SOLARSCOPE

PRACTICAL WORKS

- Primary School level
Grammar &High School Level-

CONTENTS

SOLARSCOPE		Level
Practical work - 1	**Solar day measurement**	**Primary School**

- TOOLS

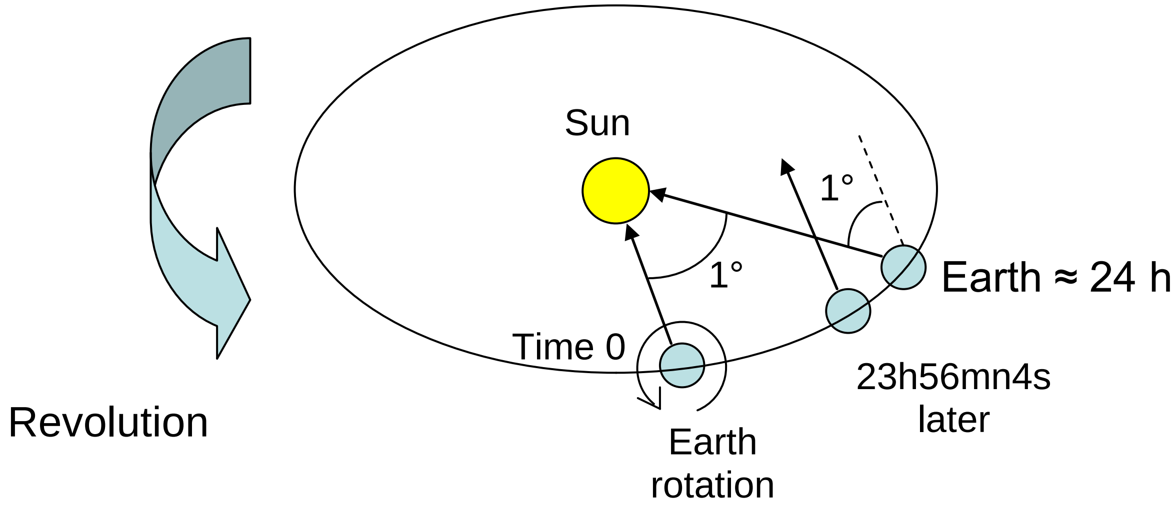
A solarscope,
A chronometer,
A measurement screen (optional),
This experience can be done inside a room southward oriented, or outside in a windless environment.

- 1 - PRINCIPLE

Earth is rotating around itself and also rotating around the Sun. The Earth has, throughout the year, a complex periodical movement. The earth revolution around the Sun determines the different stage of the year. The Earth rotation determines the different stage of the day. However there is two definition of the day :

Sidereal day (from Latin *sideris*, « star ») it lasts 23h 56mn 4s. It is the measure of the Earth's rotation. It is linked to a referential linked to distant stars.

Solar day is 24 hours. It represents the time separating two passages of the Sun at the same Meridian. Indeed if we take the Sun as a reference, Earth has to make a whole rotation to show the next day the same direction of the Sun, (see sketch bellow). This period, of approximately 24 hours, is an average. Solar Day can vary throughout seasons.
Indeed the Earth is not rotating at a constant rate along its ecliptic (plan that goes through the centre of the Sun and that includes the Earth's orbit).

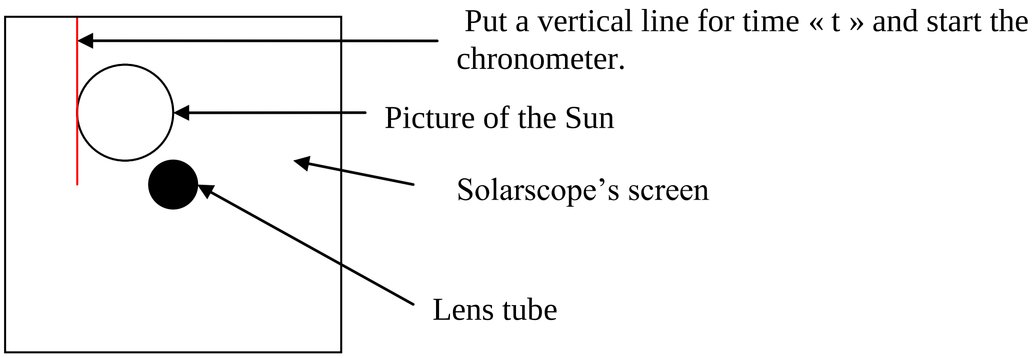


N.B : In a year (of 365 days) the Earth has a revolution of 360 ° around the Sun.
That is to say 1° degree per day.

***Rotation** is : when a star or a planet is spinning on itself.
***Revolution** is : a orbital periodical movement of a star or planet around another star or planet.

- 2 - MEASUREMENT

For children in primary school, the most important notion to remember is solar Day.
Thanks to a chronometer or a watch (that shows seconds) children are able to measure the time of a Solar Day and its slight changes throughout the year.



-1- Make a vertical line on the measuring screen (the Sun will touch this line on one point, it doesn't matter is the line is not completely vertical).

-2- In order to get a correct picture of theSun, make all adjustment necessary.

-3- Make separate groups of 2 to 4 children in order to have different results. Each group must have a watch indicating hours minutes and seconds.

-4- One child seated next to the Solarscope must give the starting time when the Sun touches the vertical line. Each group must write this time on a note pad, (in hours, minutes and seconds).

-5- Put those results on the board below.

-6- Next day, 5 minutes before the starting time, make another measurement. When the Sun touches the vertical line, note the time, (in hours, minutes and seconds). Do remember not to remove Solarscope for 24 hours. Make sure the second measurement is similar to the first one.

-7- Put those results in the table on page 6 fill in line 1 to 2.

-8- Each group must calculate the length of time, and put it in the table (page 6) form line 3.

If another class is making the same experiment at the same time, you can compare results.
To make sure children take the correct starting time, train them before the experiment.

-3- RESULTS

This experiment can make children aware on measurements and precision, and also that measurement depends on who has taken it.
There is also a whole work on Time's calculation (add, remove......).
It is important to remember that a Solar day is 24 hours (an average done on a whole year). It is due to the Earth revolution around the Sun that slightly varies throughout the year. The Earth's orbit is not a perfect circle.
We are anyway obliged to live on the same hour pattern, by having days of equal value called legal hour.

-4- EXAMPLE

	Group 1	Group 2	Group 3	Etc…
Time of the first top	11 h 07' 45''	11 h 09' 22''	11 h 04' 02''	
Time of second top (next day)	11 h 07' 39''	11 h 10' 09''	11 h 04' 13''	
Time of the day	23 h 59' 54''	24 h 00' 47''	24 h 00' 11''	
Average *	(23h 59'54''+ 24h 00'47''+ 24h 00'11'') : 3 = (71h 59' 112'') : 3 = (71 h 60' 52'') = (72 h 00' 52'') : 3 = 24 h 00' 17''			
Difference with the average (Positive value)	24 h 00' 17'' - 23 h 59' 54'' ------------------ 0 h 00' 23''	24 h 00' 47'' - 24 h 00' 17'' ------------------- 0 h 00' 30''	24 h 00' 17'' - 24 h 00' 11'' ------------------- 0 h 00' 06''	
Average of differences	(23'' + 30'' + 6'') : 3 = 59'': 3 ≈ 20 secondes			
RESULT	During the experiment the result of the calculation of the day has been : 24h00'17 with a precision of 20 seconds.			

Average * : This calculation is difficult for middle school children, teachers can make it for them, and give results, to show them who were the closest to the results.

NB: Calculation of the difference in average is for children in Grammar school.

Notice: According to the days, the picture of the Sun appears at different places.
Do remember that pictures are inverted on the Solarscope. Consequently in a period when days are growing the Sun's picture will be lower (in reality it is higher), when the days are getting shorter, the Sun's picture is higher (in reality it is lower).

Date:

Class :

Practical work - 1 : SOLAR DAY MEASUREMENT

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9
Time of the first start									
Ending time (Next day) Second top									
Length of the day									
Average:									
Difference in averages									
Averages of differences:									

RESULT :

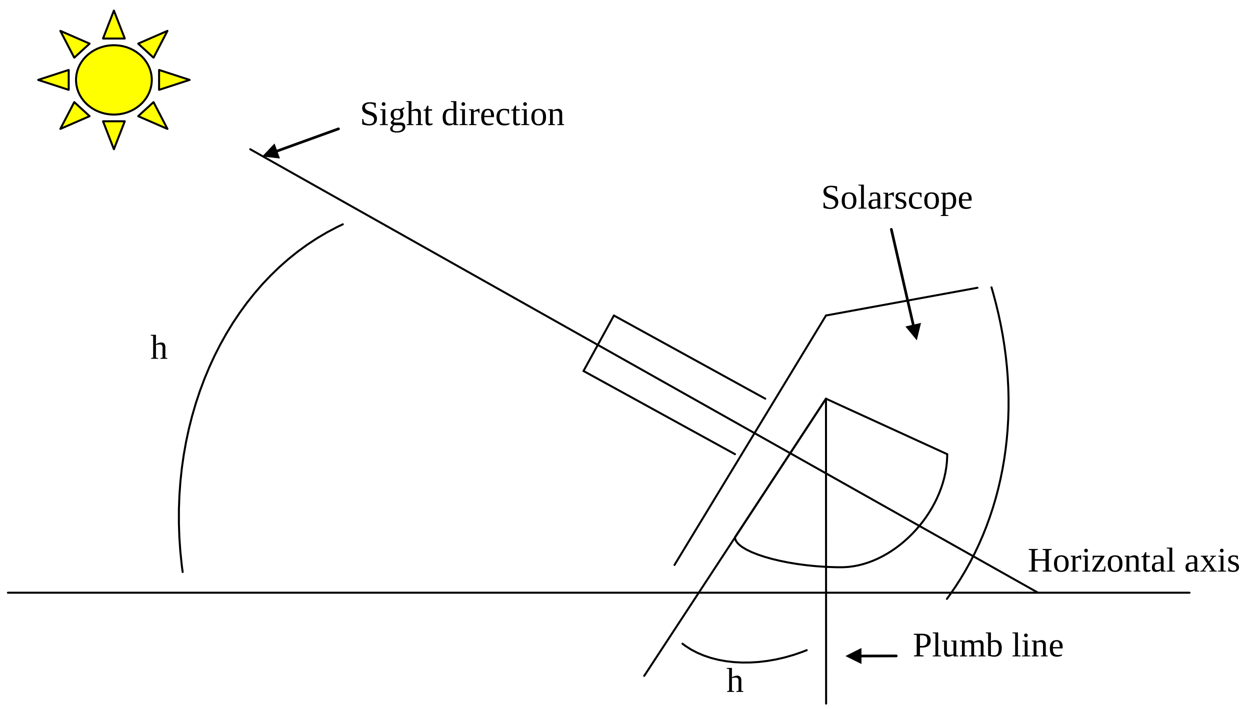
		Level
Practical work - 2	**Solar Noon**	**Middle school**

- TOOLS

A Solarscope,
A plumb line,
A watch indicating hours, minutes, seconds,
A measurement screen.
This experience can be done inside a room southward oriented, or outside in a windless environment.

- 1 - PRINCIPLE

It is noon when the Sun is at its climax (Zenith)
It is called Solar Noon. This "real" Solar Noon corresponds to a maximum angle of sight direction called (h).
The Sun is at its peak.
If we compare it with our watch it is not showing 12:00 AM.
If you wish to measure at anytime of the day the Sun's angle (h) use:
The protractor located on the left side of the Solarscope. To put the plumb line on the protractor, follow the instructions. An angle is indicated by the plumb line, this angle compared to the horizontal is the angle of direction of sight of the lens tube.
When this angle is at its climax it's Solar Noon.
The aim of this Worksheet is to determine the difference in time between Solar Noon and Noon (legal hour).



-2 - MEASUREMENT

If we follow the Sun's path, it is hard to determine exactly the maximal angle of sight. Indeed you cannot make this experimentation for more than 15 minutes in a row.

