**Optional sessions (Sequence 1)**

# Experimenting on the formation of shadows

## Concepts tackled

The first concept to tackle in the Eratosthenes project is of course the rectilinear propagation of light as it directly concerns the formation of shadows. After that, the concept of cast shadows, and then diverge rays are dealt with. Then parallelism, connected with sunrays, as it is because of this characteristic that Eratosthenes was able to achieve his measurement of a meridian. Lastly, the correlation between the evolution of a shadow (length and direction) and the motion of the light source.

Yew you wish to know more butt the concepts dealt with in this page, please read the " technical assistance " page

## Sequence division

This sequence is divided into four parts. Each one of them fills several working sessions with very variable durations. Thus, one will be able to split them up or to gather them according to circumstances. Note that the time having to be devoted to the pupils' " hard copies " in their books of experiments will not be taken into account.

(Let us specify as well that the activities suggested in parts 2 and 4 take as a starting point the work *L'Astronomie est un jeu d'enfant*, Le Pommier/Fayard).

**Sommaire de la séquence:**



## 1) Work on the rectilinear propagation of light

**Duration :** a one hour meeting, or two 40 minute meetings, according to the training of the pupils.

**Place :** on the one hand a partially shone upon room, on the other hand, a room that one is able to darken.

**Matériel :**

**For each group of 3 to 5 pupils :**

two small mirrors,
one torch ,
one black pencil,
one sheet of white paper.
A slide projector and a rag filled with chalk dust will be needed then.

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## Preliminary inquiry.

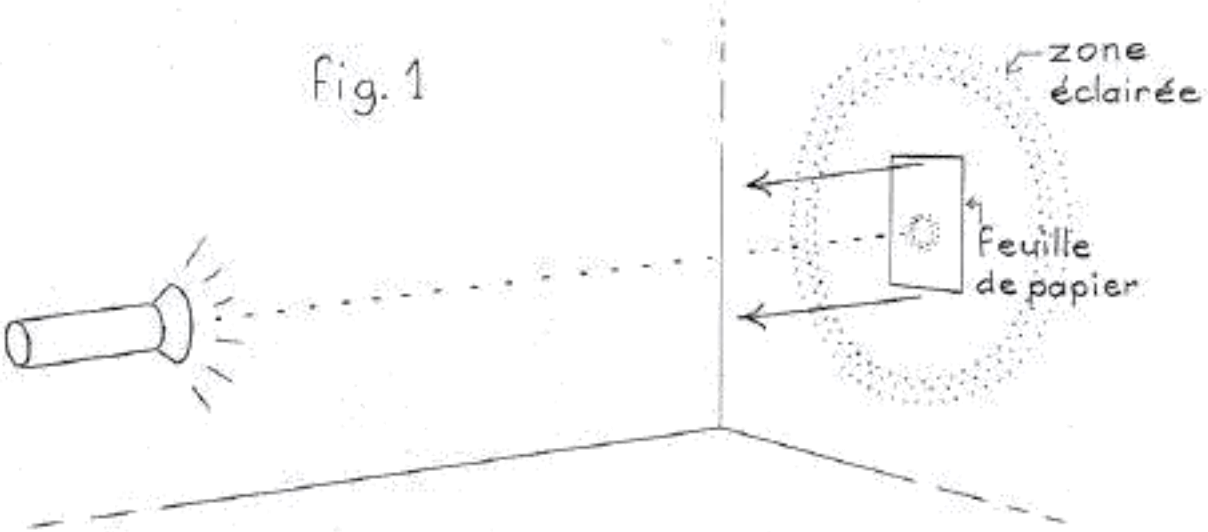
Generally, the children hardly wonder about the propagation of light, no matter what its origin is : that of the sun or that of an electric bulb (of a ceiling lamp for example): they have the intuition that the light is diffused around its source in all the directions since they are " bathed " in it, and that is enough for them. On the other hand, they intuitively understand that with a torch, things are different, because of the reflector " which sends its light only towards the object that one wants to lighten " : they specify then that its light "goes straight " to the meant object. In addition, if one questions them on the possibility of sending the sunlight " straight ahead" somewhere, some will surely think of the games that use a small mirror : " that one can send the sun to the eye of a classmate! "

