$c = \frac{IVt - m_c c_c (T_2 - T_1)}{m(T_2 - T_1)}$$

Annex C: Determination of Specific Heat Capacity of Liquids (Continuous Flow)

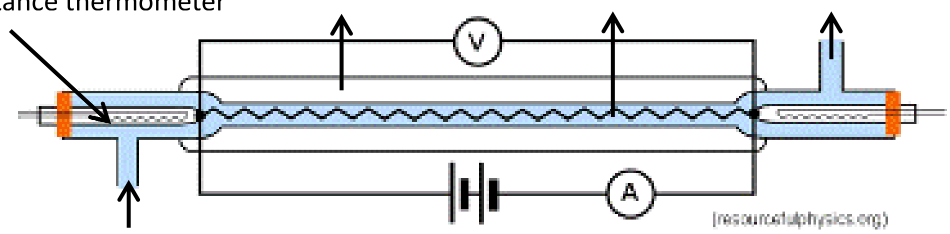


Image from http://tap.iop.org/energy/thermal/607/page_47500.html

Set-up

- Cool liquid enters one end of the continuous flow calorimeter and exits through the other end.
- The liquid is heated up by a heating coil as it passes through.
- Resistance thermometers are placed at each end to record the temperatures.
- Heat loss by conduction is reduced by placing a vacuum over the calorimeter.

Procedure

1. Pass liquid through the calorimeter and wait until a steady state has been reached.
2. Record

I_1	=	current in the heater (from ammeter)
V_1	=	potential difference across heater (from voltmeter)
R_1	=	flow rate of liquid $\left(\frac{m}{t}\right)$
T_1	=	initial temperature
T_2	=	final temperature

3. Assuming the rate of heat loss to environment is h,

$$P = \frac{Q_{liquid}}{t} + h$$

$$I_1V_1 = R_1c(T_2 - T_1) + h \qquad \text{---------- (1)}$$

Note that *c* and *h* are both unknowns. The equation cannot be solved yet.

4. The second equation is solved by repeating the experiment at a different flow rate, R_2

   The heat loss *h* is assumed to be proportional to the temperature difference between the entrance and the exit. As we wish for this to remain constant, I and V must be adjusted such that T_2 and T_1 remains the same.

   Record,

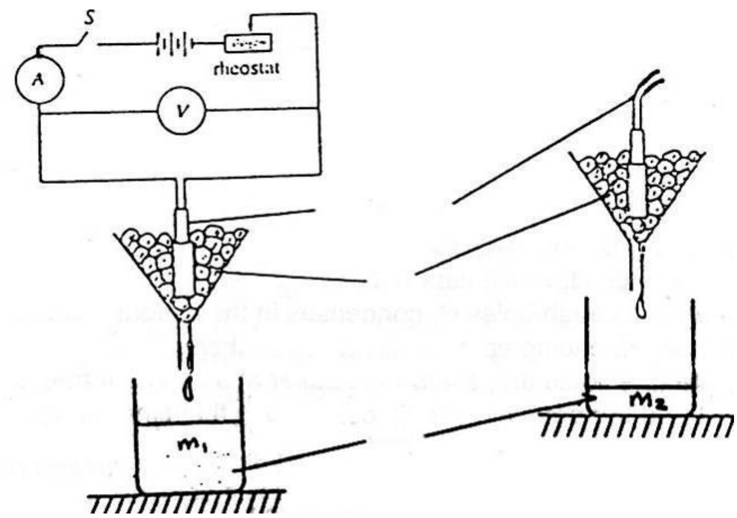
R_2	=	new flow rate
I_2	=	current in the heater (from ammeter)
V_2	=	potential difference across heater (from voltmeter)

5. Construct the second equation,

$$I_2V_2 = R_2c(T_2 - T_1) + h \qquad \text{----------} \ (2)$$

   Solve the simultaneous equations for *c* and *h*.

