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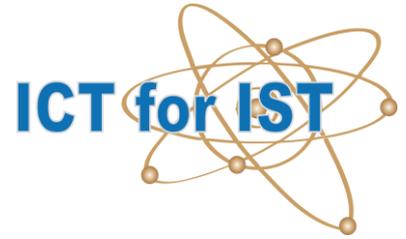
Lifelong Learning Programme

Leonardo da Vinci

ICT for Innovative Science Teachers

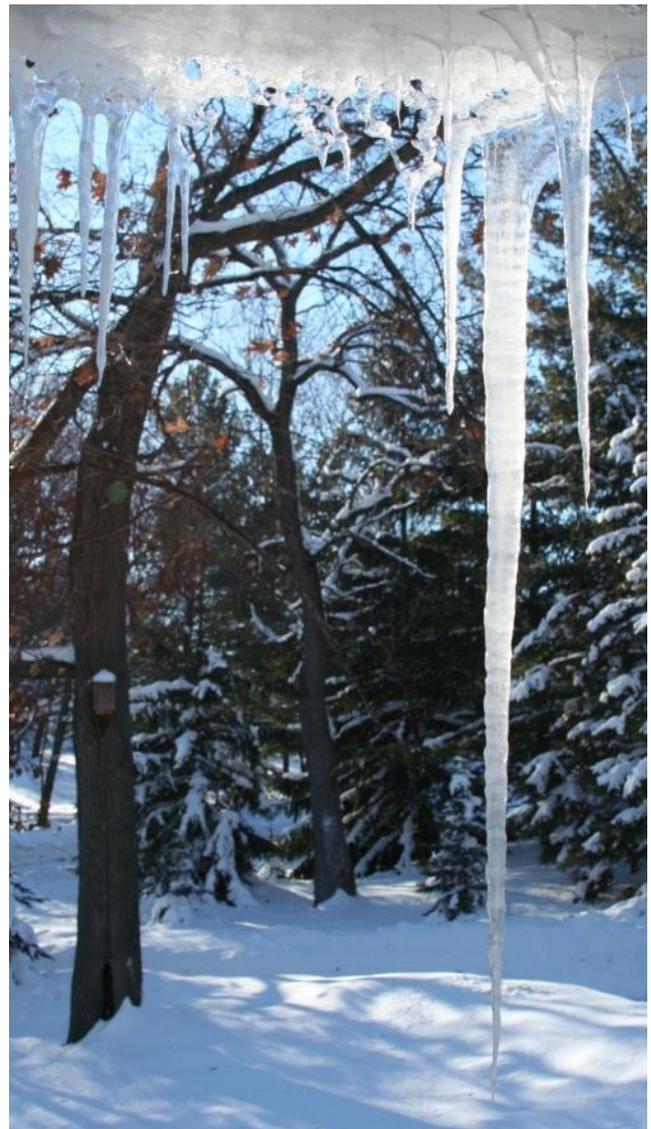
Leonardo da Vinci programme

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# Cooling and Change of State

It is well known that one of the most common liquids in everyday life, water, can be changed into a solid or a gas by raising or lowering its temperature sufficiently; below 0 °C water becomes solid ice and above 100 °C (at normal atmospheric pressure), water boils into steam. These changes of physical state are accompanied by transfers of energy; to freeze water, heat must be removed; to boil water heat must be supplied. The kinetic theory of matter has been developed to help us understand these changes and transfers and has allowed us to build models to predict the behaviour of substance during heating and cooling.



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# A. Introduction ●●

This module offers activities related to the phenomenon of substances changing their state from liquid to solid during cooling.

There are four types of activities:

- 1. Data logging:** a laboratory experiment to observe and measure the change of temperature of a liquid as it cools into the solid state. The temperature recording may also be synchronized with video capture.
- 2. Simulation:** a visual aid to assist an interpretation of the phenomenon of change of state in terms of a kinetic theory of particles.
- 3. Modelling:** a mathematical model to predict changes of temperature in a liquid when it is hotter than its surroundings.
- 4. Photo record:** a photo record of the laboratory experiment on change of state to help link observations to temperature measurements and a theory for explaining the phenomenon.

## 1. Background theory

### 1. INTRODUCTION

Most substances exist in three different physical states, each having distinctive properties:

- **Gas:** The substance fills all the space available to it by a process of diffusion. Gases are of low density, are compressible, can exert a uniform pressure on surfaces in any direction, they are often invisible.
- **Liquid:** The substance readily changes its shape and normally requires a container to stop it spreading horizontally. Usually it is constrained by gravity to form a horizontal surface. Liquids are typically 1000 times denser than gases.
- **Solid:** The substance retains a fixed shape unless it is squeezed or stretched by the action of external forces. Many (but not all) solids are denser than liquids.

### 2. TEMPERATURE AND MELTING POINT

The state of a given substance depends upon its temperature. The temperature of transition between liquid and solid is called the *melting point*. Thus a substance above its melting point is in a liquid state whilst below the melting point it is in the solid state. At room temperature, all liquids have a melting point

## Cooling and Change of State Module - 2

below room temperature, whilst all solids have a melting point above room temperature. A list of substances and their melting points allows the state of any substance to be determined at any chosen temperature. Water exists in the liquid state in the temperature range 0 to 100 Celsius. In the laboratory, the change of state between liquid and solid is most conveniently observed for substances whose melting point lies within this range.

### 3. KINETIC THEORY; BONDS, LATENT HEAT, ENERGY

The Kinetic Theory of matter envisages all matter to be composed of multiples of identical particles (atoms or molecules) in a state of perpetual vibratory or random motion. In liquids and solids the particles are sufficiently close to each other for attractive forces to prevail and hold the substance together. In the solid state, the packing of particles is so close as to make them occupy a rigid pattern in which individual particles may vibrate but not change places. In the liquid state, the particles are spaced further apart and more loosely held together, their motion is more random than in a solid and they readily change position. [In the gas state the particles move randomly at much greater speeds and are on average much further apart than in the liquid state.]

The natural motion of particles is associated with the temperature of the substance; in gases and liquids, higher temperatures are associated with higher average velocities of the particles; in solids, higher temperatures are associated with higher frequencies and amplitudes of vibration of particles.

The temperature of a substance may be thought of as being related to the kinetic energy of the particles; thus, supplying heat energy to a solid can be thought of as increasing

the average vibrational kinetic energy of the particles.

When a body loses or gains heat from its surroundings, the rate of heat transfer ( $\Delta Q/\Delta t$ ) depends upon the difference in temperature between the body and its surroundings:

$$\frac{\Delta Q}{\Delta t} = -K \cdot (T - T_s)$$

- where T and  $T_s$  are the temperatures of the body and surroundings respectively and K is a constant of proportionality.

In macroscopic terms, the heat ( $\Delta Q$ ) required for temperature change of ( $\Delta T$ ) of mass (m) is described by:

$$\Delta Q = m \cdot c \cdot \Delta T$$

- where 'c' is the specific heat capacity of the substance.