## Drawings before experiments.

Propose to the pupils to show by drawing what has just been said.
Some may have the idea of represent their luminous rays (rectilinear or not, arrow or not). Ask them whether they really can see that part of their drawings. Agree with the pupils that if that can be helpful to them, they can represent the rays. But as they are not seen, one decides to draw them in dotted lines... Adopt the same representation then systematically.
If the pupils massively represent rectilinear rays, then it is necessary to ask them whether they are certain of that... If the opinions differ, it is in any case necessary to seek to find out who is right. That introduced the problems of the following paragraph.

## Experiments

A first -rather short - time of experimentation can take place by a turnover of the groups : on the one hand, in a sunny place of the classroom, the children, using mirrors, " return the sun " to a darker part of the room, on a wall or to the ceiling, and observe the displacement of the luminous spot according to the orientation of their mirrors ; in addition, in an obscured room, the pupils observe the positions of the objects lit with their torches with regard to it, while evaluating the form and the extent of the enlightened zone. But they will also be able to try out the "returning " of the torch light with a mirror.
The rapporteurs of each group will probably confirm that the light is indeed related to rectilinear routes. But how to try to check that, for example with the torches?
Second time of experimentation: the pupils who have an idea undertake to carry it out after having gathered the necessary material. For the others, propose a white paper sheet, that they have to hold initially against a wall, in the part which is lit by a torch, so that the small very luminous central disc - that one will trace contour with a pencil on the sheet - is in the centre of this one (exhibit 1). It is then a question of slowly bringing back the sheet towards the torch (motionlessly!) by maintaining the small luminous round in the layout : the pupils notice that it is by a rectilinear motion towards the source of light that one can obtain that.




Photograph Huguette Farges ( Compiègne)

## Drawings after experiments.

Pupils make new drawings, they will probably be more complete and more precise than the former ones. They add a short caption to it.

## To go further.

The children will have noticed that the luminous rays on the outlet side of the torches are not visible: it is necessary that an object intervenes in front of them, and thus " cuts " their way, so that the eye can see the lit object, which returns the light in one's eye (the best thing to do would be to do the experimentation again in a very vast and completely dark room). It will then be a question of calling upon the memory of the pupils so that they seek in which occasions they could perceive one or more rays of light : rays passing by a shutter hole in a room where fine dust is in suspension, sun rays through foliages by fog weather, headlights of a car by hazy weather, cigarette smoke in the beam of a projector...: one will point out to them that each time, there were fine particles. Indeed, those get the light of the source and give it out back to all sides (like the Moon does): it is said that those particles diffuse the light. One can highlight that in a very dark place, if one produces for example a small cloud of chalk dust by shaking a blackboard rag above the beam of slides projector.

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## 2) Work on the shadows and their links with the light source

**Duration :** several moments of observation outside, depending on the weather ; a meeting of 20 min of laying out shades outside ; and another meeting for simulations inside.

**Location** : a sunny place where the ground is made of asphalt ; a place that can get dark.

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**Matériel :**

**For each group of 3 to 5 pupils :**

a stick of chalk,
a dressmaker ribbon or a meter rule, a calculator,
a torch,
a pencil or an elongated object,
some modelling clay,
a sheet of white paper,
a pencil,
graph paper.

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## Preliminary inquiry

After having expressed it by the drawing " of a stick to the sun " (in the quiz), the pupils say what they generally know about the shades and how they are formed. Then, one proposes to them to draw themselves " under the sun ", next to a tree and a house, according to their own opinion in relation with what was just said.

