Sequence 3

To discover solar midday

Introduction

During this sequence, the pupils will have to determine the exact time of this mysterious solar midday, then reproduce it with a lamp simulating the course of the Sun above their gnomon. Afterwards, by lighting this time two small gnomons stuck to a balloon, they will discover again the observations Eratosthene made at solar midday in Alexandria and Syrene.
It must be said that solar midday is the specific time when the Sun is at the midway of its daily course in the sky, the highest point above the southern horizon (or northern, depending on the geographic position, see below). The shadows are then at their minimum length, and directed to the north (or south) : it must be said that we mean by north (or south), the geographic north (or south), so the North Pole, which is slightly different from the magnetic north (or south) given by a compass. If your pupils can't see the difference during their tests, " north " will mean either of the two directions. It must be said also that places on the same longitude (placed on the same meridian) see the Sun culminate at the same time in the sky.

Note : for the northern hemisphere above the Tropic of Cancer, the shadows at solar midday are directed to the north during the whole year. It is the opposite in the southern hemisphere, for places under the Tropic of Capricorn : the shadows point to the south. And for places of the inter-tropical area, the question becomes more difficult, because they see the Sun cross the zenith during the year : depending on their situation, the shadows look to the north during six months, and then to the south during the other six months. In order to simplify, we decided to situate our typical pupils above the Tropic of Cancer. Schools under the tropic of Capricorn, and the ones in the inter-tropical area will simply " translate " north by south, in order to understand the example.

Interest

Course of the Sun. Evolution of its height from month to month. The concept of solar midday.
Earth's rotation. Basic concepts of meridian line.

How to begin : what about solar midday ?

We have seen in the last exercise that the pupils have already been confronted to the concept of solar midday, when observing the shadow of their gnomon change from hour to hour. The shadow turned slowly, shortening progressively and then growing in the afternoon. Their drawings opened as a fan to the north, a direction the shadow crossed at some point, undefined for the moment. Give this text to your pupils, in order to arouse their interest :

A long time ago, even before Eratosthene, man watched the evolutions of the shadow of a stick or an obelisk, in order to follow the course of the Sun during the day, but also during the year. In fact, with the use of small lines drawn to the point of the shadow, it could be used as a watch during the day, and as a calendar from season to season… But the most interesting was that, at a very precise moment of the day, the shadow could be used as a watch as wall as a calendar at the same time ! It was at its minimum size. This moment is called solar midday : everyone watched for it, Eratosthene to make his own measurements, but also caravaneers and even pyramid builders for another reason you will discover when you find this mysterious solar midday…

Making use of the remarks and discussions raising from the text, you will make the pupils understand that the first priority will be to discover what is solar midday. Another observation will provide the information needed and will explain some elements in the text, either immediately, or later in the year, after 2 or 3 other surveys..

Sequence summary :

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1) Discovery of solar midday with a second survey

Duration : Punctual activity made every hour if possible during a bright day, and at more frequent times during lunch time.

Location : Some place exposed to the Sun during the whole day.

Equipment :

for each group of 3 to 5 pupils

1 gnomon of the identical gnomons type (see sequence 2, part 3),

and the equipment needed to calibrate it (sequence 2, part 4).

A compass, a pair of compasses, 1 ruler,

1 small ruler made with graph paper,

1 sheet of tracing paper.

Discussions about solar midday.

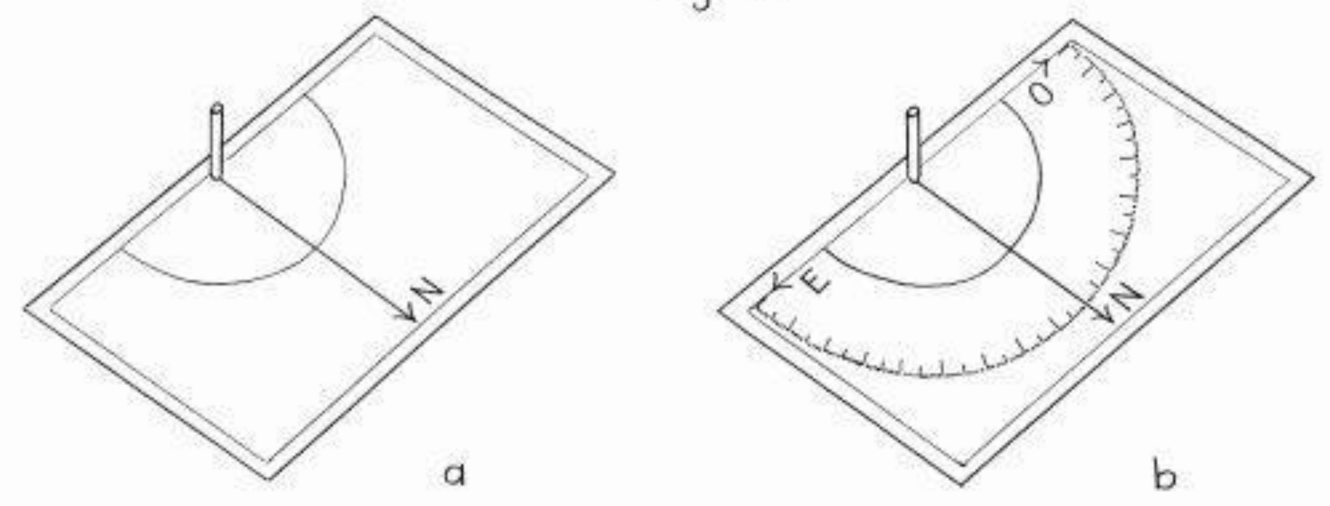
During the first survey, the pupils saw that " midday " (12 o'clock) meant nothing significant for the shadow, for it was still shortening afterwards, showing no specific direction at that time. But now, they will be curious to see exactly when the shadow will show the north, and when it will be at its shortest : they will write their hypothesis in their notebook. At the end of the discussions, the pupils will be convinced that the only way to know for sure is to put the gnomons back under the Sun...