Whilst heating a substance, at a critical temperature, the *melting point*, some of the supplied energy is used to break the attractive bonds between the particles with the result that the substance loses its rigid shape and becomes a liquid.

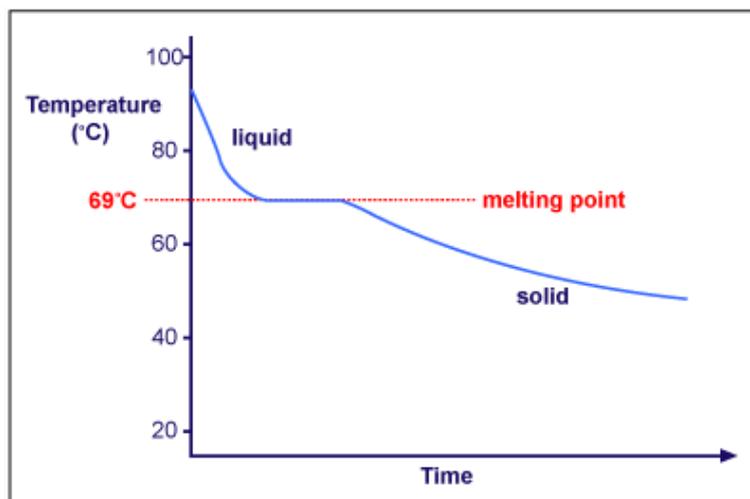
The additional energy supplied to break these bonds is the *latent heat of fusion*. Whilst the supplied energy is utilised in this way, the average temperature remains constant at the melting point. When all the substance has changed into the liquid state, the further supply of

heat causes the temperature to rise. When a liquid is cooled, the reverse process occurs: that is, the solidification of the substance liberates latent heat which becomes lost to the surroundings. The amount of liberated heat is related to the mass ( $\Delta m$ ) of substance which has solidified thus:

$$\Delta Q = L \cdot \Delta m .$$

- where L is the amount of heat liberated when 1 kg of substance solidifies.

During the transition from liquid to solid, the temperature remains steady at the melting point.



## 2. Pre-requisite knowledge required

- The physical properties which distinguish solids, liquids and gases
- Temperature measurement
- Celsius scale of temperature
- Effects of heating and cooling substances
- Temperature difference results in transfer of heat

## 3. Science concepts developed in the module

- Kinetic theory of matter; temperature and particle movement
- Latent heat of fusion
- Melting point
- The normal state of a substance depends upon relation between melting point and room temperature
- The rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings.

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## 4. Other useful information

The change of state between solid and liquid is commonly exhibited in a variety of everyday situations.

For example:

- placing food into a fridge; the water content becomes frozen
- an ice cream melting
- placing ice cubes in a soft drink
- frost and frozen roads in winter

- butter or a bar of chocolate melting when placed in sunshine.

The distinctive transition temperature between liquid and solid, *melting point* or *freezing point*, characteristic of individual substances is often not observable in complex mixtures of substances such as in the examples of butter and chocolate which tend to melt over a range of temperatures.

# B. Didactical approach ●●

## 1. Pedagogical context

Possible contexts for introducing the topic:

- Ice cream melting in mouth
- Ice cubes added to soft drinks
- Melting metals for casting into moulds
- Defrosting foods stored in a freezer
- Thawing of snow and ice in sunshine

## 2. Common student difficulties

Confusion between thermal conduction, conductivity, heat capacity, and convection.

## 3. Evaluation of ICT

This section considers some of the practical arrangements for exploiting the use of ICT to best effect, and discusses the qualities of the ICT methods which make a special contribution to students' learning.

## DATA-LOGGING

The chief benefit of data-logging in this experiment comes from making immediate observations of the data, asking questions about it, looking for links with other information, making comparisons, making predictions, looking for trends and so on. The sample questions posed in the activity sheet seek to prompt this sort of thinking. Suggested analysing activities involve observing and measuring changes and rates of change of temperature.

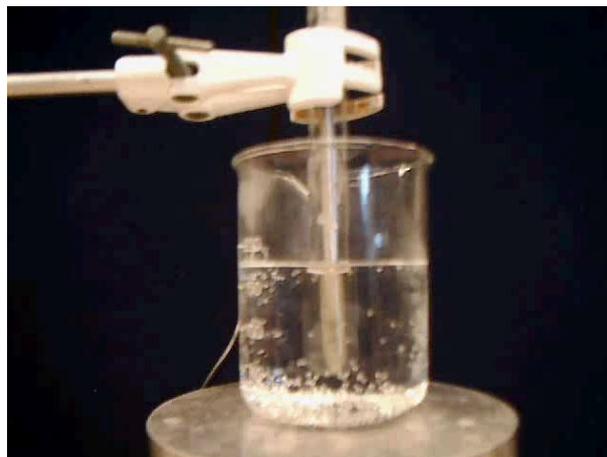
The software tools facilitate convenient measurement of these features, but it should be remembered that their meaning and interpretation requires more than routine collection of data. In short, the benefits depend upon the quality of the thinking about the data. Teachers are skilled in prompting pupils to think.

The data-logging experiment, yielding clear graphs which can be used interactively, provides a valuable context for exercising this skill. This has been highlighted in Barton's studies of pupils' interpretation of graphs presented with software (Barton, 1997).

### **Activity 1. Cooling stearic acid**

In this example, the cooling of stearic acid, changing from liquid to solid is studied. The basic experiment involves one temperature probe connected to the interface with the temperature readings reported on a real-time graph on the screen. The method makes it possible to observe the whole process, to explore the rate of temperature changes, and compare the measured values with theoretical predictions.

In the formal experimental arrangement, the substance in a boiling tube is placed in a water bath and heated until all the substance is melted. It is good practice to set the data-logging software to record data so that the temperature of the liquid can be established when the probe is inserted. Insertion usually reduces the temperature a little due to the thermal capacity of the probe. It is advisable to continue heating to raise the temperature as high as possible near the boiling point of water; this will ensure that a good range of cooling may be observed during the liquid state. To begin the experiment, remove the water bath and restart the recording of data. It is advisable to stir continuously the liquid with the probe. This ensures that all the substance maintains a homogeneous temperature. This becomes more difficult when solid begins to form, but stirring should be continued as long as possible.