Here are two methods we offer:

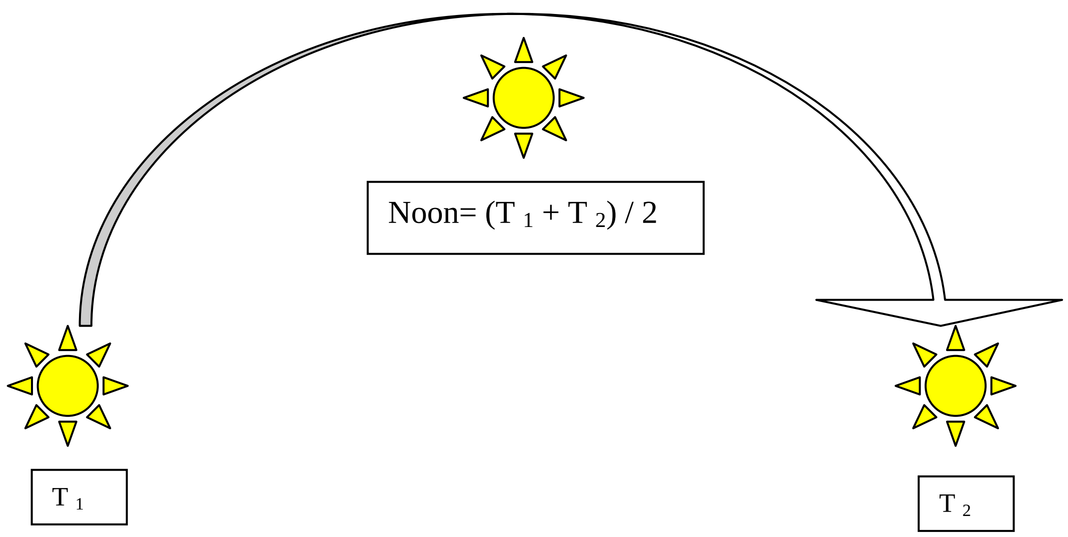
<u>Method n°1:</u>
Set Solarscope on a table. Make sure it is horizontal by using a spirit level.
Set a horizontal line on the Solarscope's measurement screen. (you can use a new measurement screen).
To put a horizontal line on the Solarscope it is best to do it when it is not fully assembled.

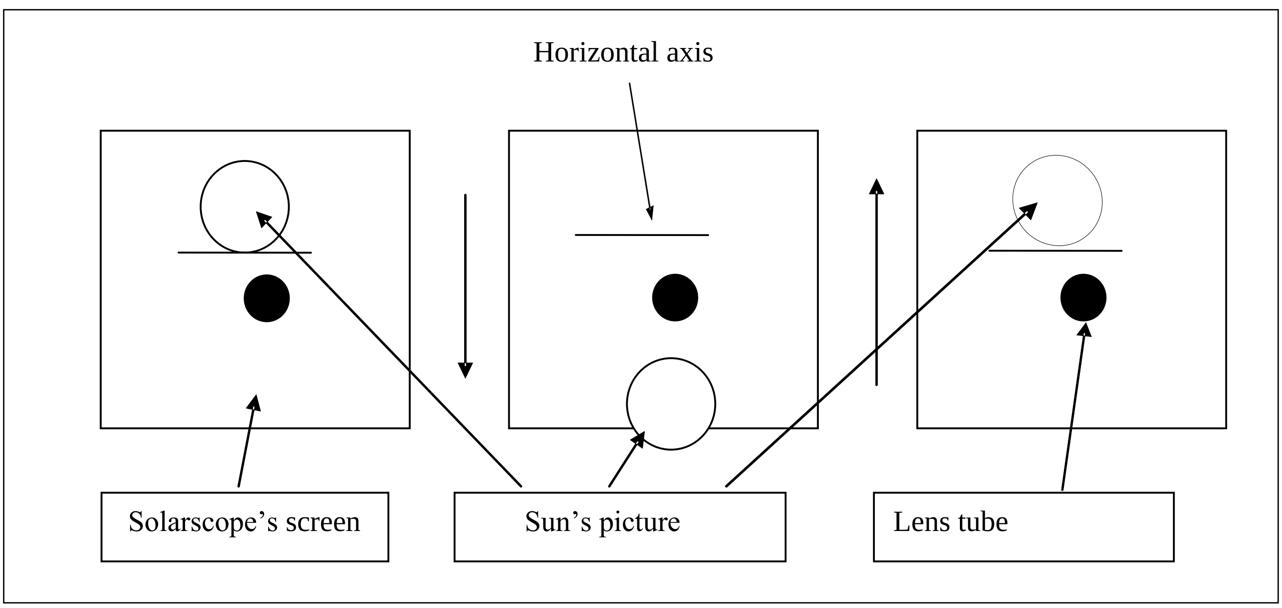
How to measure Solar Noon in 2 steps:

<u>1/ Before Solar Noon</u>:
Note both hours (use your watch) call it t1 and the angle (h) at that same time.
These two measurements correspond to the moment the Sun reaches the horizontal line previously drawn.

<u>2/ After Solar Noon</u>:
Do not modify the Solarscope's sight direction (=in declination), according to a vertical axis.
Note time t2 when the Sun's picture is reaching this horizontal line.
For this experiment adjust Solarscope only in azimuth (according to an horizontal axis).
Make sure the angle h is identical.

Solar Noon is the average of both measurements: $(t_1 + t_2) / 2$.





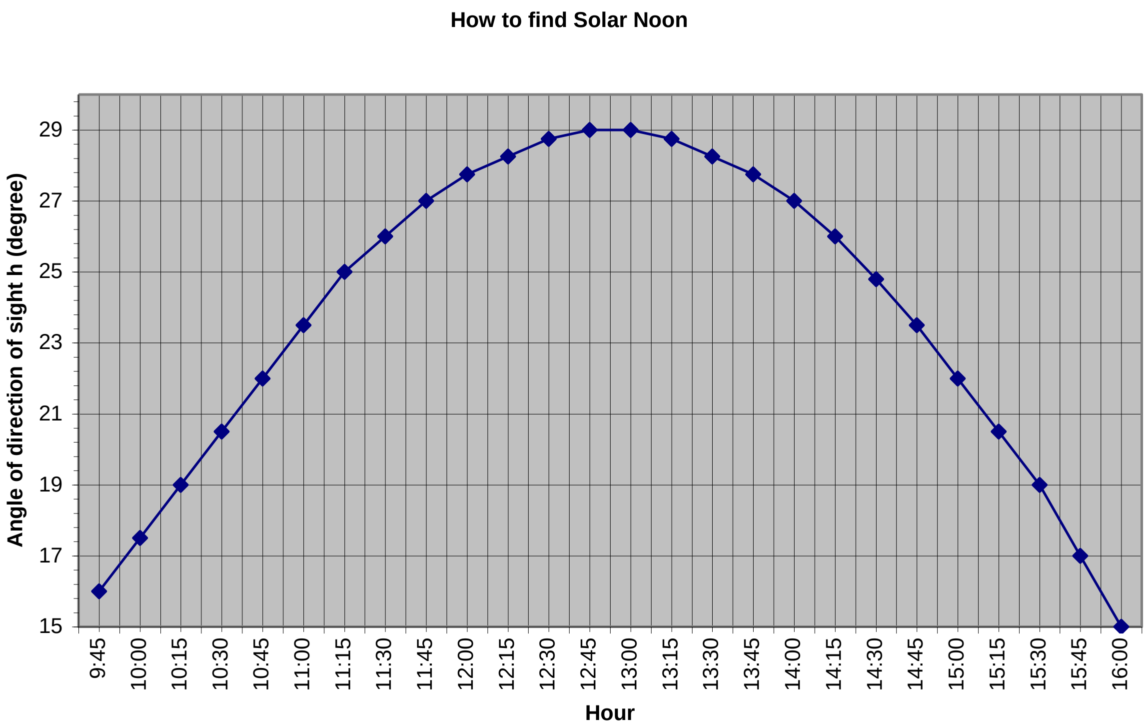
You need to constantly adjust Solarscope on a horizontal axis. This will help to keep the Sun's picture on the screen. If more than 30 minutes are elapsed between t_1 and Solar Noon then the Sun will disappear from the screen in azimuth, (according to a vertical). In this case do not change the angle of sight direction, but wait until the Sun reappears into the screen, by adjusting the Solarscope on a horizontal axis.

Notice: On the Solarscope pictures are inverted. For instance when the Sun is rising, its picture on the screen is falling. When the Sun is going from East to West it is the contrary on the screen.
If you watch at the screen it is easy to see if the Sun is rising or falling before or after Solar Noon.

Method n°2

Note the angle of sight direction on the Solarscope (you can read this angle on the protractor, indicated by a plumb line), according to the time indicated by your watch. Make at least 2 to 3 measurements in the morning and in the afternoon. Different groups can make these measurements at the same time.
Draw a curve and find Solar Noon by graphic interpolation (when the Sun is at its maximum = Solar Noon).

It is best to measure the angle of sight direction every half an hour or at least every hour.
h : corresponds to the time when a picture of the Sun and the lens tube are mixed, (on the measurement screen). The graph below represents measurements done on the 27th of January, under latitude 43°07'11''. In theory Solar Noon is at 12h48 mn AM, on the graph it is at 12h50 mn AM.



3 – RESULTS

We notice a difference in time between Solar Noon and *Noon (legal hour), it depends on what time of the year the experiment has been done. Indeed due to the complexity of Earth's rotation around the Sun: Earth's pole axis are not perpendicular to the ecliptic plan. Moreover Earth's orbit is elliptic and not circular.↔ See WS n° 6 on Time equation (Grammar and Highschool manual).

During Summer time the Sun is at its Zenith (climax) at around 01h30 PM / 02h00 PM (depending on the place of observation). So remember that sunbathing during Solar Noon (and not Noon legal hour) is of a great danger for skin.

You can also use a Gnomon to determine Solar Noon.

- 4 - SOLAR NOON (APROXIMATE VALUE) DEPENDING ON LONGITUDE AND DATE OF OBSERVATION

Date Longitude (degree)	01/01	01/02	01/03	01/04	01/05	01/06	01/07	01/08	01/09	01/10	01/11	01/12
- 5°	13h23’	13h33’	13h32’	14h24’	14h17’	14h18’	14h24’	14h26’	14h20’	14h09’	13h04’	13h10’
- 4°	13h19’	13h29’	13h28’	14h20’	14h13’	14h14’	14h20’	14h22’	14h16’	14h05’	13h00’	13h06’
- 3°	13h15’	13h25’	13h24’	14h16’	14h09’	14h10’	14h16’	14h18’	14h12’	14h01’	12h56’	13h02’
- 2°	13h11’	13h21’	13h20’	14h12’	14h05’	14h06’	14h12’	14h14’	14h08’	13h57’	12h52’	12h58’
- 1 °	13h07’	13h17’	13h16’	14h08’	14h01’	14h02’	14h08’	14h10’	14h04’	13h53’	12h48’	12h54’
0°	13h03’	13h13’	13h12’	14h04’	13h57’	13h58’	14h04’	14h06’	14h00’	13h49’	12h44’	12h50’
1°	12h59’	13h09’	13h08’	14h00’	13h53’	13h54’	14h00’	14h02’	13h56’	13h45’	12h40’	12h46’
0°	12h55’	13h05’	13h04’	13h56’	13h49’	13h50’	13h56’	13h58’	13h52’	13h41’	12h36’	12h42’
3°	12h51’	13h01’	13h00’	13h52’	13h45’	13h46’	13h52’	13h54’	13h48’	13h37’	12h32’	12h38’
4°	12h47’	12h57’	12h56’	13h48	13h41’	13h42’	13h48’	13h50’	13h44’	13h33’	12h28’	12h34’
5°	12h43’	12h53’	12h52’	13h44’	13h37’	13h38’	13h44’	13h46’	13h40’	13h29’	12h24’	12h30’
6°	12h39’	12h49’	12h48’	13h40’	13h33’	13h34’	13h40’	13h42’	13h36’	13h25’	12h20’	12h26’
7°	12h35’	12h45’	12h44’	13h36’	13h29’	13h30’	13h36’	13h38’	13h32’	13h21’	12h16’	12h22’
8°	12h31’	12h41’	12h40’	13h32’	13h25’	13h26’	13h32’	13h34’	13h28’	13h17’	12h12’	12h18’
9°	12h27’	12h37’	12h36’	13h28’	13h21’	13h22’	13h28’	13h30’	13h24’	13h13’	12h08’	12h14’

Theses figures have been found by taking into account changes of time for Summer and Winter. (Time is changed on March and October).

