

## Free Fall with Digital Display

Ref. 002 050

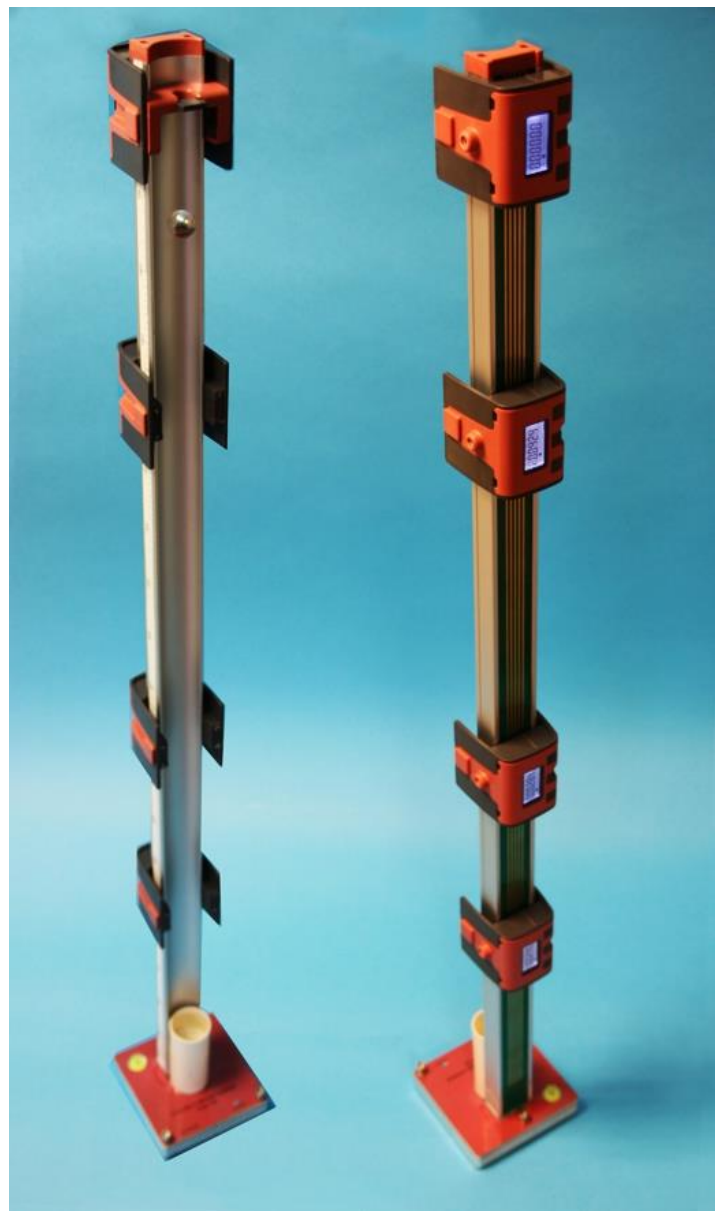
### I - Object

This apparatus is designed for detailed study of free fall, using a graduated column with 4 optical timing forks, which measure time and instantaneous speed of a falling ball at four positions. By sliding the timers to different positions it is possible to record data and plot 3 relationships :  $z(t)$ ,  $v(t)$  et  $v^2(z)$ . For simpler operation only two forks are required.

### II. Specification

The apparatus comprises :

- An alloy column graduated from 0 to 900 mm, welded to a heavy base with a spirit level and three levelling screws. Gold plated PCB tracks provide communication between the timers.
- Four optical timing forks with digital displays.
- Manual ball release system
- Two balls
- Ball catching receptacle
- Four long screws for attaching the forks to laboratory clamps for use without the free fall column, for example on an air track or ramp.



### III. Operation

#### 1. Timing forks



See the detailed instruction sheet for the optical timing forks at the end of this document.

## 2. Operation

- Place the four timing forks on the column. The buttons must be on the right, with the gold connecting pins at the top. The scale on the column should be visible through the side window on the fork.
- Clip the ball release mechanism to the top fork.
- Adjust the levelling screws until the spirit bubble is centred. **IMPORTANT.** The column must be precisely vertical or the ball will not pass through the lower gates in the right position.
- Position the ball on the release mechanism.
- Select the mode for each timer : standalone or master/slave.

