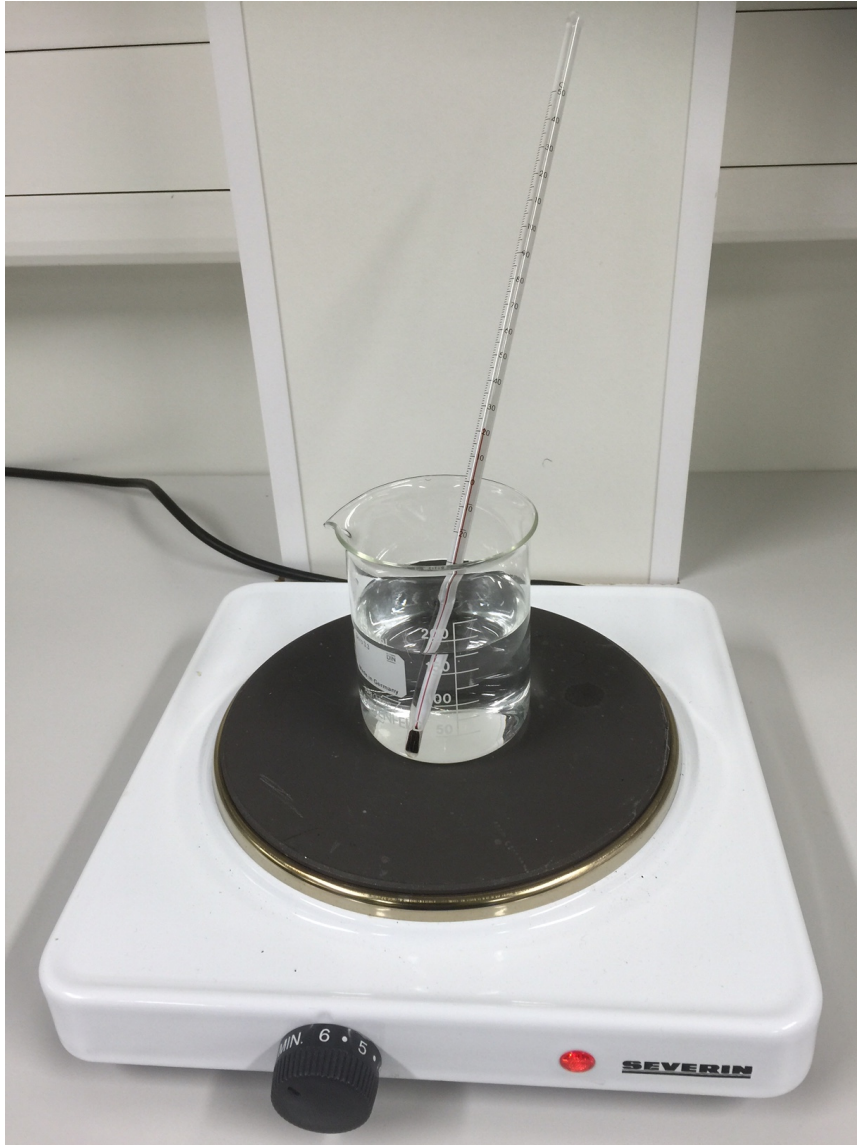


## **PRACTICALS IN PHYSICS AS A NATURAL SCIENCE FOR 15IB**

In this document you have the practicals in the Physics as a Natural Science Course. The listed understandings are the topics you should pay special attention to in an experiment. You find more information in the course book.

## 1.1 Fundamentals of Measurement



In this experiment you are about to measure the temperature of water (dependent variable) as a function of time (independent variable) until the water boils.

**Note!**

Be careful with hot water. The beaker may break accidentally during heating.

The understandings include

- Instrumental uncertainty
- Random uncertainty
- Uncertainty in a measurement
- Graphical representation of data
- Independent and dependent variable
- Best estimate for the measured quantity
- Probable range
- Reference value

### Instructions

**In a physical experiment we try to obtain as accurate data as possible.**

In doing so we have to know how to use the measurement devices so that the uncertainty in a measurement is as small as possible.

