Sequence 2

Making and using the gnomons

Introduction

During this sequence, the children will discover that the shadow of a stick turns around and that its length changes during the day. They will then put under the sun their miniature self-made "obelisks", i.e. the gnomons, different at first, and similar afterwards. They will sketch and measure the shadows at five or six moments of the day. Comparing their results with those of their classmates, they will feel the necessity to stick their gnomon strictly vertical on a horizontal stand.

Notions

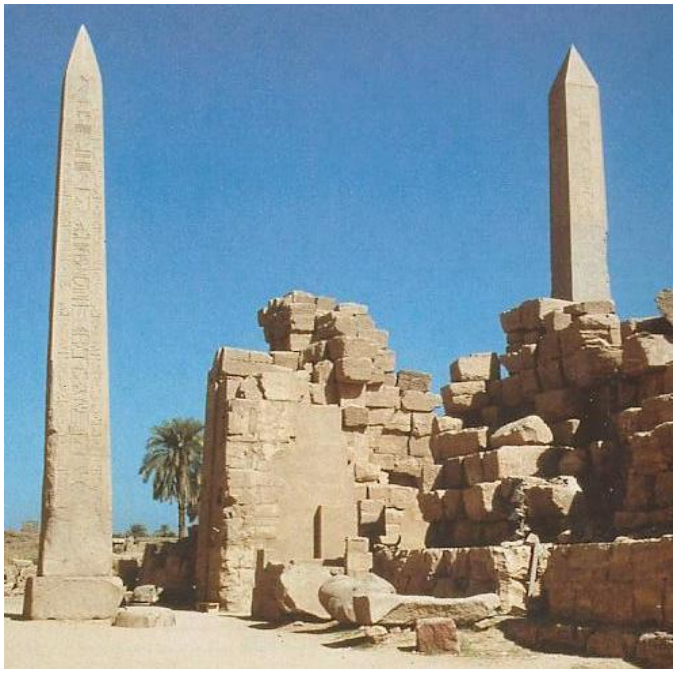
Global evolution of the shadows during a day. First line drawing and measures. First locatings of the direction of the shadowswith regard to the North given by a compass. First comparisons. Notion of vertically and horzontality.

Preliminary : the obelisk of Alexandria

Show the following text to your pupils :

During the first sequece of this project, you partly solved the mystery of Eratosthenes. Here is the continuation of the story.

" Eratosthenes had learnt thanks to the papyrus that the stick stuck in Syene had no shadow and tryied to understnd this surprising phenomenon. He himself stuck a stick under the sun and observed it for long hours. As the stick wasn't straight up and the shadow was so tiny, he decided to observe th shadow of a big granit needle aised at the entrance of one of the temples in Alexandria. The needle was stuck very straight in the ground, it was nearly 20 meters high and cast a much bigger shadow than his stick, it was called the obelisk. Its summit was in the shape of a small pyramid covered with gold, so that it shone in the sun and you could see it from very far away! The obelisks often decorated the entrances of egyptian temples and pharaohs' tombs, Eratosthenes had no trouble finding one near his library. He observed it for long hours during the day and his observations allowed him to solve some of the mystery..."



What did he noice observing the shadow of the obelisk during an entire day? It is your part to discover it doing the same experiment as Eratosthenes under the sun!

The children are brought to think about the instruments used by Eratosthenes to realize his experiment. Then they must ask themselves how to reproduce this experiment in their classroom and which instruments they have to build. But

before being able to build actual gnomons, they will have to put a stick under the sun, and observe in their turn the strange ballet of the shadows.

Since it had not been precised in the text the children read at the bigonning of the project, tell them that shade observed and carefully measured by Eratosthenes was that of an obelisk. Some documents will be welcomed to show what this "big granit needle" set up at the entry of the Egyptian temples looked like.

Then pupils will look for objects that can stand for a small-scale obelisk and bring them to school. But before then can create gnomons advisedly, they will have put a stick under the sun, no longer for a simple observation of its shade, but to answer the question raised by a strange precision given in the text: it was at a special moment, solar noon, that the measures had been made... Would this indicate that shadows change during the day ?

Duration : This sequence is made of four parts, each one of them can be done in one or two sessions, or in simple moments of activity during a sunny day.

Summary of the sequence:

1) **Reading the variations of the shadow of a stick at different times of a class day.**
2) **Making and using several gnomons.**
3) **Making and using a few similar gnomons.**
4) **Using the notion of verticality and horizontality to adjust the gnomons.**

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1) Reading the variations of the shadow of a stick at different times of a class day.