If you wish to know the longitude of your place of observation, go to the Geography Institute web site. (also see Worksheet – 4 for longitudes of some French cities).

To improve these figures make a proportion between dates and places.The accuracy will be of 1 to 2 minutes.

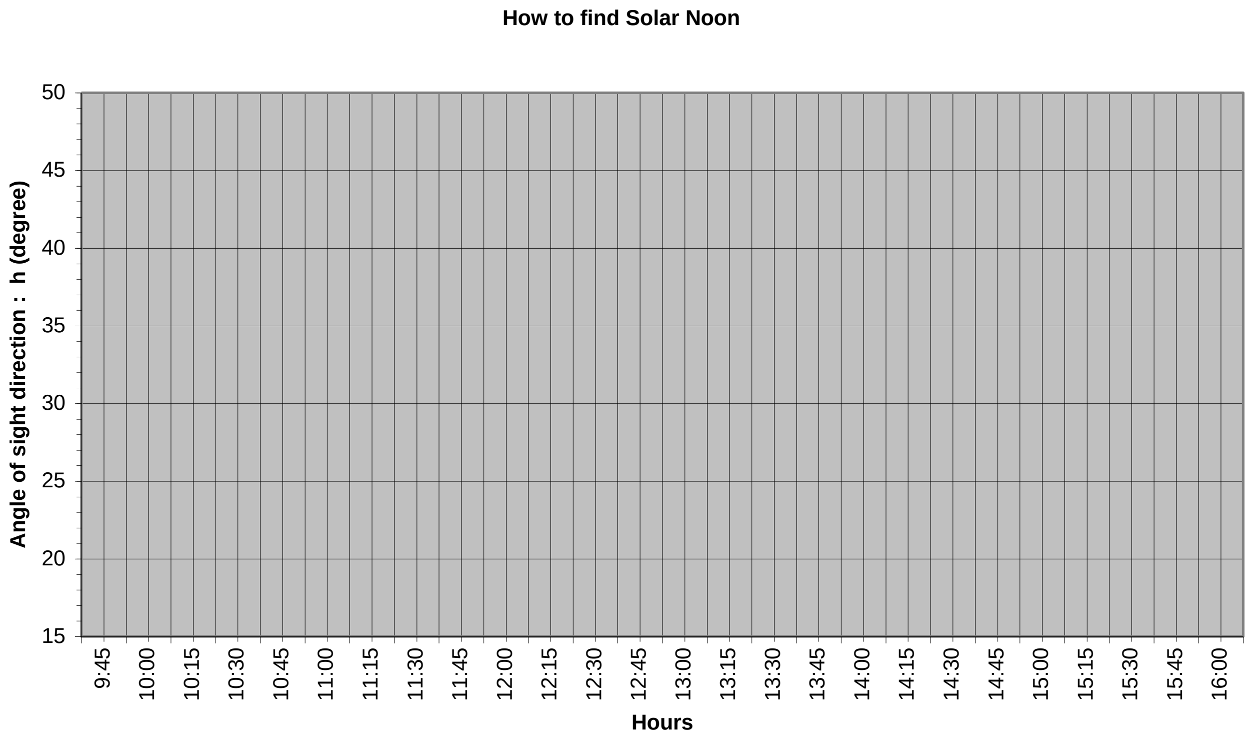
Example : Place of observation : Vannes (Brittany) on the 19th of April. Longitude: – 02°45’37’’.

On the 01/04, for a longitude of -3°, the solar noon is at14h16mn. On the 01/05, for a same longitude, the solar noon is at 14h09mn; consequently on the 19/04 solar noon is round about 14h12mn.

When longitude varies from +1°, Solar Noon put back 4 mn.
In Vannes, on the 19th of April, solar noon is round about 14h 15mn…… It is to be confirmed by experimentation !

Practical work -2 - SOLAR NOON

Name :			
Class :			
Date :			
Longitude :			
Theorical Solar Noon :			
h (degrees)	Hour (hour, minutes)	h (degrees)	Hour (hour, minutes)



SOLARSCOPE		Level
Practical work - 3	**Sun rotation rate (1)**	**Primary School**

- TOOLS:

A Solarscope,
A chronometer,
A measurement screen,
This experience can be done inside a room southward direction, or outside in a windless environment.

- 1 – PRINCIPLE:

The Sun is a star among the 200 000 000 000 ones in our galaxy; it is located at 30 000 light-years (1 Light-year = 9 500 milliard of km) of the galactic center. Its revolution around the center of the galaxy represents 225 million of years at a speed of 250 km/s !
-The Sun is 4,5 milliard years old,
- Its diameter is 1 392 000 km at equator (it is 110 times bigger than Earth).
- The Sun is composed of gas, mostly Hydrogen and Helium (ionised at high temperature).
- Its nucleus is the center of nuclear chain reactions and freeing a great amount of energy, its temperature is 14 millions of degrees.

Photosphere is the limit between the Sun and its atmosphere (from Greek phôtos, « Light »), and is the brightest part of the Sun. Small convection movements are active on 2000 km of thickness. The Sun's surface seems full of « Rice crips » or « granule », these are hot rising bubbles surrounded by fiber of colder matters, therefore less bright. The sunspot appears dark because it is about 2000°K cooler than the surrounding photosphere. As the temperature of the photosphere is around 5700°K, a sunspot is still extremely hot by earthly standards and only appears dark compared with the brilliant photospheres. Those black spots are at an average number of 5 to 10. It is visible thanks to the Solarscope correctly focused. Those sunspots come in all shape and size (from single, isolated spots to complex group containing anything from a few spots to over a hundred). Sunspots are forming and dying out all the time, and the Sun's appearance is never quite the same from one day to the next. The size of sunspots gives some appreciation of the vastness of the Sun. A typical small to medium-sized sunspot is about the same size of the Earth, while some of the largest spots have length ten times the Earth's diameter. Most of groups« live » for about 3 months. Due to the Sun's rotation, sunspots are moving. To avoid parallax errors you must observe the Sun on a daily basis. The number of the sunspots present is not constant but varies in a cycle from a maximum to a minimum and back to maximum again over a period of 11 years. At sunspot maximum, the Sun is heavily spotted on the most days, whereas sunspots may be entirely absent for days at a stretch at minimum.

Astronomers use the term "solar cycle"; why solar activity varies in this manner is another great mystery of solar science.

Some more information on the Sun:

- Its temperature on surface is 5700 ° K.
- Its maximum wave length radiation is: 0,5 micron (well centred on the visible spectrum),
- Rotation rate is different at equator and pole axis due to the viscosity of the Sun.
-Rotation rate at the equator: 24.9 days
-Rotation rate at pole axis: 35-40 days
-Inclination axis: 82°49' (compared to ecliptic)

Thanks to latitude, you can calculate the Sun's rotation speed:

$$\text{Sun's rotation time} = 24.9 - 0.0188\,|l| + 0.00216\,l^2$$

l is either North or South latitude in degrees (see worksheet - 4 for the definition of latitude).

Synodic rotation is: 27,5 days * (at the equator). The Sun and Earth have the same rotation direction, therefore from Earth, the Sun seems to rotate more slowly.

* It is an average. This varies throughout the year, due to the Earth's unequal speed around its orbit.

- 2 - MEASUREMENT:

It is best to make those measurements in group of 2 persons.

- 1 –Clip the measurment screen on the Solarscope. (See instruction).

- 2 – Point sunspots you wish to use for the experiment.

- 3 - To be sure the Sun's path will be parallel to the lines on the measurement screen, rotate the screen around the lens tube.

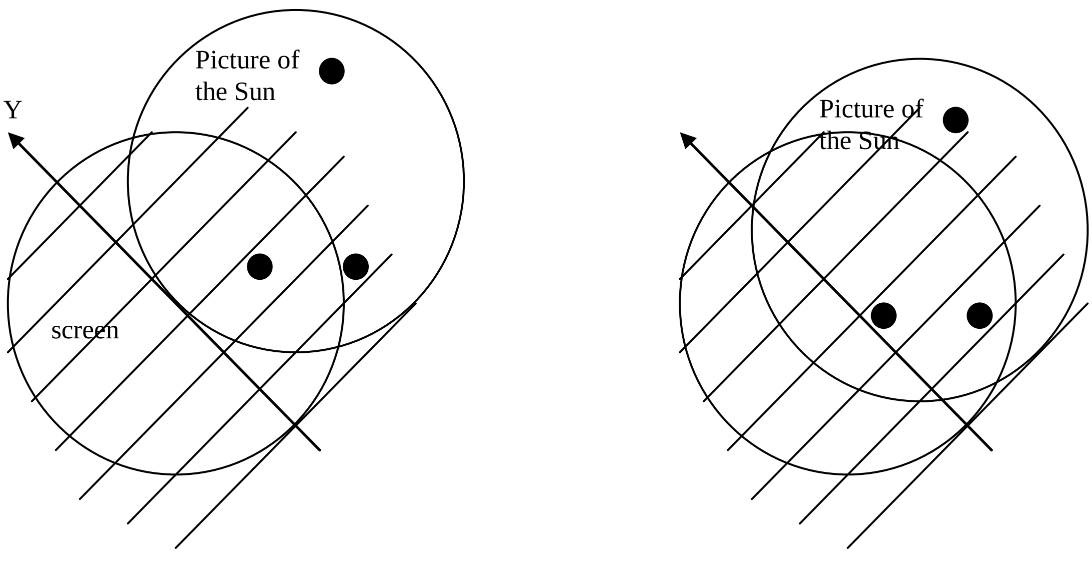
- 4 – As indicated in the drawing, rotate Solarscope on its base in order to make correspond the Sun and its picture.
To avoid parallax with other measures, indicate the precise time of experiment.

- **5** – To measure Sun spots movement:

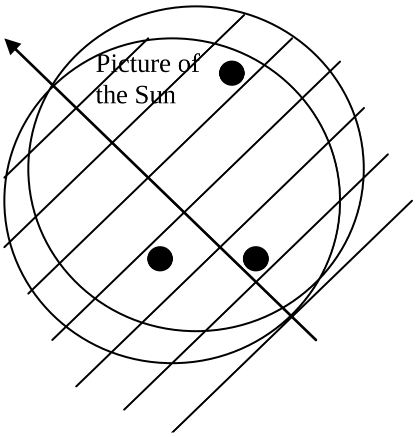
Note when a sunspot reaches the vertical line (Axis: Y) on the measurement screen.
t_0 : Time when the left limb of a spot is reaching the vertical axis.
t_f : Time when a sunspot reaches the vertical axis by its right limb.

Example: $t_0 = 0$ sec. The left limb of a sunspot is touching the Y axis,
$t_1 = 0.48$ sec. A sun Spot is reaching the axis,
$t_f = 2.16$ sec. The right limb of a sunspot is touching the Y-axis.
Picture's size: 122 mm.

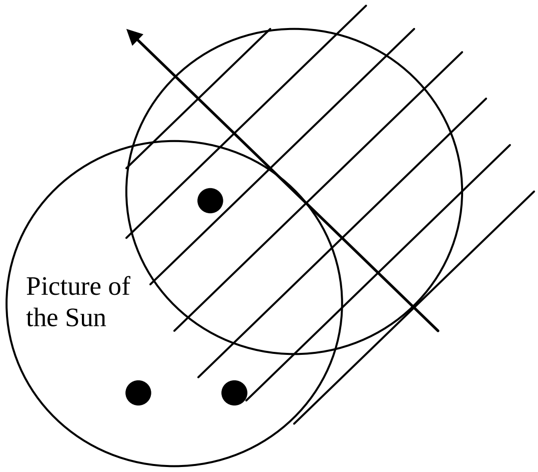
The sunspot is at: $0.48*122 / 2.16 \approx 27$ mm from the left side of the Sun's picture.
Y-axis is inclined in order to improve the accuracy of the measurement.



Instant to   Instant t_1



Instant t_2, etc…



Instant t_f

N.B : Measures has been done in the morning consequently the Sun path is going down.