For example, in measuring the temperature of water, the thermometer must stand upright without touching the bottom of the beaker, and the values must be read in horizontal direction to avoid parallax.

### Procedure

Measure 200 ml of water into the beaker. Measure and record the temperature of water at one minute intervals in a table until the water boils.

Record the boiling point of water also with a temperature sensor connected to a multimeter.

### Graphing

Construct a coordinate system for the temperature  $\theta$  as a function of time  $t$  on a graph paper so that at least a half of the paper is in use. Mark the measurement points on the coordinate system.

### Sources of Uncertainty

Estimate the instrumental uncertainty in the traditional thermometer, and in the digital multimeter.

Record the boiling point of water with uncertainty for the two thermometers as instructed in the book.

In your notebook, draw the probable ranges for the results. How do the results compare?

Check the accuracy of the digital thermometer from the manual. Draw the probable ranges and compare the results. How do the results compare now?

Compare your results with the reference value of 100 °C for the boiling point of water.

## 1.2 Manual Timing in Free Fall

In this practical you measure the falling time of an object in groups of six using manual timing.

### Understandings

The understandings in the Manual Timing in Free Fall practical include

- Estimation of experimental uncertainties.
- Recording data in tables with uncertainties.
- Calculating percentage (fractional) uncertainties in a single and repeated experiment.
- The percentage uncertainty as a measure of reliability of data.
- The effect of increasing the number of measurements in a repeated measurement.

### Procedure

Work in groups of six. Drop a small solid object, such as a ball or an eraser, from a selected height, such as 2.10 m. Measure the falling time by following the procedure below.

1. Choose a steady stand, and measure the falling height as accurately as possible. Estimate the absolute uncertainty in the measurement of height. Record the falling height  $h_i$  in a table with absolute and percentage uncertainties ( $\Delta h_i$  and  $\Delta h_{i,\%}$ , respectively).
2. Drop the object on the floor from rest, and measure the falling time. While one person lets the object go, the others measure the falling time by their timing devices. Estimate the absolute uncertainty in manual timing. Record the falling time  $t_i$  in a table with absolute and percentage uncertainties ( $\Delta t_i$  and  $\Delta t_{i,\%}$ , respectively).

Record the results in a table with uncertainties as instructed in the next section.

Calculate the average of the falling times, and the associated absolute and percentage uncertainties according to the instructions in subsection **Instructions for Analysis in the Free Fall Experiment**.

What can you say about the fractional uncertainties in manual timing?

### Recording Raw Data

In this section we give you instructions for the recording of raw data.

As you measure the value of a quantity, you should always record the value with the associated uncertainty. Usually, the data are recorded in tables. Below you have an example of recorded data in a free fall experiment for three timers. Note that the uncertainties are not necessarily correct for the experiment.

Table 1.1: Raw data in a falling time measurement.  $h$  is the distance fallen, and  $t_1$ ,  $t_2$ , and  $t_3$  are the respective falling times measured by three observers. **Note that the uncertainty in height is the uncertainty in the measurement, but the uncertainties in time are instrumental uncertainties.**

$h/\text{m} \pm 0.05\text{ m}$	$t_1/\text{s} \pm 0.4\text{ s}$	$t_2/\text{s} \pm 0.4\text{ s}$	$t_3/\text{s} \pm 0.4\text{ s}$
0.70	0.32	0.42	0.37
1.20	0.41	0.36	0.42
1.50	0.73	0.61	0.62
2.00	0.65	0.81	0.72
2.30	0.82	0.75	0.79

The data is recorded in tables with uncertainties. The uncertainties are rounded to one significant figure. The data in a column should be as precise as the uncertainty.

In the table above, the precision in the uncertainty of the height matches the precision of the height data. In the timing data, the recorded values are too precise in comparison to the estimated uncertainty. How would you fix the problem?

The layout of the table is crucial. The structure of tables should always follow the conventions presented exactly – no improvisation is allowed.

The symbols of quantities, units and uncertainties are recorded in the first row of the table. The units are not repeated in the following cell. The precision of data should be consistent and match the uncertainty stated.

In a single measurement, the recorded uncertainty is the uncertainty in the measurement.

