

CONVECTION CURRENTS AND ANOMALOUS BEHAVIOUR OF WATER

Objective:

To compare the thermal behaviour of water with that of other liquids, specifically alcohol and edible oil. To point out the anomaly of water in the temperature interval $0^{\circ}\text{C} - 4^{\circ}\text{C}$. To investigate convection currents

This set of experiments aims at investigating the process of heating a liquid that is initially frozen and then warmed up at room temperature. Temperature vs. time is measured at different levels inside the vessel containing the liquid.

Theoretical issues

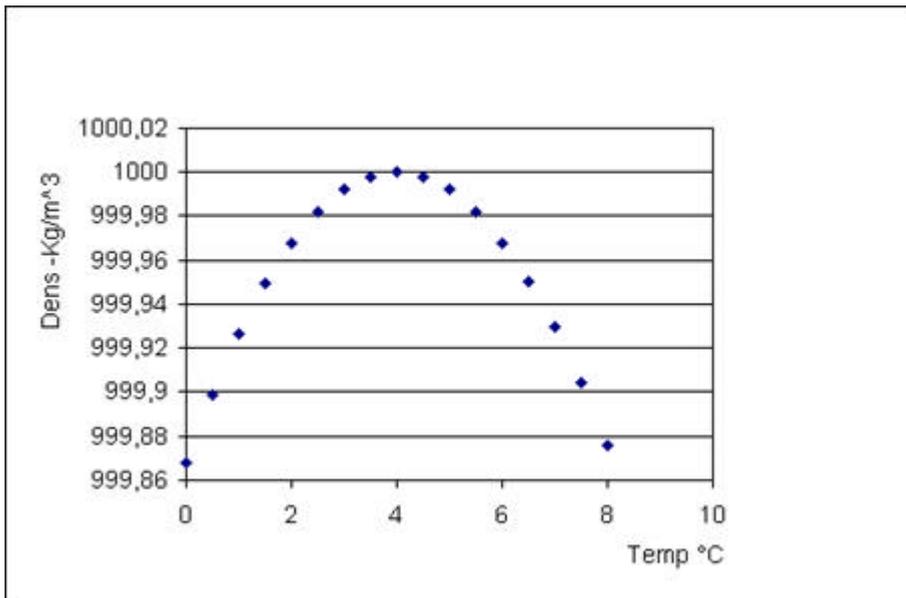
Fluids have very low thermal conductivity. Heat transmission in liquids mainly occurs through convection.

To heat a liquid we usually put it on a heat source. The layer that warms up first is the lower one that is in contact with the source. The temperature increase causes a change in density; density usually decreases as temperature increases. The lower layer becomes less dense and therefore, according to Archimedes principle, tends to rise to the surface pushing down some liquid at lower temperature that warms up and moves upward in its turn. This process generates a transport of matter within the fluid and produces convection currents.

If we try to heat the liquid from the top, by using a hair dryer for example to warm up the upper surface of the container, we cannot succeed; whereas a quick propagation of heat occurs if the source is put beneath.

If we leave a liquid initially cold warm up in contact with the environment (as it happens to a canned drink left out of the fridge) we can notice that its temperature is not uniform. Because of the process described above the whole mass of liquid warms up but the temperature of the upper layers is always higher than that of the lower layers.

Different liquids show similar behaviours with the exception of water but only in the temperature interval between 0°C and 4°C where its density increases instead of decreasing.



The anomaly can be observed by letting a mass of cold water (from the fridge with ice cubes in it) warm up in contact with the environment. Heating curves in this case are different from those of other liquids: near to 4°C the two curves corresponding to the temperatures at different levels cross each other.

Other features of this phenomenon are described in the experiment of the Frozen Lake.

Experimental setup

This set of experiments aims at investigating the dynamics of heating a liquid that is initially cooled down and then allowed to warm up in contact with the environment. Temperature vs. time has been measured at different levels in the vessel containing the liquid. Cylinders like those in figure 1 can be used, but also PET bottles like in figure 2.



Fig. 1: The first cylinder is filled with alcohol and the second with oil; three temperature probes can be seen in each one.



Fig. 2: Measurements can be performed also in a plastic bottle, this one is filled with water.