Duration : 5 to 6 moments of 5 to10 minutes during a sunny day to carry out the readings of the shadow outdoor

Location : endroit dégagé et bien exposé car devant rester ensoleillé toute la journée.

Matériel :

Pour la classe :

a stick (30cm minimum) stuck in a pot filled with earth or humid sand,
a chalk,
a tape measure,
two compasses,
a sheet of tracing paper,
a few straight objects including screw,
a piece of paper to take notes.

Débat.

The children first discuss this experiment and try to imagine what Eratosthenes could observe that was so remarkable. Every one elaborates their own hypotheses and will share his ideas with the classmates, and then writes it down in the science notebook. Some of them might remember the manipulations of the eletric lamp over the map of Egypt and will assume that also shadows move when the sun moves in the sky. To verify the ideas that will have come up and part the candidates, only one solution, do yourself the experiment under the sun!

Installing a stick in the sun.

From the morning, you should place the stick in the pot in a place that remains in the sunduing school time. It will therefore all be about measuring the shadow at several moments of the day. But a question is set : if the shadow moves, how will we do to note the shift? "We will have to draw the shadow on the ground!" Therefore, you should put the pot on a hard floor (if it can't stay in place all day long, draw a line around the pot).

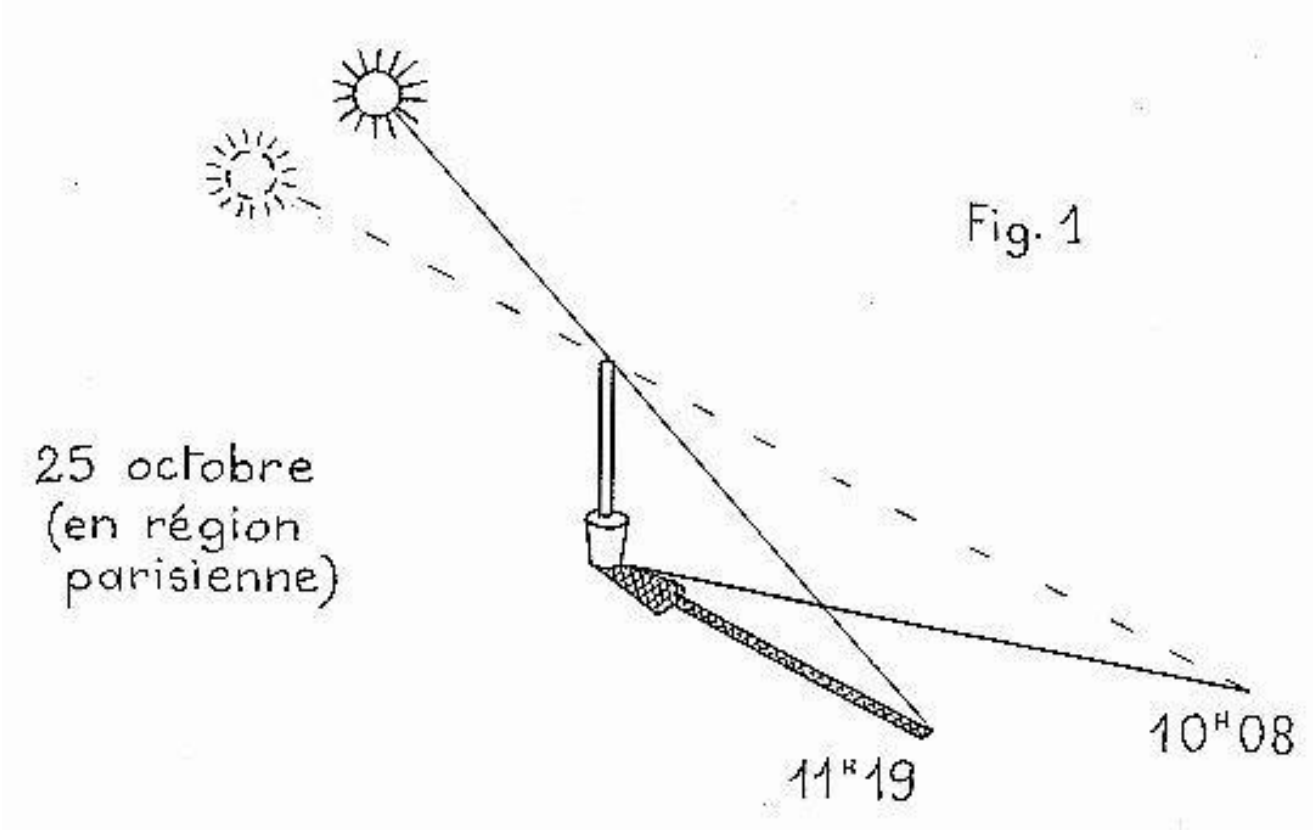
Discuss to agree on the moments of the observations of the shadow without disturbing the life of the class : for example, at the beginning of the morning break, then just before lunchtime, before class starts again, during the afternoon break and before the end of class. Moreover, if lunchtime is at 11h30, the pupils that have lunch at school will surely insist on staying for an extra observation of the shadow of the stick at "sharp noon".