In a **repeated measurement** we do not record the experimental uncertainty, but the **instrumental uncertainty of a measurement device**.

#### Instrumental uncertainty

The accuracy of a measurement device is called the instrumental uncertainty.

You will find the instrumental uncertainty of digital measurement devices from the manual of a device. If a manual is missing, **you may assume that the uncertainty is the precision of the digital device**. For example, if mass is measured by a digital scale as 76.3 g, you may estimate the uncertainty as 0.1 g which is also the instrumental uncertainty of the device.

You can have the instrumental uncertainty for analogue devices from the manual, also. In the absence of the manual, the uncertainty has to be estimated. For example, the uncertainty in a mercury thermometer may be estimated as  $\pm 1^\circ\text{C}$ .

### Instructions for Analysis in the Free Fall Experiment

Repeated measurement is a way of reducing the effect of random uncertainties in a measurement.

#### Repeated measurement

The process in which the value of a quantity is measured several times exactly the same way is called a repeated measurement.

For example, in the free fall experiment, five persons measure the falling time at the same time. As a result, we have five measurement values for the falling time, which should in principle be equal. The process is equivalent to a repeated measurement, where the object is dropped three times from the same height, and the falling time is recorded in each case.

In a repeated experiment we have to calculate the average of the measurement values. In the practical work in the IB, you are allowed to use a simple method of finding the uncertainty in the average.

**Uncertainty in the Average**

The uncertainty in the average is

$$\Delta \bar{x} = \frac{x_{\max} - x_{\min}}{N} \quad (1.1)$$

where  $x_{\max}$  is the maximum and  $x_{\min}$  the minimum value in the sample, and  $N$  is the number of measurements.

**Question.** What happens to the uncertainty as the number of measurements  $N$  increases? Calculate the uncertainty in a case were the range  $x_{\max} - x_{\min}$  is unchanged (use the value from the data of your group), and the number of measurements is 1000? Explain briefly, is the value obtained a reasonable estimate of the uncertainty in the average?

## 1.2.1 Answers to questions in Free Fall experiment

The uncertainty in the measurement of height may be estimated as  $\pm 0.5$  s. The factors that affect the uncertainty are

1. the ribbon is not standing upright, and
2. parallax due to person standing below 2.1 m (systematic uncertainty), and alternating viewing angle (random uncertainty).

The systematic uncertainty of the device itself  $\pm 0.001$  m is negligible. The uncertainties in the range 0.03 m to 0.06 m are acceptable.

Uncertainty in manual timing is approximately  $\pm 0.2$  s. The fractional uncertainty in a 2.1 m fall is, for example,  $\Delta t_{\%} = \frac{0.2 \text{ s}}{0.76 \text{ s}} \approx 0.3 = 30\%$ , which is away too much. **As rule of thumb, the fractional uncertainty in a physical measurement should be at maximum 5%.**

The table represents the data acquired in an experiment.

Table 1.2: The uncertainty in the height column is the uncertainty in the measurement whereas in the timing data the instrumental uncertainty is recorded instead.

$h/\text{m} \pm 0.05 \text{ m}$	$t_1/\text{s} \pm 0.01 \text{ s}$	$t_2/\text{s} \pm 0.01 \text{ s}$	$t_3/\text{s} \pm 0.01 \text{ s}$	$t_4/\text{s} \pm 0.01 \text{ s}$	$t_5/\text{s} \pm 0.01 \text{ s}$
2.10	0.68	0.84	0.72	0.76	0.69



**Note!**

Since we are about to calculate the average of the falling times, we do not record the uncertainty in time, but the instrumental uncertainty of a mobile phone.

The average of the falling times is

$$\bar{t} = \frac{0.68\text{ s} + 0.84\text{ s} + 0.72\text{ s} + 0.76\text{ s} + 0.69\text{ s}}{5} \approx 0.74\text{ s.} \quad (1.2)$$

The uncertainty in the average is

$$\Delta\bar{t} = \frac{0.84\text{ s} - 0.68\text{ s}}{5} \approx 0.03\text{ s.} \quad (1.3)$$

**The uncertainty in the average is unrealistically small.** It is not realistic to assume that in manual timing we would get a result with the uncertainty of only three hundredths of a second.