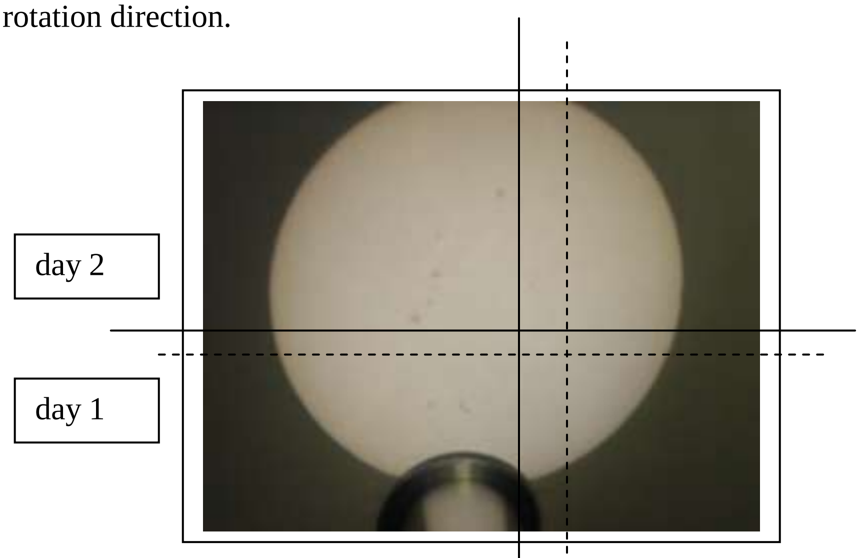
- 6 – Put all your measurements on the board to make all calculation you wish.

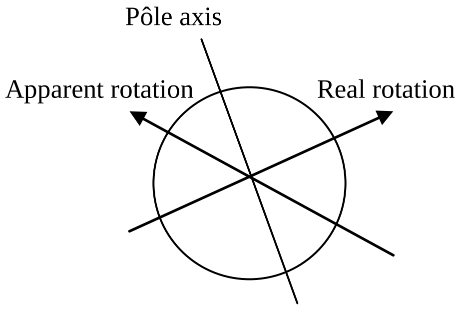
- 7 – Make several measurementss of sunspot position, for instance every other day at the same hour (to avoid parallax).
Parallax **:** due to the Earth rotation sunspots seems to change of direction.

- 8 – For each day, indicate on the measurement screen different position of sunspots of measurement (t_1, t_2,…),
It shows a movement due to the Sun's rotation.

In order to correctly materialise the Sun's rotation, you need to make measurements during 15 days in a row, up to 3 to 5 measurements.
The best is one month; indeed the Sun's rotation is 25-34 terrestrial days from equator to poles.

Do not forget that pictures on the Solarscope are inverted it helps to know it if you wish to define the Sun's rotation direction.





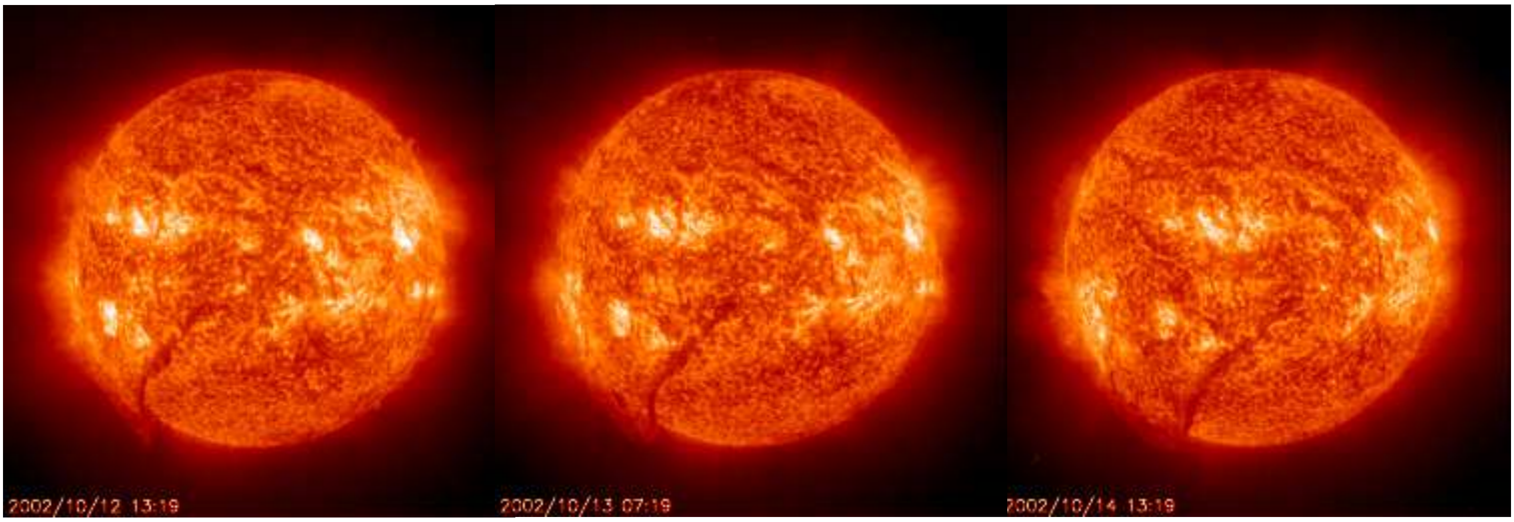
3 – RESULTS

It is important that you transfer your sunspot counts in a standard format. It enables you to compare your own observation directly with the results published by Soho.
Put on a same measurement screen all the position of the sun spots done on different days.

Students can observe outbreaks and disappearances of sunspots, also the approximate 30 days rotation speed.

4 - EXPLOITATION

- *Option :* compare theses sunspots with pictures given by satellite SOHO (available on the net : www.soho.com) .

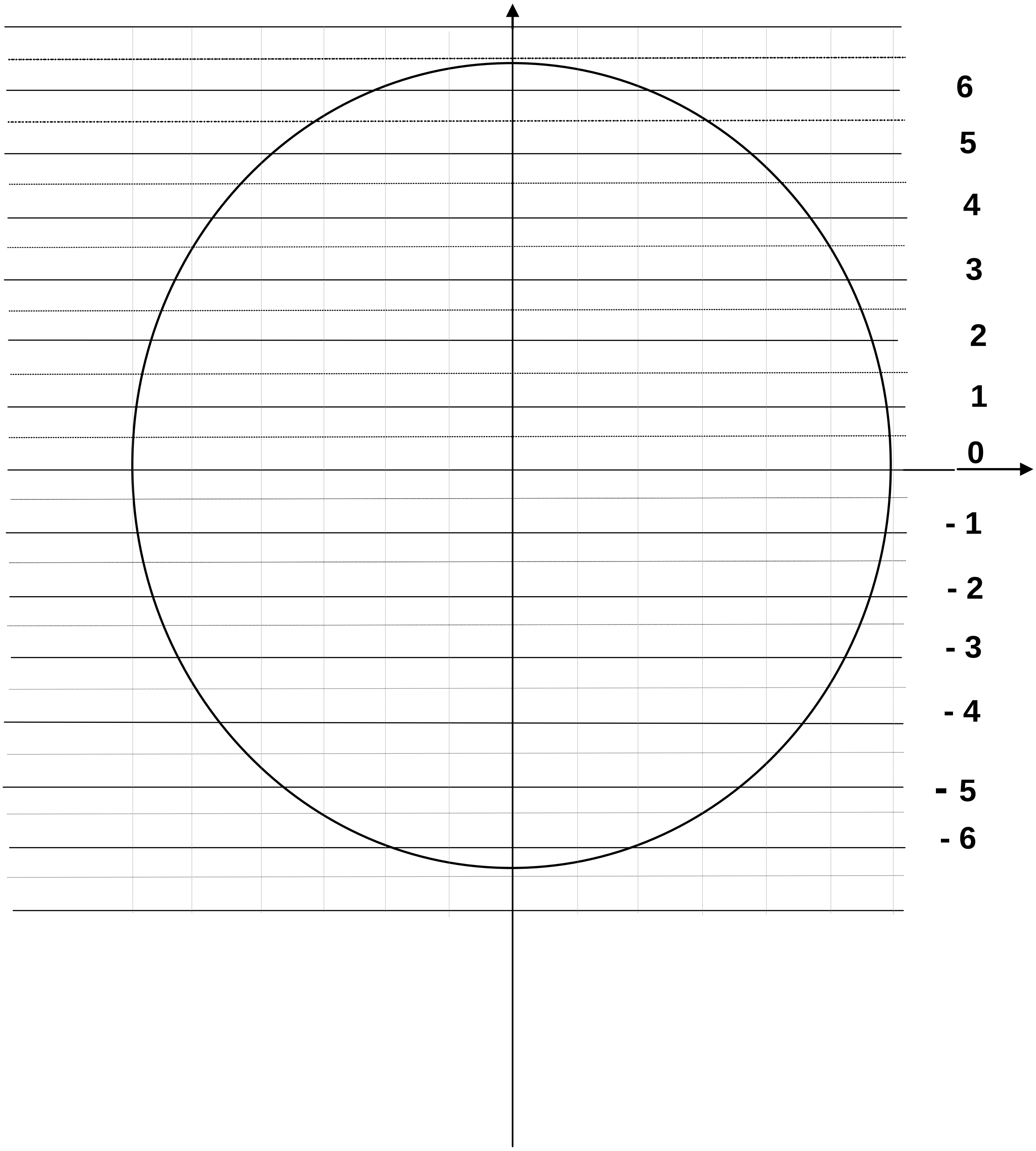


3 pictures taken by satellite SOHO, at 3 following days, available on the net.

- 5 - TABLE OF MEASUREMENT:

Practical work - 3 : SUN ROTATION RATE (1)			
Name :			
Class :			
Date :			
Hour :			
Size of the picture (Width) : X = mm			
		Position according to X axis	Position according to Y axis
Left limb of the Sun	$t_0 =$ 0 s	$X_0 = 0$	$Y_0 = 0$
Sunspot n° 1	$t_1 =$ s	$X_1 = X * t_1 / t_f =$ mm	$Y_1 =$ mm
n° 2	$t_2 =$	$X_2 =$	$Y_2 =$
n° 3	$t_3 =$	$X_3 =$	$Y_3 =$
Right limb of the Sun	$t_f =$	X =	

- **6 – MEASUREMENT SCREEN :**



To obtain a full size screen enlarge it twice.

SOLARSCOPE		Level
Practical work - 3	**Sun rotation rate (2)**	**Grammar and high School**

- TOOLS:

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- 2 - MEASUREMENT:

It is best to make those measurements in group of 2 persons.

- 1 - Clip the measurement screen on the Solarscope. (See instruction).

- 2 - Point sunspots you wish to use for the experiment.

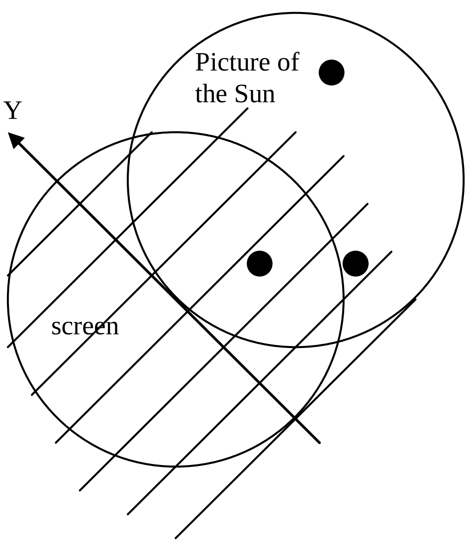
- 3 -To be sure the Sun's path will be parallel to the lines on the measurement screen, rotate the screen around the lens tube.

- 4 - As indicated in the drawing, rotate Solarscope on its base in order to make correspond the Sun and its picture.
To avoid parallax with other measures, indicate the precise time of experiment.

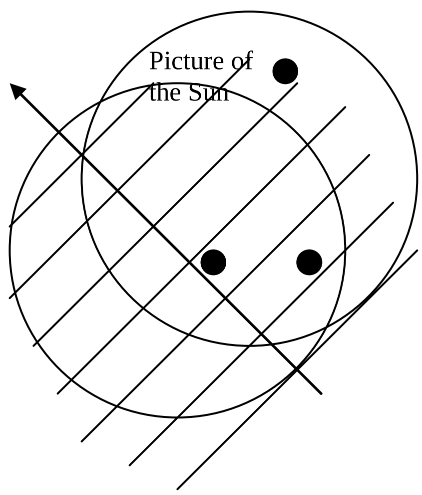
- 5 - To measure Sun spots movement:
Note when a sunspot reaches the vertical line (Axis: Y) on the measurement screen.
t_0 : Time when the left limb of a spot is reaching the vertical axis.
t_f : Time when a sunspot reaches the vertical axis by its right limb.