**The standalone mode** measures and displays the passage time of the ball between the two phototiming gate slots set 1 cm apart on the fork to measure instantaneous speed. This mode is used for the study of the velocity of the ball as a function of its distance and establish the relationship  $v^2(z)$ . This mode is ideal for the study of conservation of mechanical energy of the ball during its fall.

**The master/slave mode** measures the time elapsed between the first slot of the master fork and the first slot of lower slave forks. The master fork triggers all slave timers to start. Each slave fork also measures instantaneous speed using the twin slots set 1 cm apart.

This mode allows the study of the distance travelled by the ball over time  $z(t)$ .

Note: The slave mode also allows the study of the speed versus time  $v(t)$  with good accuracy.

## IV. Experiments

- In the following experiments the optical timing forks are set up as follows :

Experiment	Fork No.1	Fork No.2	Fork No.3	Fork No.4
1st	0	10 cm	35 cm	60 cm
2nd	0	15 cm	40 cm	65 cm
3rd	0	20 cm	45 cm	70 cm
4th	0	25 cm	50 cm	75 cm
5th	0	30 cm	55 cm	80 cm

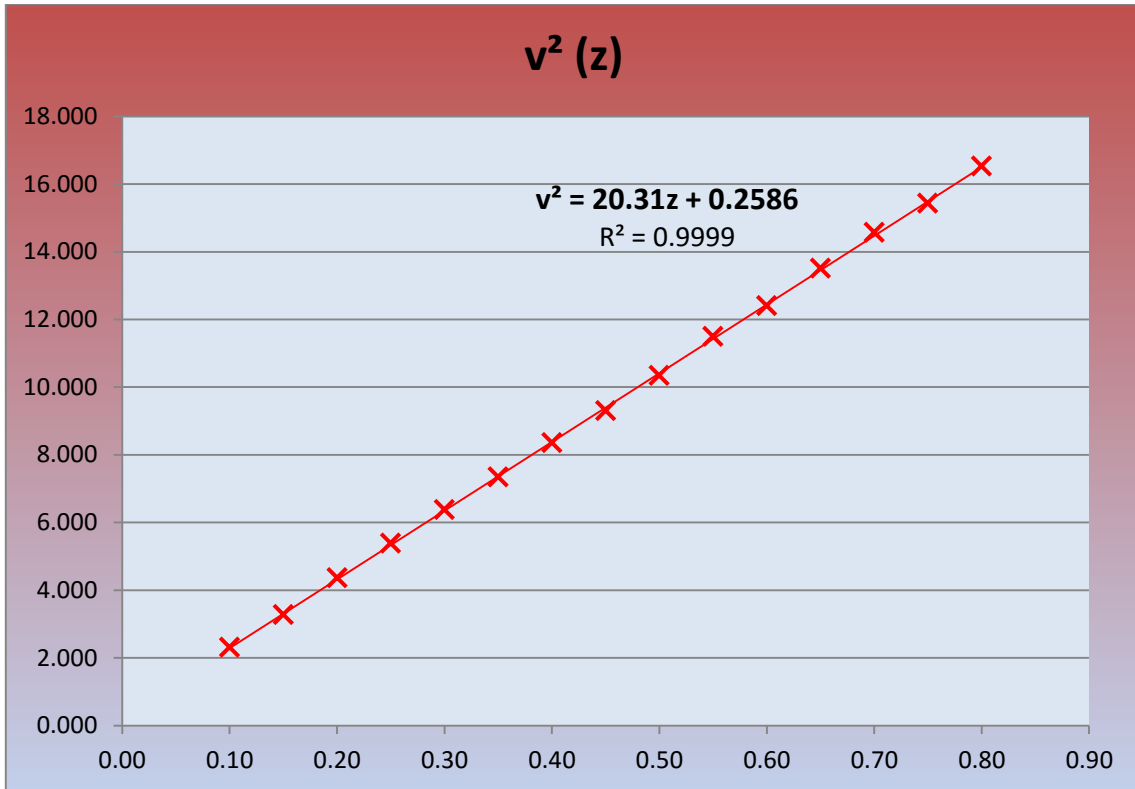
- Switch on the forks (button A)
- Before each experiment, press the button C to set the forks in acquisition mode.
- Slowly pull the tab to release the ball so that its speed in passing to zero of the graduated column is always substantially the same value. After each experiment note the time and speed data of the ball in a spreadsheet,(press button B).