## Confrontation of the drawings

The pupils, during the pre-test, have produced drawings with inevitable divergences. The teacher

reproduces those which show contradictory characteristics and first asks the pupils, in groups , to think of the mistakes which they comprise.
The observation of the following paragraph is more structured.

## Observations

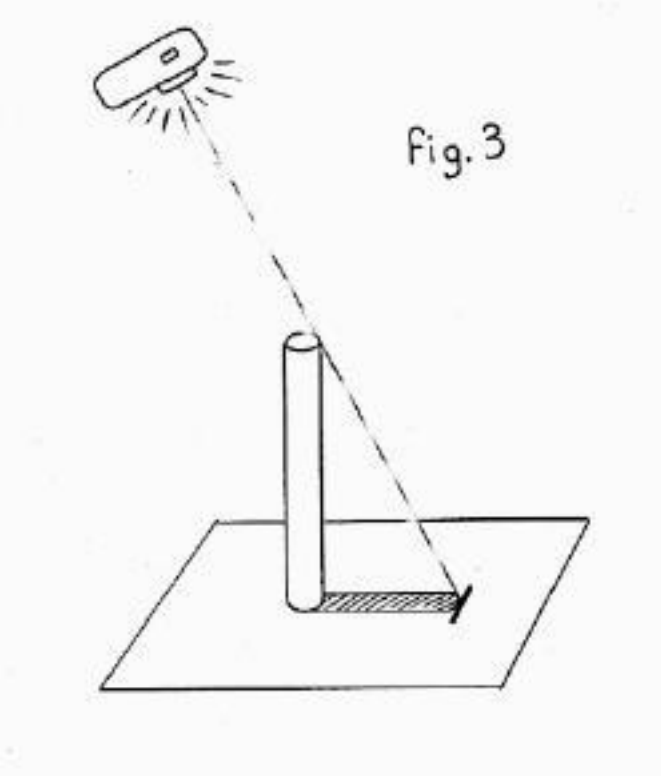
Those are done in sunny weather but also when the sun is slightly veiled, so that the pupils can note that the shades can be more or less clear, contrasted, and that they can of course disappear as soon as a cloud passes in front of the Sun. Their shape is related with the shape of the object itself according to the face presented to the sun (face, profile, three-quarter, above...).

## Experiments

The children will find out that the shade, actually, is not limited to the two dimensions that one generally attributes to him: while passing their hands behind an object placed under the sun, or better, behind a classmate, they note that their hand darkens and that that happens whatever the distance between the child-object and the screen on which its shade projects (wall or ground): they find out that the shade has actually three dimensions but that it does not have a consistency by itself, it is an area in which the light coming from the Sun does not arrive. When an object interposes between a source of light and a screen, one can see on the screen a " shade " which one calls solid drop shadow. (As it will only be dealt with this one in all the following activities, it will not be necessary any more to give this precision).

## Interpretation of layouts of shade

Pupils realize that their shade does not have the same " size " as themselves: how to check it? By carrying out comparisons using measurements of layouts. The children gather in binomials: while one faces the sun, the other traces the outline of his shade with chalk on bituminized ground, that, by including feet since we " walk " on our shade.
How to check now if the layouts are of identical size, larger or smaller than the stature of the pupils? Each binomial choose their process and carry it out (the easiest being to lengthen on one's own layout!).




## Experimentations with a torch

Meanwhile, the pupils will have wondered about the cause of this difference between their stature and the length of their shade, and they will have understood that the height of the sun above the horizon is there for something. In order to be able to control the phenomenon, they will carry out simulations by small groups, with a flashlight and an unspecified object (a pencil planted on a ball of modelling clay being the ideal): they will soon have noticed the existing bond between the height of the lamp and the length of the shade of the object.