For a thousand measurements we would get

$$\Delta\bar{t} = \frac{0.84\text{ s} - 0.68\text{ s}}{1000} \approx 2 \times 10^{-4}\text{ s.} \quad (1.4)$$

which is less than the instrumental uncertainty of a timing device.

In the equation

$$\Delta\bar{x} = \frac{x_{\max} - x_{\min}}{N} \quad (1.5)$$

the uncertainty approaches zero as the value of  $N$  increases (approaches infinity). This is not realistic. There must be a practical limit for the uncertainty in a measurement. For example, **there is no way the uncertainty could be less than the instrumental uncertainty.**

## 1.3 Air Bubble in a Water Filled Tube

You are about to measure the position of an air bubble as a function of time in groups of six. **In this practical you learn how the value of a physical quantity can be determined from the slope of a best fit line.**

In uniform motion the speed is constant. The speed is

$$v = \frac{s}{t} \quad (1.6)$$

where  $s$  is the distance travelled, and  $t$  is time taken.

Solving for the distance travelled gives

$$s = vt \quad (1.7)$$

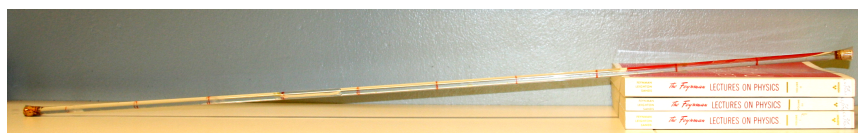
**which is an equation of a straight line through the origin in a time distance coordinate system.**

### Understandings

The understandings include

- the position,
- the line of best fit,
- the slope of a line and
- uniform motion.

#### 1.3.1 Measuring the position as a function of time



**Figure 1.** An air bubble travels in a tube.

### Preparation

Choose a reference mark on the left end of the tube (position  $s = 0$  cm). This is the origin of motion. Construct the position axis by measuring the position of the successive marks with respect to the reference mark by a tape measure.

Estimate the **instrumental uncertainty** of the tape measure, and estimate the uncertainty in the position measurement. Record the positions on a table with uncertainties.

Record the instrumental uncertainty of a timing device, and estimate the uncertainty in manual timing. Record the estimate as the uncertainty of time.

Make sure that the tube lies straight and stable at an incline on the table. Use for example books for the support.

Select five timers from your group. Use your mobile phones for timing. Choose a unique end position for each timer where he or she stops timing. Timing starts when the bubble reaches the origin of motion. Timing stops as the bubble reaches the end position.

### Observing motion and position measurement

Take the tube, and move the bubble to the left end of the tube. Put the tube back on the table, and observe the motion of the air bubble. **How does the bubble appear to move?**

Next, measure the position of the bubble as a function of time. Record the results on a table with uncertainties.

$t/s \pm 0.2\text{ s}$	4.4	8.3	13.2	17.3	21.3	25.5	30.9
$s/\text{cm} \pm 0.1\text{ cm}$	10	20	30	40	50	60	70

Table 1.3: An example of the results in a bubble experiment. The position  $s$  of the bubble in a water filled tube as a function of time  $t$ .

### 1.3.2 Analysis

Construct a  $(t, s)$  coordinate system on a graph paper, and mark the measurement points on the graph.

1. Do the measurement points fall on a line? Explain.
2. Which kind of dependence there is between the variables? If it is linear, draw a best fit line through the points.
3. Does the line go through the origin? Should it? Explain.
4. Calculate the slope of the line. Remember to express the result in the correct number of significant figures with units.
5. Does the slope of the line have any physical meaning? Explain the meaning of the slope in your own words.
6. Would the reciprocal of the slope have any physical meaning?

### 1.3.3 Analysis in Logger Pro

1. Put the data in Logger Pro.
2. Perform an automatic linear fit.

3. Record the slope.
4. The y intercept may be an indication of an systematic error in the measurement. Is there appreciable systematic error in your measurement?
5. Finally, compare the speed of the bubble from Logger Pro to the one you got from the graph paper.