Prepare for the " hunt " of solar midday.

Everyone agrees that the readings must be made at very regular intervals during the estimated time of solar midday. As this time is the time of midday break, the teacher can hope that most of his pupils will have lunch at school ! (They will try to take turns, in order not to disturb the sitting). During this period, each group of 3 to 5 children will be autonomous, and will choose when to begin and when to make their survey.

In order to find the best time to watch the shadow pointing to the compass north, and the time it is at its shortest, make your pupils draw upon a sheet (placed under the tracing paper) a half circle with their pair of compasses, with a radius approximately similar to the length of the shortest shadow obtained during the prior survey. The sheet will then be centered at the base of the toothpick, from which they will draw a line cutting the half circle in two halves, pointing to the compass north (see fig 1a). Then, the pupils will be able to see at the same time the changes in the length of the shadow, compared to the half-circle, and where they point, compared to the line (which should also be seen on the tracing paper).

Fig. 1



If your pupils are really thrilled by this survey, they will be able, if they calculate precisely the length of the shadow at every measure made, to give an estimate of its angle regarding the north (or east or west for morning and afternoon readings). They could do it by enlarging a protractor with a photocopier, and keeping only the external graduated arc, without the figures. This arc will be enlarged, to put it on an A4 sheet of paper for example, the degrees will be put at approximate intervals of 2 mm, giving a one-third-degree accuracy.

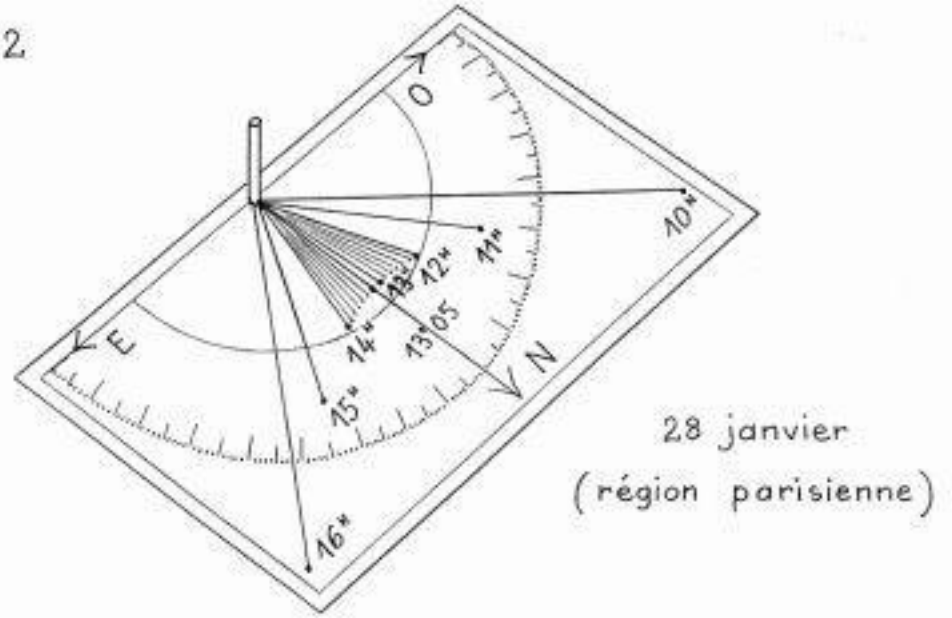
Measurements.

In order to solve the mystery of " watch-shadow " and " calendar-shadow " at the same time, , the pupils will understand that it is necessary to make readings every hour, and then closer ones during midday interclass. In order not to disturb class life, every group will proceed at the same time, on the dot of each hour. But, if this becomes too restricting, it is possible to resume the rhythm of the former survey (see sequence 2, part 1), and write down precisely the time (hour and minutes) of each reading.

At the first bright day, after the gnomons have been calibrated, point carefully your line on the tracing paper to the north and write down the date. The pupils will make their shadow-readings every hour in the morning, including midday. Some will want to calculate the angle of these drawings compared to the west and deduce Sun's orientation.