Example: $t_0 = 0$ sec. The left limb of a sunspot is touching the Y axis,
$t_1 = 0.48$ sec. A sun Spot is reaching the axis,
$t_f = 2.16$ sec. The right limb of a sunspot is touching the Y-axis.
Picture's size: 122 mm.

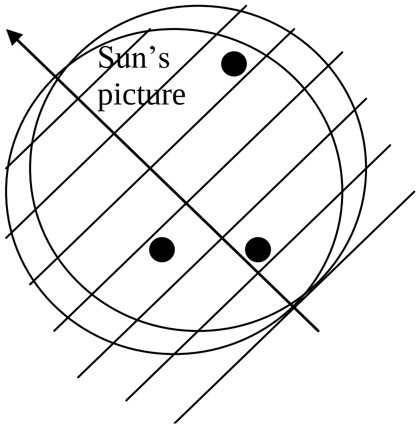
The sunspot is at: $0.48 * 122 / 2.16 \approx 27$ mm from the left side of the Sun's picture.
Y-axis is inclined in order to improve the accuracy of the measurement.



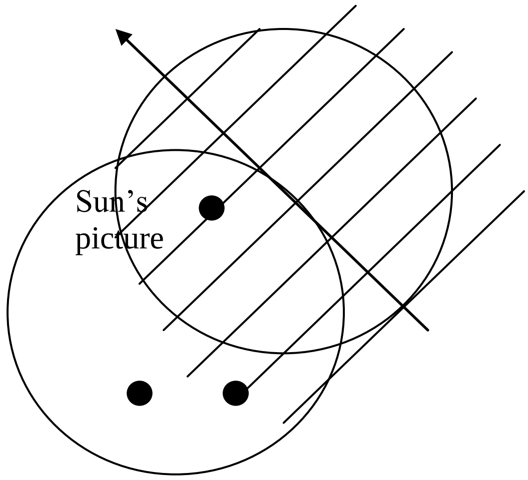
Instant to



Instant t_1



t_2, etc …..



Instant t_f

N.B : Measures has been done in the morning consequently the Sun path is going down.

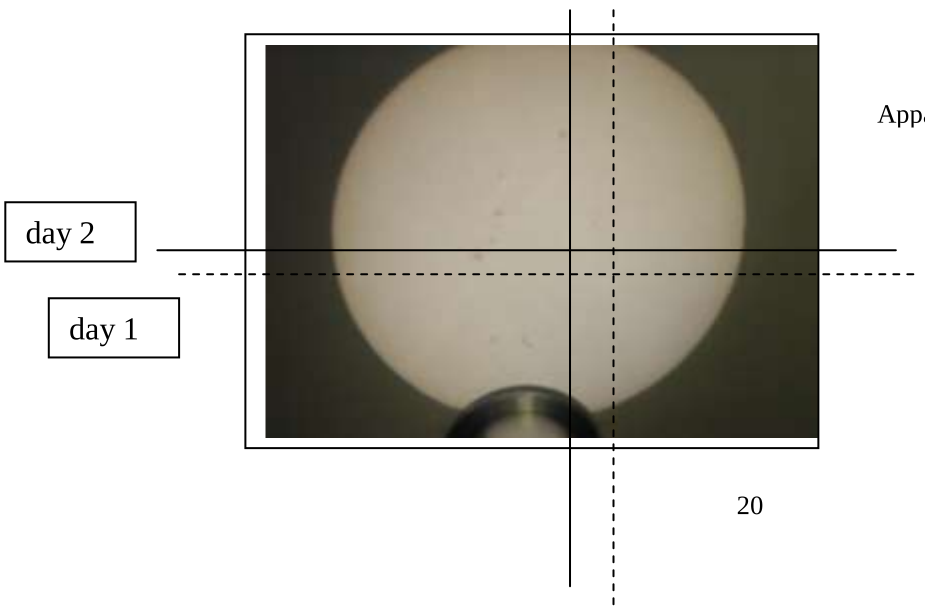
- 6 – Put all your measurements on the board to make all calculation you wish.

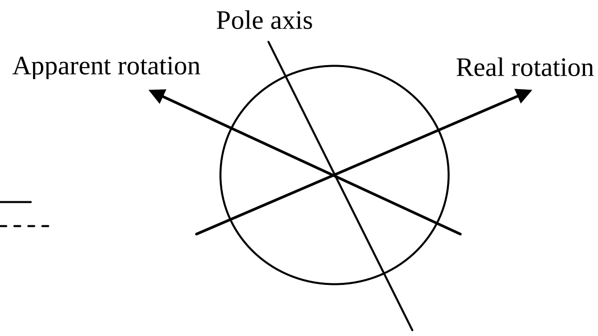
- 7 – Make several measurements of sunspot position, for instance every other day at the same hour (to avoid parallax).
Parallax **:** due to the Earth rotation sunspots seems to change of direction.

- 8 – For each day, indicate on the measurement screen different position of sunspots of measurement (t_1, t_2,…),
It shows a movement due to the Sun's rotation.

In order to correctly materialise the Sun's rotation, you need to make measurements during 15 days in a row, up to 3 to 5 measurements.
The best is one month; indeed the Sun's rotation is 25-34 terrestrial days from equator to poles.

Do not forget that pictures on the Solarscope are inverted it helps to know it if you wish to define the Sun's rotation direction.

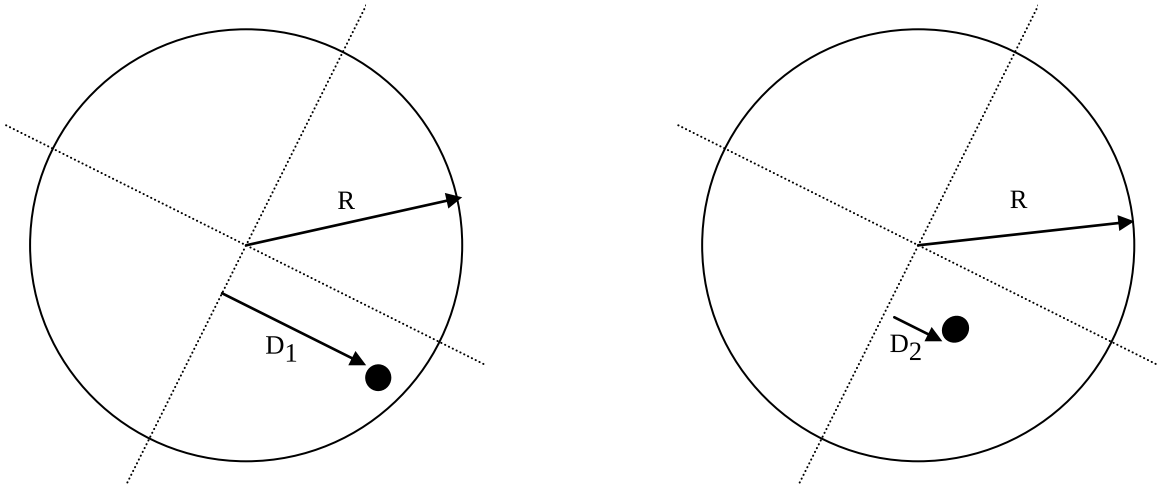




- 3 - RESULTS

Sun Spots are useful to measure the Sun's rotation.

- Use 2 pictures of the Sun made at different time: T_1 and T_2, make a line reaching the center of the Sun's picture , and parallel to a Sun spot.
- Draw another line perpendicular to the first line reaching the center of the Sun's picture.
- Measure : R. (distance between the center of the Sun's picture and its side).
- Measure the length D_1 and D_2 as indicated above.



Sun at day T_1 Sun at day T_2

- Sun's rotation is given by this formula :

$$\text{Sun's rotation speed (apparent)} = \frac{\text{Arcsin}^*\left(\frac{D_2}{R}\right) - \text{Arcsin}\left(\frac{D_1}{R}\right)}{T_2 - T_1}$$

in degrees per day. (to be used for an absolute value)

* : Arcsin (x) : means an angle whose sinus is x. Example Arcsin (0.5) = 30°.

Do remember that Sun's observation are made from Earth,(whose rotation is 0.986°/day). To obtain the real rotation of the Sun, you have to put into account the Earth's rotation rate around the Sun.

Real Sun's rotation rate = Rotation rate measured + 0.986° /day.

How to calculate the Sun's rotation time:

$$\text{Sun's rotation time} = \frac{360}{\text{Real rotation rate}} \text{ days.}$$

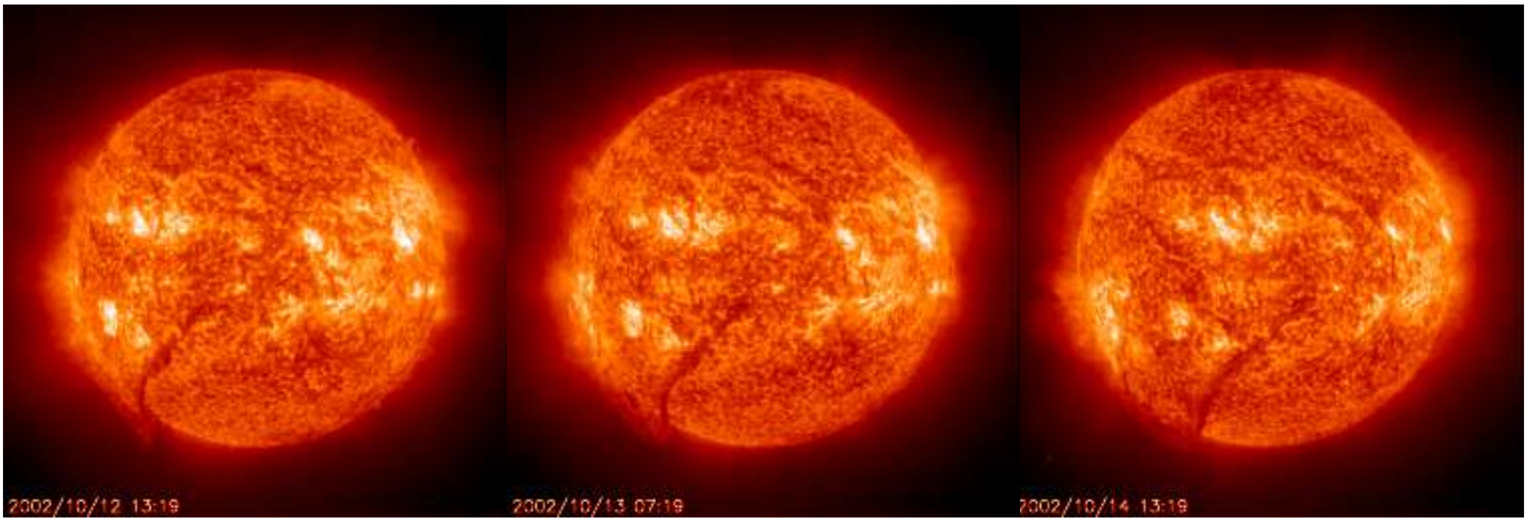
- 4 – Table of Measurement :

Practical work - 3 : SUN'S ROTATION RATE (2)			
Name :			
Class :			
Date :			
Hour :			
Size of picture (width) : X = mm			
		Position according to the x Axis	Position according to the y Axis
Left side of the Sun's picture	$t_0 =$ 0 s	$X_0 = 0$	$Y_0 = 0$
Sun spot n° 1	$t_1 =$ s	$X_1 = X * t_1 / t_f =$ mm	$Y_1 =$ mm
n° 2	$t_2 =$	$X_2 =$	$Y_2 =$
n° 3	$t_3 =$	$X_3 =$	$Y_3 =$
Right side of the Sun's picture	$t_f =$	$X_f=$	

- 5 - CONCLUSION

- If you compare all the measurement done on the screen, you can observe Sun spots' movement. A different colour can be used for every Sun spot marked on the screen. This helps to determine Sun spots' life time.

