THE FROZEN LAKE

OBJECTIVE:

What happens to fishes who live in a lake when it becomes very cold outside and the lake freezes? To try to answer this question we have built and analysed a model that mimics the freezing of the lake when the outside temperature goes below 0°C, in order to understand what happens at the surface and underneath.

The main objective is to study the freezing process of a water mass when it is cools down from the surface, introducing the concept of model and of lab simulation of a natural phenomenon.

In this experiment you will be able to reproduce in the lab experimental conditions similar to those present in a lake when the outside temperature goes below 0°C. The analysed system is interesting for understanding some relevant properties of water and studying some biological mechanisms involved. In order to build the physical model you will use simple and low cost materials. To study the process you will need three temperature probes linked to a data acquisition system.

THEORY

1. Density of water
2. Convection currents
3. Ice formation

1. Water density as a function of temperature

The density of liquids varies with temperature. Volume of liquids usually increases as temperature increases. The principle of construction of bulb thermometers is based on this phenomenon.
At a temperature above 4°C water shows a behaviour similar to the majority of liquids. The warmer layers have lower density and have a tendency to rise to the surface. This effect is known from everyday experience: when swimming in the sea at the surface and below it is easy to recognize that lower layers are colder than superficial ones.

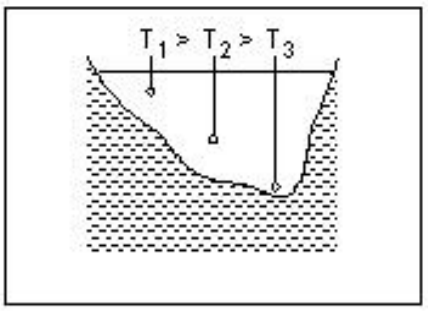

Fig. 1: Temperature differences in a mass of water for temperatures higher than 4°C.

On the contrary between 0°C and 4°C water shows a different behaviour from other liquids: its volume becomes smaller instead of bigger. At 4°C the maximum density is reached. Water at this temperature has a tendency to sink to the bottom of the vessel where it is contained.

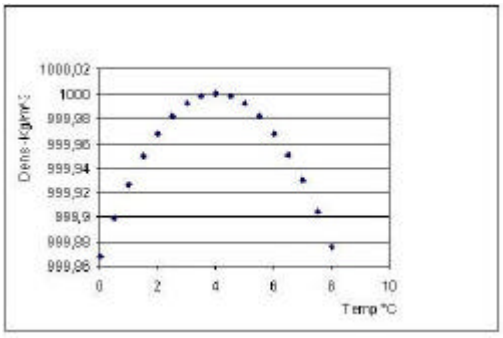

Fig. 2: Water density as a function of temperature.

2. The convection currents mechanism

If we think of the outside environment getting colder in winter, what happens to the lake water? The lake water exchanges heat with the environment through its surface, the inner part being thermally insulated by earth and rocks.
As far as the temperature remains above 4°C, if the lower layer gets cooler its density increases and the layer sinks raising to the surface warmer water that can be cooled down and sink in its turn. By this mechanism convection currents are created and water gradually gives heat away to the environment.

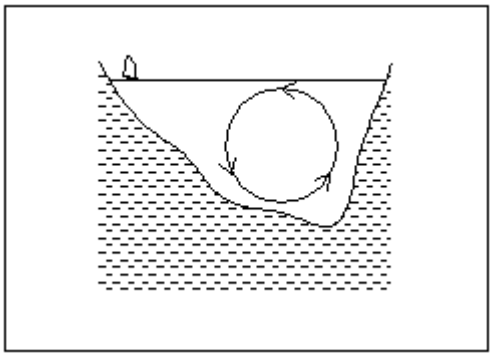

Fig. 3: Above 4°C all the water is involved in the phenomenon of convection currents.

When the external temperature goes down the convection mechanism involves decreasing quantities of water. When water reaches 4°C its density is maximum and stays at the bottom without being involved in the convection mechanism.