Annex D: Determination of Specific Latent Heat of Fusion



Set-up

- An electric heater is placed in a funnel containing the melting substance, in this case, ice. Ice must be crushed to ensure maximum contact with heater. Ice must be melting to ensure temperature is 0 ˚C
- A disconnected heater is placed in another similar funnel with melting ice. This is to determine the amount of water collected due to heat gain from the environment.
- When switch *S* is closed, a beaker is placed below each of the funnels to collect water from the melting ice.

Procedure

1. Heat the ice with the heater for a known time *t*.
2. Measure the final mass *m* of the liquid collected in both cases.
3. Record

I	=	current in the heater (from ammeter)
V	=	potential difference across heater (from voltmeter)
t	=	time elapsed
m_1	=	mass of liquid from funnel with heater on
m_2	=	mass of liquid from funnel with heater off

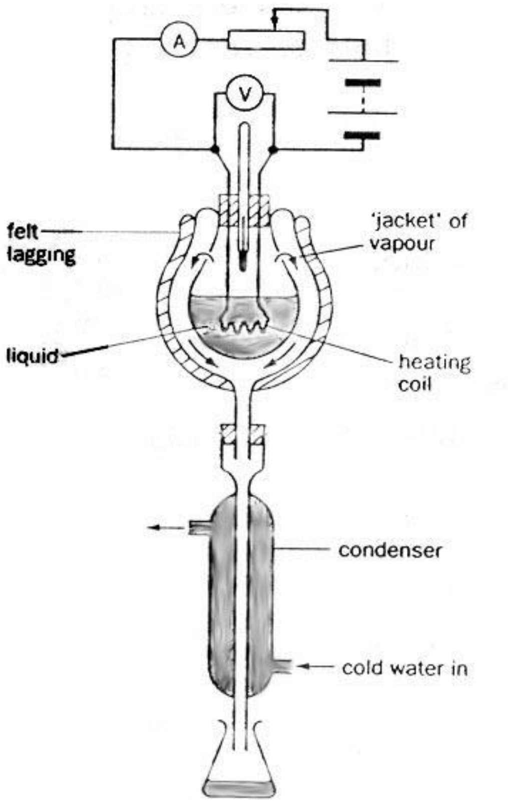
4. The heat capacity may then be computed from,

$$Pt = m_{\text{melted by heater alone}} l_f$$

$$IVt = (m_1 - m_2) l_f$$

$$l_f = \frac{IVt}{m_1 - m_2}$$

Annex E: Determination of Specific Latent Heat of Vaporisation



Set-up

- Liquid is placed in vessel thermally insulated by felt lagging.
- Heater heats the liquid until boiling, causing it to vaporise.
- The vapour escapes through holes and travels down the vapour jacket where it condenses in the condenser. The fluid may then be collected in the beaker.

Procedure

1. When liquid boils and drips into the beaker at a steady rate, place the beaker under the condenser to collect the fluid for a fixed time *t*.
2. Record,

I_1	=	current (from ammeter)
V_1	=	potential difference across heater (from voltmeter)
t_1	=	heating time
m_1	=	mass of liquid collected

3. From conservation of energy,

$$I_1V_1 = \frac{m_1}{t_1} l_v + h \qquad \text{---------- (1)}$$

Where h is the rate of heat dissipated to the environment.

4. As there are two unknowns, a heater at a different power rating is used.

Record,

I_2	=	current (from ammeter)
V_2	=	potential difference across heater (from voltmeter)
t_2	=	heating time
m_2	=	mass of liquid collected

5. Form the equation,

$$I_2V_2 = \frac{m_2}{t_2} l_v + h \qquad \text{---------- (2)}$$

Solve the simultaneous equations for l_v and h.

Temperature Scales

Self-Attempt Questions

1. Two objects, with different sizes, masses and temperatures, are placed in thermal contact. Energy travels

   (a) from the larger object to the smaller object.

   (b) from the object with more mass to the one with less.

   (c) from the object at higher temperature to the object at lower temperature.

   Which statement(s) (a), (b) or (c) is/are true?