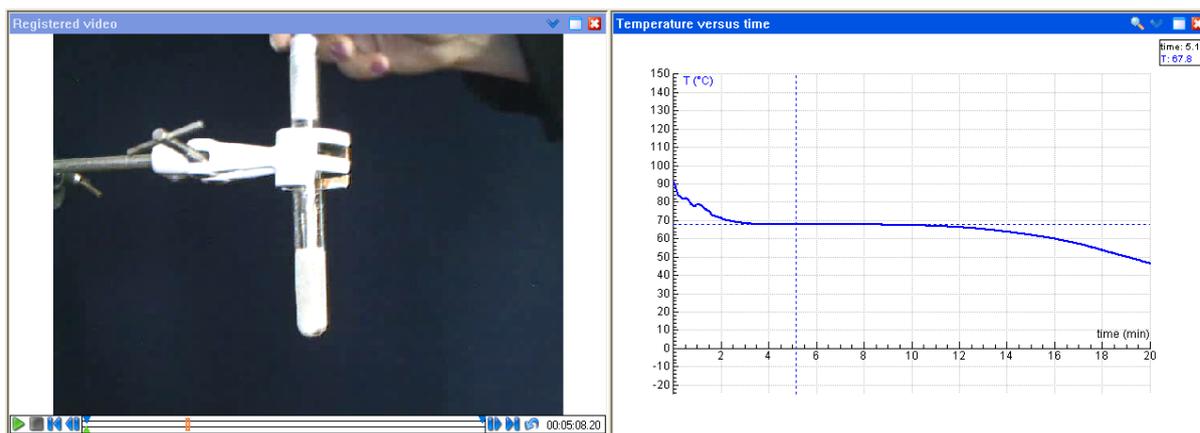
The reasons for this may be discussed with pupils. If the experiment is repeated without stirring, the resulting graph may be compared and discussed.

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The exact melting and freezing points of the stearic acid may not be exactly the same and will depend on the purity of the product and where it was purchased from, but are usually around 55-70 °C.

### **Activity 2. Cooling stearic acid with synchronized video**

The temperature recording can be synchronized with video capture taken during the course of a measurement. In this way the temperature measurement results can be illustrated by video images in real-time. By comparing the video frame-by-frame with the graph of temperature against time, it is possible to verify the appearance as liquid or solid for each portion of the graph. The flat region is most interesting in that this is where the transition between liquid and solid is in progress.



When scanning in the diagram the corresponding video frame is shown.

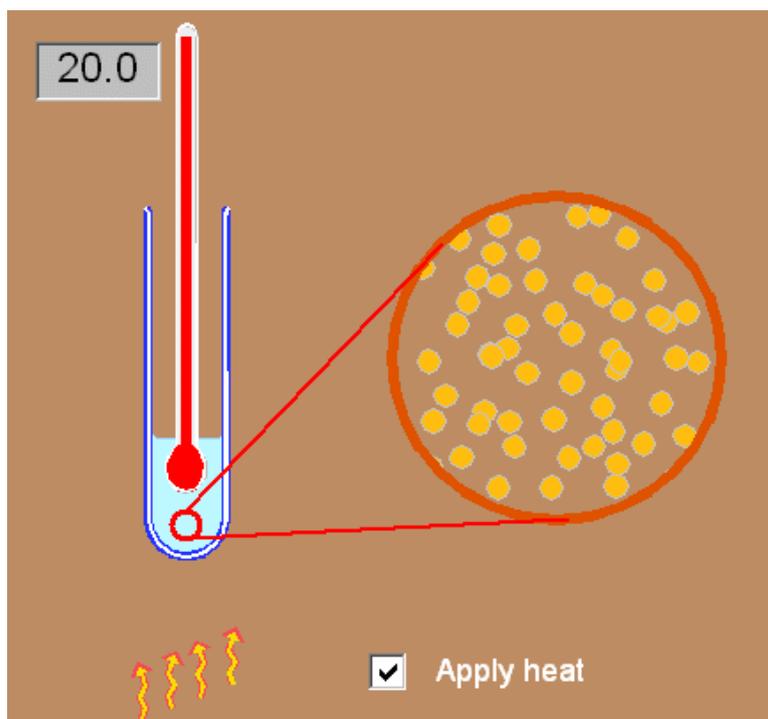
## SIMULATION

### Activity 3. Simulation of cooling

The graphical simulation is designed to assist visualisation of the changes during cooling in terms of the kinetic theory matter. It depicts the behaviour of particles in the solid and liquid states. As heat is supplied, the particles move more vigorously. In the solid state the movement is restricted to vibrations about fixed positions. When the substance is allowed to cool, the reverse process occurs, that is, movement gradually reduces as heat is lost to the surroundings. The simulation permits selection of any stage during the cooling process, and shows the corresponding temperature and particle behaviour. Students may study the change of state in terms of the movement of particles. This may be related directly to the Temperature vs Time graph.

Of particular interest is the flat horizontal part of the curve. This corresponds to the change from liquid to solid. As you move along the flat region, the proportion of liquid progressively reduces. At the right hand end of this region all the liquid has changed to solid. A constant temperature is maintained throughout this transition because heat energy is released from the particles as they form cohesive bonds in the solid state. Heat continues to be lost to the surroundings, but the release of particle energy, 'latent heat' prevents the temperature from falling during the transition region.

In the solid state, particles continue to move, but this is constrained to vibrations about fixed positions, unlike the liquid state in which the particles are able to move around to new positions.



## MODELLING

The purpose of this activity is to use a model to investigate the process of cooling. The model performs a sequence of calculations, aimed at calculating small changes of *temperature* and *mass* of liquid during short intervals of *time*. The result is a set of data showing the temperature and mass of liquid varying with time. By studying the formulae and rules, and experimenting with different values for the starting mass and the surrounding temperature, the physical assumptions implicit in the model may be evaluated.

### **Activity 4A. Modelling the cooling process (using Simulation Insight)**

The model assumes these physical concepts:

1. The rate of change of temperature due to the loss of heat to the surroundings is assumed to vary in proportion to the difference in temperature between the hot substance and its surroundings.
2. At the melting point, the rate of loss of heat is in balance with the latent heat yielded by liquid as it solidifies.
3. At the melting point, the mass of liquid changing into solid occurs at a uniform rate dependent upon the rate of loss of heat and the latent heat of the substance.
4. The temperature of the substance remains at the melting point until the total mass of liquid has changed to solid.

The first concept is represented in the formula which calculates the change of temperature  $\Delta T$  during a regular time interval  $\Delta t$ :

$$\Delta T = -\frac{a}{M} \cdot (T - T_s) \cdot \Delta t$$

where  $T_s$  is the temperature of the surroundings.  
 $a$  is a constant of proportionality  
 $M$  is the total mass of substance (liquid and solid).

[A more sophisticated model might consider transfer of heat energy ( $\Delta Q$ ) rather than temperature changes ( $\Delta T$ ). The latter approach using temperature only is proposed here in order to keep the model as simple as possible and avoid obscuring the modelling process with distracting detail such as additional calculations and constants. In respect of the relationship  $\Delta Q = m \cdot C \cdot \Delta T$ , where 'M' is the mass of substance and 'C' is the specific heat capacity, it can be seen that, since M and C are constants, changes in T are proportional to changes in Q.]