But it may be that a crafty one makes a lucky find coming to contradict this fact : he will put at the challenge his classmates to find the means of lowering or of raising their lamp without the shade obtained at the beginning varying in length (one will trace a reference mark on a paper sheet supporting the object). Exhibit 3 shows that the angle formed by the pencil of light and the sheet-support must remain constant: for

that, the lamp must be lowered, in a rectilinear motion, towards the top of the object (simplest being, of course, that this angle is equal to 90°): in this case, the lamp, during its descent, remains with the balance of the object from which the shade " disappears " then, as in the history of Eratosthenes!

And other pupils may also discover that, when the lamp is moved laterally, the shade makes in the same way " but with back! " They will find that back a little later...

## Drawings with captions

The pupils consign their observations related to this part by sketches and captions. One can also ask them to reproduce on a 1/10 scale on graph paper, a character seen of profile having their stature, with his shade in front of him (thus seeming on the left or on the right on exhibit 3), and of which the length will correspond to their own statement ; they will seek how to place the sun in the most exact possible way : some will think of tracing the solar ray oblique passing by the top of the head and leading at the end of the shade, and they will prolong it upwards to place the sun there.
Note : If the pupils represent the rays, they should do that in dotted lines...

## To go further.

It is possible that pupils wonder about the fact that contours of the shades appear more or less vague: they can, by very simple experiments, be brought to discover that this blur constitutes what is called the half-light, and that the formation of this one is related to dimension, specific or not, of the source of light. We will not detail these experiments here since the implied phenomenon does not intervene - or very little - in the Eratosthenes project. For the interested teachers nevertheless, let us announce that they will find all the details necessary in the Eclipses file of the site sequence to initiate itself with the Moon eclipse and sequence to reveal the half-light.

## Intermediate evaluation

One can envisage an intermediate evaluation, completely formative, to see whether, at this stage, the pupils acquired the concepts on which it will be necessary to be based later.

The teacher can propose a very simple drawing to them.
1. Out of cut, a roadway bordered of two pavements and an electric post on one of the pavements (THEY MUST NOT DRAW THE SUN!). Question : how to position the sun so that the shade of the post reaches the pavement of opposite?

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## 3) Divergent rays and parallel rays concepts

**Duration** : a simulation of 15 min approximately ; experiments and measurements in outside of 20mn.

**Location** : a room which can darken ; a sunny place outside .

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**Matériel :**

**For each group of 3 to 5 pupils :**

one torch,
three or four pencils,
some modelling clay,
one large sheet of paper , one
graduated rule ,
some thin string,
some tracing paper.

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## Simulation

The teacher makes a statement on the situation : several pencils will be raised on line on the table and a flashlight will light them from behind, then ask the pupils to anticipate : what will occur when you light the lamp? (the lamps have not been distributed yet).

Note : This moment of anticipation makes it possible to the teacher to evaluate what his pupils have understood about rectilinear propagation, and to the pupils to become aware the way they think. If, after checking, the experiment invalidates the forecast, the pupils will undoubtedly understand better the origin of their mistakes.

One distributes to each group of pupils the flashlights. This time, with their flashlight, the pupils light several pencils installed as on exhibit 4 but on a large paper sheet. They write down what they notice : the children who have aligned their pencils, by more or less parting them and lighting them from behind, immediately note that the shades " deviate towards the end ", more especially as the lamp approaches the pencils (exhibit 4a). They also see that while moving the lamp away, the shades " straighten out " but without being able " to get to do it, because the lamp is not enough strong and that one does not have enough place to move back again ". Ask them which source of light could be powerful and distant enough to check if the shades will be able " to straighten up completely " . At least one of them will end up thinking of the sun!