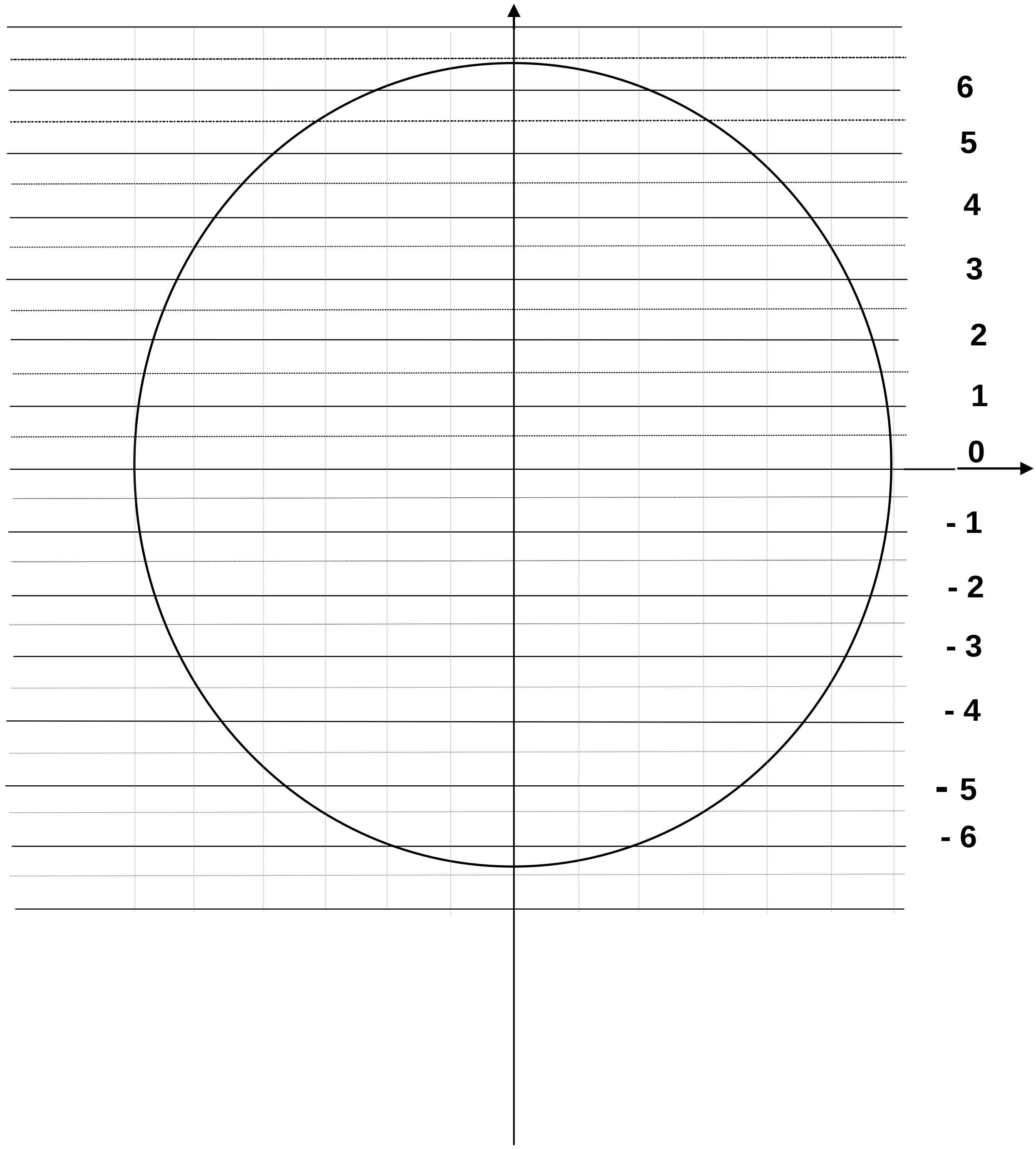
- Option : Results can be compared with pictures taken by SOHO available on the net : www.soho.com .



3 pictures taken by satellite SOHO at 3 following days.

- It confirms the length of this event.
- It shows that Sun's rotation has a different rotation rate at the equator or at the pole axis.

- **6 – MEASUREMENT SCREEN :**



To obtain a full size screen enlarge it twice.

SOLARSCOPE		Level
Practical work - 4	**Latitude of a place and pole axis inclination.**	**Grammar and High School**

- TOOLS

A Solarscope
A plumb line
A clock
A measurement screen (optional).
This experience can be done inside a room southward oriented, or outside in a windless environment.

- 1 – PRINCIPLE:

-Latitude of a place is the angle between the Place's vertical and the equator's plan.

This angle is measured along the spot's meridian, from 0 to 90°, (either from the North or South direction).

-Longitude of a place is the angle between Greenwich meridian (conventional meridian) and the spot's meridian, between 0 to 180° (towards East or West).

-**Terrestrial meridian** of a place is: a half circle of a spherical celestial place. Comprising terrestrial poles and the half plan goes by the spot.

-Earth's axis of rotation: Goes through both poles**.** This axis is inclined compared to the regular ecliptic.

This angle α is about : 23°27.

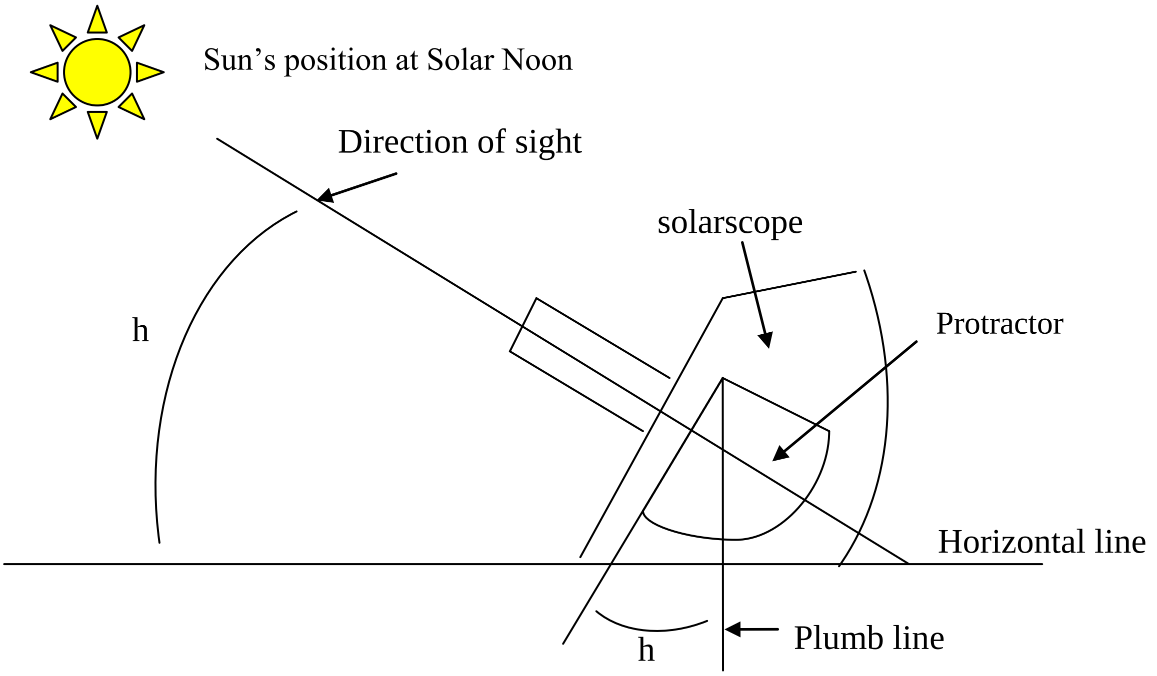
-**The Ecliptic**: is a plan going through the Sun's center and comprises the Earth's orbit.

Due to other planets, Earth's movement is irregular, consequently the ecliptic plan is irregular too.

The Sight direction at Solar Noon varies according to an annual sinusoidal function.

It is due to the fact that the Earth has an inclination axis and its rotation around the Sun.

How to calculate latitude and pole axis: by measuring the sight direction during Solar Noon. For this, use a board with all direction of sight angle measures taken throughout the year. Draw a graph where h =f(t) which will be an annual sinusoidal function. Its lower point and its peak will represent winter and summer solstice.

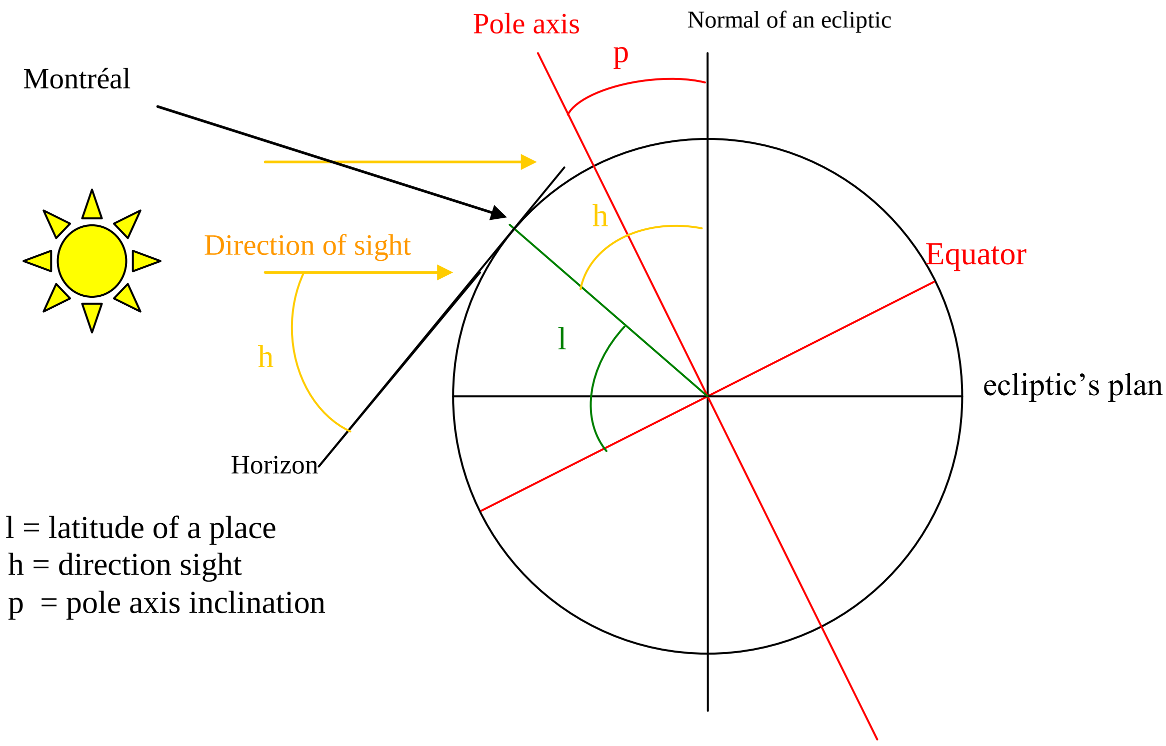


A measurement each month is sufficient.

It is important to take measurement for summer and winter solstice, spring and fall equinoxes, (measures can be reported by 4 to 5 days, if there is a lack of Sun).

For this experiment, solar noon is calculated use worksheet # 6 on Time's equation. This will be the moment for the experimenter to measure the direction of sight "h".

Earth's position during Summer solstice compared to the ecliptic.