2. Is it possible for two objects to be in thermal equilibrium if they are not in contact with each other? Explain.

3. Describe how the observations of thermal equilibrium lead to the concept of temperature.

4. How does the absolute (Thermodynamic) scale of temperature differ from the empirical temperature scale?

Discussion Questions

5. The table below gives data for two thermometers at three different temperatures (the ice-point, the steam point and room temperature).

Types of Thermometer	**Property**	**Value of property**		
		ice point	**steam point**	**room temp**
Gas	Pressure in mmHg	760	1040	795
Thermistor	Current in mA	12.0	54.0	15.0

   (a) Calculate the temperature of the room temperature according to each thermometer.

   (b) State why the thermometers disagree in their value for room temperature.

6. The following readings were taken for a constant pressure gas thermometer in order to find a thermodynamic temperature T.

Readings at temperature T		Readings at the triple point of water	
Pressure P/Pa	Volume V/ cm^3	Pressure P/Pa	Volume V/ cm^3
100 000	503.30	100 000	398.53
50 000	1006.20	50 000	798.19
10 000	5031.50	10 000	3997.20

(a) For each of the three pressures find a value for the unknown temperature.

(b) Explain why the values of temperatures calculated in (a) differ.

(c) Briefly explain how the exact value of T can be found.

[343.8 K]

Specific Heat Capacity & Specific Latent Heat

<u>Self-Attempt Questions</u>

7. Define ***heat capacity*** *and* ***specific heat capacity*** of a substance. How are these quantities related? What are their units?

8. When alcohol is rubbed on your body, it lowers your skin temperature. Explain this effect.

9. 10.0g of ice at –10˚C are introduced into 100g of water at 50˚C contained in a copper calorimeter with a mass of 50.0g. Calculate the final temperature reached.
(specific latent heat of ice = 0.34 x 10^6 $J.kg^{-1}$
specific heat capacity of ice = 2.09 x 10^3 $J.kg^{-1}.K^{-1}$
specific heat capacity of copper = 380 $J.kg^{-1}.K^{-1}$
specific heat capacity of water = 4200 $J.kg^{-1}.K^{-1}$)

[38.1 ˚C]

10. Liquid of unknown specific heat capacity flows at the rate of 0.1500 kg min^{-1} through a tube and is heated by a heater dissipating at 25.2 W. The inflow and outflow temperatures are 15.5 ˚C and 17.4 ˚C respectively. When the rate of flow is increased to 0.2318 kg min^{-1} and the rate of heating increases to 37.8 W, the inflow and outflow temperatures are unaltered. Find the rate of loss of heat from the tube.

[2.1 W]

11. 1 kg of vegetables, having a specific heat capacity 2200 $J.kg^{-1}.K^{-1}$, at a temperature of 373 K are plunged into a mixture containing some ice and 1 kg of water at 273 K. After all the ice has melted, the final temperature of the entire

mixture is 300 K. Calculate the mass of ice originally present. Assume no heat loss to the container and the surroundings.
Specific latent heat of fusion of ice = 3.34×10^5 J.kg^{-1}

[0.105 kg]

Discussion Questions

12. A thermally insulated vessel containing liquid water and water vapour is connected to a vacuum pump which removes water vapour continuously. When the temperature reaches 0˚C, the vessel contains 110 g of liquid water. What mass of ice has been formed when no liquid remains?
Specific latent heat of fusion of water = 3.40×10^5 J.kg^{-1};
Specific latent heat of vaporisation of water = 2.52×10^6 J.kg^{-1}

[96.9g]

13. Suppose you pour hot coffee for your guests and one of them wants to drink it with cream, several minutes later and then as warm as possible. In order to have the warmest coffee, should the person add the cream just after the coffee is poured or just before drinking? Explain.