The experimental apparatus is made of:

- 3 cylinders or 3 plastic bottles
- 3 flexible temperature probes
- Graphing calculator Ti84Plus
- Calculator Based Laboratory unit CLB or CBL2

- Unit-to-unit standard cable ([see photo](#))
- Acquisition software DataMate (downloadable)
- TI-GRAPH LINK cable and software (optional, for data transfer to PC)

Info: <http://education.ti.com/us/product/accessory/connectivity/features/software.html>

Downloadable from: <http://education.ti.com/us/product/accessory/connectivity/down/download.html>

Other calculators can be used (for 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.

It is advisable to have three probes, but the experiment can be performed also with two.

Practical notes about setting up and performing the experiment :

- Arrange three flexible probes sticking them to the container so that one is at the bottom, one at the middle and one at the surface of the liquid;
- Setup the data acquisition system;
- Take some cold water and add some ice to it;
- Stir the liquid soon before starting to measure;
- Dip the probes, take care that they do not touch the borders;
- Start the acquisition (if you need help go to Data Acquisition at the bottom of this page).

In the sample experiment, temperatures have been taken 90 times every 30 seconds. The measurement lasted 45 minutes.

How did your plots come out?

If you wish, you can compare them with the plots of the sample data ([water](#), [alcohol](#), [oil](#); see also teacher's guide). If you are unable to perform the experiment you can use the data downloadable from Data Sample, at the bottom of this page.

You can observe how temperature changes at different levels in the liquid by warming up the bottle with a hair dryer pointing at the upper or at the lower part of the bottle. Measurements are very quick now. You can follow what happens in 3 minutes, taking 60 measures every 3 seconds. In Data Sample data are available about heating alcohol from the top and from the bottom.

The teacher can find some suggestions in the section about educational issues.

DATA ACQUISITION (Ti84)

Heat transmission in liquids: convection currents and anomalous behaviour of water

In this experiment we shall collect the temperatures measured by the three probes.

Measure can be collected using DataMate program.

Procedure can be divided into two stages: setup and collection.

Setup:

Connect all cables:

- the calculator to the interface with the black cable (see photo)
- the probes to channels CH1, CH2, CH3 (see photo)

Arrange all necessary materials:

- fill the bottle with water and ice
- shake before starting data collection. Start DataMate program:

CHECKING SENSOR appears and near the channel labels CH 1: TEMP (C) - CH 2: TEMP (C) - CH3: TEMP (C) the temperature of each probe can be read.

To setup the measurement

- select 1:SETUP by pressing 1
- select MODE:TIME GRAPH and press ENTER
- from the menu SELECT MODE select 2:TIMEGRAPH
- select 2:CHANGE TIME SETTINGS
- when ENTER TIME BETWEEN SAMPLE appears press 30
- when ENTER NUMBER OF SAMPLES appears press 90,
- then ENTER to confirm select 1:OK by pressing 1.
- Insert the probes in the containers and start measurements by selecting 2:START.

While measurement occurs the plots of the temperatures from the three probes is shown in real time; when the collection of data is over the plot is rescaled.

Collected data are recorded in the lists

- L1 time
- L2, L3, L4 temperature

To have a look at the plot obtained click on [water](#), [alcohol](#), [oil](#).

Repeat the measurement using the hair dryer: observe how temperature changes at different levels in the liquid by warming up the bottle with a hair dryer pointing at the upper or at the lower part of the bottle. Data collection setup is very similar. You can follow what happens in 3 minutes, taking 60 measures every 3 seconds. On page Data Sample a sample of data and the corresponding plots about the alcohol experiment are available.

Data sample TI84

Data have been collected using:

- TI84 graphing calculator
- CBL2 interface ([see photo](#))
- Three temperature probes
- Black connecting cable ([see photo](#))
- DataMate program
- [TI-GRAPH LINK TM](#) cable and [software](#) (optional)
- 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:

Water:

- **L1** times
- **L2** first probe temperature
- **L3** second probe temperature
- **L4** third probe temperature

Alcohol from the bottom:

- **L1** times
- **L2** first probe temperature
- **L3** second probe temperature
- **L4** third probe temperature

Alcohol:

- **L1** times
- **L2** first probe temperature
- **L3** second probe temperature
- **L4** third probe temperature

Alcohol from the top:

- **L1** times
- **L2** first probe temperature
- **L3** second probe temperature
- **L4** third probe temperature

Oil:

- **L1** times
- **L2** first probe temperature
- **L3** second probe temperature

Sample data (MS Excel):

In order to see or download sample data in MS Excel [klik here](#).

Data about heating alcohol from the [bottom](#).

Data about heating alcohol from the [top](#).