Observing, drawing and measuring the shadow of the stick.

During the first observation on location, after writing down the precise date and time, a pupil is in charge of drawing the shadow with simple straight line running from the pot to the tip of the shadow.

Then, someone else willmeasure the drawing with a tape measure, and you will write down the figure found as some pupils note an important fact : the precision of the measure in relative because the shadow (pot included), very clear at the bottom, is blurrier as you reach the tip (even mre if the stick is long, due to the penumbra).And if the tip is very "sharp" (you can put a screw on top of it, pointing the sky), the pupils see - even better - that the imprecision is even more obvious! (As well, next time you go to the pot, they will bring straight objects of different length and shapes at the tip : holding them straight on the ground, they will see that the shorter the object is and the flatter the tip is, the better the precision of the shadow is, which they will remember when they make their gnomons).

During the secind moment of observation (before which you will have stuck the two compasses in your pocket), they will noice: "the shadow has turned!", "And it is shorter!". The children then discuss to interpret the phenomenon : they quickly reach the agreement that the sun must have moved in the skyan that it is higher up than it was before.



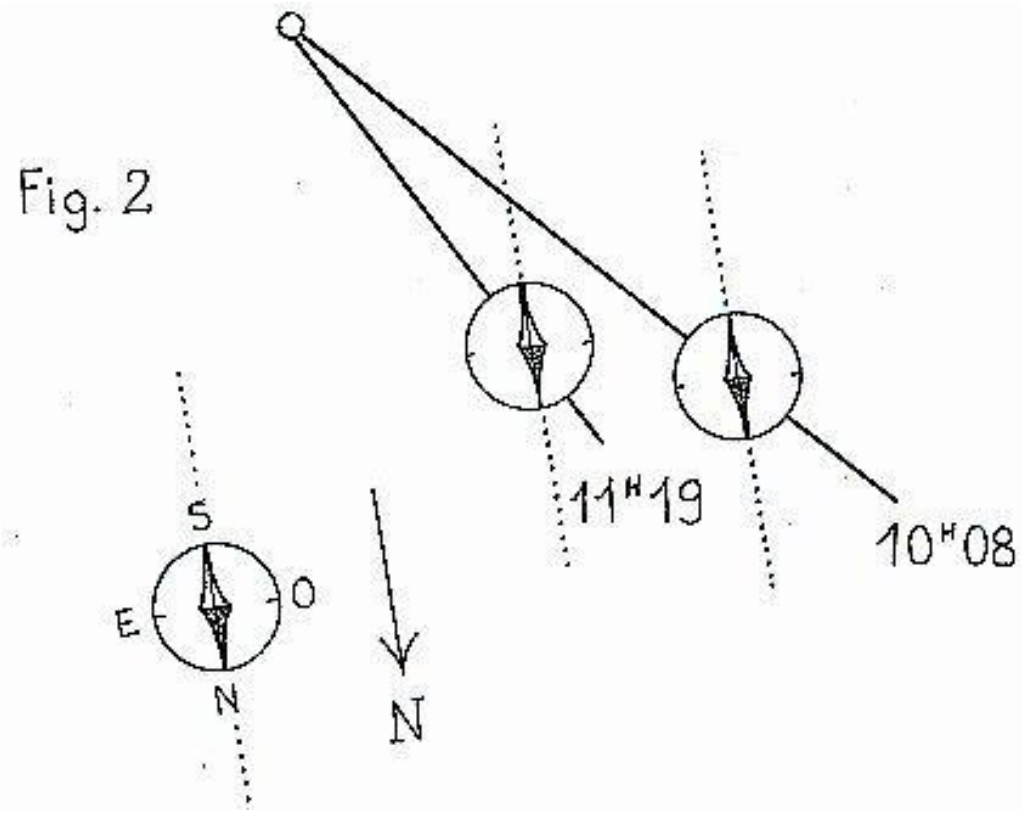
In the same run, they will try to foresee how the shadow will be at the moment of the next observation : if it is noon, tey will think that the shadow will be shorter but that it will grow longer afterwards, until night time ; as for its moving, they will be sure it will go the same way "since the Sun isn't going to go backwards!"