Then, each group will take its turn during the interclass -after they all set their watch. They will write down their readings according to the chosen frequency, without forgetting 1 PM on the dot. Each time, the hour and the length of the shadow will be drawn on the graph paper, and maybe the difference in degrees with the north, and of course the time when the shadow falls upon the line. The readings will then be resumed at each hour until 4 or 5 PM.

Fig. 2



How to read the interclass survey.

As soon as the lessons begin in the afternoon, and so precisely after the probable time of solar midday, the classroom will analyze the tracing papers (and put them back on their gnomons for the end of the survey).

Each group has already seen that the length of the shadow did not change much about the line pointed to the north, and that the slight blur at the end of the shadow prevented precise comparisons. Nevertheless, everybody is now sure that the time when the shadow was at its shortest is very close to the time when the shadow crosses the north line, even if it is not absolutely accurate. How can they be sure, then ?

Each group made its survey at a different time during the probable solar midday time. By superimposing two or three tracing papers will give a better reading of the period, and it will become possible to find the "shortest" shadow. And they will see that the shortest is also the closest to the line.

But it is possible that the most careful readings show a slight difference between this shadow and the north : you will have to explain, then, that compass north is not the " real " north given by the shadow, the geographic north giving the North Pole, and that it is possible to find this direction as will be explained later (see " how to draw a meridian " at the end).

Confirm the discovery of solar midday.

Ask then how to describe the position of the Sun at that time : they will probably answer " Sun is at its highest in the sky, and right to the south (or north, see above) ". It is a good definition for this mysterious solar midday, the fundamental key in Eratosthene's experiment.

Write on the blackboard the time found. The pupils will ask why their watch doesn't give them the same midday. Explain then that it is for practical reasons that man does not live anymore with Sun's time, and that they will understand with another simulation (see end of sequence).

At the end of this day, make copies of the tracing paper showing the solar midday and give them to your pupils, so that they can stick it into their notebooks : they will outline in color the good shadow and the time of the reading, then discuss the results. They will understand afterwards that solar midday's time at the watch changes from week to week, plus or minus 20 minutes approximately (plus one hour if the country is an adept of summer hour).

We will see, at the end of this sequence, how to determine precisely this hour everywhere and everyday, in a fast and easy way. In France, it is about 1 PM in winter and 2 PM in summer (because of summer hour). But more to the east, this will come half an hour sooner, and more to the west nearly 20 minutes later.

Using shadow as a " watch ", then as a calendar

Duration : The day after the previous survey (or 8 days after at most). Punctual observation made every hour if possible during a bright day, then repeated survey during the year.

Location : Some place exposed to the Sun during the whole day.

Equipment

For each group of 3 to 5 pupils

1 gnomon of the identical gnomons type (see sequence 2, part 3), and the equipment needed to calibrate an direct it (sequence 2, part 4).

The previous tracing papers, and one more - blank.

During the days and weeks that follow, as we progress on the project, the pupils will understand more and more of the small text given in the beginning of the sequence. We'll see later that the simulations described later will become deeper and more accurate.

The shadow as a " watch ".

If it is still sunny on the day after the great discovery (or let's hope it will be during one of the eight following days), the pupils will put back their gnomons under the Sun, with the sheet of their last readings. They already think, for most of them, that the shadow will get back a the right hour upon the right outline, and the second survey will comfort them : " The shadow turns, just like the hands of a watch : it gives the hour in the day ". (You can show them that shadow turns clockwise : would it be the reason we used that way for our first clocks ?) Then, ask the shadow could be used each day, then week after : the pupils will write down their hypothesis and argument in their notebook. The experiment will be made later, and that will help the children understand how the shadow could be used as a " calendar ".

The shadow as a " calendar ".

Ideally, you could try repeated surveys at different times in the year, in order to study the different drawings of the shadow's course. See the optional file : " solar calendar " made with different shadow

layouts.
If you cannot, after having made a few surveys at the time of solar midday, your pupils will compare their different measures and see that shadow's length changes from day to day (shortening from the 21st of December to the 21st of June and lengthening afterwards, up to the 21st of December again) : they will understand then why from one season to the other this shadow can be used as a calendar.
Furthermore, a very accurate survey at the exact solar midday can show a slight difference in the drawings from one week to the other, showing that, compared to a typical watch, solar midday is not exactly at the time it was eight days before. Other surveys will show that this difference can be recorded during the whole year, the time of solar midday changing regularly, compared to " official " time. This is because " official " time do not count some irregularities in Earth's movement caused by the fact that poles' axis is not perpendicular to the plane of our course around the Sun, and that this course is not circular, but slightly elliptic.
At the end of these experiments, the pupils will be able to understand the most difficult points in their text : they know why the marks of a stick's shadow can give for a few days a fairly accurate time, but also why the fact that this time will not be valid during the whole year can help to keep track of the seasons. They will understand, also, why the shadow at the time of solar midday can be of both uses during the weeks, since its length changes. And they will have seen, of course, as soon as their discovery of solar midday, another interest of this shadow for " caravaneers and pyramid builders " : the north will help the first ones to orient themselves during their course, and the others will be able to orient their buildings.
If they make a study on Egyptian pyramids, the pupils will see that their ground, a square, is precisely oriented regarding the cardinal points, each side being made to look right towards one of the four directions. The most curious will see that some pyramids are surrounded by a rectangular east-west wall, and that the famous sphinx in Gizeh is looking right to the east, where raises Amon-Râ, the Sun-god, where are built the tombs and funerary temples.

