

# OPTICS

## Objectives

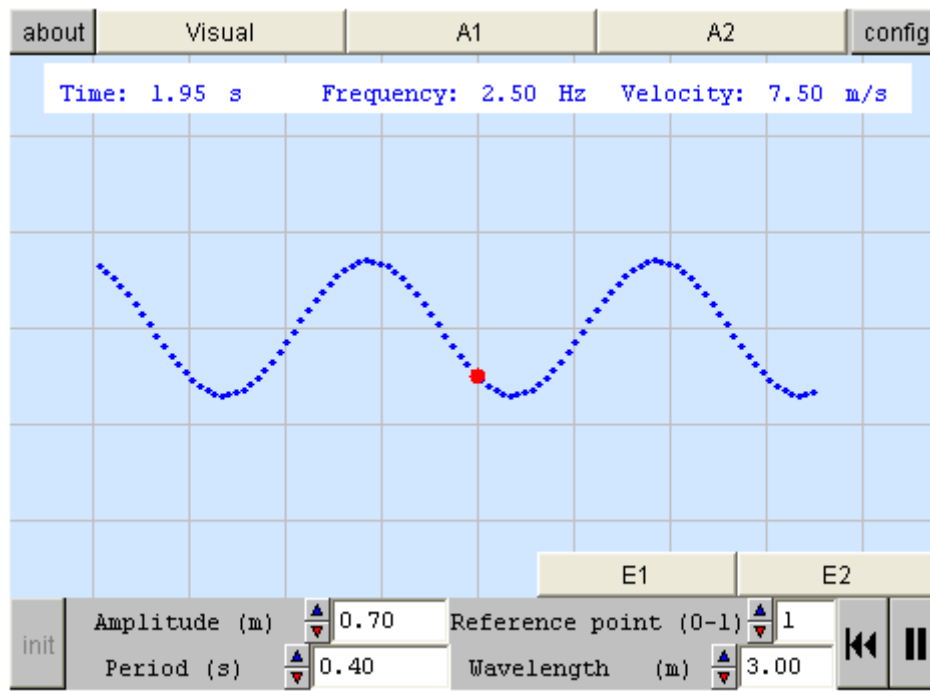
To study this unit it is advisable to have already studied WAVES.

In **Optics** you will learn:

- To distinguish when light behaves as a particle and when it behaves as a wave.
- What reflection is and how a ray of light behaves when it hits a flat, concave or convex mirror.
- To understand what refraction is and how light behaves when it passes through convergent and divergent lenses.
- To understand the way a telescope works and to know what to look for if you go to buy one.
- The way a photoelectric cell works and what consequences you can deduce from it.

### 1.1 Light as a wave. What type of wave is light?

In **WAVES**, we were able to see how light travels in transverse waves. This visual will serve to remind you what these waves are like.



Visual: We will study some of the magnitudes proper to this movement. You may choose to use a reference point or not.

A1: Select a reference point, click on play. Observe the movement of the point and answer the following question. What angle does the movement of this particle form with the direction of propagation of the wave?

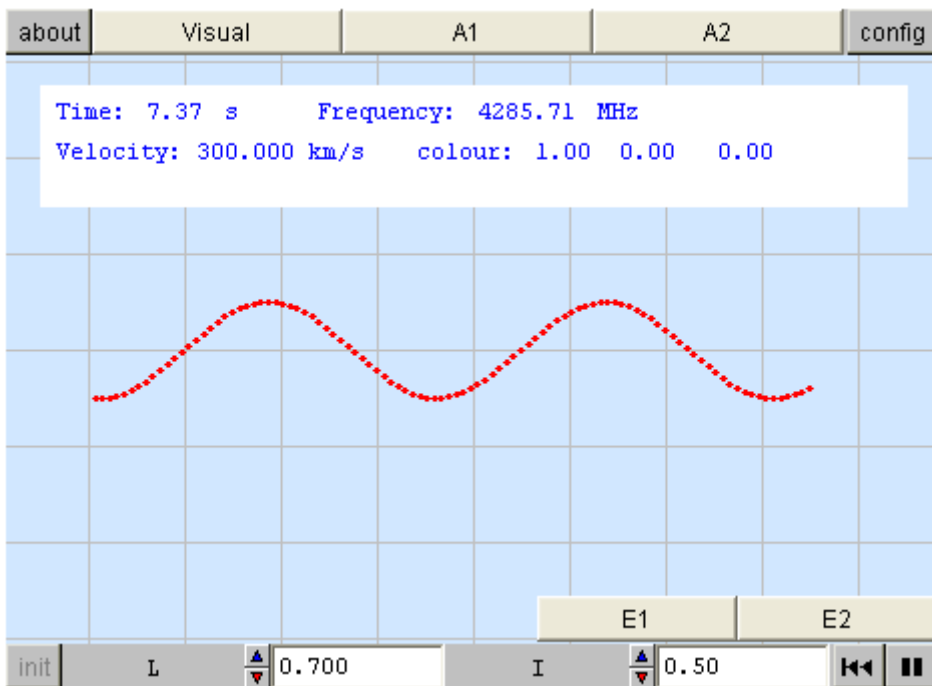
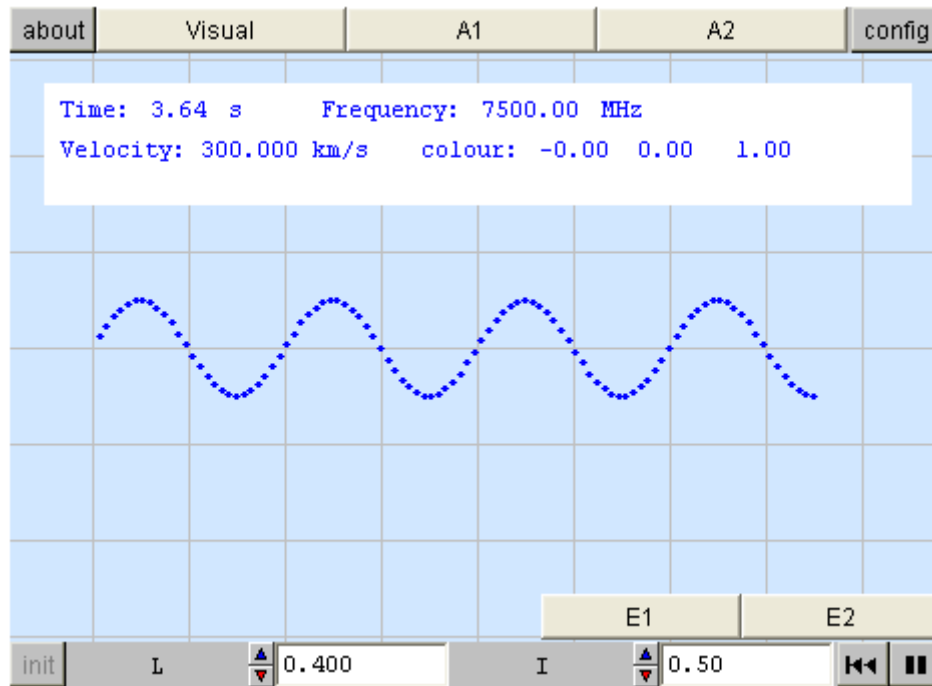
A2: Modify the values of the amplitude, period and wavelength and remember the concepts that you learnt in WAVES.