14. In an electrical constant flow experiment to determine the specific heat capacity, c, of a liquid, heat is supplied to it at a rate of 27.4 W. When the rate of flow of the liquid is 0.192 kg.min^{-1} the inlet and outlet temperatures are 10.4°C and 13.5°C respectively.
    a) Calculate an approximate value for c.
    b) The experiment is now repeated with a flow-rate of 0.132 kg.min^{-1}. In order to maintain the same temperatures, the power supplied is adjusted to 19.3 W. What are the advantages of this method of determining the specific heat capacity of a liquid using two sets of data? Why must the temperatures be made the same for both trials? Calculate an accurate value for c.

[2.76×10^3 J.kg^{-1}.K^{-1}, 2.61×10^3 J.kg^{-1}.K^{-1}]

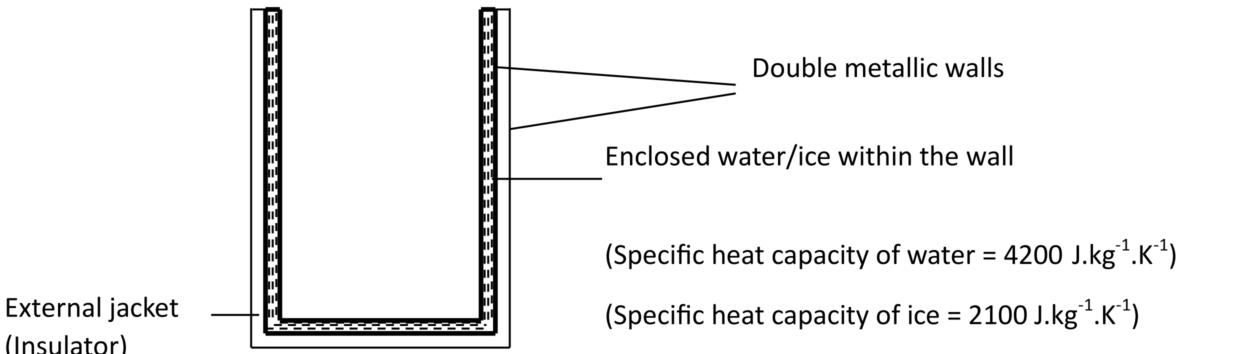
15. A lead bullet is fired with a muzzle velocity of 320 m.s^{-1} and becomes immediately embedded in clay. Estimate the fraction of the mass of the bullet which melts, assuming that all the heat generated remains as internal energy in the lead.
Given that the muzzle temperature of the bullet is 30˚C,
    a) melting point of lead is 330$^{˚C}$,
    b) the specific heat capacity of lead is 130 J.kg^{-1}.K^{-1} and
    c) the specific latent heat of fusion of lead is 2.1×10^4 J.kg^{-1}.

[0.58]

16. A thermally insulated vessel containing air, water vapour and liquid water, initially at room temperature, is connected to a vacuum pump. As air and vapour are removed from the vessel, it is observed that the temperature of the liquid water remaining in the vessel falls and that finally ice is formed.
   (a) Making reference to the *simple kinetic model* for matter, explain why the water temperature falls.
   (b) If 75 g of water remains when the temperature of the contents of the vessel just reaches 0 °C, what mass of ice is formed when no liquid remains?
   (Specific latent heat of vaporisation of water at 0 °C = 2.52 x 10^6 J.kg^{-1};
   Specific latent heat of fusion for water at 0 °C = 0.34 x 10^6 J.kg^{-1})

[0.066 kg]

17. A typical design of a cup to keep drinks cold is shown in the figure below. The internal hollow wall of the cup is filled with water which is enclosed within the sides and bottom of the cup by double metallic walls. An external jacket houses the cup to reduce heat gain. Before being used, the cup would be placed in the fridge to freeze the enclosed water.
Assume no heat gain/lost to surroundings as well as to the double metallic walls



The mass of enclosed ice is 50 g and the initial temperature of the cup is -4˚C.
330 g of drinking water at an initial temperature of 25˚C is poured into the cup.
(i) Determine the equilibrium temperature.
(ii) Sketch the heating curve of the enclosed water during this process.

[10.8˚C]