Note: If for any reason a timer was not triggered or did not stop, repeat the experiment putting only this stopwatch in acquisition mode (button C). If the problem persists, reset the offending optical fork by pressing twice on the button A. This may happen if the column is not precisely vertical.

**1. Study of  $v^2(z)$  (forks in standalone mode)**

After each free fall, press button B on each timer to read the speed of the ball. Here is an example result:

z (m)	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
v (m/s)	1.520	1.810	2.088	2.320	2.525	2.710	2.890	3.050	3.216	3.390	3.521	3.676	3.817	3.928	4.065
$v^2$ (m <sup>2</sup> /s <sup>2</sup> )	2.310	3.276	4.360	5.382	6.376	7.344	8.352	9.303	10.343	11.492	12.397	13.513	14.569	15.429	16.524



The value of g is therefore 10.15 m/s<sup>2</sup> (Uncertainty : 3.5%)

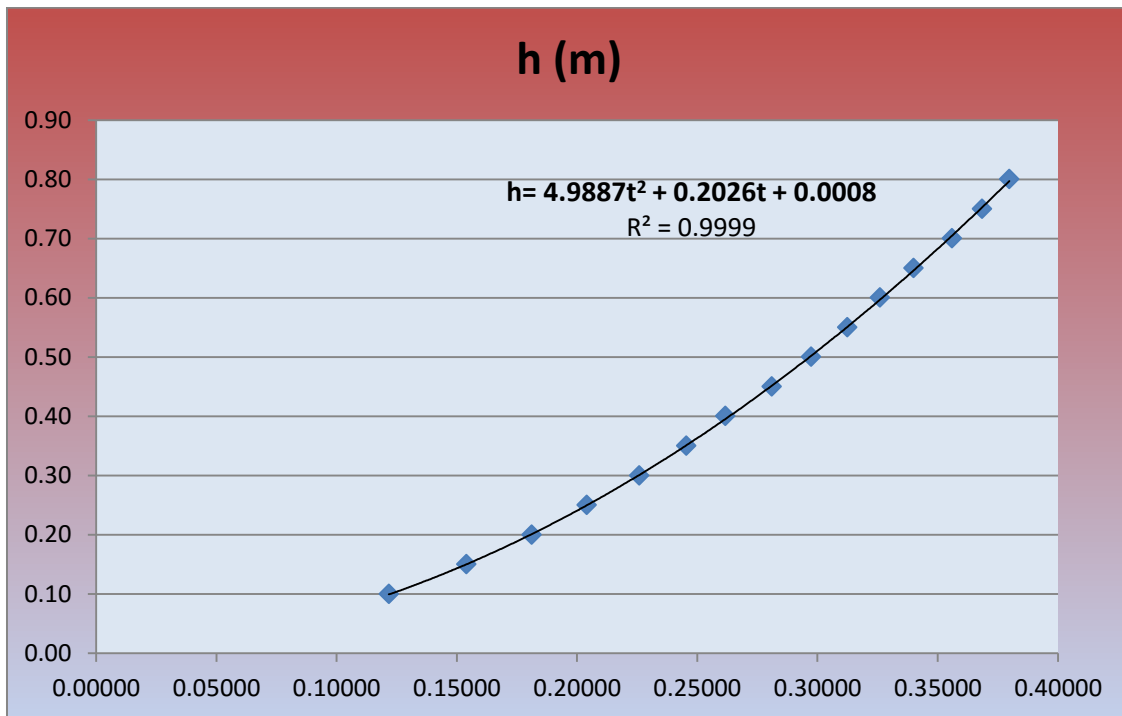
**2. Study of z(t) (Forks in Master-Slave mode)**

A long press of button C on the 1<sup>st</sup> timing fork puts it in « master » mode. The other forks are then « slaves ».