The first rule simply ensures that, above the melting point (the liquid state), the mass of liquid 'm' equates with the mass of substance 'M':

$$\text{If } T > T_m, \text{ make } m = M$$

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where  $T$  is the temperature of the substance  
 $T_m$  is the temperature calculated by the model  
 $m$  is the mass of substance in the liquid state  
 $M$  is the total mass of substance (liquid and solid)

The second and third concepts are expressed in the rule for calculating changes in  $m$ , the mass of liquid remaining. Whilst the temperature remains constant at the melting point, the rate of loss of heat is constant, which in turn makes the transition from liquid to solid occur at a uniform rate. The second rule progressively reduces  $m$  by a fixed amount  $b/L$ :

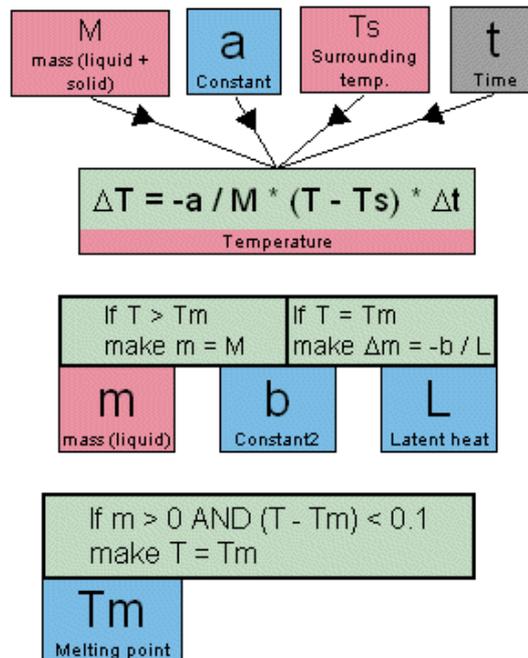
$$\text{If } T = T_m, \text{ make } \Delta m = -b/L$$

where  $T$  is the temperature of the substance  
 $T_m$  is the temperature calculated by the model  
 $m$  is the mass of substance in the liquid state  
 $b$  is a constant  
 $L$  is the specific latent heat of fusion

The fourth concept is implemented by the third rule which ensures that the temperature remains at the melting point so long as there is a finite mass of liquid.

$$\text{If } m > 0 \text{ AND } (T - T_m) < 0.1, \text{ make } T = T_m$$

The second part of this condition  $(T - T_m) < 0.1$  checks to see if the temperature has fallen to a value near the melting point (within 0.1 Celsius).



Computer model of a cooling process from liquid to solid (Insight)

### **Activity 4B. Modelling the cooling process (using Coach 6)**

In the model is assumed that the heat lost by a cooling substance to surroundings is proportional to the difference in temperature of the substance and the temperature of surroundings. The rate of change of heat during a time interval  $\Delta t$  is:

$$\frac{\Delta Q}{\Delta t} = -K \cdot (T - T_s)$$

where  $T_s$  is the temperature of the surroundings and  $K$  is a constant of proportionality.

In the process of cooling the following phases can be distinguished:

#### **Phase 1: Liquid, as long as $T > T_{\text{melting}}$**

This phase occurs at temperatures higher than the melting temperature, In this phase a substance is in liquid state. The temperature of the substance is changing due to the loss of heat to the surroundings. The rate of temperature change during a time interval  $\Delta t$  is:

$$\frac{\Delta T}{\Delta t} = \frac{1}{m_l \cdot c_l} \frac{\Delta Q}{\Delta t}$$

Where  $m_l$  is the mass and  $c_l$  is the specific heat capacity of substance in the liquid state.

#### **Phase 2: Transition from liquid to solid, as long as $T = T_{\text{melting}}$**

This phase occurs at the melting temperature. During this phase the liquid changes into solid. The rate of loss of heat is in balance with the latent heat yielded by liquid as it solidifies.

The mass of liquid changing into solid occurs at a uniform rate dependent upon the rate of loss of heat and the latent heat of the substance. The rate of mass change during a time interval  $\Delta t$  is:

$$\frac{\Delta m}{\Delta t} = \frac{1}{L} \frac{\Delta Q}{\Delta t}$$

where  $L$  is the specific latent heat of fusion.

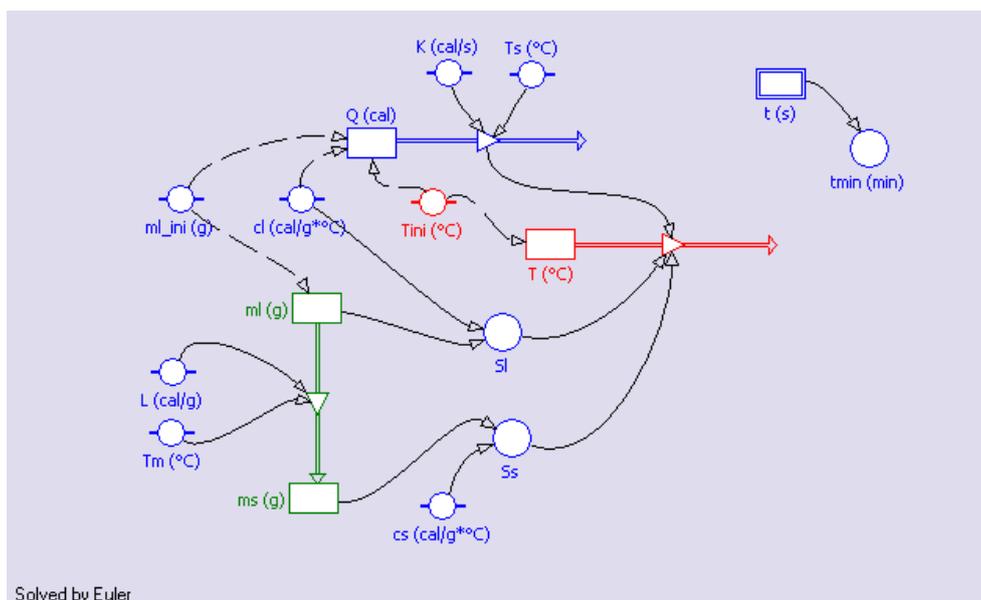
The temperature of the substance does not change in this phase; it remains at the melting point until the total mass of liquid has changed to solid.

#### **Phase 3: Solid, as long as $T < T_{\text{melting}}$**

In this phase a substance is in solid state. The temperature of the substance is changing due to the loss of heat to the surroundings. The rate of temperature change during a time interval  $\Delta t$ :

$$\frac{\Delta T}{\Delta t} = \frac{1}{m_s \cdot c_s} \frac{\Delta Q}{\Delta t}$$

Where  $m_s$  is the mass and  $c_s$  is the specific heat capacity of substance in the solid state.