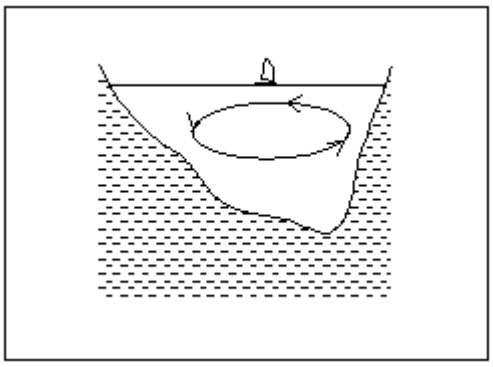

Fig. 4: Below 4°C the water mass involved in the convection currents becomes smaller.

3. Ice formation at the surface.

In the above conditions the prevalent mechanism of heat exchange is conduction. Higher layers gradually cool down and if the external temperature is low enough (below 0°C) ice forms at the surface that reduces heat exchange with the environment.
This mechanism is fundamental for life on Earth; even if water at the surface freezes, deep water is still liquid allowing many organisms to survive.

EXPERIMENTAL SETUP

We wish to reconstruct a lab situation similar to the natural one of the lake when the external temperature goes below zero. It is a system that exchanges heat only through its surface.

The lake will be simulated by a test tube, insulating material around it will reproduce the role of earth and rocks around the lake, the external environment at low temperature will be obtained with a cryogenic mixture

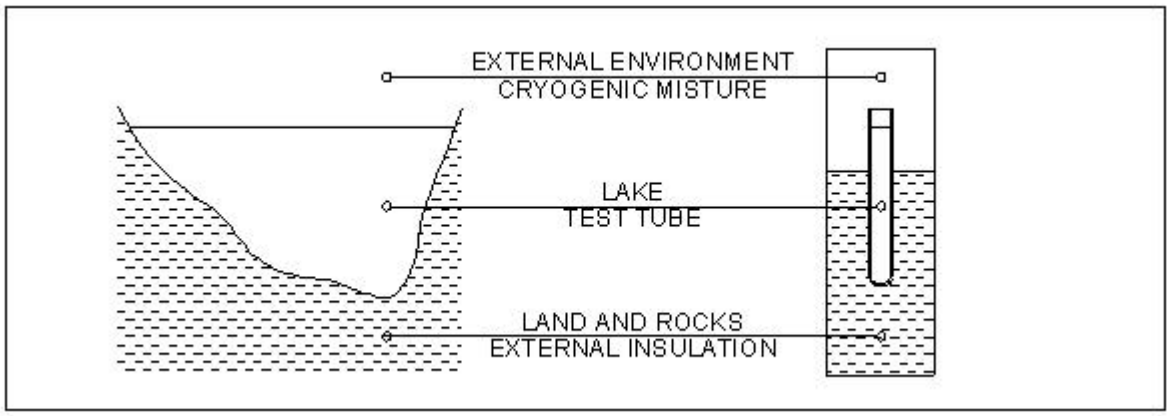

Fig. 1: Correspondence between physical system and lab model.

Three temperature probes collect data from the lake bottom, the lake surface, the external environment.

To set up the experiment you need:

- plastic bottle
- test tube
- a few elastic bands
- cloth for insulation
- pipette or syringe
- plastic balloon
- mixture of water and salt at low temperature.

Figure 2: Experimental setup.

The measuring system contains:

- 3 temperature probes
- CBL2 interface
- Graphing calculator TI84Plus
- Standard connecting cable
- Acquisition software DataMate (dowloadable)
- TI-GraphLink cable and software (optional, for data transfer to PC)

Info: http://education.ti.com/us/product/accessory/connectivity/features/software.html
download: http://education.ti.com/us/product/accessory/connectivity/down/download.html

Other calculators can be used (fro example TI83 Plus, TI83 Plus SE, TI89, TI92, TI92 Plus, TI Voyage 200) and other softwares (for example Physics or Chembio) or even other data acquisition systems.