Note : *It is possible (but not sure) that the pupils notice that while moving away the lamp, shades straighten up . In the same way, one can ask the pupils if it is possible to obtain parallel shades. Once again, an anticipation sentence is interesting before experimenting (it would temporarily be necessary to take away the flashlights).*
*If the idea of the sun appears, so much the better, but do not validate it. Keep it like an assumption. " Some think that with the sun, one will obtain parallel shades, what do the others think about it?... " If the idea does not appear, the teacher will ask the question : " how do you think that the shades will be with the sun?". That will make it possible to introduce the following experimentation.*

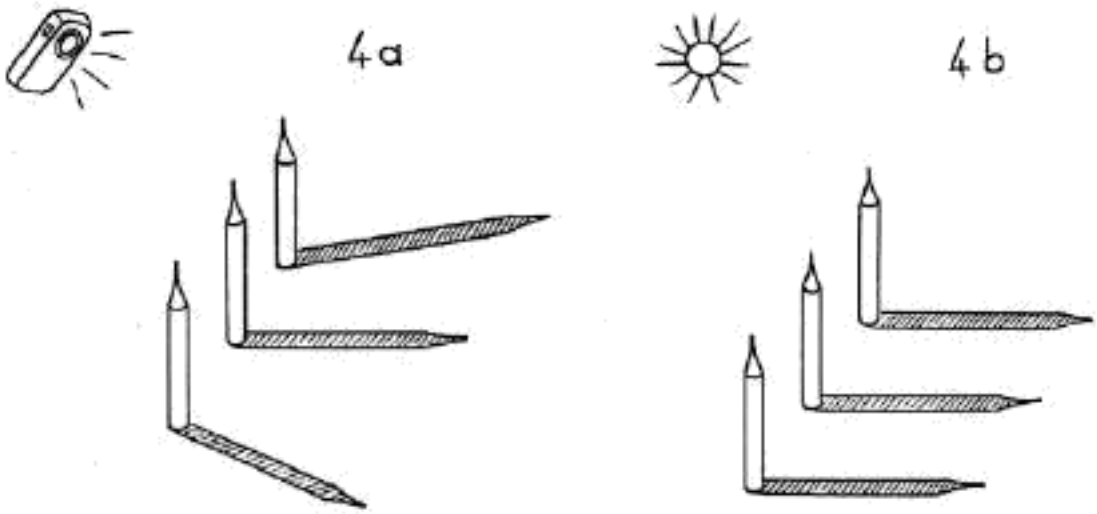


Figure 4

## Outside experimentation

The pupils reinstall their pencils under the sun. Provided that objects are almost parallel (but not inevitably vertical), and that the ground is plane in that place (but not inevitably horizontal) they note that the shades seem " to have been completely straightened up " (exhibit 4b). The children having answered well the n°4 question of the quiz will perhaps remember the " parallel " word. How to check this parallelism? Some will propose to measure the spacing of the shades at their base and their end, " but only if the pencils have the same height", conditions which one will seek to obtain as well as possible, just as the parallelism of the pencils with one another. The installation will be done on a large paper sheet on which one will trace the shade of the pencils carefully, in order to carry out measurements once returned in class.

## Measurements and interpretations

Measurements once carried out and compared, by admitting differences not exceeding the half centimetre per excess or defect, the pupils will show probable parallelism from the shades. Before they can deduce parallelism from the solar rays, they will have to make certain observations during two other simulations, initially with a flashlight, then with the sun.

## New observations

First of all, how to see why the shades diverge with a flashlight? Remembering the sketch carried out on the graph paper, a few pupils will undoubtedly propose to materialize with string the way of the luminous rays on the basis of the lamp, passing on the point of each pencil, and leading at the end of their shade (practically, it will be necessary to seek the means of reducing the parasitic shades to the minimum generated by the strings on the level of the lamp glass and the end of the shades). The children will note that " it is because of the deviated strings that the shades also deviate " (exhibit 5a). .