E1: The vibration is: a) parallel to the propagation; b) perpendicular to the propagation; c) in the same direction as the propagation.

E2: a) Period, b) wavelength, c) amplitude. Is there any relation between wavelength and amplitude? Is there any relation between wavelength and frequency?

## 1.2 Light as a wave. Colour and luminous intensity

In this visual you can see some characteristics of light in a vacuum:



Visual: ... some characteristics of light in a vacuum: the relation between wavelength and colour, the constant value of the speed of light and the relation between amplitude and intensity.

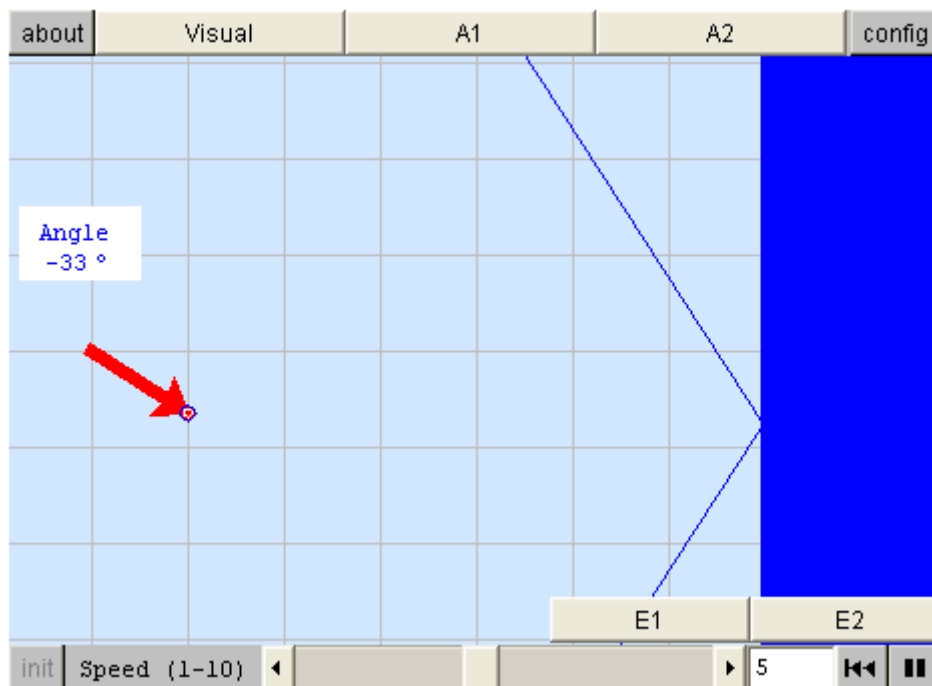
A1: ...and observe whether the modification of the wavelength changes the colour, frequency, amplitude or speed.

A2: ...and observe whether the modification of the intensity changes the colour, frequency, amplitude or speed.

E1: Which of these factors changes: wavelength, colour, frequency, amplitude or velocity?

## 2.1 Reflection. What is it?

When an undulatory movement meets an obstacle which stops its propagation and does not absorb its energy, the waves change direction, they are reflected.



Visual: A wavefront propagating along the surface of a pond towards its edge, formed by a vertical wall. Dragging the end of the arrow you can change the direction of the wavefront. The speed control can be used to regulate the speed of the simulation.