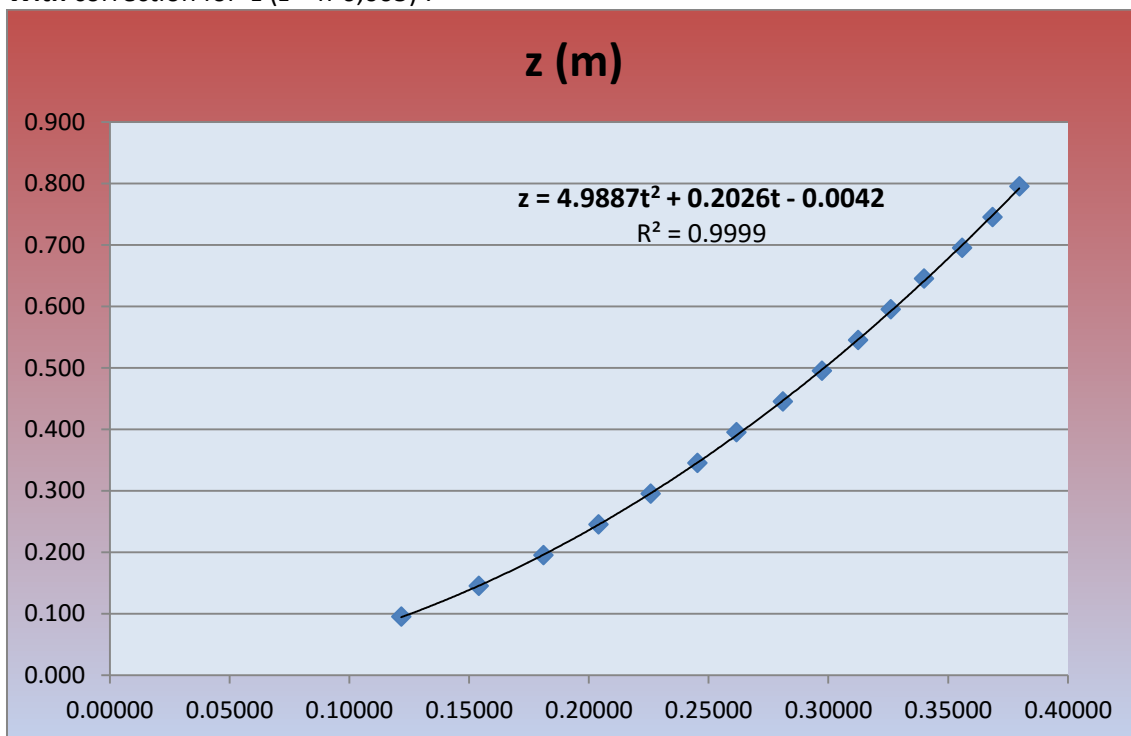
As the average speed between the two optical slots is the speed half way between them it is possible to correct the values of z by .005m. Corrected z = h - 0.005. Here is an example set of results:

h (m)	0.100	0.150	0.200	0.250	0.300	0.350	0.400	0.450	0.500	0.550	0.600	0.650	0.700	0.750	0.800
z (m)	0.095	0.145	0.195	0.245	0.295	0.345	0.395	0.445	0.495	0.545	0.595	0.645	0.695	0.745	0.695
t (s)	0.122	0.154	0.181	0.204	0.226	0.245	0.262	0.281	0.297	0.312	0.326	0.340	0.356	0.368	0.380

Without correction of z, z (z ≈ h) :



With correction for z ( $z = h - 0,005$ ) :