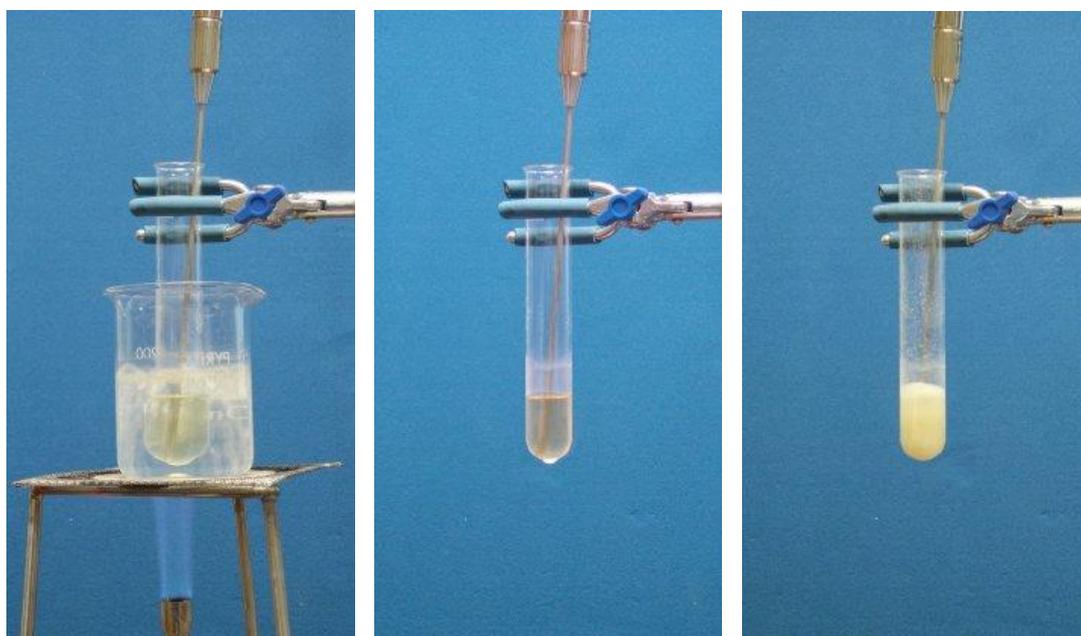


Computer model of a cooling process from liquid to solid (Coach 6)

## PHOTO RECORD

### Activity 5. Photo record of cooling stearic acid

The *photo record* of the data-logging experiment offers a record of direct observations. By comparing the photos frame-by-frame with the graph of temperature against time, it is possible to verify the appearance as liquid or solid for each portion of the graph. The flat region is most interesting in that this is where the transition between liquid and solid is in progress. Stirring action becomes progressively more difficult towards the end of the flat region where the amount of substance in solid form tends to a maximum.



## 4. Teaching approaches

The four activities presented here offer distinctive but complementary insights into the science involved in this topic. For the activities to be effective for teaching and learning, it is helpful for teachers to consider two types of skills in using the software tools:

- **Operational skills** which concern the manipulation of the computer hardware and knowledge of the features in the software.
- **Procedural skills** which concern the manner in which the software tools are employed in the lesson context for the purpose of achieving learning benefits. A dominant aspect of these skills is the development of an inquiring approach to the analysis and interpretation of data and to making links with previous knowledge.

Such skills are important for the preparation of pupils for the activities, and the activity sheets below each contain indications of the skills needed for the particular activity.

For the teacher, there are further *pedagogical skills* which contribute to the effectiveness of the activities:

1. Clarity of learning objectives for each activity.
2. Understanding of the special value of the ICT method and exploiting its full potential in purposeful ways.
3. To manage the activity in a way which promotes 'appropriate' rather than 'indiscriminate' use of ICT.

4. To integrate the learning from each activity to develop pupils' understanding of the topic.

The development of the last of these is a particular aim of the ICT for IST Project, and the activities presented have been specially selected to illustrate how integration might be achieved. Comparisons of the observations and results of each activity form a central role in this integration process. For example:

- Compare the data-logging experiment graph with video record, relating visual observations to the graph;
- Compare data from the model with experimental data;
- Compare each *Temperature vs Time* graph with the simulated motion of molecules;

In these, the graph is a key tool in facilitating comparisons and interpretations and skills with graphs generally provide a common thread in exploiting ICT for IST activities.

The management of the classroom setting also has an important influence on the successful integration of activities. When access to computer equipment is scarce it is likely that the teacher will wish to present the activity as a demonstration in a didactic manner. In this mode, the teacher can give strong guidance to pupils' thinking about the comparisons between the activities.

Alternatively, pupils could perform the activities in small groups of three

or four pupils, each group engaged on a different activity.

Integration might be achieved by each group making a presentation of their results to the whole class. In chairing these presentations the teacher can prompt discussion of the significant findings of each group.

It is worth considering that all the activities may be used in a variety of learning contexts.

Although the activities have been designed to provide complementary experiences, it is not essential to use all of them; two or three activities might be chosen according to how well they suit the needs of teachers and pupils in a particular context. In varying conditions between schools and within schools at different times of the year or different

stages in the curriculum, needs and appropriateness are likely to change; for example, data-logging equipment might not be available at the time of need, an individual pupil might need a revision or extension activity, an enrichment activity might be required to occupy some spare time, a quick activity might be needed if time is scarce. The overlapping features, such as graphical presentation, between the activities allows them to be used to a certain extent as alternatives, but their distinctive features also allow them to be used as complements to each other.

The table below summarises the distinctive potential learning benefits of each. It is a useful guide to the special value of each ICT activity.

Activity	Potential learning benefits, 'ICT value'
Data-logging  With video capture	<p>Whole process of cooling may be observed without interruption.</p> <p>Graph of temperature changes is displayed during experiment.</p> <p>Results may be linked with visual observations.</p> <p>Graph analysis tools facilitate detailed investigation of data.</p> <p>The video sequence focuses attention to links between visual observations of the cooling substance with the collected data.</p> <p>The pictures confirm the physical state of the substance represented in each section of the temperature graph.</p>
Simulation	<p>Animated graphics provide a link between kinetic theory explanation of change of state and a graph of collected data.</p> <p>The effect of the surrounding temperature and insulation of the test substance may be explored. Control of these variables allows the basic practical experiment to be extended.</p>
Modelling	<p>The model demonstrates how the relevant physical principles can be expressed in simple stages using mathematical formulae.</p> <p>The model calculates temperature data which can be compared with data obtained from a real experiment (data-logging).</p> <p>The effect of altering parameters such as surrounding temperature, mass of substance, insulation and latent heat capacity may be investigated.</p>
Photo record	<p>The photo record focuses attention to links between visual observations of the cooling substance with the collected data.</p> <p>The pictures confirm the physical state of the substance represented in each section of the temperature graph.</p>

#### REFERENCES:

Barton, R. (1997) 'Computer-aided graphing|: a comparative study' *Journal of Information Technology for Teacher Education*, (6) 1, 59-72.