Keep in mind the orientation of the two first shadow drawings, thn the next ones. A qustion will doubtlessly emerge from the second time of observation or the following ones : if it is easy to read every timethe length of the drawing, how will we do to store the "spread", i.e. the way the shadow turned around? the pupils first think of locating an object in line with each drawing (a tree, a door...), but it is unpredictable and not very accurate! Others will suggest to put a big piece of tracing paper under the pot in order to reproduce the start of the drawings. New problem : when the rain will have erased everything, how will we put the tracing paper back right if we want to carry ou the manipulatio again for later comparisons? Hre comes the necessity to locate near the pot and then on the tracing paper a precise and everlasting direction, like the North , for example, that we find on he maps... "We would need a compass!"

Then make a quick investigation on the knowledgeyour pupils have of that instrument, and foresee a few activities to make them familiar with its use (see activities with the compass)

While the pupils remark that the shadow already turned slightly while they were talking, take a compass out of your pocket. Ask a pupil to show the others how it works, when you put it on the ground : once the needle is stable, the pupil will mke the blue arrow coincide with the letter N for each of the four letters of the cardinal points to be able to point at the four directions. The one from the North is materialized by an arrow (see image 2).

Remark : if you are in the South hemisphere outside of the intertropical zone, replace North with South in the continuation of the text because the sun will reach its height north in your case and the shadow of the stick will point south. If you are in the intertropical zone, it will be either of these cases depending on the moment of the year you do the experiment. As well, the indication of time in the continuation of the session correspond only to what we would observe in France in winter time. You have to adapt considering the moment the sun is the highest in your region.