This drawing represents Summer Solstice. The direction of sight (measured at Solar Noon) is at its maximum h = h (max)

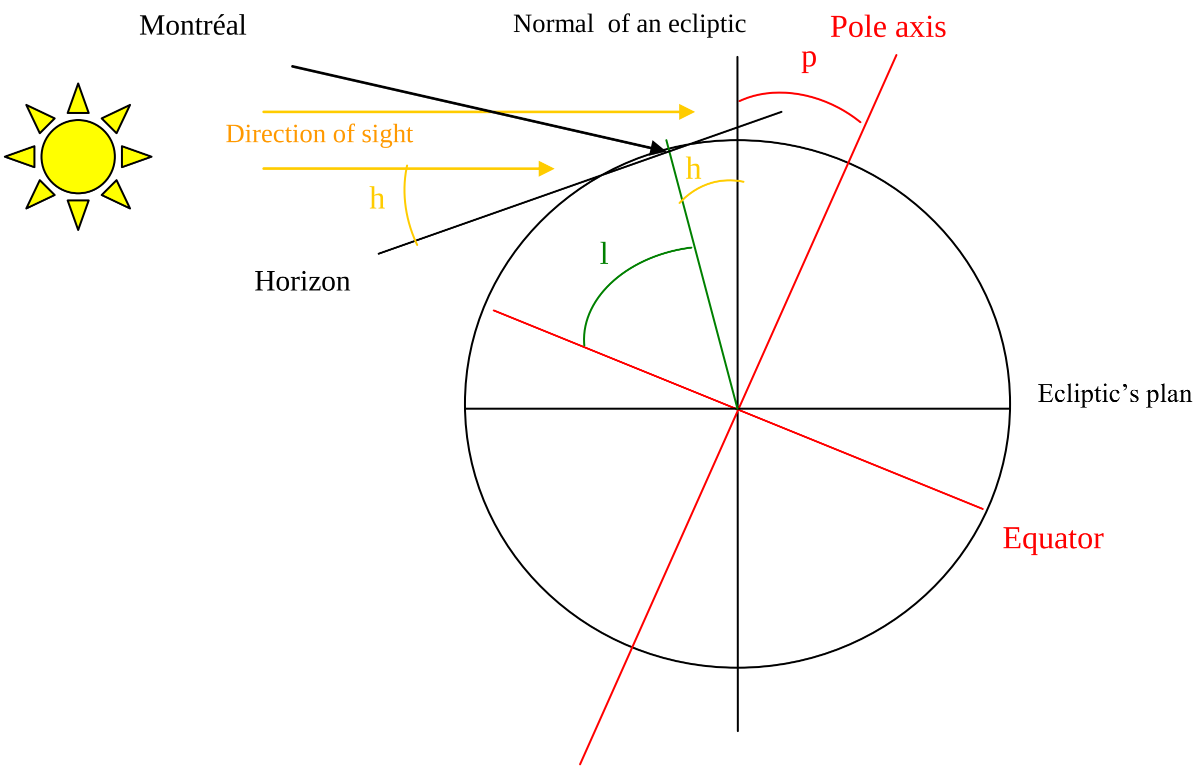
According to the drawing: h (max) + l - p = 90° (1)

Those calculations are valid for a city in North Hemisphere (whose latitude is comprised between North Pole & Cancer Tropic, it is valid for other latitude).

Notice: At spring and fall equinoxes pole axis are perpendicular to the ecliptic plan. The direction of sight directly gives latitude (see end of paragraph) however there is less precision.

This experiment does not give pole axis inclination.

Earth's position during winter solstice compared to the ecliptic



During winter solstice, at solar noon, the direction of sight is at its minimum : h = h (min).

According to the drawing : h (min) + l + p = 90° (2)

Those calculations are valid for a city in North Hemisphere (whose latitude is comprised between North Pole & Cancer Tropic, it is also valid for other latitude).

Latitude l of a place: $\boxed{\mathbf{l = 90° - [\ h\ (max) + h\ (min)] / 2}}$

This formula is valid for a place located in North Hemisphere (for a latitude comprised between Cancer Tropic 23°27 North and Polar Circle 66°33 North).

Value of pole axis α: $\boxed{\mathbf{p = (h\ (max) - h\ (min)) / 2}}$

Same note as above.

<u>- Note concerning measures made at time of equinoxes</u> : the direction of sight measured at that time is an average of h (max) and h (min), that is to say : h (equinox) = [h (max) + h (min)] / 2

Latitude is determined directly at that time and at Solar Noon by this formula : $\boxed{l = 90° - h\ (equinox)}$

- 2 – MEASUREMENT

-2- 1 –When to start the experiment :

To determine Solar Noon refer yourself to « Worksheet # 6 – Time's equation » This time is useful to start the experiment of the direction of sight.

Legal Hour = Solar Hour + longitude Corrected + Correction of Time Zone + Correction of « Time's equation »

Example : if a measure is made on the 15th of March at Hyères (French Riviera) :

-We are still in winter time for a longitude of 6° 07'46''East Greenwich,

-You can refer to the web site of National Geography Institute to find the latitude of your place. If the city is not mentioned, pick the closest one (draw a vertical line and pick the city which is the closest on the right side).

- Solar hour: 12 hours,
- Correction of longitude: The Sun is moving of 1 degree every 4 minutes (360° in 24 hours). Hyères is at the Eastern side of Greenwich. The correction is - 4 mn * 6° 07'46''= - 24mn 31s 04.

- Jet Lag corrected: + 1 hour
- Correction of « Time's equation »: according to the counting frame of Worksheet # TP 7 it is : +9 mn

Legal Hour corresponding to Solar Noon = 12h – 24mn 30s + 1h + 9mn = 12h 44mn 30s

This measure has to be done at around: 12h 45 PM.

Another way to obtain it: (with less precision) is to measure the Solarscope's angle's direction of sight. When the Sun is moving along a horizontal line (located in the middle of the screen, and also by the center of the lens tube).

- 2 - 2 – How to measure the angle's direction of sight thanks to the protractor :

At around 12:45 pm point the Solarscope's lens tube at the Sun.
-The picture of the Sun and the lens tube must be concentric, (make all necessary adjustments),
-Note the angle on the protractor indicated by the plumb line,
-This value is called: h (with an accuracy of 1 degree).
Repeat this measure every 2 weeks.
This will help to fill the graph: h = f (t), t is the time when the measure has been made.

- 3 -RESULTS

According to the latitude of the place we obtain a curve similar to the one on the graph below. However Y-axis depends on the latitude of the place.

If you wish to determine at once latitude and polar axis inclination:

-use the formula above and the graph below,

-draw a line parallel to the other line,

-note coincidences between the line and the graph for summer and winter solstice (h max) and (h min),

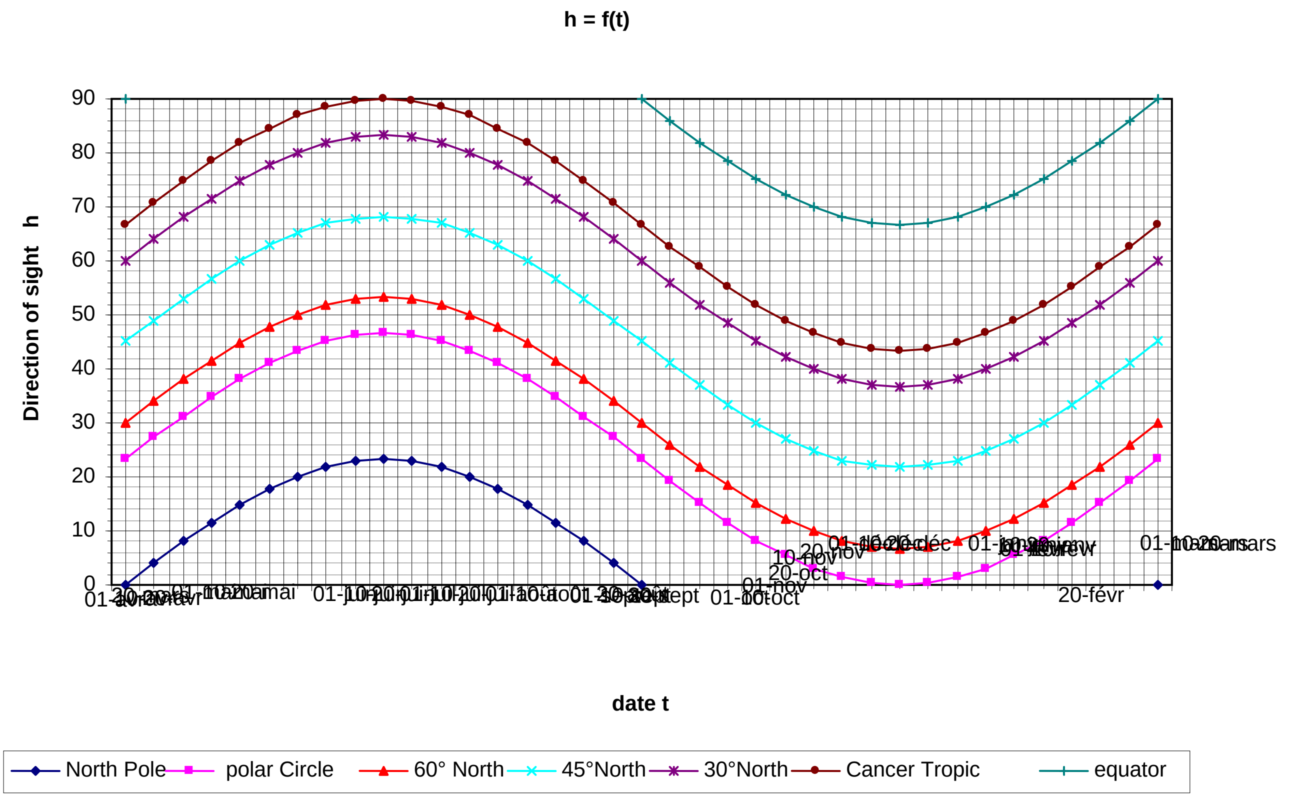
- On Y-axis: note the angles,

Then you can calculate “p”and “l” as explained before. This calculation is quite accurate.

Example: in Hyères on the 20th of January 03, h(measured) = 27°. So, by reporting this point on the graph, we find by interpolation: h (min) = 24°, h (max) = 70°

Latitude l = 90° - (70° + 24°)/ 2 = 43° (theoretically: 43°07’11’’)

Pole axis inclination p = 70°- 24° / 2 = 23° (theoretically: 23°27’).



- 4 – THEORICAL DATA :

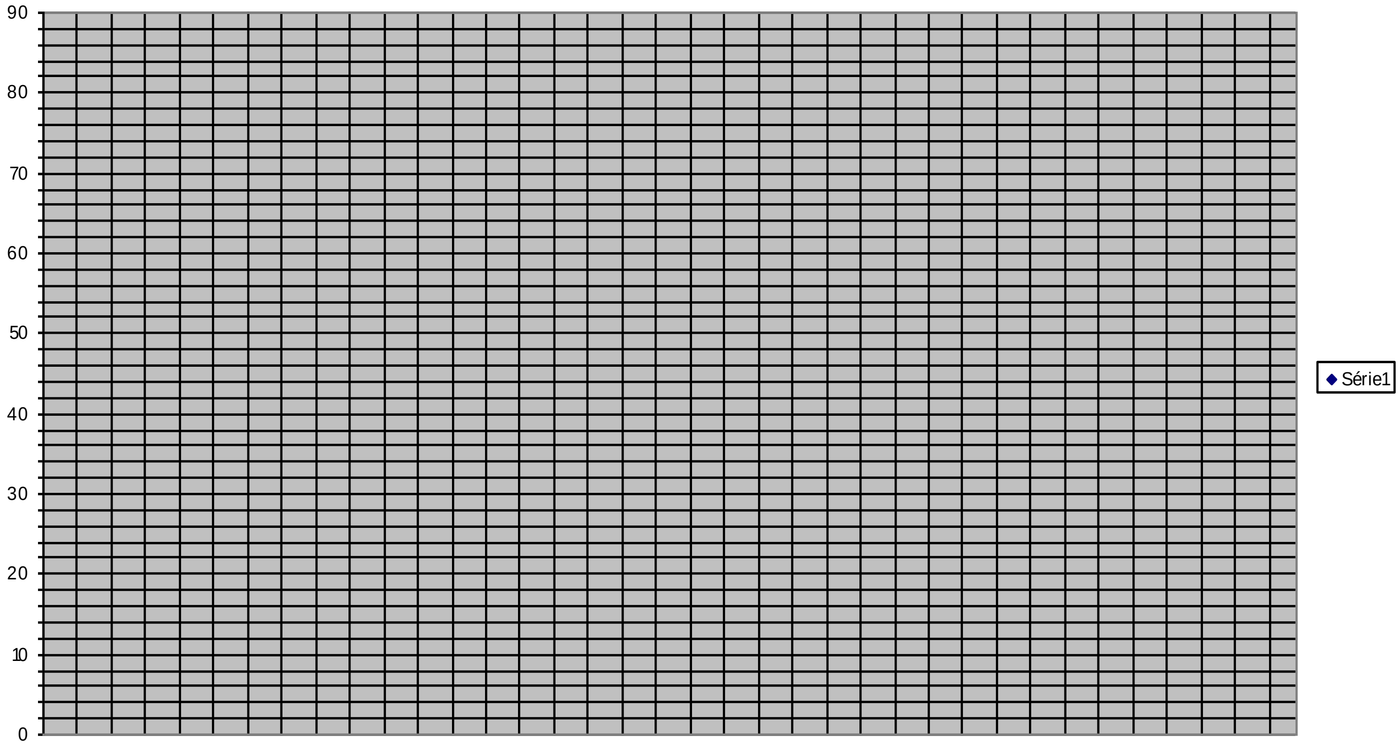
Pole axis inclination: p = 23°27’