## 5. Resources for Student Activities

### USING INSIGHT SOFTWARE

Activity	Software program	Files available
1. Data-logging	Insight iLOG	Set-up file: 'Cooling logging set up' Open this file to configure the program ready for the experiment. Data file: 'Cooling logging data' <i>This file contains a sample set of data.</i>
3. Simulation	Simulation Insight	Open file: 'cooling simulation'
4A. Modelling	Simulation Insight	Open file: 'cooling model'
5. Photo record	Simulation Insight	Open file: 'cooling video'

### USING COACH SOFTWARE

Activity	Software program	Files available
1. Data-logging	Coach 6	1.Cooling stearic acid.cma (activity file) 1.Cooling stearic acid.cmr (result file with exemplary data)
2. Data logging synchronized with video capture	Coach 6	2.Cooling stearic acid with video capture.cma (activity file) 2.Cooling stearic acid with video capture.cmr (result file with exemplary data)
4B. Modelling	Coach 6	4B.Modelling the cooling process.cma (activity file) 4B.Modelling the cooling process.cmr (result file with exemplary data)

### **EQUIPMENT AND MATERIALS FOR ACTIVITY 1 (DATA-LOGGING)**

- Computer
- Software – *See tables above*
- Interface (data-logger)
- Temperature sensor
- Stand and clamp
- Boiling tube containing about 10g stearic acid
- 250 ml beaker containing water
- Electrical Heater or (Bunsen, tripod and gauze) for heating water bath
- (Web) camera for Activity 2

# C. Student Activities ●●

## ACTIVITY 1. EXPERIMENT TO OBSERVE THE COOLING OF STEARIC ACID

### Learning Objectives:

1. To observe temperature changes in a sample of stearic acid as it cools from the liquid to the solid state
2. To associate each region of the graph with the liquid, solid and the transition between them
3. To associate the flat region on the graph with the change of state at the melting point temperature

APPLIED ICT TECHNOLOGY:  
DATA LOGGING

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY IF  
ENOUGH EQUIPMENT  
AVAILABLE OTHERWISE  
TEACHER DEMONSTRATION

### Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Starting and finishing real-time logging
- Using the cursor tools for analysing the shape of the graph

### Procedural Skills:

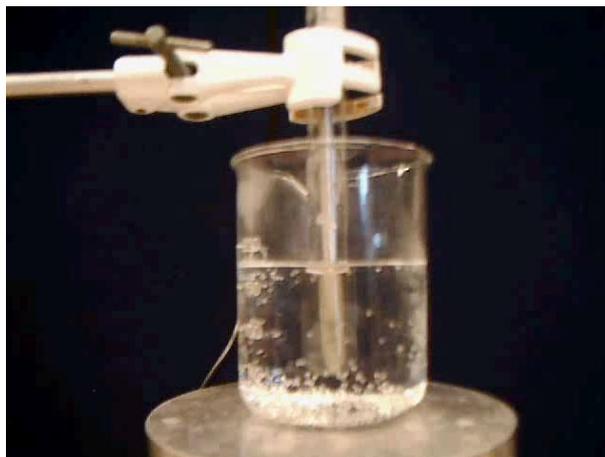
- Active observation during real-time logging
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes
- Using time bonus

## Materials:

- Interface (data-logger)
- Temperature sensor
- Stand and clamp
- Boiling tube containing about 10g stearic acid
- 250 ml beaker containing water
- Electrical Heater or (Bunsen, tripod and gauze) for heating water bath

## Activity method:

1. Connect the temperature sensor to the input 1 of the interface.
2. Place some stearic acid crystals in the boiling tube to a depth of about 2 cm.
3. Place the tube in the beaker half filled with water. Clamp the tube so that it can be lifted out of the beaker safely.
4. Light the bunsen burner and heat the water to boiling. Continue boiling until all the stearic acid has melted.
5. Carefully insert the temperature probe into the boiling tube and boil the water for a further half minute.
6. Set the data-logger to record temperature for 20 minutes.
7. Stop heating the water and carefully lift the boiling tube out from the beaker, keeping it in the clamp.
8. Start recording temperature.
9. Stir the substance gently as long as possible, using the probe.
10. Watch the graph of Temperature vs. Time as you observe the visual changes in the substance in the test tube.



## Questions:

- How can you tell from the graph which part shows the liquid state?
- Which part shows the solid state?

- At what temperature did the liquid start solidifying?
- How long did it take for the liquid to solidify?
- The temperature of the stearic acid does not change as it sets solid. What evidence is there that it is actually losing heat?
- The temperature continues to fall after it has set solid. Why?
- What does the shape of the graph show you about the loss of heat by the substance?
- What do you think would happen to the graphs if you had kept taking results for another 10 minutes?
- Explain what is happening in molecular terms for each region of the graphs.

### Analysing activities (using *Insight iLOG*):

#### 1. *Sweeping cursors*

After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect.

#### 2. *Add captions to graph*

Annotate each section of the graph to show where the substance was liquid, where it was solid and where the change from liquid to solid took place.

#### 3. *Take readings from the graph*

Find the highest and lowest temperatures

Find the melting point temperature from the flat region on the graph

Find the range of temperature for the substance in the liquid state.

Find the range of temperature for the substance in the solid state.

#### 4. *Time measurements*

Find the time needed to change from liquid to solid; measure time interval

#### 5. *Measure rate of change*

Use the *Change, Interval, Rate* and *Gradient* graphing tools to measure and compare the rate of cooling at different stages during the experiment.

At which part of the expt. did the temperature change at its maximum rate?

#### 6. *Comparing graphs*

When the experiment is repeated under different conditions (e.g. with different substances or different quantities), take readings and measurements as above to make useful comparisons.

### Analysing activities (using *Coach 6*):

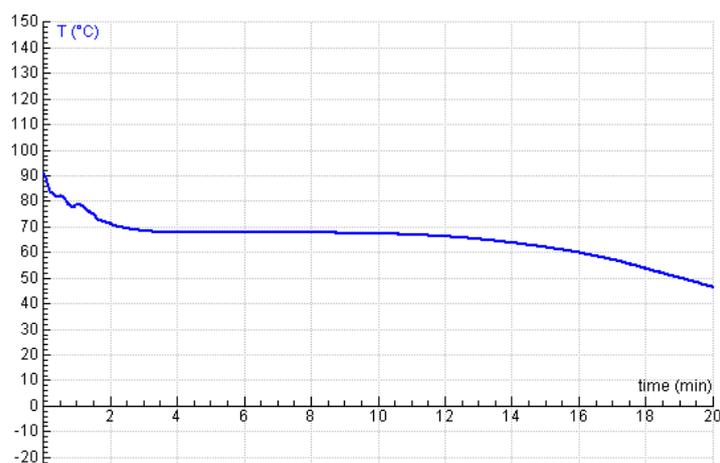
Students measure the temperature during the cooling process and analyze the resulting graph.

After the experiment, the real-time experience can be re-lived to a certain extent using the graph cursors and meter display by using the Scan option.

Students can annotate each section of the graph to show where the substance was liquid, where it was solid and where the change from liquid to solid took place. They can take temperature readings and find:

- the highest and lowest temperatures,
- the melting point temperature from the flat region on the graph,
- the range of temperature for the substance in the liquid state,
- the range of temperature for the substance in the solid state,
- the time needed to change from liquid to solid.

Students can compare the rate of cooling at different stages during the experiment (by using the Slope option) and find out at which part of the experiment the temperature change was its maximum rate?



Exemplary data: cooling of stearic acid.