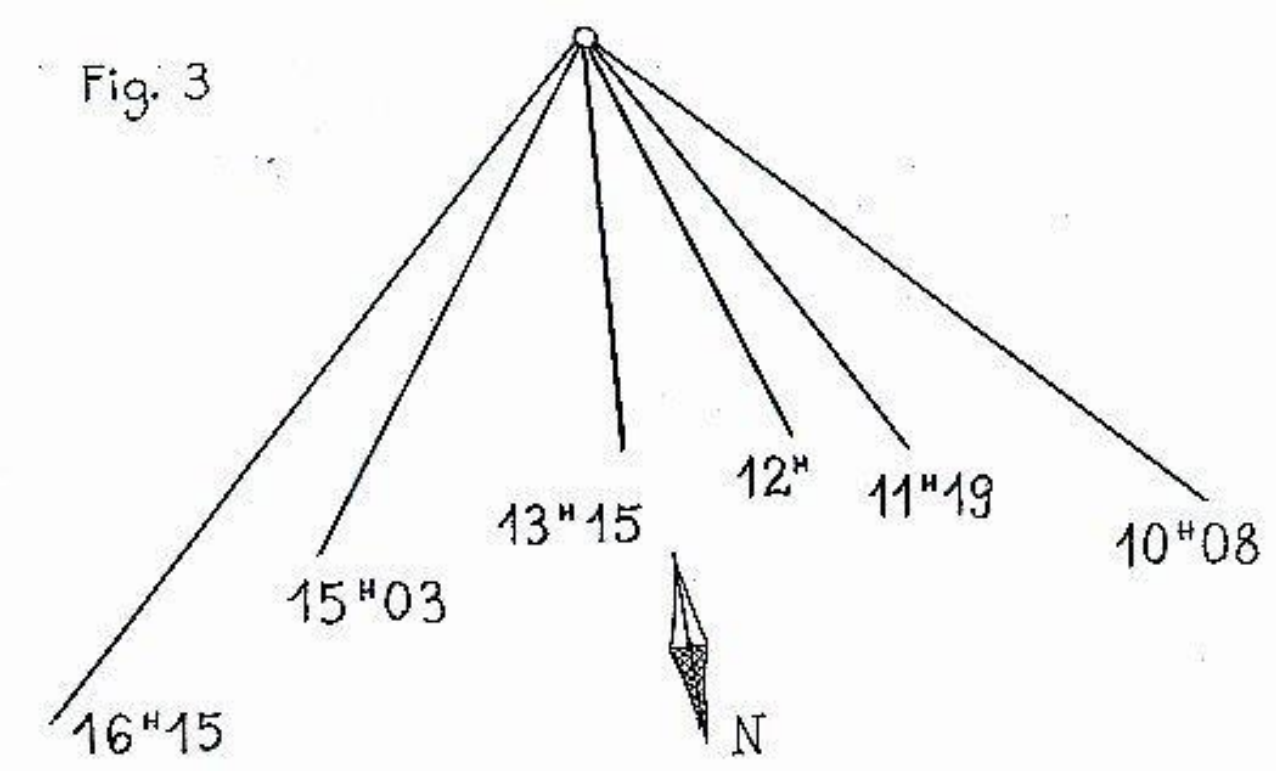


The children notice that both drawings don't follow the direction North : they suggest to place the compass (and the secondone you will have taken out) on each of them to see how they "spread out".Some of thm might add that the drawings are oiented North-East : it us not about making them determin precisely the orientation of the drawings - it is a very difficult thing for the children knowing nothin about angles - but locating how the shadow turns around in regard with the orientaion North (which will remain in center of all further observations). Indeed, the children will foresee that the next drawing will approach that direction, which of course can be checked later.

The following readings. Let's remind that thet third moment of observation takes place whether at lunchtime or when school starts again after lunch : therefore, we proceed to the drawing of th shadow on the ground and comment on its length and its orientation in regard with the first ones and the direction North. If the reading takes place at noon as some children might have wanted, the latter notice that the shadow is shorter and that it doesn't yet coincide with the direction North of the compass. They assume it will later.Until when will it shorten? Will it end up disappearing? At what time? What will happen later in the afternoon? Will the shadow grow again?

The pupils will then share their intuitions, they will write down in their notebook their observations and their answers to all these qustions and will quickly make new readings to check the hypotheses.

If the next reading is carried out a little after 1pm, it will show very well that the shadow crossed the direction North but, however, will reveal that it is slightly shorter than it was at noon, but still there(except on the very particular case if you are in the intertropical zone and the sun has reached its zenith)! Then, the two last drawings will confirm the chilren's hypothesis, thy will see the shadow lengthen again until gigantic proportions until sunset.



Before leaving the school, they will reproduce on trcing paper the "funny fan opening north", or at least the start of the drawings, including the arrow pointing North (or the needle of the compass) : the children will refer to it to sketch the readings on their notebook.
Keep in mind to save 10 minutes at the end of the day to take stock on the conclusions of the experiment. They have discovered wht Eratosthenes had himself ralized observing the obelisk > the shadows turn and change length depending on the time of the day. Some pupils may then refer to sundials used bythe Egyptians. Then, they will carefully write down ll the new questions that have come up with this experiment. After that, they might want to do the manipulation with miniatureobelisks stuck on a large stand that can contain the wide morning and afternoon shadows. That's what the next sequence is about.

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2) Making and using several gnomons

Duration : moment of concertation, short do-it-yourself time, and then, during a sunny day, 5 or 6 moments of shadow reporting, moment of exchange and discussion.

Location : classroom ; then, for the reports, sunny room all day long (oriented South) or a clear outdoor location.

Equipment :

For the class :

Objects brought in class to make the gnomons, i.e. the tiny "obelisks" (one for each group of 3 to 5 children), fixes on borad-stands ; appropriate tools ; a few gnomons previously made at home ;
a compass and a sheet of tracing paper for ach group.

While the children will bring from home several objects to be used as sticks and plane surfaces, some of them will be proud to bring a manufactured gnomon with them! (You are advised to encourage your pupils to have a self-made gnomon at home in order to reproduce the manipulations carried out in class during weekends and holidays : the families will therefore be involved in the adventure!).

Concertation.

In groups, the pupils discuss to choose which of the objects they brought is most appropriate to make one or two gnomons. (It can also be decided that every child can make his own, but beware of the space required to expose around 30 not too small boards!) Making the gnomons : Some groups choose to stick their gnomon in a polystyrene board, or to stick a big rivet on a plywood board ; others simply stick with adhesive paste a pencil (whether they think of blunting it before) or a piece of a tube, on wrapping board, etc.
Remembering that the shadows are very long in the late fall and that the "blur" of their contour increases "at the tip", the children will be careful to choose a short gnomon, i.e. 10 cm to the most, to prevent the board from taking up too much space ; nevertheless, if the stand they foresee is not big enough or if they are not careful to stick the gnomon on a side of the stand, they risk to run over more or less... (indeed, inour latitudes, at the time of the solstice and of the local solar midday, the shadows, although as short as can be, reach two and a half times the size of the object!)