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3) Simulation of Sun's course at its height at the time of solar midday

Duration : 30 to 40 min (without the drawings)

Location : Classroom, slightly dark (or any other place)

Equipment :

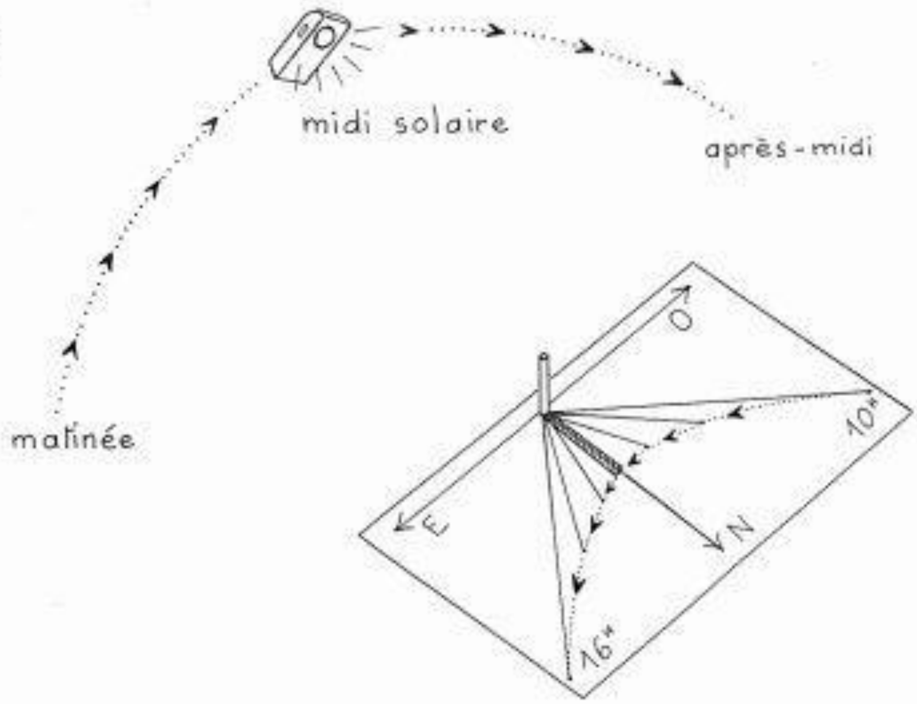
For each group of 3 to 5 pupils
The gnomon used for the discovery of solar midday,
the tracing paper showing this specific survey,
a great sheet of white paper,
a pocket light.

This experiment will interest passionately your pupils (some may even have already tried it). They will have to reproduce with a lamp the course of the Sun, with a drawing made during the day they discovered solar midday. Each group will put the drawing on the base of the gnomon, and the gnomon on a table.

Reproduce the track of the shadow.

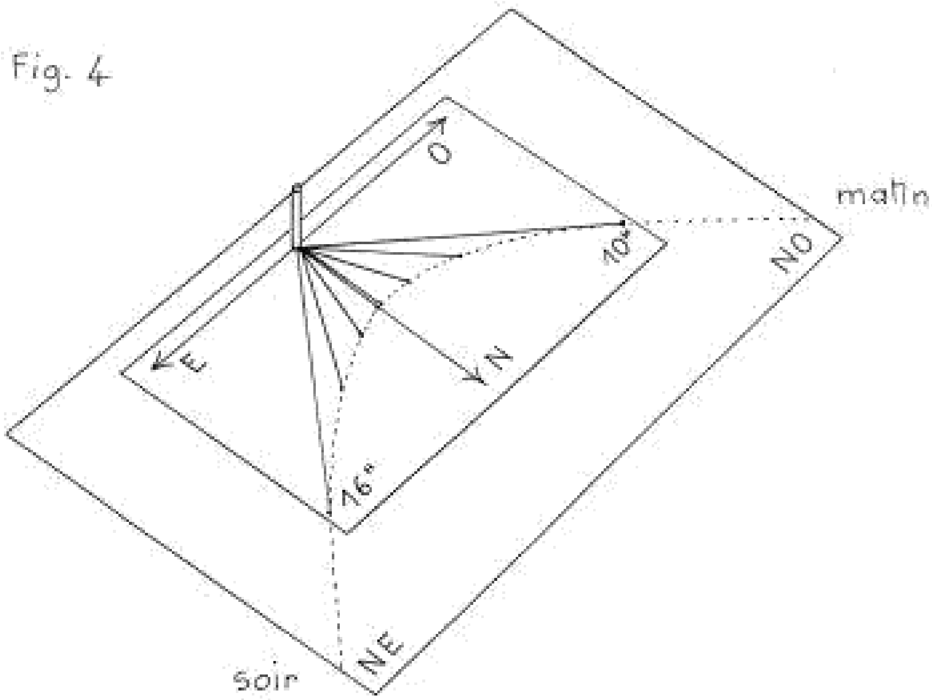
One after the other, by lighting the gnomon with a torchlight, le children will try to make the shadow of the gnomon glide upon the different drawings, according to its direction and length. Their comrades will watch carefully the lamp's movement in both of the aspects : rotation in the " back " of the gnomon and change of height, at its highest at the time of solar midday (cheered as it should be). With trials and errors at the beginning and a slight stop upon each mark, the pupils will finally be able to use their lamp in a fluid and continuous motion.