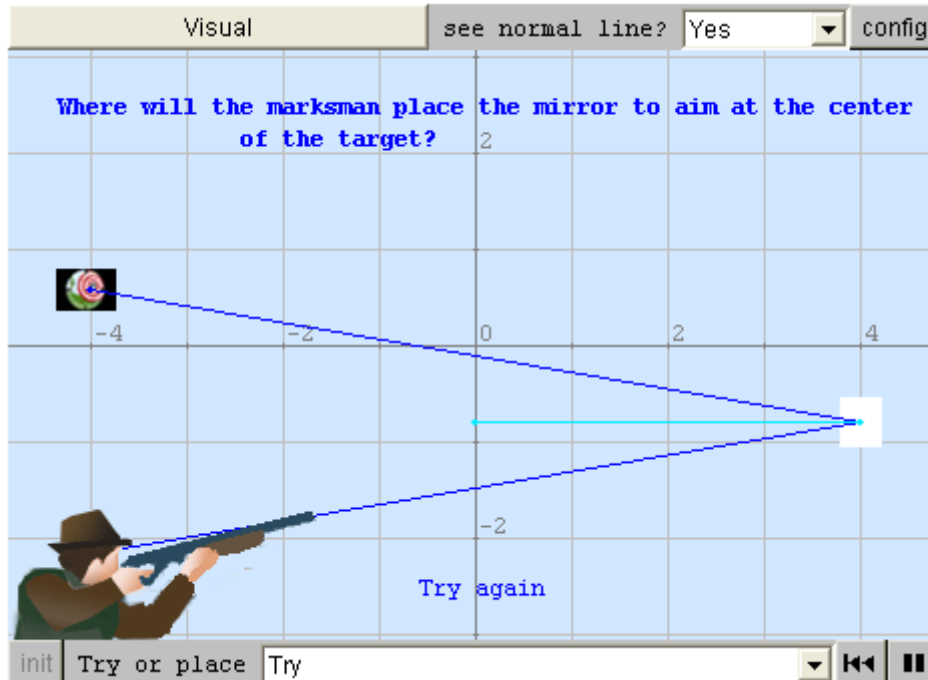
A1: With the direction angle set to  $0^\circ$ , click on play. What happens after the wavefront hits the edge?

A2: Change the angle of the direction of the wavefront. Observe the result for different angles and try to determine a general law (a coordinate grid may be helpful).

E1: After hitting the edge, a) the wave is reflected without changing its direction, b) the wave is reflected with a change in its direction, c) the wave is reflected with a change in its velocity.

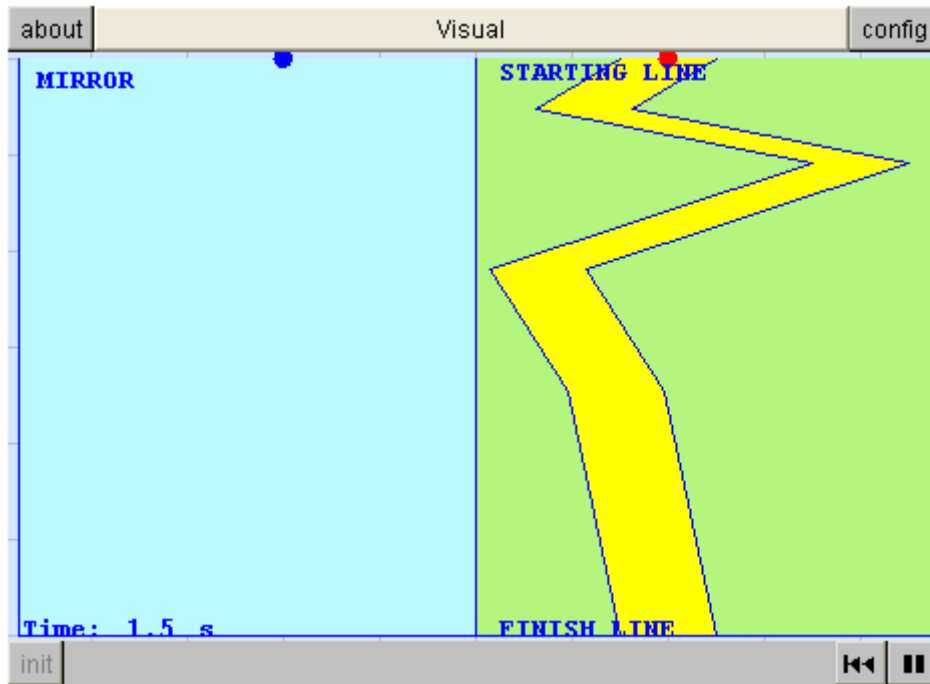
E2: After the wavefront hits the edge, a) the wave is reflected without changing its direction, b) the wave is reflected by changing its direction by  $45^\circ$ , c) the wave is reflected with a change in its velocity. As a general rule, it is true that the incident angle and the reflected angle are: equal? proportional? similar? the inverse of each other? complementary?, etc...

The centre of the mirror is marked with a red circle. Move it until you think that this is the point where the marksman sees the centre of the target. Then click try. Good luck!



Visual: Place the mirror in the right place for him to hit the target. Hint: the image of the target must be EXACTLY on the hunter

It is very difficult to do "mirror writing". If you play with this visual you can practise this ability and at the same time understand what a mirror image is.



Visual: Move the blue dot along the left side of the screen and try not to leave the path drawn to the right (the mirror image). If you click on init, new paths will be generated.

## 2.2 Spherical concave mirrors

Have you ever looked at yourself in a spoon? Try it.

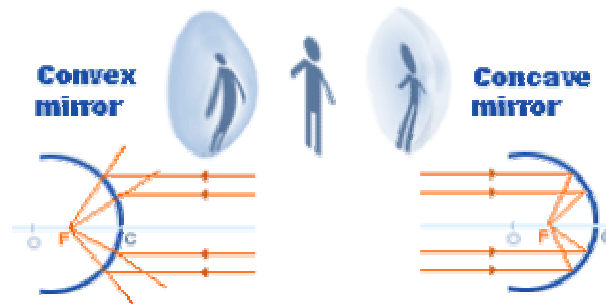
The surface of a spoon is concave.