Experiment can be repeated under different conditions e.g. with different substances or different quantities.

### Hints and tips:

1. Stearic acid,  $\text{CH}_3(\text{CH}_2)_{16}\text{COOH}$  can act as an eye, skin and respiratory irritant so the laboratory should be well ventilated.
2. During the experiment it is advisable:
  - to continue heating to raise the temperature as high as possible near

## Cooling and Change of State Module - 21

the boiling point of water; this will ensure that a good range of cooling may be observed during the liquid state.

- to stir continuously the liquid with the probe. This ensures that all the substance maintains a homogeneous temperature. This becomes more difficult when solid begins to form, but stirring should be continued as long as possible. The reasons for this may be discussed with pupils. If the experiment is repeated without stirring, the resulting graph may be compared and discussed.

#### **FURTHER WORK - IDEAS FOR RELATED AND EXTENDED ACTIVITIES**

1. Investigate the effect of stirring the substance as it cools.
2. Use different quantities of substance and compare the times for cooling.
3. Investigate the effect of using a cold water bath to cool the tube.
4. Place the tube in a water jacket to measure the loss of heat during cooling.
5. Compare the cooling of different substances e.g. biphenyl.

## ACTIVITY 2. COOLING OF STEARIC ACID WITH VIDEO CAPTURE (using *Coach 6*)

### Learning Objectives:

1. To understand how visual observations of the cooling of stearic acid can be associated with the corresponding temperature vs. time graph
2. To identify the parts of the graph which correspond to the liquid phase, solid phase and the transition from liquid to solid

APPLIED ICT TECHNOLOGY:  
VIDEO MEASUREMENT

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY OR  
TEACHER-LED CLASS  
DISCUSSION

### Operational Skills:

- Using the cursor tools for obtaining readings from the graph

### Procedural Skills:

- Relate the appearance of the substance to various parts of the graph

### Activity method (using *Coach 6*):

This activity is very similar, to Activity 1. Additionally, a webcam is connected to the computer which allows capturing video during the experiment.

The video capture is synchronized with the measurement i.e., it starts automatically when the green Start button is pressed, and stops when the measurement is finished or the Stop button is pressed.

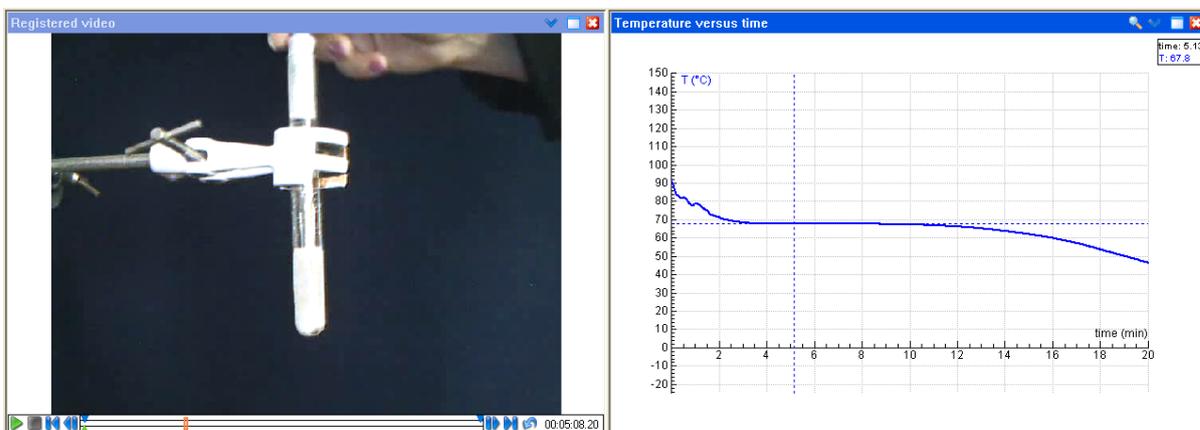
To execute a measurement with synchronized video capture:

- Right click the Video pane and select the Capture option.
- Right click the Video-Capturing window and mark the Synchronized Capture option. Notice that the Record button becomes disabled.
- If needed specify the capture settings. The maximal capturing time is disabled. This time depends on the selected type of measurement and is set automatically.
- For slow measurements (measurement frequency of 1 per second or lower) it is possible to select the Frame rate follow measurement option. Then the frame rate of the captured video will be the same as the measurement frequency.
- Click the green Start button or press <F9> to start the measurement/capture process. Coach measures/captures according to the specified measurement settings and capture settings (but the capture time is neglected).

- The measurement/capture stops when the measurement process is finished. Then the Video-Capturing window is automatically closed and the recorded file with the name Registered video is placed in the Video pane. Depends on the video size this process may take a few moments.

### Analysing activities (using Coach 6):

See 'Analysing activities' for the Activity 1.



Exemplary data: cooling of stearic acid with synchronized video

- After a measurement is completed, it is possible to replay it by clicking the **Replay** button. The replay can be done in real-time (default), but it is also possible to speed it up or down.
- During scanning in the diagram/table (via the Scan option) Coach shows the corresponding video frames of the Registered video.

## ACTIVITY 3. SIMULATION OF COOLING AND CHANGE OF STATE (using *Insight*)

### Learning Objectives:

1. To understand the particle descriptions of solids and liquids
2. To associate temperature with the amount of particle movement in liquids and solids
3. To understand that the Latent heat of fusion is liberated when the liquid changes to a solid
4. The change of state occurs at a fixed temperature called the *melting point*
5. The normal state of a substance depends upon the relation between melting point and room temperature
6. The rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings

APPLIED ICT TECHNOLOGY:  
SIMULATION

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY OR  
TEACHER-LED CLASS  
DISCUSSION STUDENT  
ACTIVITY

### Operational Skills:

- Using the software controls for running the simulation
- Using the cursor tools for obtaining readings from the graph

### Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph
- Distinguish between translational and vibrational movement of particles
- Describe observations and link these with theoretical explanation

### Activity method:

1. Open the *Insight* file 'cooling simulation'.
2. Look carefully at the simulation window and notice the substance in the test tube and the microscopic view of the particles in the substance.
3. Look at the graph and notice that this shows temperature of the substance against time.
4. Tick the 'Apply heat' box to heat up the substance. Observe how the particles behave as the temperature rises.
5. Cut off the heat when the temperature reaches 100 celsius and allow the

substance to cool.

6. As the substance cools, observe how the particles behave and how the shape of the graph develops.

### Questions:

- From the graph, at what temperature does the substance change from liquid to solid?
- Describe the behaviour of the particles in the liquid state. How does temperature affect this behaviour?
- What is happening to the particles during the solidifying process?
- Describe the behaviour of the particles when all the liquid has changed to solid. How is this motion different from when the substance was a liquid?
- Notice that heat is still lost to the surroundings whilst the temperature levels out at the melting point. Where is this heat coming from?

