Sequence 1

Technical assistance for sequence n° 1

Fiat lux !

These sequences, especially the first one, involve a whole set of concepts linked to light phenomena (propagation of light, reflection, diffusion, shadows, and parallelism of light rays,...). We'll not tackle here with the very nature of light, but we advise you to carefully read the following points in order to spare you many predictable problems...

How do we see light?

Unlike what many children think, we can see an object because light rays left its surface and got into our eyes, not the contrary! It is difficult for them to realize that an object that is not a lamp or the Sun can "send" light by itself.

To understand that concept, we have to establish a clear difference between two types of sources : those that produce light (candles, filament of a light bulb, Sun) and those that reflect a light that hits them (any object and living being around us that we can see). So, a usual object that do not produce light can only be seen if it is lit and if the rays it sends back can get to our eye. If you are interested in the principles of sight, you can read the file about the eye.

Propagation of light

In order to understand how light is propagated, you have to know the milieu it gets through (vacuum, air, liquid or glass cube,...). The most simple is in a homogeneous milieu, which properties (temperature, pressure, composition) are the same at every point. In such a milieu, light is propagated in a straight line provided it does not encounter any obstacle, and consequently follows the path adapted to the shortest time course.

If the milieu is not homogenous (for example when there is a great difference of temperature within the milieu), the shortest path (in time) is not the straight line any more, but a kind of curb. That explains, for example, the existence of mirages. And when a light ray gets into a different milieu (from air to water, for example), its course changes. You can easily see it by putting a staff into a pool of water : the stick seems "broken" because the rays that get to us from its immersed part are all suddenly deflected when they get into the air and then our eyes. This very simple fact inspired the physicist Descartes his famous laws about reflection and refraction (passing from a milieu to another).

You should now make the difference between transparent milieus (air, glass) that let at least some part of light pass through them and opaque ones (wood or metal) that stop them.

Encounter with an obstacle and shadows

Diffusion of light

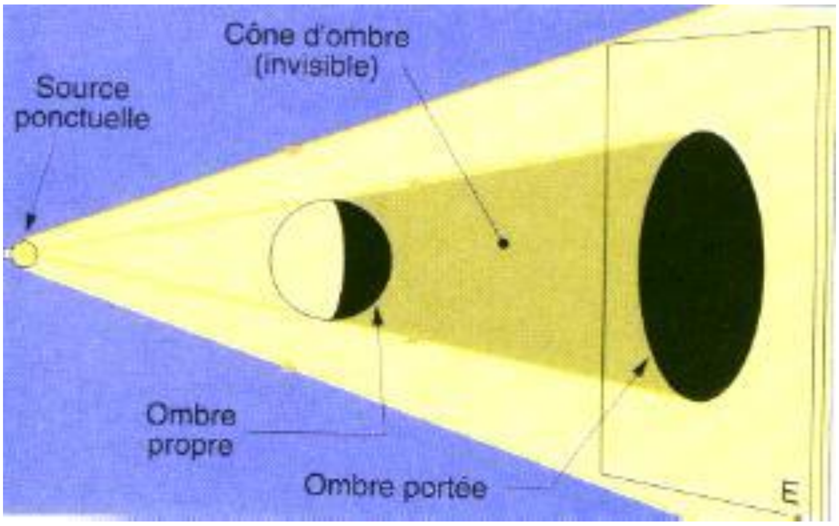
When a ray of light strikes an opaque object, it is partly reflected by its surface. Take a mirror, in a huge room in total darkness and lit by a simple pocket lamp. The ray that strikes the mirror seems to be reflected towards only one direction, which depends on the angle made by the mirror and the light ray (turn the mirror and the reflection changes). This is a simple use of one of Descartes' laws, easy to see.

Let's get a closer look : the surface of the mirror is not perfectly plane : it is formed with a number of facets that reflect the light. On an average, if the mirror is well polished, nearly all the facets are directed in the same way, but some of them are inclined randomly and reflect the light in other directions. Anywhere you are in the room (if you are on the right side of the silver surface), the mirror can still be seen. This is the proof that the light rays coming from its surface have been reflected in every direction, even if they are not the most numerous.

This phenomenon is called **diffusion** : when a light ray strikes some point of an object (opaque or transparent), this point becomes a source of light, by sending light rays in every direction, which allows us to see it from the area on the source of light. Let's see now what happens on the other side of an opaque object.

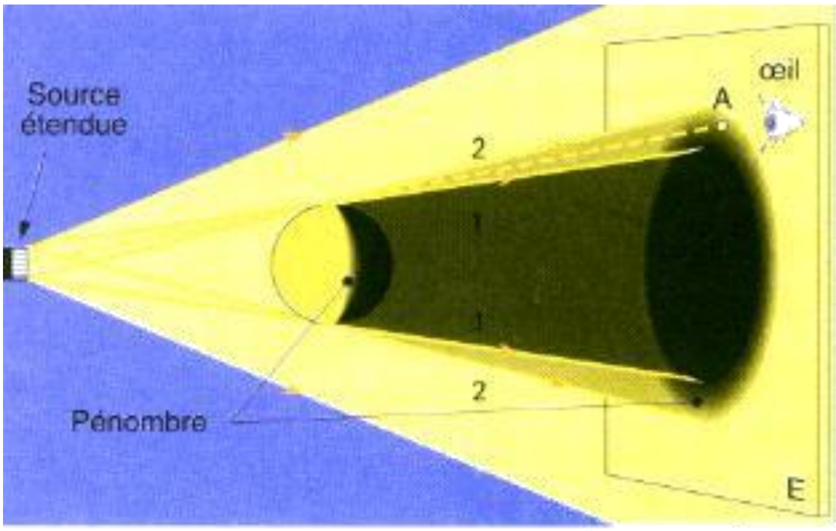
Shadows

Let's try the following experiment : illuminate a tennis ball with a **point source.** A perfect point source does not exist in nature, so we can simply use a pocket lamp. The filament of the bulb being very thin and small, we can deem it as a point source.