Fig. 3



Simulation of the course of the Sun from sunrise to sundown.

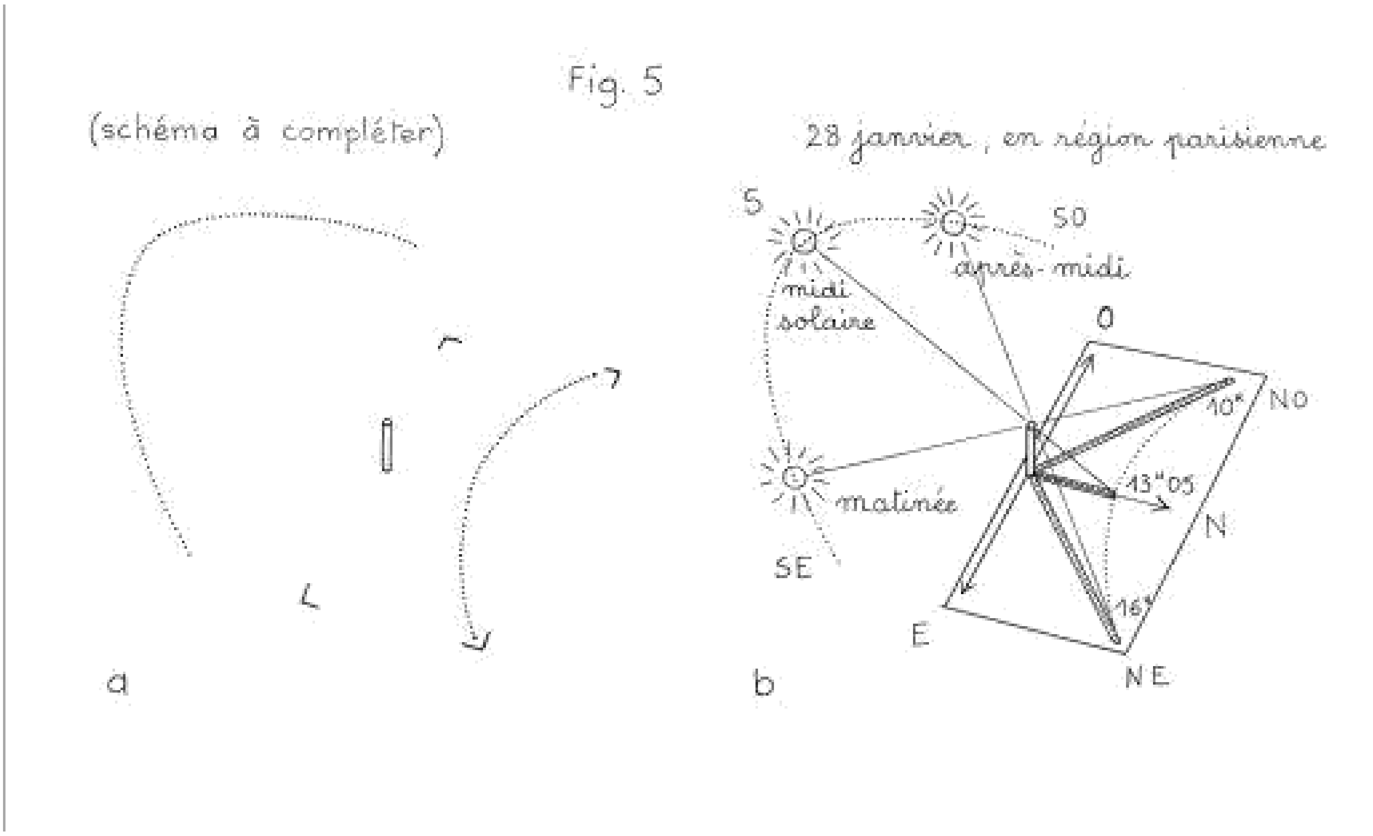
You can then ask the pupils to deduce from their drawings on the tracing paper the complete course of the Sun in the sky from dawn till dusk, and then simulate it. Some will spontaneously try to continue the movement of their light, and others will analyze the length and direction of the drawings, trying to deduce those before and after : they can feel then the need to link the ends of the existing drawings and continue both sides of the curve. They will need a large sheet of white paper to put under their tracing paper, then continue the curve right and left of the fan. They will use their light to draw at the point of the shadow the course of the shadow : those who succeed in a continuous movement can boast that they " copied the real Sun ! "