Written traces.

Each pupil will describe the instrument made by the group or by himself reporting the dimensions of the stick and the stand, but also what justifies hit choices : why these materials? Why these dimensions? Did they voluntarily choose a round end instead of a sharp one?

Installation of the gnomons.

The ideal, of course, would be to have a room oriented South with enough space not too far from the windows to be able to set all the gnomos under the sun! (At this time of the year and during all the winter, the Sun, very low in the sky, penetrates widely in well oriented rooms). But, snould i be indoor or outdoor, the first thing to do is to set the orientation of all the gnomons because, even those that can stand in place will risk to be bumped into. Each group will then test the way they oriented the gnomon by moving it and puting it bck into the very same place. A sheet of tracing paper to keep precisely the drawing of the shadow will be temporarily stuck on the stands. The North will be materialized by an arrow.

Concertation and reading of the length of the shadow

Reach an agreement on the timetable for the reporting for the times to be similar to the ones with the stick under the sun. Nevertheless, to be able to compare the results of the line drawings, a child holding a watch will be in charge of gving the signal to start the reports. On the other hand, pupils may volunteer to check what happens between noon and

the time of the next report : they will delay the drawing carried out at "sharp noon" - judged as uninteresting - and starting the next one earlier in the afternoon to obtain perhaps that one of the drawings coincides with the North...
During another sunny day, the pupils in each group will carry out the instructions switching the task between the members. Maybe they will encounter problems here and there : long shadows cut (the stick being to long for the stand, or placed wrong, direction North too far from the axis of the stand), difficulty to report acurately the axis of the shadow (stick being too thick or irregular), lack of precision in the reporting (stick still too sharp)...

Confrontation of the results.

Superimposing in two-two time the tracing papers of the complete reports, the pupils of course see that the shadows of the highest gnomons give longer lines. But, while noticing that the very wide ranges show that the shadows globally turned around the same way, they admit that important gaps question the precise orientation of several shadows : particularly the ones from mid-day, likely to approach most th direction North...
The children will argue and understand that the comparisons would be easier if the solar sticks were identical... To th question : "Do you think that if you start again the eperiment with the similar nomons and taking all th needed care, you will obtain similar results?" they will all answer positively! Defy them to check it out...

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3) Making and using a few similar gnomons

Duration : short do-it-yourself session, then, during a sunny day, 5 to 6 moments of reporting the shadow ; moment of exchange and discussion.

Location : classroom ; then, for the reports, a room which is sunny all day long (oriented South) or a clear outdoor location.

Equipment :

For each group of 3 to 5 pupils :
a toothpick,
a 18 x 25cm cardboard sheet (or a" carton-plume ") ,
a measuring ruler(10cm long)made out of graph paper pasted on a Bristol board rectangle,
a sheet of tracing paper,
a compass.

Making this half a dozen instruments more or less will be very simple and fast: the rod will consist into a simple toothpick for instance, but unpointed at one end (which will be used for the reference marks) to obtain for example a length of 5.5 cm. The pointed end will be completely drkiven into a plate of 5mm wide corrugated board: in our example, this will give a 5 cm height to all the solar sticks. Hence the support could have reduced dimensions, that is to say 18 x 25 cm. Before sticking the toothpick, one will fix, temporarily though, a tracing paper sheet: the pupils will remember that tracing paper allows immediate and straightforward comparisons, by simple superposition. Before and after the readings, one will take all the precautions decided altogether: inspection of the height of the toothpick with a small rule made in millimetered paper pasted on Bristol board to get the zero matching the support, accurate reading of the support orientation (mark the North or South direction with the compass), global readings (give the "start" signal), very careful plots (with a well cut black pencil) from the toothpick's bottom until its shadow's end (flat and not pointed as we have seen).

Confrontation of the new results. It will be enough to take off the tracing papers and superimpose them pair by pair making the reference marks in the North direction matched. What a (bad) surprise! Within a few exceptions, the drawings will not match really, either in angles nor in lengths ... The children will look after the causes. After suspecting the lack of rigour of the drawers of especially weird tracing papers, they will examine closely the involved solar stoicks and they will claim: "Of course! That toothpick is not absolutely straight! " They will be able to check that making a solar stick oscillated even very slightly on its support will significantly modify the length of its shadow and its orientation. But maybe another solar stick pointed out will not reveal this defect ...