### Analysing activities:

1. *Sweeping cursors*  
After running the model and observing the cooling, replay the changes using the graph cursors and bar display: Drag the X cursor slowly across the screen, and note how the bars grow and shrink in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect. Observe the corresponding changes to the movement of the particles in the substance.
2. *Add captions to graph*  
Annotate each section of the graph to show where the substance was liquid, where it was solid and where the change from liquid to solid took place.
3. *Take readings from the graph*  
Find the melting point temperature from the flat region on the graph.  
Find the range of temperature for the substance in the liquid state.  
Find the range of temperature for the substance in the solid state.
4. *Time measurements*  
Find the time needed to change from liquid to solid; measure time interval.

### Further activities:

Investigate the effect of heating the substance up to different starting temperatures.

## ACTIVITY 4A. MODELLING THE COOLING PROCESS (using *Insight*)

### Learning Objectives:

1. To understand that the rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings
2. At the melting point, latent heat is released when the liquid changes to a solid
3. The temperature remains constant during the change from liquid to solid.

APPLIED ICT TECHNOLOGY:  
MODELLING

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY OR  
TEACHER-LED CLASS  
DISCUSSION

### Operational Skills:

- Using the software controls for running and analysing the model
- Adjusting the values of constants and variables in the model
- Using the cursor tools for obtaining readings from the graph

### Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph

### Activities (using *Simulation Insight*)

1. Open the *Insight* file 'cooling model'.
2. Click on the START button to run the simulation.
3. Compare the graph of the calculated data for temperature with the experimental data. Comment on the similarities and differences.
4. Notice how the formula produces the curve shape during cooling.
5. Notice how the first rule reduces the mass in the liquid state and the second rule makes the temperature constant during the change of state.
6. Investigate the effect of starting with a different mass of substance: Reduce the value of the mass 'M', run the model and observe the effect on the graph. Explain your observation.
7. Investigate the effect of cooling the substance with a different surrounding temperature: Adjust the surrounding temperature, run the model and observe the effect on the graph. Look at the formula which

calculates temperature changes, and use this to explain the new shape of the graph.

8. Investigate the effect of cooling the substance with a different surrounding material (thermal conductivity)
9. Investigate the effect of changing the melting point. This implies changing the substance for another.
10. Investigate the effect of changing the value for latent heat. This also implies a change of substance.

## ACTIVITY 4B. MODELLING THE COOLING PROCESS (using *Coach 6*)

### Learning Objectives:

1. To understand that the rate of cooling of a substance depends upon the temperature difference between the substance and its surroundings
2. At the melting point, latent heat is released when the liquid changes to a solid
3. The temperature remains constant during the change from liquid to solid

APPLIED ICT TECHNOLOGY:  
MODELLING

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY OR  
TEACHER-LED CLASS  
DISCUSSION

### Operational Skills:

- Using the software controls for running and analysing the model
- Adjusting the values of constants and variables in the model - using the Simulation option
- Using the cursor tools for obtaining readings from the graph

### Procedural Skills:

- Relate temperature and temperature changes to the shape of the graph

### Activity method:

The given in the activity model calculates lost of heat to surrounding and temperature changes during the cooling process.

Students explore a given model and use it for simulating different cooling conditions.

### Questions and Assignments:

- Describe the resulting graph of the Temperature versus time  $T(t)$ .
  - How many phases can you distinguish?
  - Explain what happen with temperature in each of the phases?
  - Find out what is the melting temperature  $T_m$ ?
  - Find out what is the temperature of surroundings  $T_s$ ?
- Describe the resulting graph of the Heat versus time  $Q(t)$ .
  - Find our the initial heat of the substance, how is it calculated?
  - Explain what happen with heat  $Q$  in each of the phases?
  - Find out how the rate of change of heat changes in each of the phases?
- Describe the resulting graphs of the Mass of liquid and Mass of solid versus

time  $m_l(t)$  and  $m_s(t)$ .

- Explain what happens with mass of the liquid  $m_l$  in each of the phases?
- Explain what happens with mass of the solid  $m_s$  in each of the phases?
- Investigate the effect of cooling the substance with a different surrounding temperature ' $T_s$ '. Adjust the surrounding temperature, run the model and observe the effect on the graph. Explain the new shape of the graph.
- Investigate the effect of starting with a different mass of substance: Reduce the value of the mass ' $m_{l\_ini}$ ', run the model and observe the effect on the graph. Explain your observation.
- Investigate the effect of cooling the substance with a different surrounding material (thermal conductivity).
- Investigate the effect of changing the melting point. This implies changing the substance for another.
- Investigate the effect of changing the value for latent heat. This also implies a change of substance.
- Compare the graph of the calculated data for temperature with the experimental data (load the measurement data via the Import the Background Graph option).
  - Comment on the similarities and differences.
  - Adjust your model to get the best fit to the measured data.

### Analysing activities:

Students investigate the graphs of different model variables: heat  $Q$ , temperature  $T$ , liquid mass  $m_l$  and solid mass  $m_s$ . They interpret the respective graphs and observe what happens with these variables in each phase.

They change parameters in the model, observe and explain the effects of changes.

They compare the model results with the experimental results and look how well the model fits the measured data.

### Coach 6 Activity:

4. Modelling the cooling process

### FURTHER WORK - IDEAS FOR RELATED AND EXTENDED ACTIVITIES

1. Modify the model to create the model for a cooling in a water bath (for an experiment in which the cooling tube is placed in a water jacket).
2. Modify the model to create the model for warming up.

## ACTIVITY 5. PHOTO RECORD OF THE COOLING PROCESS (using *Insight*)

### Learning Objectives:

4. To understand how visual observations of the cooling of stearic acid can be associated with the corresponding temperature vs time graph
5. To identify the parts of the graph which correspond to the liquid phase, solid phase and the transition from liquid to solid

APPLIED ICT TECHNOLOGY:  
VIDEO MEASUREMENT

STUDENT LEVEL:  
AGE 15-17

RECOMMENDED SETTINGS:  
STUDENT ACTIVITY OR  
TEACHER-LED CLASS  
DISCUSSION

### Operational Skills:

- Using the cursor tools for obtaining readings from the graph

### Procedural Skills:

- Relate the appearance of the substance to various parts of the graph

### Activity method:

1. Load the Insight file 'cooling video'.
2. *Sweeping cursors*  
Activate the cursors to be ready to take readings from the graph. Drag the X cursor slowly across the graph, and observe the photographs of the cooling substance. In particular, notice the appearance of the substance for different parts of the graph.
3. *Add captions to graph*  
Annotate each section of the graph to show where the substance was liquid, where it was solid and where the change from liquid to solid took place.
4. *Take readings from the graph*  
As you move the cursor across the graph, note how the bar grows and shrinks in the same manner as the changes of the temperature values during the experiment, creating an 'action replay' effect. Note the temperature of the flat part of the graph (melting point).
5. *Compare rates of change*  
Use the cursors to obtain the average rate of change in temperature whilst the substance in the liquid state. Repeat this for the solid state and explain the comparison between the two values.