You can then ask them to define, from this curve, an idea of where the Sun rises and sets. Later on, if new simulations are made after new surveys, the pupils will understand that these directions also change : after winter solstice where it rises to the north-east, the Sun rises more and more to the east, being easternmost at spring equinox. Then, it rises more and more to the south-east until summer solstice, and back till winter solstice.

How to sketch the simulation

After a few trials, the pupils will understand that it is difficult to draw efficiently this simulation without using some effects of perspective, which is not really easy for most of them. You can give them copies of the gnomon (the toothpick), the two curves in dotlines and the four corners of the base. (Fig. 5a). From what is shown on their tracing paper, the pupils will have to complete the whole sketch. But, in order not to spoil the central part, they will only draw the three major beams and their shadow. (Fig. 5b).



To continue further, you can see the optional experiment : " how to simulate seasonal variations of a gnomon's shadow ".

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4) How to simulate the solar midday with a balloon.

Duration : Two session of about 30 minutes each (without writing).

Location : Classroom, slightly dark (or any other place).

 **Equipment**

For each group of 3 to 5 pupils

1st session : a balloon not too small (smooth and plain if possible), a Bristol cylinder wider than higher to put the balloon ; 5 to 6 identical " mini-gnomons ", no higher than 1 cm (tapestry nails, seeds, small screw, bits of matches or small sticks of modeling clay) ; sticking gum ; a torchlight.

2nd session : same equipment, plus a small map of Egypt (reduced with a copier) : the distance Alexandria-Syrene will be approximately 1/7th of balloon's circumference (measured with a string), which is purposely bigger than on a globe ; the mini map will be cut in order to keep only the interesting part : the delta and the Nile valley to Syrene

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If your pupils were interested by the former simulation, the following ones will be even more interesting for them. They will survey, from " space ", the effects of the rotation of an " Earth-balloon " upon itself, on which have been put " mini-gnomons ", lit by a motionless " Sun-lamp ". The conditions are opposite to the ones of the previous simulations, where the " Sun-lamp " was in motion and the " Earth " was still and plane.

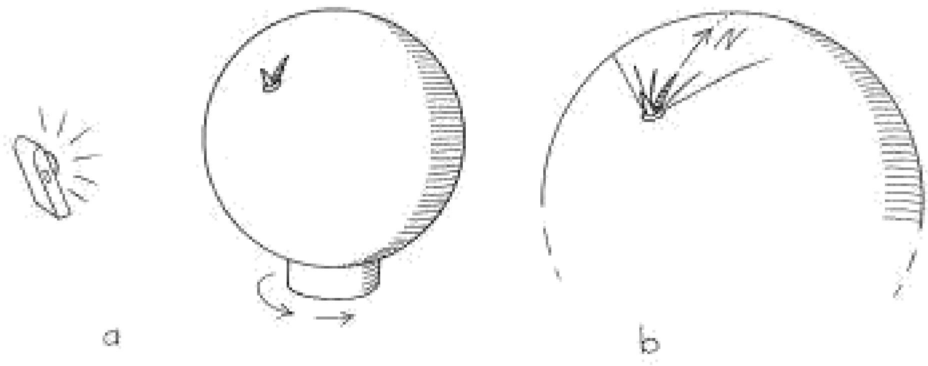
First session

a) How to get the same observations made with the gnomon under the Sun.

Each group places a " mini-gnomon " (a small screw for example) on the balloon, puts the balloon on the cylinder, the whole thing on a table and, to stabilize the cylinder, fixes it with four points of modeling clay around its base. Challenge them to reproduce, with the motionless lamp lighting the screw on the rotating balloon, the movement and changes in length of the shadow seen the other day with the gnomon in the Sun.

Several problems will arise -very interesting- : where must be the lamp in relation to the balloon ? How will the balloon be turned ? How to locate the time of solar midday ? What is to be done if, at that time, the shadow is too long or too short for the screw ? Numerous occasions of debates and trials ! But the pupils will finally solve all these problems and will see the shadow of their tiny screw act like that of their gnomon " with the real Sun ". To do that, they would have to understand numerous concepts, especially that the balloon should turn " the other way of the shadows ", so anti-clockwise.