Then, one will have to search another explanation, maybe considering the support: "Well, this board does not seem to be perfectly put flat ... Indeed, a rule was left underneath!" Making this time the support oscillated while keeping the solar stick absolutely straight, the children will note that the shadow of the toothpick immediately starts moving. Hence they will understand that, in order to obtain similar measurements of the shadows, it is necessary that, in addition to all the precautions already taken, all the solar sticks remain straight and that all the supports stay flat.

Actually the real need is that all the solar sticks at the same geographical place are identical and parallel (whatever the inclination is), and that the supports are also all parallel: some additional experiments would show that one can obtain equality of the length of the shadow from solar sticks having an identical height and totally flat supports having the same inclination one to each other. The verticality of the solar sticks and the horizontality of the supports (that the children are now going to strive to get) are in fact a particular case, a pure convention, but very convenient for our project on Eratosthenes' experiment!

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4) Using the notion of verticality and horizontality to adjust the gnomons.

Duration : 2 preparatory sessions lasting around 30 minutes ; short moments to adjust the gnomons before later reports.

Location : classroom then location of reports.

Equipment :

For each group of 4 to 5 pupils:
one ordinary set square,
one Bristol board rectangle (for the double square),
one tracing paper sheet,
the small rull made in graph paper,
the water level built up by the children;
a sheet of tracing paper for the new reports.

Taking stock.

The answers to the pre-test will already have provided you with some elements about the knowledge of the children on the notion of verticality qnd horizontality (let's add here "on location" since your pupils will later see that the parallelism between two vertical lines in two different places on the planet, no longer exists, and as well for orizontal lines).

In function of this report (and of the time that will remain afterwards), you can have the pupils work in an experimental way on verticality and horizontality, but also on the straight angle formed by these two directions : consult the page on verticality and horizontality (you will also find there how to simply make a plumb line but also a water level, and then how to use them).
The pupils must take the time to manipulate water levels ; if you associate them with set square give you the vertical. After that they understand that the most simple way to adjust the gnomons will be by starting with putting the toothpicks in a straight angle in regard with the stands because, once they are adjusted horizontally, the toothpicks will automatically be vertical!

Setting with squares

Beforehand, a new tracing paper sheet is put on each support. By maintaining their square put (on the edge of its base) on the support and against their solar stick to verify that the latter is correctly fixed, the children realize that the square itself can oscillate more or less on its base during this experiment, and hence agree with a solar stick that would be slightly leaning. Then, they propose to move the square a couple of times around the toothpick to be sure that the latter well agrees every time.
While we are on the subject, a very simple folding permits to obtain a double square which will be absolutely stable, hence allowing a fast and reliable adjustment: the children will build it in a Bristol board rectangle of about 32 x 12 cm, whose base will be perfectly rectilinear to permit a folding "edge on edge".