If its curvature were equal to the surface of a spherical cap, we would say that it was a concave spherical surface (which is rather difficult for normal spoons).



### 2.2.1 Concave and convex spherical mirrors

A mirror which looks like a satellite dish aerial or the inside of a spoon is called a **concave mirror**. On the other side the mirror **is convex**.

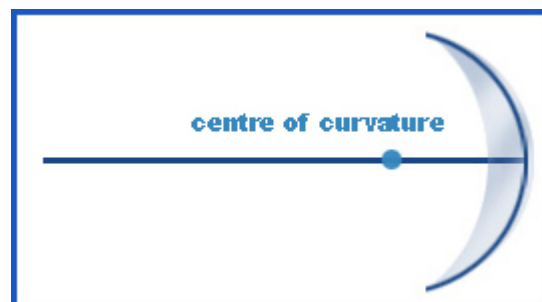


## 2.2.2 Spherical mirrors: optic axis and focal point

**Elements of a mirror:** Place the cursor on the corresponding element

### *centre of curvature:*

the centre of the imaginary sphere constituted by the mirror



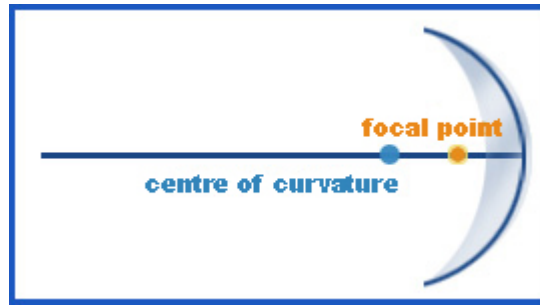
### *optic axis:*

the horizontal line that goes through the centre of curvature.



**focal point:**

the point on the optic axis through which the reflected parallel rays pass. It is situated midway on the line joining the centre to the mirror.



**2.2.3 Concave mirrors: formation of images**

**¿What happens to rays of light when they hit a mirror?**

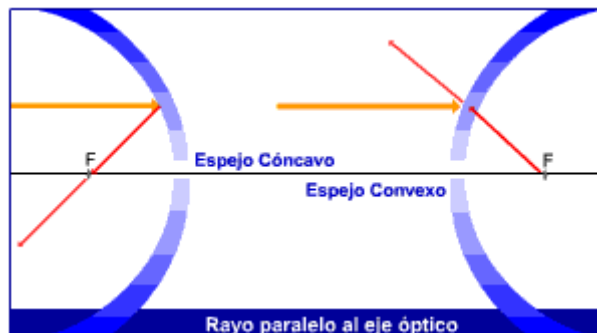
They are reflected according to the laws of reflection.

Let's see what happens to three particular rays separately and then all together.

a ray on the optic axis

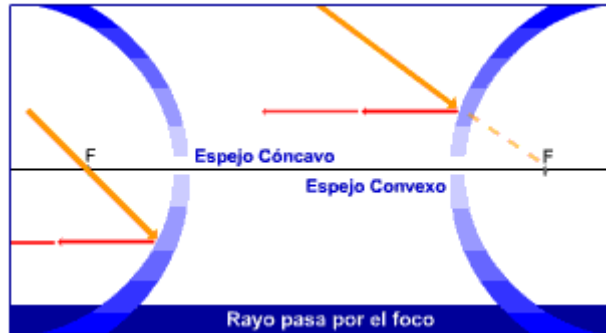


a ray parallel to the optic axis

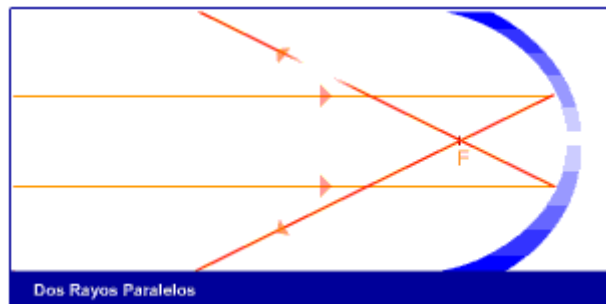




a ray passing through the focal point



two rays parallel to the optic axis, simultaneously



## 2.2.4 Concave mirrors: the formation of images

How do we know what images are formed when we place a body in front of a concave mirror?

We will place a simple object: an arrow, in the optic axis. We will only concentrate on the rays of light which are parallel to the axis and another one which goes through the focal point. Remember that they are reflected according to the **laws of reflection**.