Fig. 6

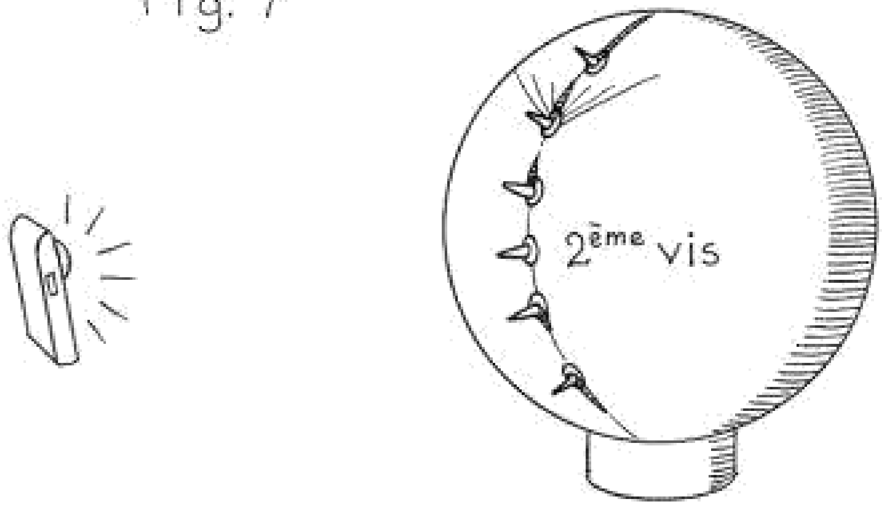


In some groups, the detail of the shadow screw will have been drawn, and it is even possible that they had the excellent idea to materialize the direction of the North pole by an arrow going up to the top of the balloon (see below). All the children will have, of course, observed the two faces of the balloon : the " day " side and the " night " side, and the way the screw crossed the lines of " morning " and " evening ".

b) place several " mini-gnomons " so tat their solar midday will happen at the same time.

Here, your pupils will make an experimental approach of the notion of meridian.
Upon each of the balloons, the screw being in " solar midday " in front of the lamp lit, challenge them again : " Take a second screw and, without having to turn the balloon or moving the lamp, discover where you could place it so that it doesn't have any shadow. Add then two or three other screws for them to be also in solar midday. Then, turn the balloon to check your result ".
The pupils can understand that the second screw will be the equivalent of the staff in Syrene, the first being the one in Alexandria. So, they will easily find its place to the " south " of the first one. The ones who had the idea to draw their line up to the north pole of the balloon will see immediately that the second screw must be placed somewhere on the continuation of this line. Then, they will easily find a place where to put the other screws, linked in the same fashion, and discover interesting things for the continuation of the project : that the shadows coincide with the line, that their length grow progressively towards the " poles ", and that the screws " south " of the second see their shadow pointing towards the " south pole ".

Fig. 7



You can then ask what could do the line upon which are stuck the screws if it was continued both sides. " It will go all around the balloon ! ". The pupils will then predict that if they put screws " on the back " and make the balloon turn, they will also be at solar midday all at the same time, thing they will of course check.

Furthermore, after having seen a globe or sketches seen in a book, some will ask themselves what could happen with a " leaning Earth " : they won't easily admit that the shadows at solar midday could point the poles in the same way they do with the balloon " straight " on its base. But how can they see it ? The simplest -and funniest- way to do it is to hold the balloon between their fingers placed on the " poles ", tip it slightly and make it turn with the thumbs : the children will see that, whatever the inclination -even when the balloon is " horizontal "-, the shadows in the solar midday are still lined up on the meridian !

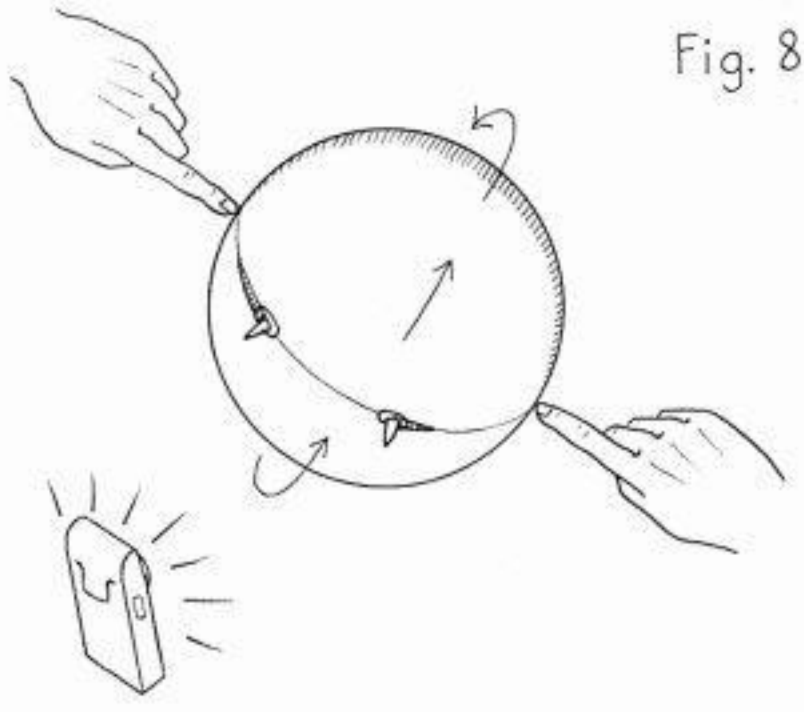


Fig. 8

Second session

a) Reproduce solar midday in Alexandria and Syrene.