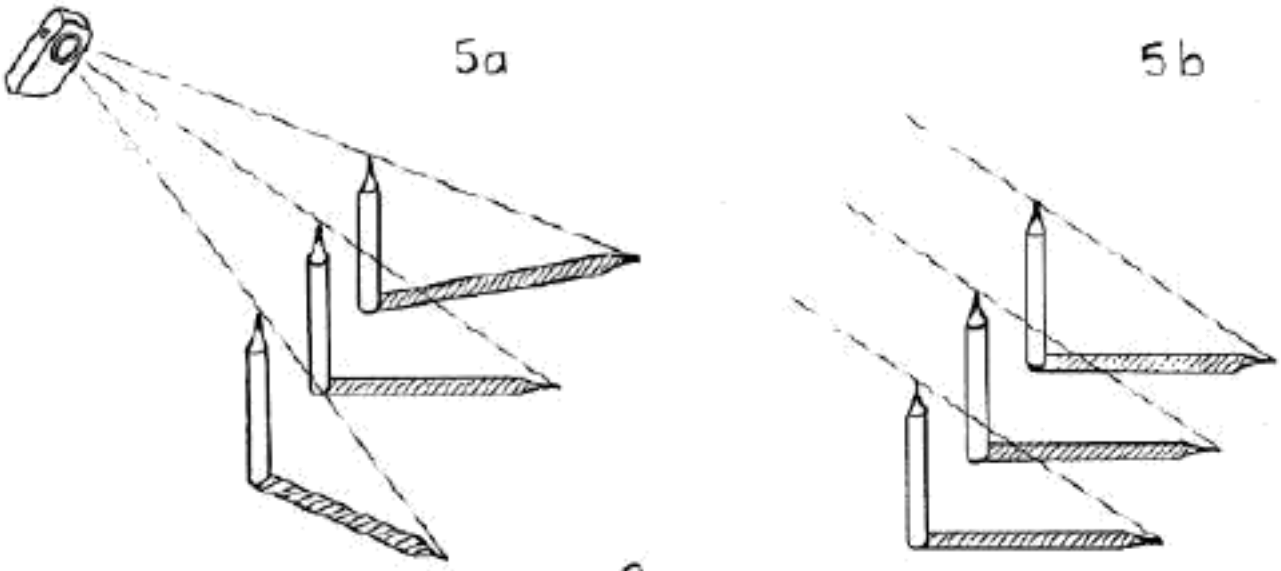


Figure 5

The crafty one will certainly add : " But then, with the Sun, the strings should be parallel! " (exhibit 5b). Of course, they will check that on the spot and will deduce from it that the solar rays must themselves be parallel.

## Hard copies

The children will illustrate those discoveries by drawings and captions.

## To go further

The teacher proposes to try to plot straight lines as parallel as possible, at a rough guess, then to check their parallelism in various ways, in which those:
The pupils reproduce on tracing paper a really parallel line network, thanks to the rulings of sheets of copies: this network, tightened enough, is posed then on the parallel alleged lines: while making one of those coincide with one of the network, that makes it possible to check the parallelism of all the others (exhibit 6a)