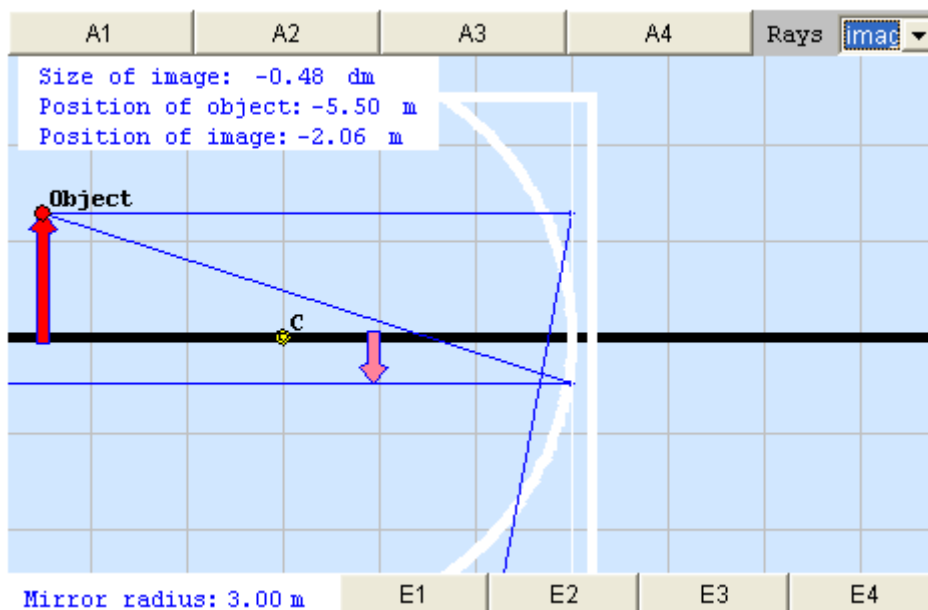
The image formed,  $O'$ , can be, with regard to the object,  $O$ :

the right way up or inverted		
bigger or smaller		



## 2.2.5 Concave mirrors : how are images formed?

WHY when we stand in front of a concave mirror can we see ourselves a different size, or even, not see ourselves at all?



A1: Drag the red dot to a different position.

A2: Drag the yellow dot to a different position.

A3: Click on any part of the screen and you will see its coordinates. The vertical coordinate is equal to zero along the optic axis. The axis intersects the mirror at (1,0)

A4: Choose a ray of light with the control at the top right of the visual.

E1: According to your observations, if we move .... does the reflected ray...? What is the name of this point?

E2: According to your observations, if we move... through what point is the parallel ray always reflected? In what way is the ray that goes through the focal point reflected?

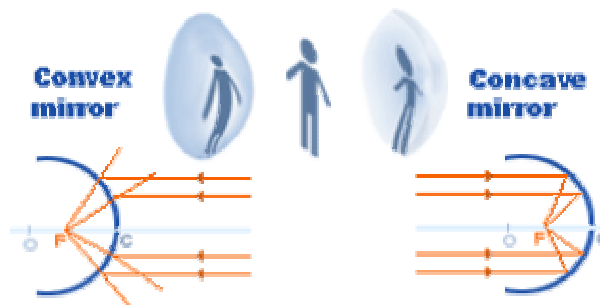
E3: We get real images when the object is a) before the focal point, b) between the focal point and the centre of curvature, c) Between the focal point and the mirror, d) further away from the focal point.

E4: We get virtual images when the object is a) before the focal point, b) between the focal point and the centre of curvature, c) between the focal point and the mirror, d) further away from the centre of curvature.

## 2.3 Convex spherical mirrors

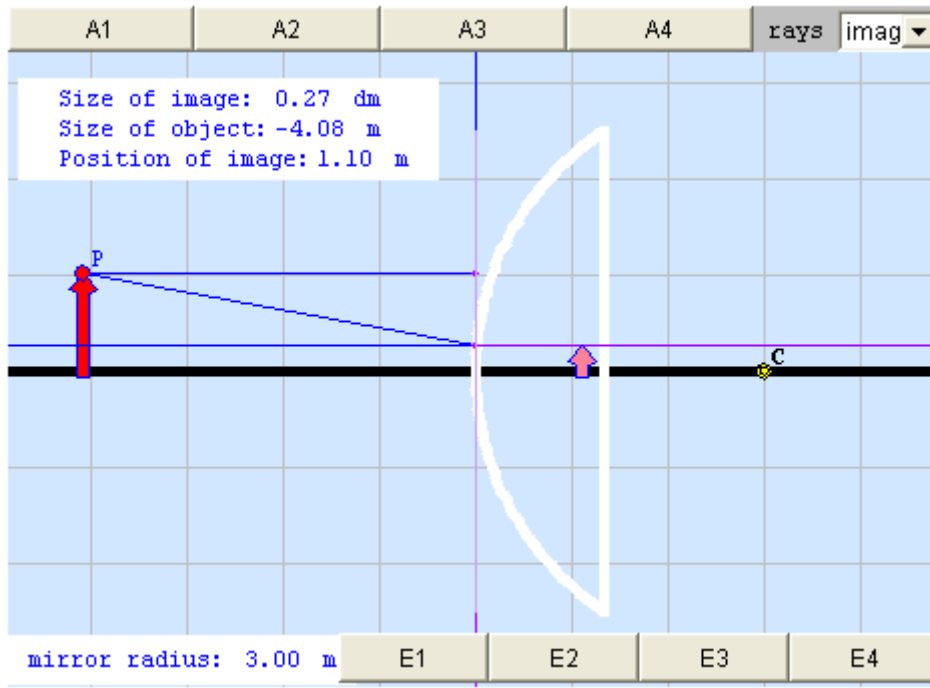
Imagine a sphere with a mirror on its exterior surface and another on its interior surface.

The exterior surface is said to be convex and the interior concave.



### 2.3.1 Convex spherical mirrors: how is the image formed?

Here we have a convex mirror.



A1: Drag the red dot to a new position.

A2: Drag the yellow dot to a new position.

A3: Click on any part of the screen and it will show you its coordinates.

A4: Select the number of rays with the control at the top right hand corner of the visual.

E1: When we select a single ray we can see that the ray goes through a point called...

E2: When two rays are selected, the extension of the reflected ray goes through... and the extension of the ray that goes through the focal point...

E3: Images formed in convex mirrors are a) larger than the object, b) smaller than the object, c) the same size as the object.