Figure 3: test tube at the end of the experiment. The layer of ice in the upper part is visible; the elastic bands are placed at mid tube, the probes are at the bottom and inside the ice layer; the plastic balloon is used to avoid "pollution" of the lake with salt water.

Practical notes about setting up and performing the experiment.

The materials used are not in any way dangerous for the students performing the experiment; nevertheless care and ability is required for performing it successfully.

Recipe for cryogenic mixture:

- mix up 500g of kitchen salt with 750 cm^3 of water obtaining a supersaturated mixture of salt and water that freezes at about -20°C;
- leave the mixture in the freezer for one night in order to obtain a liquid well below 0°C.

While performing the experiment (around one hour duration) it is necessary to have some mixture handy; it is therefore advisable to perform the experiment near the freezer or to prepare more than one bottle of mixture to take out of the freezer at different time.

To set up the "lake":

- cut the plastic bottle in two halves so as to obtain a sort of funnel from the upper part;
- insert a test tube in the hole taking care to choose the tube diameter as near to that of the hole as possible;
- insert the test tube in the funnel as shown in the photo (figure 2);
- the funnel should contain the cryogenic mixture; to prevent liquid leaking use the elastic bands as shown in figure 3;

- fill the test tube with water;
- insert two temperature probes, connected with cello tape, one at the bottom and one at the surface of the water;
- close the test tube with the plastic balloon cut so as to allow the cables to pass through as shown in figure 3;
- wrap the cloth around the lower part of the test tube in order to reduce heat exchange with the environment;

- insert the fennel with test tube and probes in the lower part of the plastic bottle that acts as support of the system.

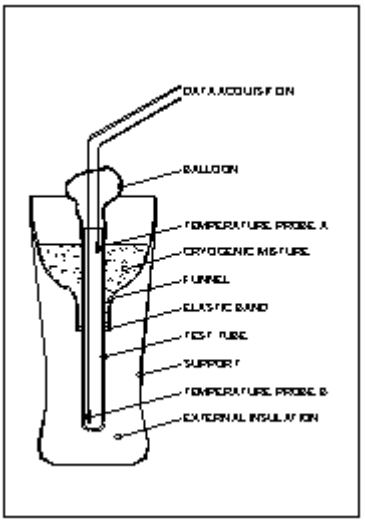

Figure 4: Sketch of the experimental apparatus.

When everything else is ready the mixture can taken from the freezer and poured into the funnel taking care not to contaminate the lake with salt water. The plastic balloon helps avoiding this. Take care that the mixture temperature does not rise above -8/-10°C throughout the measurement. Check the temperature and add some cool mixture with a pipette or syringe as soon as you notice that it is raising above the limit. The mixture temperature is too low to be shown on the plot of the calculator but is shown on the screen together with the values of the other two probes.
Insert in Channel 1 the probe measuring the temperature of the cryogenic mixture in Channel 2 the one measuring the surface temperature in order to check when it goes beyond zero.

The data collection for the Sample Data lasted 60 minutes. 120 data have been collected every 30 seconds. The duration may vary according to different environmental conditions (lab temperature). A detailed guide to data acquisition is provided in the corresponding page (see menu at the end).

How did your plot come out?

If you wish to compare it with the one we obtained you can do so by clicking here or by clicking on Teacher's Guide at the bottom of this page. If you cannot perform the experiment you can analyse collected data by clicking on Data Sample at the bottom of this page.
Discuss with your teacher and the other students the results and the meaning of this experiment and record your conclusions.

The teacher can find some suggestions for teaching in the Teacher's Guide.

When the measurement is over, after saving the data, you can allow… spring to come! And repeat data acquisition while letting the system reach the room temperature.