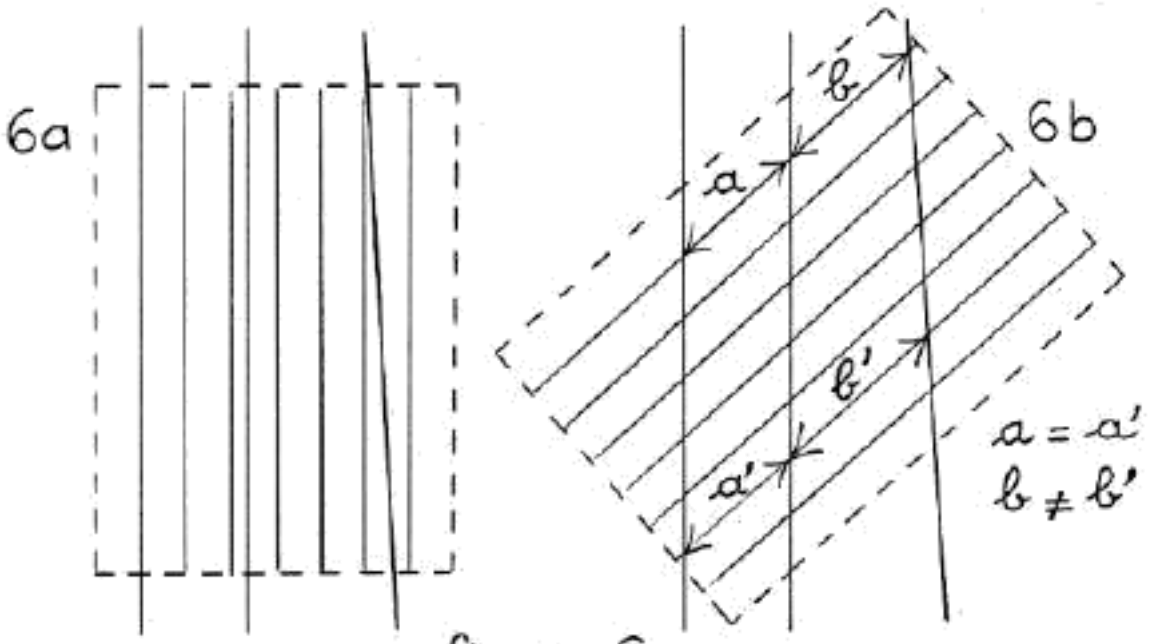

figure 6

By putting this network, but this time in an unspecified way on the lines in question, then while carrying out for each one measurements of a couple of segments obtained, they compare the results (exhibit 6b). In addition, the pupils will see that it is easy to trace oblique parallels on graph paper.

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## 4) Observation of the evolution of shades during the day

**Duration** : moments of observations and rather short layouts but renewed during one day ; meeting of simulation from 30 to 45 min.

**Location** : sunny place all the day, with bituminized ground ; place which can darken.

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### Matériel :

**For each group of 3 to 5 pupils :**

a 10 to 15 cm length object which can stay upright or on a base of modelling clay,
some stick of chalk,
a large sheet of tracing paper,
a marker,
a torch ,
a large sheet of white paper

## Preliminary inquiry

Questioned on the variations of the shades during one day, the pupils are unanimous for saying that they will lengthen about the evening " since the Sun will lie down " They deduce from it that the morning, they must be very long also " since the Sun has just risen ". As for the rest of the day, they think that they are shortened initially until the moment " to go to eat at the canteen since the sun is all in top in the sky " to lengthen then. If one asks them to draw themselves at those various times, they generally only represent the variations of the length of their shade, with the Sun behind them at several heights, without representing an unspecified displacement of the star and thus of the shades.

## Observations

To know some more, the pupils will observe the shade of elements located outside, under the sun, once in the morning, another time in the interval of midday and twice in the afternoon. If the variations of the length envisaged prove to be exact overall, the fact that the shades change direction at the same time, surprises them initially. But they quickly understood the cause of it: " It is because the Sun changes place in the sky! ".

## Layouts of shades

How then, to locate precisely the evolution of the shades during one day, and to keep its trail? By drawing the shade of the same object at various times! The pupils, gathered in small groups, choose an unspecified object (but not exceeding a score of 20cm height) and put it on the ground in a place shone upon throughout the day : if the object cannot remain in place, they draw with chalk the contour of its base in order to be able to replace it exactly at the same place later on and with the same orientation.

Approximately every hour, and in turn, a member of each group comes to carry out the new layout of shade. At the end of the day, all the pupils go back to the site to note that the shades " turned " around the base of the objects, while changing length. Then, some must transfer, on large tracing paper sheets, their series of layouts of shade for a forthcoming use.

Caution : After the departure of the pupils, the teacher, using a compass, will discreetly locate the NORTH-SOUTH direction on one of the series traced on the ground, then he will do the same on the corresponding calk, we will see why in the following sequences.