E4: Images formed in convex mirrors are a) always real, b) always virtual, c) real or virtual, depending on the distance from the object to the mirror.

### 3.1 Refraction

#### What is refraction?

When light passes from one material medium to another it changes direction;

this phenomenon is called refraction. The refraction of light depends on the relationship of its velocities in each medium and its angle of incidence

**Velocity of light in m/s**

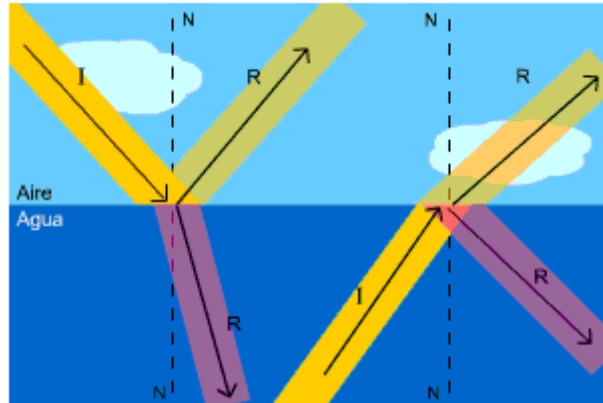
**Vacuum**  $2,99792 \cdot 10^8$

**Air**  $2,99702 \cdot 10^8$

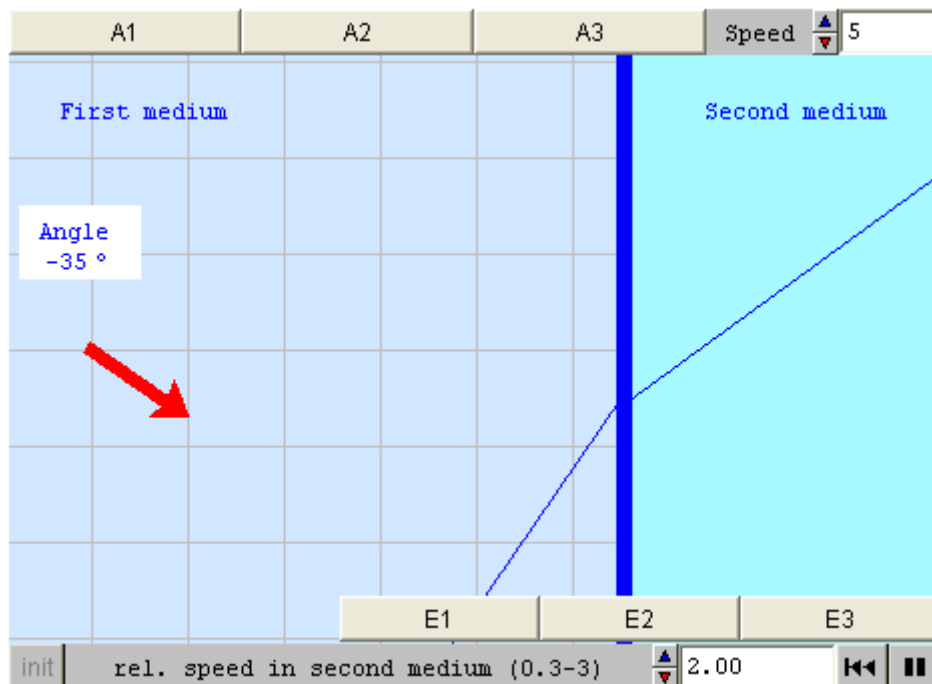
**Water**  $2,25407 \cdot 10^8$

**glass**  $1,99861 \cdot 10^8$

**diamond**  $1,24034 \cdot 10^8$



Imagine that a wave passes from an area of deeper water to an area of shallow water, or vice versa. There is refraction.



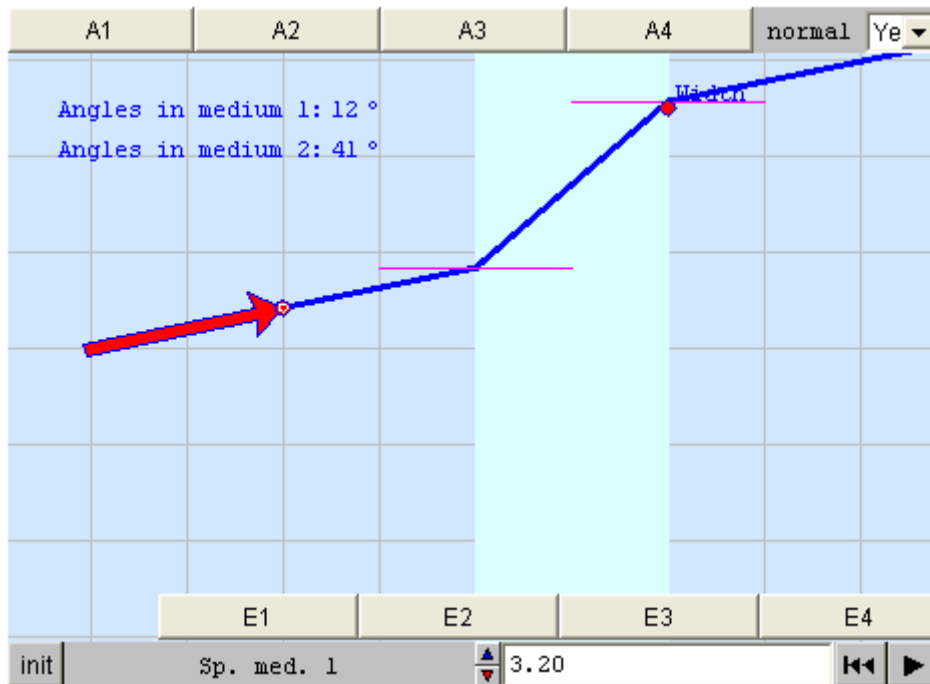
A1: What happens when the wave changes to another medium?