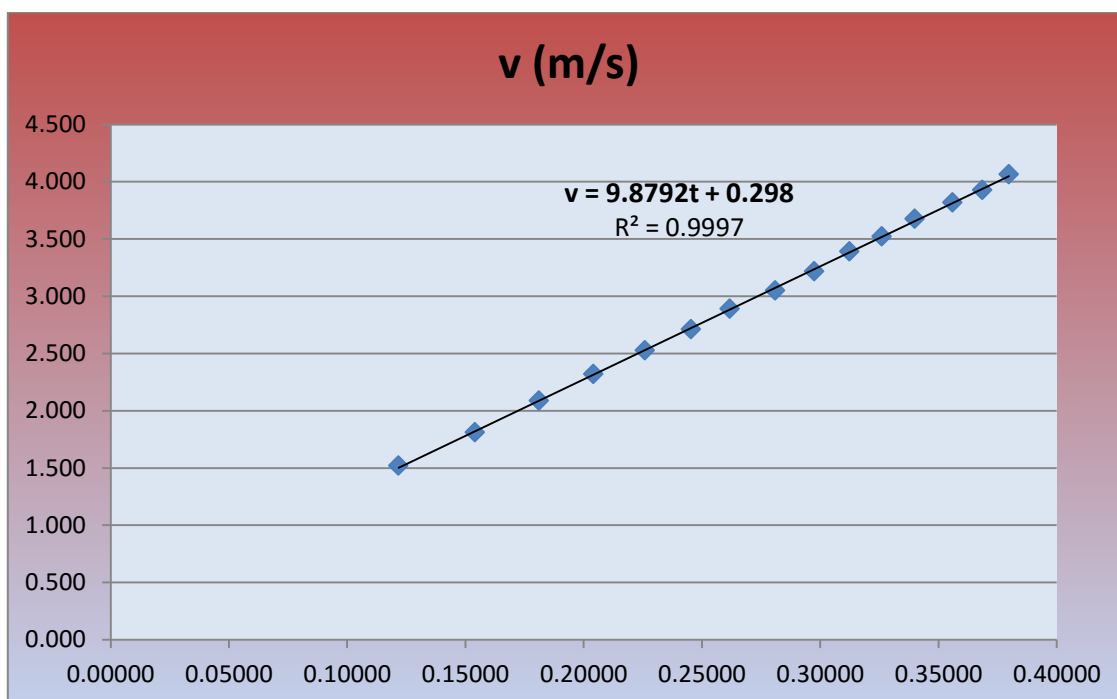
It turns out that the adjustment does not affect the value of  $g = 9.97 \text{ m} / \text{s}^2$  (Uncertainty: 1.6%).

### 3. Study of $v(t)$ (Forks in slave mode)

It should be noted here that the passage time before the first slot is not exactly the same as that which corresponds to the speed displayed (transition to the middle of the two slots). After each free fall, push button B on each timer to read the values of  $v$ .

Here is an example set of results :

t (s)	0.122	0.154	0.181	0.204	0.226	0.245	0.262	0.281	0.297	0.312	0.326	0.340	0.356	0.368	0.380
v (m/s)	1.520	1.810	2.088	2.320	2.525	2.710	2.890	3.050	3.216	3.390	3.521	3.676	3.817	3.928	4.065



The value of g is 9.88 m/s<sup>2</sup>. (Uncertainty : 0.7%).