## Drawings with legend

The children try as well as possible to translate the observed phenomenon. Some have the idea of drawing as many small suns as there are layouts of shade, while trying to place each one of them in opposition, thanks to ray tracings passing by the top of the object and leading to the end of the shade, proving thus that they understood the implied mechanism well.

## Simulation

It is now a question of reproducing the phenomenon observed in its double dimension: variation of the length of the shades but also, and jointly, rotation of those shades. In an obscured place, the objects having been useful previously for the layouts shades are installed on a large white paper sheet. In each group, one tries to find back the movement of the lamp allowing to simulate, in accelerated, the apparent movement of the Sun! That is done in order to manage to reproduce at the same time the movement of the shade of the object and the evolution of its length. Certain pupils, remembering the effect produced by side displacement of their lamp behind an object, find the manner of curving this displacement to obtain the desired effects (exhibit 7).

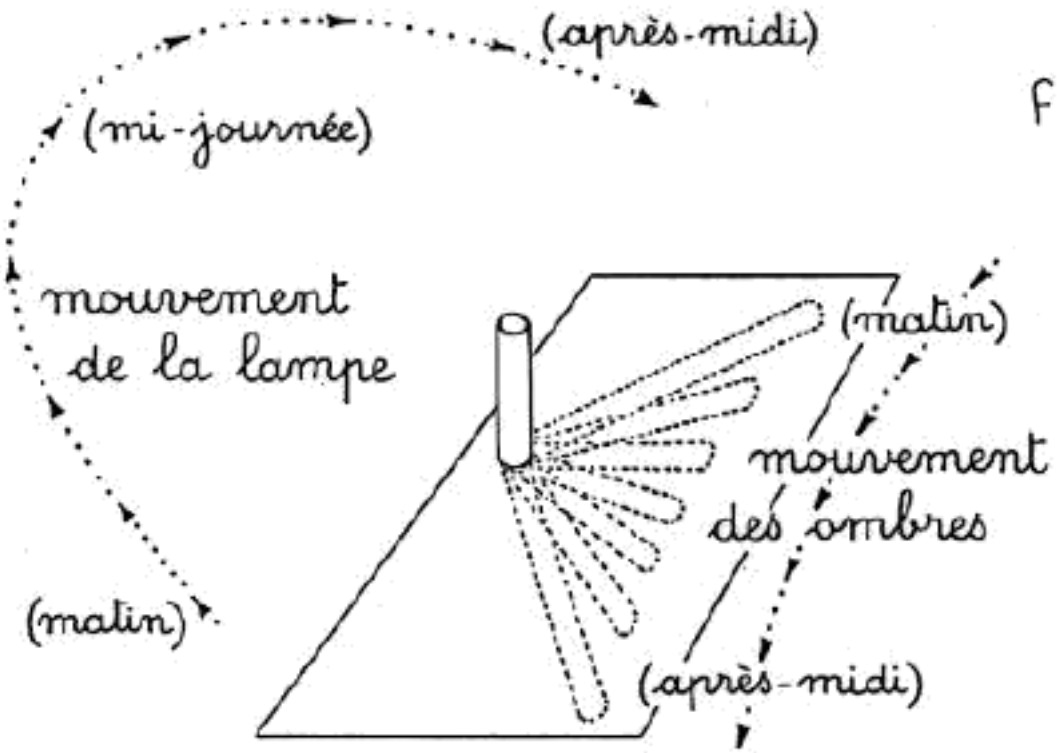


Fig. 7

Then, while placing this time their object on the tracing paper sheet reproducing the layouts of its shade during one day, each pupil, in turn, tries successively to replace the shade of the object in each layout : in a discontinuous way initially, while groping more or less, then continuously, which requires a good coordination of the gesture and glance. Some reach that point rather well and are then praised to have succeeded in imitating " the true Sun! "

The following stage will thus consist in locating more precisely the apparent movement of the Sun.