A3: When the relative speed of the medium is greater than one, then ... And if it is smaller than one what happens is...

E1: If we change the relative speed of the second medium.

E2: If the relative speed of the second medium is smaller than one, then...

**When a ray of light passes through a sheet of glass it is also refracted. In certain circumstances there can be total reflection.**



A1: Drag the red control for the ray of light

A2: Drag the red dot to change the width.

A3: Use the control at the top of the visual.

A4: Choose different coefficients  $v_1/v_2$ .

E1: The refracted angle in the second medium...

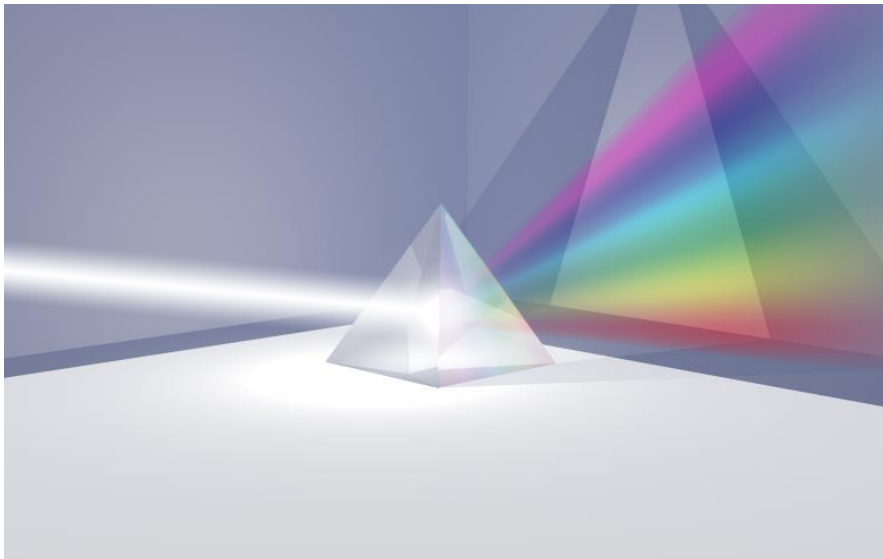
E2: The angle of the incident ray is a) equal to the angle of the ray that leaves the glass, b) similar to the angle of the ray that leaves the glass, c) greater than the angle of the ray that leaves the glass.

E3: a) depends on the coefficient  $v_1/v_2$ , b) is independent of the coefficient  $v_1/v_2$ , c) depends only on the incident angle.

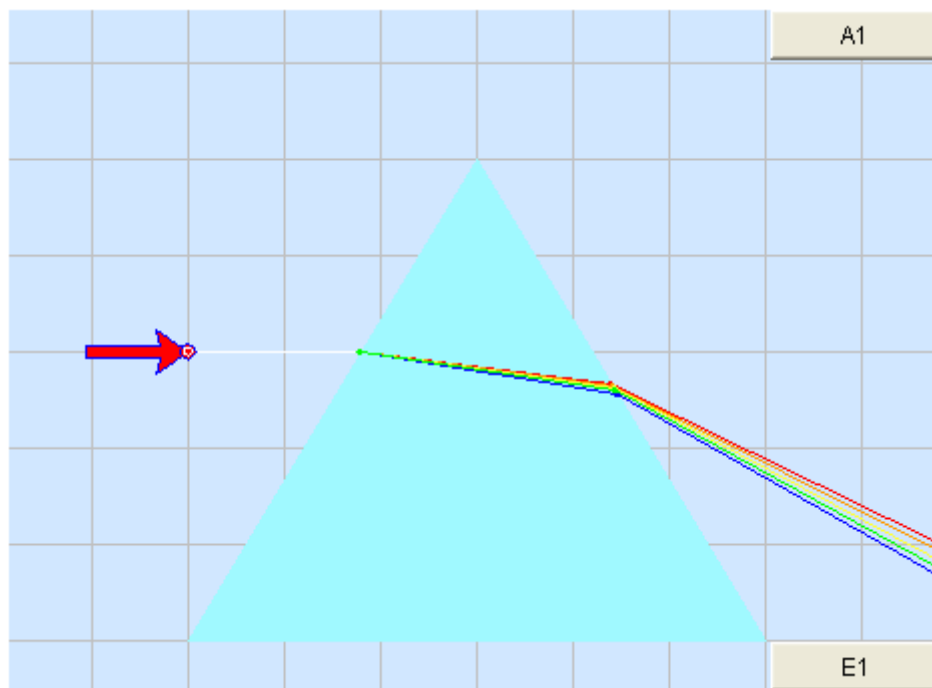
E4: By changing the width of the second medium, are the values of the angles of the incident and refracted rays changed or do they remain constant?

### 3.2 Refraction according to colour

The rainbow produced when light passes through a prism is a good example of the refraction of light. It is due to the fact that light is formed by numerous waves of different wavelengths; each of them is refracted in a different way.



Play with the rainbow.



A1: Drag the red dot and watch the results.

E1: The colour that deviates most is...

### 3.2.2 Refraction according to colour. What are the stars made of?

The light coming from the stars can be analyzed, by passing it through a prism. A detailed analysis of this light tells us what matter there is in that star.