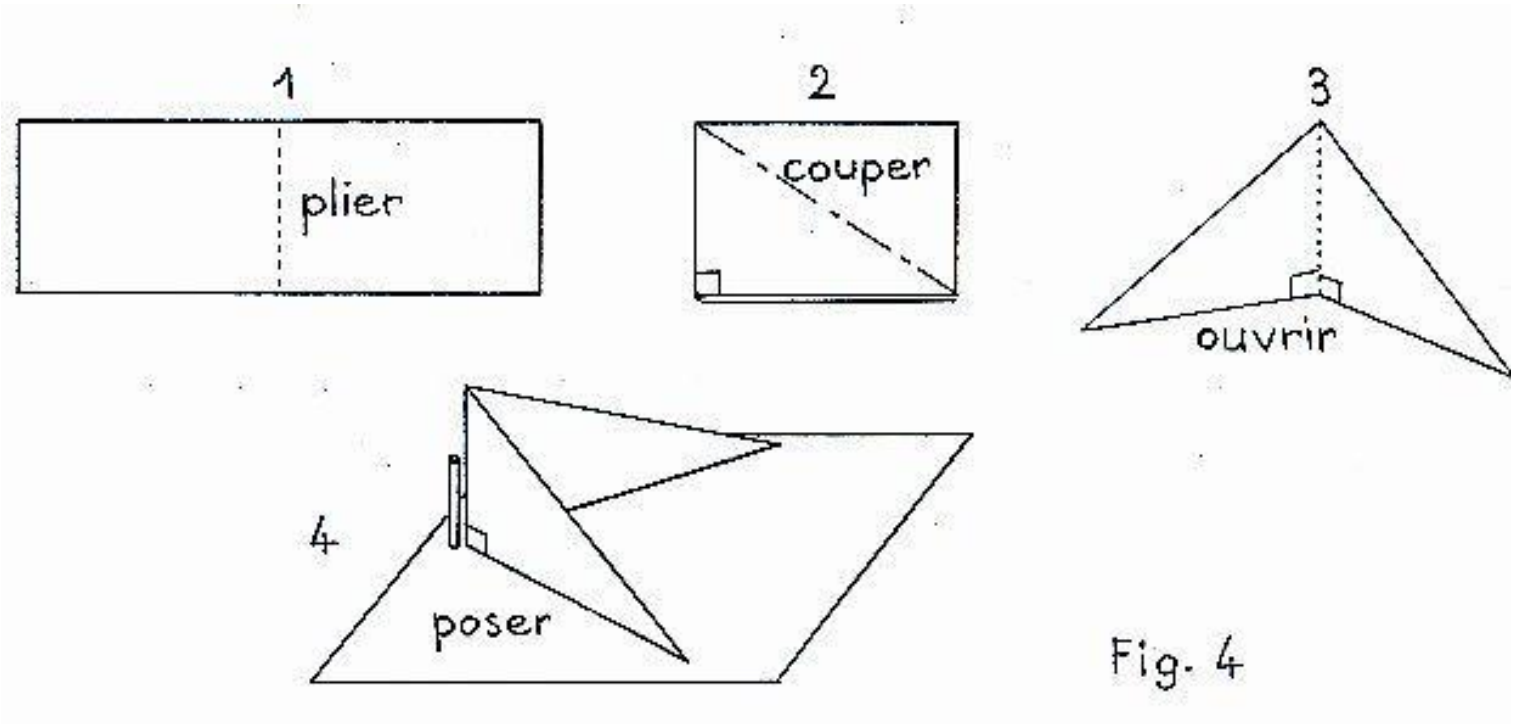

Fig. 4

One will also have to think of checking the common height of the toothpicks with the help of small rules made in millimetered paper.

Setting the spirit levels.

Once their solar stick are absolutely perpendicular to their supports, the children will only have to adjust the horizontality of the latters either with a unique water level that they will direct in several ways on the support, either with two levels (totally adjusted together) making an angle very open in front of the solar stick, like the double square.

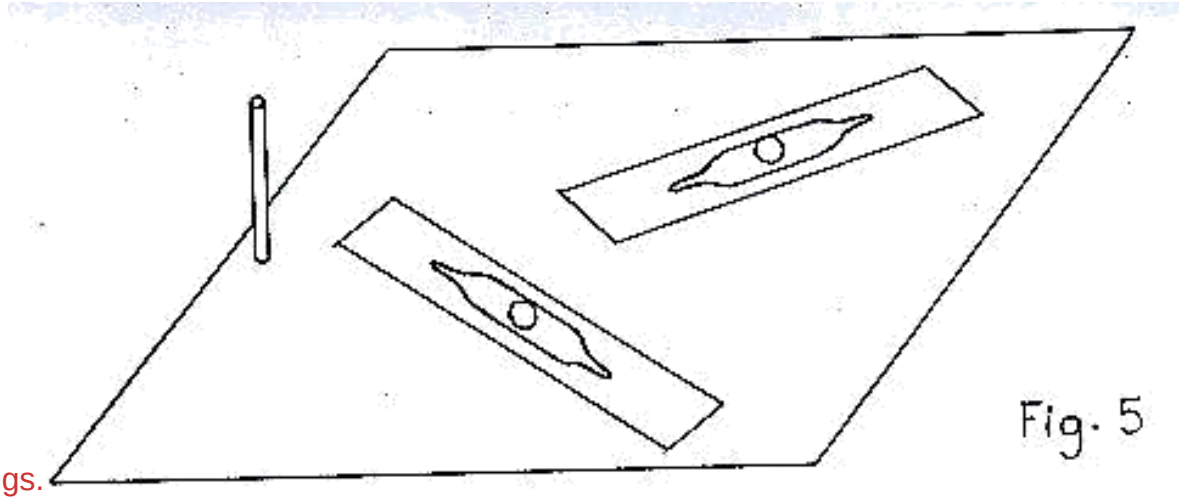

Fig. 5

New readings.

Very proud of their well adjusted solar sticks, the children will perform many new readings: let us bet that this time the results will match their expectation, that is to say that they will agree!