If we get behind the ball, in the area where the lamplight doesn't come, we cannot see the bulb. The whole area behind the ball is called **shadow zone.** The ball prevents the light from the bulb to get to it. On the screen, you can see a spot of shadow. Between the ball and the screen, there is an area the light rays from the bulb cannot reach. Actually, because of the spherical ball, it is called a **cone of shadows**.

When the light source is extended, which is nearly always the case (Sun, street lamps,...), on the screen appears a frontier between the illuminated area and the one in shadow : it is the penumbra. The eye cannot determine the exact line between the shadow and the penumbra. If you get into the penumbra area and look towards the source, you can see a part of the extended source (try it!).



To get a graphic view of the shadow and penumbra areas, you only need to draw lines between the extreme points of the bulb and the one of the object (see drawing). No line leaving any point of the bulb can get to the shadow, since the object is here to stop them. Similarly, you will see an illuminated object only if there is a line going from the object to your eye, without any obstacle : get under a table and you won't see the objects upon it. But a few rays from the source get to the penumbra. If you put your eye (receiver) into the shadow cone, the eye will not see the source of light.

Let's replace the bulb of the first experiment by the Sun, the tennis ball by the Earth, and add a new factor : the Moon. If the Earth gets into the cone of shadow of the Moon and reciprocally, a well-known phenomenon appears : the eclipses.

The size and angle of a shadow can also tell us the place of the light source. And so, the shadow of a gnomon can precisely tell of the regular course of the Sun during the day. You can build a sundial thanks to this concept.

Traps to avoid !

Don't say "The shadow is the area that does not get light" : it is in general inaccurate, because of its imprecision : in most cases, there is always a surface (a wall, the floor, other objects,...) that reflect some part of the light towards the object observed. Then, our object gets multiple shadows even if they are not easy to see ! But, if you had an infinite black room without any wall (giving a real total darkness) and lit a staff with a lamp, the shadow of this staff would get absolutely no light.
In common life, the shadow created by the primary source is not necessarily without light, it is more accurate to say that it is the place from which one cannot see the light source because it is hidden by the object. The penumbra is the area from which you can see only part of the extended source masked by the object.

Parallelism and divergence

A major point in Eratosthenes' experiment : the parallelism of solar rays. How to understand this point easily?

The light rays emitted by a source are deemed parallel if the source is placed at an infinite distance from the observer. In practice, and without philosophical consideration about the concept of infinity, we'll consider that a distance exists (according to the dimensions of the source), beyond which we can tell approximately that the light rays coming to us are parallel between themselves.

The case of the Sun.

Let's take two rays emitted from the same point at the surface of the Sun, that strike the two ends of a two-meter high wall. It is easy to estimate the angle between these two rays, with the following ratio : height of the wall (2 meters) divided by the distance from the point on the surface of the sun (about 150 millions of km, so 150 billions of meters!). The angle found (expressed in a unit called "radian") is extremely small (you can imagine), and it cannot be seen by a human eye. As such, we can deem that these two rays are parallel.

Would it be the same for a department, a region, a country or the Earth itself? Change the height of the wall and use the distance you need (between two cities, or the North and the South poles) and see : in every case, you will find a very small angle. Consequently, we can deem that the rays that come to the Earth from the same point on the Sun are parallel.

But the Sun is not only a point : it is an extended source, widely extended, in fact. Its diameter is no less than 1.4 million kms! The light coming from the Sun is contained in a light beam, a cone which solar surface is the base and our eye the vertex (the point). All the rays contained in that cone are not strictly parallel between them, but make a small angle. The maximum angle is the one that divides the rays coming from the opposite rims of the Sun disc. You can estimate this angle the same way as before : the ratio being the diameter of the Sun divided by its distance from Earth ~ 1/100.

This angle (equal to 0.5 degrees) is almost negligible and it can be deem at first that all the rays are parallel. But it is only a rough estimate : you only need to observe the shadow of a pen on a table to understand that the "blur" in the shadow is in fact the mark of the slightly diverging rays from the Sun. If the rays were absolutely parallel, the shadow would be perfectly clear, and the Sun would appear as a point in the sky. This is the case for the stars one can see at night : suns so far from us that their discs become a single point, and their rays all get parallel to us (or nearly!).

Beware!

Looking directly to the Sun is extremely dangerous, and you absolutely need to use special filters (goggles given for solar eclipses, for example). Painless but permanent injuries will be done to your eyes, but will be felt only a few hours or a few days after an unprotected observation. Tell the children about these risks : it is extremely inadvisable to look at the Sun without a protection. The special goggles will give you the opportunity to look at the sun disc and see its diameter safely.

A trap to avoid

Children draw sunrays as a crown around the disc, showing implicitly extremely diverging rays. Is it a mistake? Yes and no. The surface of the Sun sends rays in every direction (anyone can see it from anyplace in space), so the rays drawn really exist, but do not get to us! The majority of these light rays go through space towards distant stars, and only a very small part of them get to us (those contained into the cone above mentioned). To draw an accurate idea of the rays getting to the surface of the Earth, you should not draw the Sun disc, but the parallel rays that come to us. (to be absolutely accurate, we should draw around each parallel ray a small light cone to remind that Sun is not a point source!). Try to draw a scale map of the Sun and the Earth to understand the huge distance that separate them. Try it!