DATA ACQUISITION (TI84 and DataMate)

We plan to observe the temperature change at our "lake" surface and bottom during one hour. The third probe is needed to control the temperature of the cryogenic mixture (simulating the external environment).
Before starting the acquisition be sure to have the mixture handy and that probes are fixed in the right positions, one at the bottom and the other at the surface. Check also that the balloon is correctly set.
During the measurement you must check that the mixture temperature is around -10°C. Since the temperature of the environment is much higher than that of the mixture you must put the mixture back to the freezer and take it out only when you need it. If the freezer is not near prepare more than one bottle of mixture.
To obtain a more convenient graph at the end you should connect the probe at the bottom to Channel 3, that at the surface to Channel 2 and that in the mixture to Channel 1.

The procedure is divided into two parts: setup and data acquisition.

Setup
- Link the calculator to the CBL2
- Connect the three probes into channels CH1, CH2, CH3 of CBL2
- Arrange the lake and the probes as explained in the page Experimental Setup
- Switch on the calculator
- Press the key APPS on the calculator. The menu Applications appears showing all programs in your calculator
- Scroll the menu till you find DATAMATE
- Press ENTER to start the DATAMATE program.

Acquisition
- The program identify the probes and shows the corresponding temperature values. CHECKING SENSOR appears on the screen and you can read CH 1: TEMP (C) - CH 2: TEMP (C) - CH3: TEMP (C); near to each channel the measured value appears.
- To set the measurement select 1: SETUP by pressing 1
- Select MODE: TIME GRAPH and press ENTER to set the number and frequency of data to be collected
- From SELECT MODE menu select 2:TIME GRAPH
- Then select 2:CHANGE TIME SETTINGS
- Set the time between sample to 30 seconds and 120 the number of samples
- To confirm select 1:OK by pressing 1
- Select 2:START to start measuring

DataMate shows the data from the three probes in real time in a plot temperature vs. time. Temperature span is from 0°C to 100°C and cannot be modified. Therefore during the data collection temperature below 0°C cannot be seen on the graph. The collected values are shown however on the screen. This allows to keep under control the temperature of the cryogenic mixture and of the "lake" surface.
Before starting to measure pour the mixture (around -10°C) in the funnel. When you see that the temperature raises you must take away part of it with a pipette or a syringe and pour some at a lower temperature.

An example of collected data can be found at the page Data Sample.

DATA SAMPLE TI84

Data have been collected using:
- CBL2 interface
- TI84 graphing calculator
- Black connecting cable (see photo)
- DataMate program
- TI-GRAPH LINK TM cable and software
- PC with TI Connect software (optional)

http://education.ti.com/us/product/accessory/connectivity/features/software.html
http://education.ti.com/us/product/accessory/connectivity/down/download.html.

Original data in the TI84 calculator can be found in:
- **L1** times
- **L2** mixture temperature
- **L3** surface temperature
- **L4** bottom temperature

Data in MS-Excel format can be found in the document dati.xls.

DATA ANALYSIS (TI83 or TI84)

This experiment does not require data reduction but only the analysis of the plot produced by the calculator.
Discuss the plot with your teacher and the other students. Identify the three curves: that of the cryogenic mixture, the one at the water surface and the one at the bottom: What can you notice?

DATA ANALYSIS (MS Excel™)

This experiment does not require data reduction but only interpretation of the plotted data. Graphs can be made and analysed using programs for data analysis on PC (like MS-Excel).

Transferring experimental data to the PC

When collection is finished data can be transferred from the calculator to the PC.
For this purpose you need a TI GRAPH LINK cable and TI Connect Software that allows the content of the calculator to be explored (TI DEVICE EXPLORER) and data to be edited (TI DATA EDITOR).

Data are recorded in the calculator as follows:

- time in **L1**
- temperatures, in centigrade, in **L2, L3, L4**

Instruction for data transfer are available here.
A MS Excel document with sample data and data plot is available here.