Longitude and Latitude l of French cities :

City	**Agen (47)**	**Ajaccio (2A)**	**Bastia (2B)**	**Belfort (90)**	**Biarritz (64)**	**Bordeaux (33)**
Longitude	00°37’10’’	08°44’13’’	09°27’01’’	06°51’00’’	- 01°33’22’’	- 00°34’42’’
Latitude	44°12’15’’	41°55’36’’	42°42’03’’	47°38’30’’	43°28’54’’	44°50’19’’
City	**Bourges (18)**	**Brest (29)**	**Calais (59)**	**Chamonix (74)**	**Cherbourg (50)**	**Grenoble (38)**
Longitude	02°23’47’’	- 04°29’08’’	01°51’23’	06°52’11’’	-01°36’53’’	05°43’37’’
Latitude	47°05’04’	48°23’27’’	50°56’53’	45°55’23’’	49°38’22’’	45°11’16’’
City	**Lannion (22)**	**Lille (59)**	**Limoges (87)**	**Lyon (69)**	**Marseille (13)**	**Montpellier (34)**
Longitude	- 03°27’15’’	03°03’30’’	01°15’45’’	04°50’32’’	05°22’38’’	03°52’38’’
Latitude	48°44’00’’	50°37’57’’	45°50’07’’	45°45’35’	43°17’51’’	43°36’43’’
City	**Nantes (44)**	**Nice (06)**	**Paris (75)**	**Perpignan (66)**	**Poitiers (86)**	**Rennes (35)**
Longitude	- 01°33’10’’	07°16’09’’	02°20’43’’	02°53’44’’	00°20’10’’	- 01°40’46’’
Latitude	47°13’05’’	43°42’10’’	48°51’ 39’’	42°41’55’’	46°34’55’’	48°06’53’’
City	**Strasbourg (67)**	**Toulon (83)**	**Toulouse (31)**	**Vannes (56)**		
Longitude	07°44’55’’	05°55’53’’	01°26’34’’	- 02°45’37’’		
Latitude	48°35’04’’	43°07’33’’	43°36’19’’	47°39’21’’		

Practical work – 4 - LATITUDE OF A PLACE AND POLE AXIS INCLINATION :

Name :												
Class :												
City :												
Longitude :												
Theoretical Solar Noon : (see board on WS # 2)												
Date (day/month/year)												
h (degree)												
Date (day/month/year)												
h (degree)												
h minimum : (degree)												
h maximum : (degree)												
Inclination of pole axis. p = (h max. – h min.)/2 =												
Latitude l = 90° - [(h max + h min)/2] =												



DATE

SOLARSCOPE		Level
Practical work - 5	**Earth's orbit ellipticity**	**Grammar and High School**

In construction
- available soon -

Means :

A Solarscope, a chronometer or a computer.

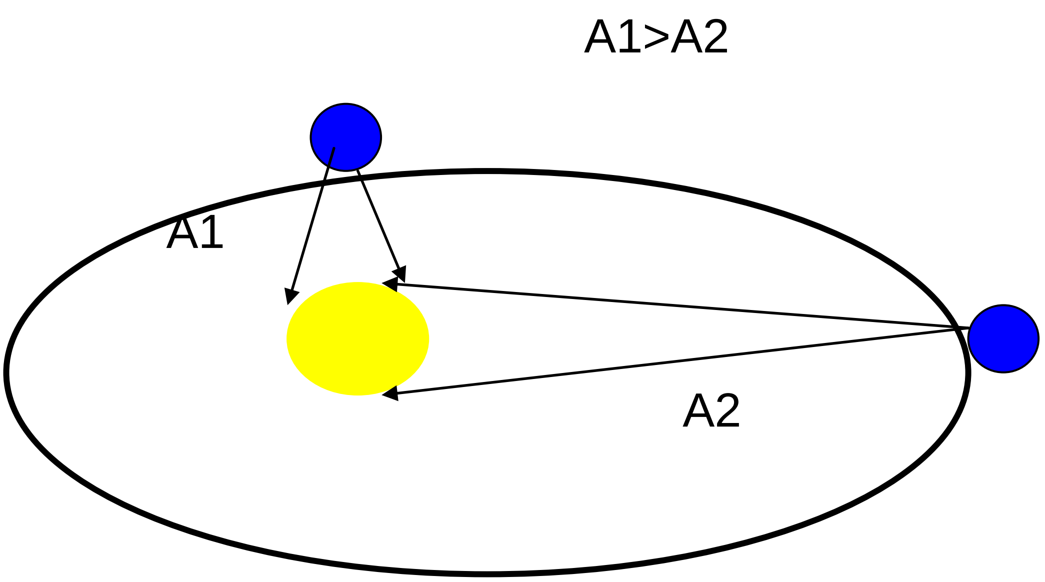
GUIDELINE

To demonstrate and measure terrestrial orbit.

MEASURES

The apparent diameter during the year,
With a chronometer or a computer,
Available soon a software on our web site www.solarscope.org.

RESULT



To draw terrestrial orbit.
Ellipticity

		Level
Practical work - 6	**TIME'S EQUATION**	**Grammar and High School**

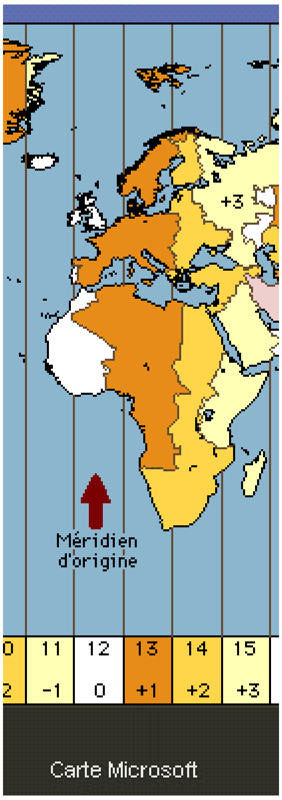
- TOOLS :

A Solarscope (used behind a window)
A measuring screen (optional)
A watch showing hours, minutes, seconds.

-1- PRINCIPLE

Its Solar Noon when :
Sun is at its climax (Zenith) of its diurnal path.
If we compare it with our watch we see a difference.
Here is a way to calculate this difference between Solar Noon and legal time :

LEGAL HOUR = SOLAR HOUR + CORRECTED LONGITUDE + CORRECTED TIME ZONE + CORRECTED « TIME'S EQUATION »



How to correct Longitude :

To be done according to 0 Meridian (= Greenwich Meridian). Knowing that 360° = Earth's full rotation = 24 hours.
To correct Longitude you need to :
Calculate the proportionality between time and angles.
NB : For cities located on the Western side of Greenwich meridian : add time's correction on the contrary for cities located on the Eastern side of Greenwich Meridian you need to remove Time's correction.
Example : Hyères' longitude 6°07'46''on Eastern side ↔ 6,1294° towards West
Correction = - 24*3600*6,1294°/ 360° = - 1471 s = - 24 min 31s
N.B : Longitude and Latitude of cities can be found on the net.

How to correct Time Zone: For instance France is in Central European Time Zone and not Greenwich one.
To correct a jet lag add an hour and add another hour for summer season.
The Time Zone correction is : + 1 hour for winter period and +2 hours for summer period.
This is for France For United Kingdom there is no correction in Winter and only add 1 hour in Summer.

How to correct «Time's equation »
It can vary from more or less 16 minutes, and varies also throughout the year.
What causes this : from one part it is due to the Earth's orbit ellipcticity and for another part to the Earth 's poles angle axis.(This causes seasons).
Approximately, this « Time's equation » can be modelized as a sum or 2 sinusoidal functions :it is an annual period's sinusoidal function , which are coming to zero when Earth is at its perihelia (closest terrestrial orbit's point from the Sun). This happens approximately on the 4th of January.

The amplitude is linked to the terrestrial eccentricity orbit, another sinusoidal function for a mid year period is coming to zero at both equinoxes, and its amplitude linked to the poles angles.

To get a real sample of « Time's equation » make many experiments throughout the year (about 3 per month) when the Sun is at its climax (Zenith or Solar Noon), This might help students of a higher level to find the Earth's orbit eccentricity.

- 2 – SET UP :

How to calculate Solar Noon thanks to Solarscope :

Tools : Solarscope
            A watch showing hours, minutes, seconds

The experience can be done inside a room behind a window in a wind proof environment,
put an horizontal axis on the measuring screen when you want to calculate the Sun's path at a certain height when the Sun is coming up (before solar noon).
Put another horizontal line at the same height when the Sun is coming down (after Solar Noon). The average of both measures gives the real Solar Noon.
This measure can be improved by using different angle of sight and making an average of it.
This experience is established in detail in Worksheet # 2 : « How to determine Solar Noon ».

Few things to notice:

The path on the measurement screen gives us information on before and after « Solar Noon ». Do remember that the Sun's picture is inverted, (Solarscope is a small telescope), that is to say a combination of a convergent lens and of a spherical mirror. For instance if the Sun is going from right to left on the screen and form top to down, in reality the Sun is going East to West and down to top.

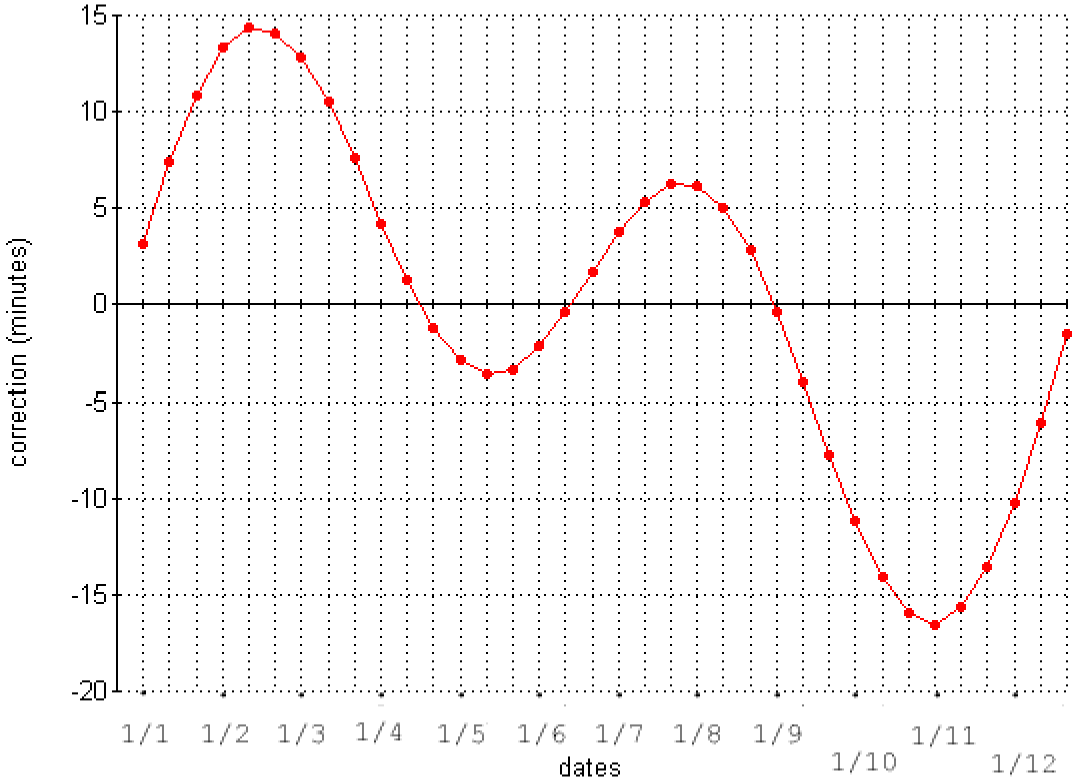
3- RESULTS

For Grammar School students, you can demonstrate how a result might vary from one group to another. Thanks to this experiment they can draw an experimental graph of Time's equation, and compare it to other graph for different cities.

For High School students, they can interpret this Time's equation by a method called simple reduction, in order to evaluate Terrestrial orbit exentricity E (E = 0.0167).

This reduction mode can be done by a Fourier analysis, thanks to calculation software available at School.

Time’s equation



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