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## Optical Timing Forks

Ref. 002 049

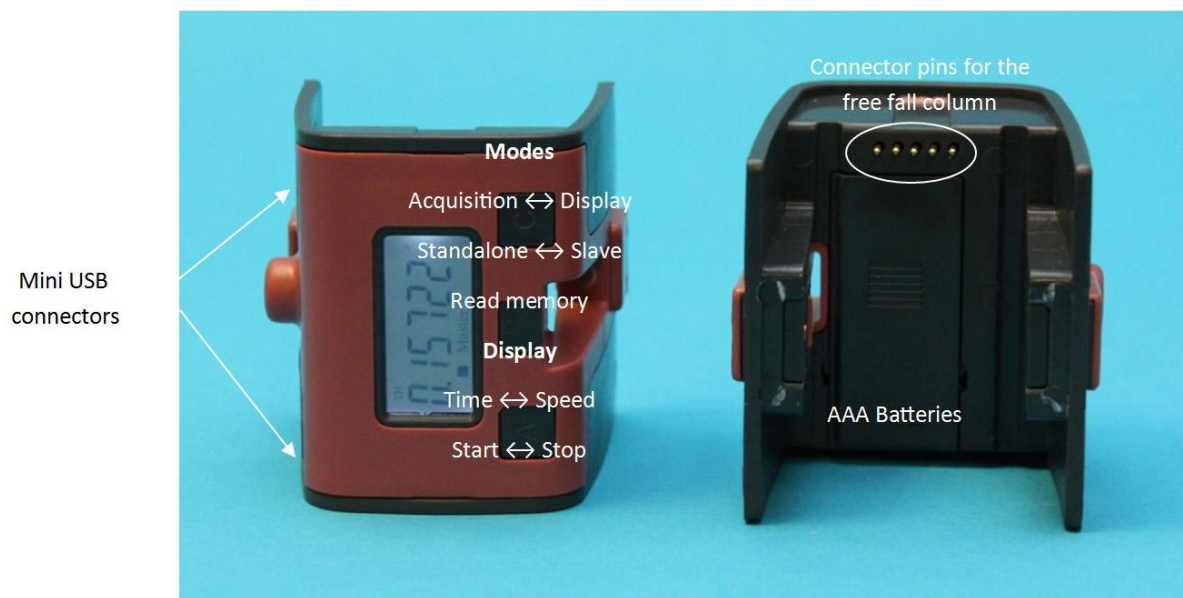
### I - Object

The optical timing forks measure elapsed time and speed.

Used in standalone mode the forks measure speed using two light gates set 1 cm apart.

Used in master/slave mode the master fork starts the timers in all slave forks allowing elapsed time to be measured between the forks.

### II. Specification



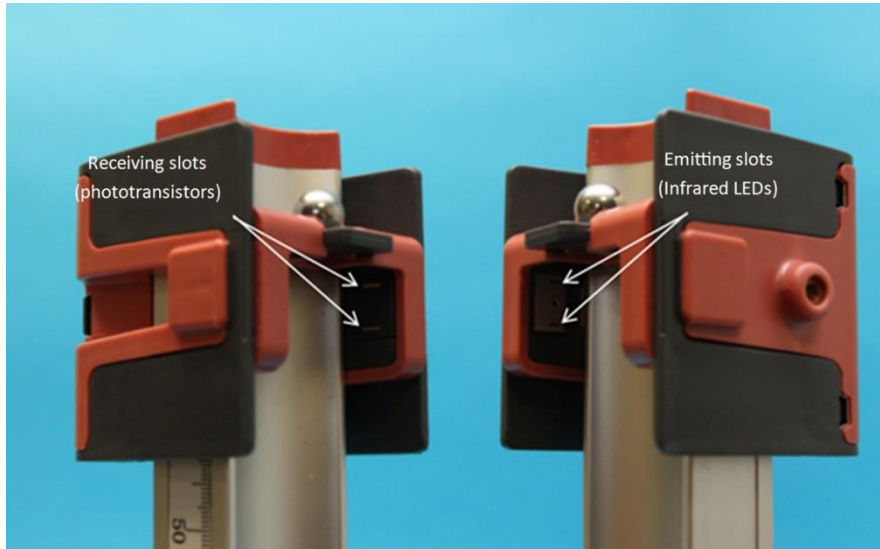
- Display : LCD 6 digits
- Timer : in seconds, resolution 1/100 000 s, precision 1/1000 s
- Speed display : units displayed : s, m/s, cm/s, km/h
- 5 non-volatile memories (data survives without power)
- Power from 2 x LR03 AAA 1.5 V batteries(not supplied)
- Long bolt and clamp nut for fixing to standard lab clamps
- Two mini USB connectors to allow timers to be powered and connected with a mini USB to mini USB lead (not supplied). Please order separately\*
- A USB to mini USB power adapter can be used to power the timing forks through the free fall column (not supplied). Please order separately.



Not supplied

\* Connection between the timers can be made using the free fall column or by the USB cable, but not both. Use without the column is normally in standalone mode and does not require cable connection.

### III. Description



#### 1. Two timing modes

The fork has two emitters (infrared LEDs) and two receivers (phototransistors) set in slots 1cm apart. These phototiming gates start and stop the timer when each light path is blocked.