Because the two cities are not on the same meridian (about 3°,5 separate them in longitude, like Le Havre and Auxerre in France), the pupils will have other problems to solve…. Give the retailed mini-map of Egypt to each group (see Equipment) and challenge them for the third time : " Place the map on the balloon so as to reproduce Eratosthene's observations : solar midday in Alexandria and Syrene ".
When the two screws will be put upon the mini-map, the pupils will place it vertically upon the balloon, facing the light, and make it slide until the shadow in Syrene is reduced to the minimum, then they fix it. Bu the problem is that the shadow in Alexandria " is not exactly straight ", and is not pointing the north pole. (This should be easily seen, even if the objects are small, because of the difference between the width of the paper and the curve of the balloon).

Fig. 9

To compensate, the children will slightly turn the balloon, and the shadow will straighten -and shorten, also-, but the problem is that a small shadow appeared in Syrene !
Remembering the previous simulation, some will want to put the two cities on the meridian drawn upon the balloon. They will make the shadow in Alexandria point the north pole, and the one in Syrene disappears. But the map is now bent ! Suggest then to " righten " the map and carefully survey the movement of the two shadows from " sunrise " to " midday "…
The children will discover that in Syrene " solar midday comes slightly before Alexandria " and again, there is a problem with the text saying that Eratosthene's observations were made at the same time… But which time were they talking about ? Not watch-time -no watch existed at that time-, but the time given by the Sun, so different from one place to the other around the Earth, exactly the same as with the balloon ! They also understand that the two cities are on different meridians, and that it could be possible to draw an infinite number of meridians on a sphere. We will get back to that point.

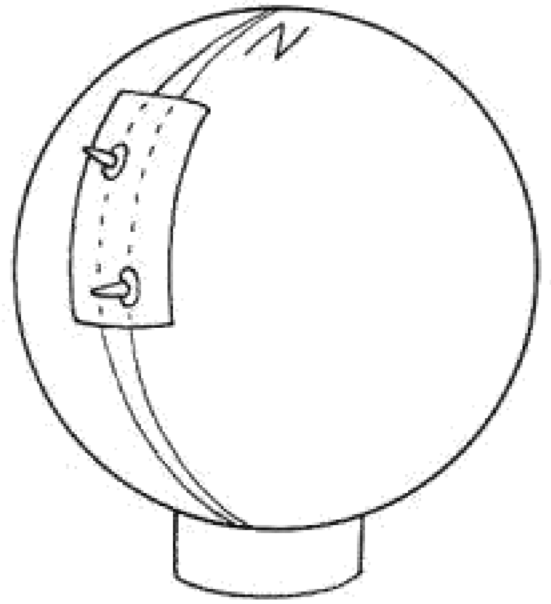


Fig 10

Note : Specify if necessary (or have your pupils calculate it later) that there is nearly half an hour of difference between solar midday in Syrene and in Alexandria, but this slight difference did not hamper Eratosthene when he computed the meridian…

After that, the pupils will understand that in our modern world, one cannot live anymore at Sun-time : a state must have the same hour on its whole territory, and all the countries in the world must agree upon a common " legal " clock system (we'll see that later).

From another part, the use of a balloon lit by a torchlight can also simulate in an entertaining way the evolution of the shadow of a mini-gnomon with the seasons (see file about the seasonal changes of a gnomon's shadow)

b) How to know the time of solar midday anywhere all along the year.

How can anyone know in an easy manner, for the rest of the project, the exact local time of solar midday, in order to make only one shadow survey ? Several solutions can be used :

1. Use a compass to determine north, knowing that the direction is slightly different from geographical north, therefore making a slight error. Then, the pupils will only have to watch the shadow, to see when it crosses the north line.
2. Draw upon the base of the gnomon (carefully placed on the ground) what is called a meridian : a fragment of the actual meridian, in order to get the geographical north. This is a very interesting thing to do, once and for all, optionally (see the file : " draw the meridian ")
3. Connect you to the site of the B.D.L. (Bureau des Longitudes) who, according to the place you are and the date chosen, will give you the time of solar midday, but in Universal Time. In France, you'll have to add 1h if you are in winter time, and 2h in summer time.

(Note that when you have made the first drawing at the time given by the B.D.L, you will be able to draw the meridian of the place, since it will be the same as the shadow drawing)
Finally, you can also continue this session with the games devised by J. Carole in 2001 : she shows how to materialize Sun's path on a transparent half-sphere (an upturned salad-bowl or a very fine colander).

This can be made any time in the year, provided the sky is clear !

In the following session, the pupils will tackle with the question of the angle of sunbeams : how to draw, measure and interpret them.