The timer can be started and stopped in two ways:

- **In standalone mode**, each timing fork is independent : In this case the timer is triggered by the occlusion of the first gate and stopped by the second gate. The timer displays the time elapsed and speed of an object passing through the gates.
- **In master/slave mode**, all the forks are interconnected. The « slave » forks are controlled by the « master » top fork: In this case, the occlusion of the first gate of the « master » triggers all the « slave » timers simultaneously. The « master » timer is stopped when its second gate is occluded. Each « slave » timer is stopped when its first gate is occluded. So in this mode we are measuring the time elapsed between the master and each slave fork being occluded.

#### 2. Data Memory

The optical timing fork has 5 memories, D1, D2, D3, D4 and D5. At each acquisition the measured time is stored. (this data will remain even if power is interrupted). See the example below :



The value 0.00284 s is acquired and stored in memory D1.  
 The symbol ■ indicates that the timer is in display mode.

#### IV. Operation

Insert the batteries into the battery holder on the rear face of the fork, or connect to a USB-Mini USB cable connected to a 5 V USB-mains adapter. Switch on by pressing button A.

**Presses on buttons A, B or C can be short <1s, or long >3s.**

##### Button A

Short press	Stop/Start
Long press	Clear memory



### Button B



Short press	Each short press selects successive readings of : Speed in m/s, Speed in cm/s Speed in km/h, Time in s. etc.
Long press	Scrolls through memory locations : D1 → D2 → D3 → D4 → D5 → D1 → etc.

### Button C





Short press	By default the symbol ■ is displayed ■ A short press puts the fork in acquisition mode indicated by the symbol ► . Subsequent presses increment the memory location D to D+1.
Long press	Sets the mode to Master A second long press deselects Master mode

Some display examples :

#### Button C

	
<p><i>Short press :</i> Acquisition (symbol ► displayed) in standalone mode</p>	<p><i>Long press :</i> Acquisition (symbol ► displayed) in master-slave mode (image shows the « master » timer)</p>

**Button B**

	
<p>Display of time (this is the time between the first and second gates in the timer).</p>	<p>1<sup>st</sup> press : displays instantaneous speed of passage through the fork in m/s.</p>
	
<p>2<sup>nd</sup> press : displays the speed in cm/s.</p>	<p>3<sup>rd</sup> press : displays the speed in km/h.</p>

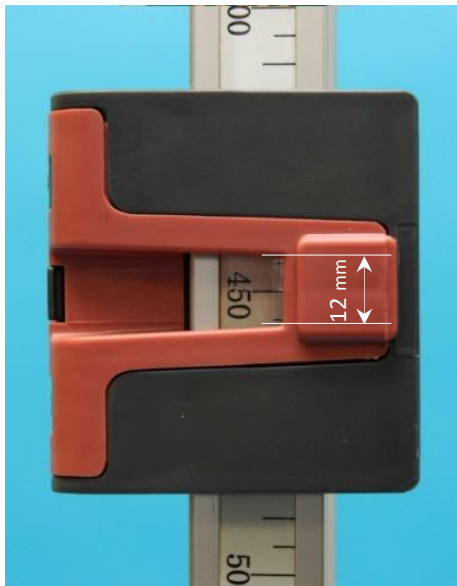
**Important note :**

The speed displayed (after pressing the button B) is the average speed calculated since the occlusion of the first slot to the occlusion of the second slot (distance of 1 cm from the 1st). This speed is substantially equal to the instantaneous speed reached in the middle of the two slots.

In master-slave mode, the occultation of the first slot of the fork-optical "slave" will stop the clock that displays the time elapsed since the occultation of the 1st slot of the "master" fork. The speed is displayed (after pressing the button B) remains one of the instantaneous velocity of moving its passage through the two slits of this slave fork.

The timing forks cannot display average speed between forks as they do not know the distance between the forks.

### V – Positioning the fork



Position the optical timing fork so that the scale can be read through the window as shown here.

The centre line of the window is in line with the mid point between the two phototiming gates in the fork

In the photo on the left the mid point of the timing gates is at 450 mm. The first 1<sup>st</sup> gate is therefore at 445 mm and the 2<sup>nd</sup> at 455 mm.

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