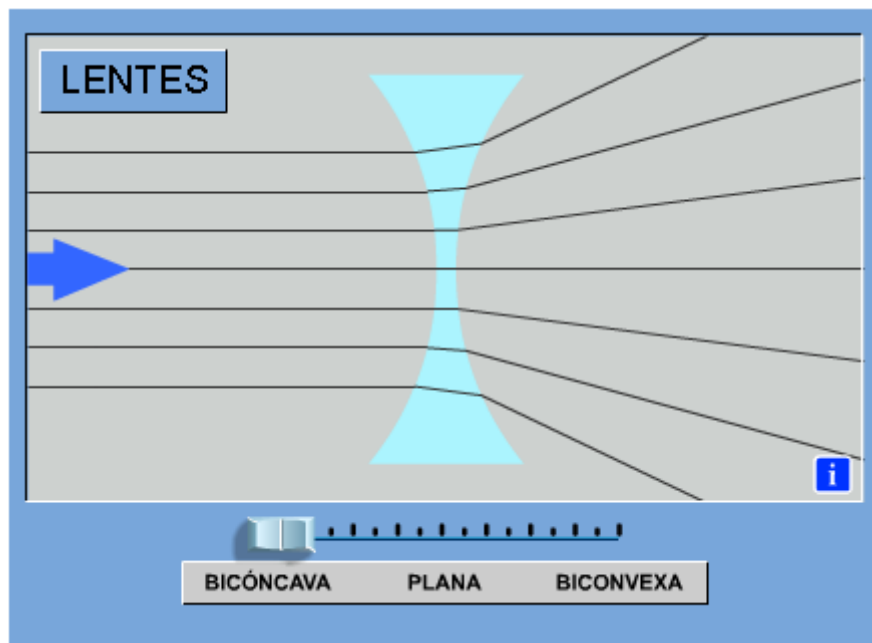
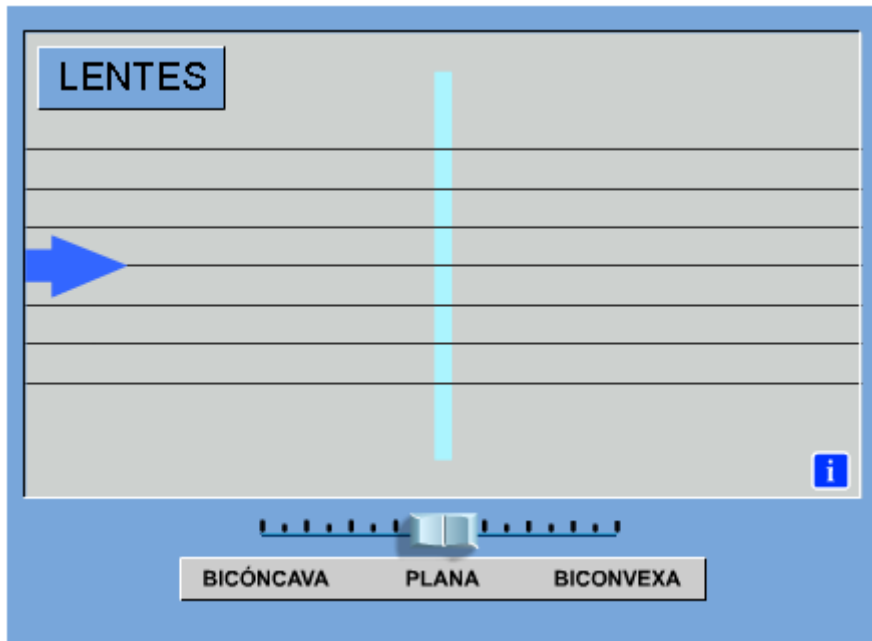
When sunlight passes through a prism we get the so-called spectrum of white light:

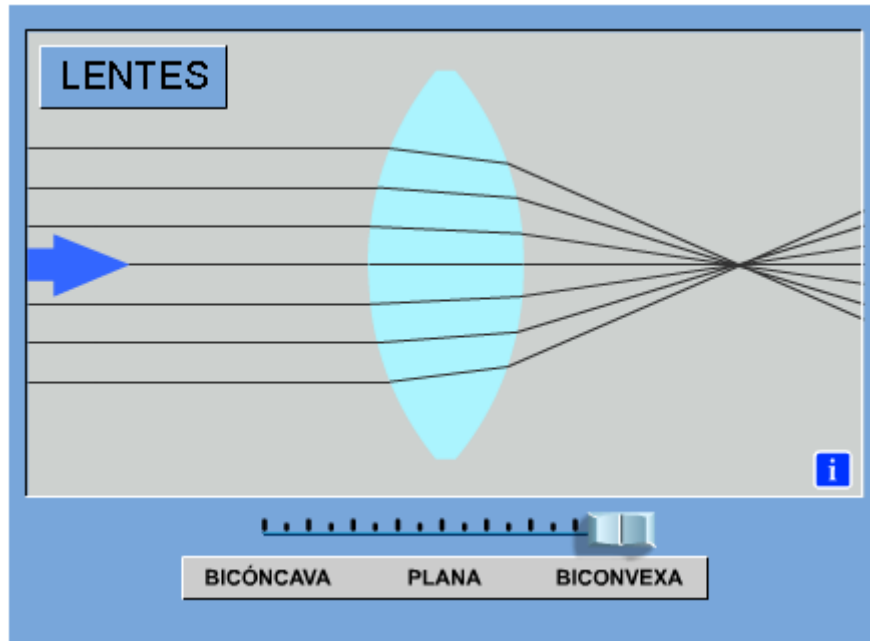




### 3.3 Converging and diverging lenses

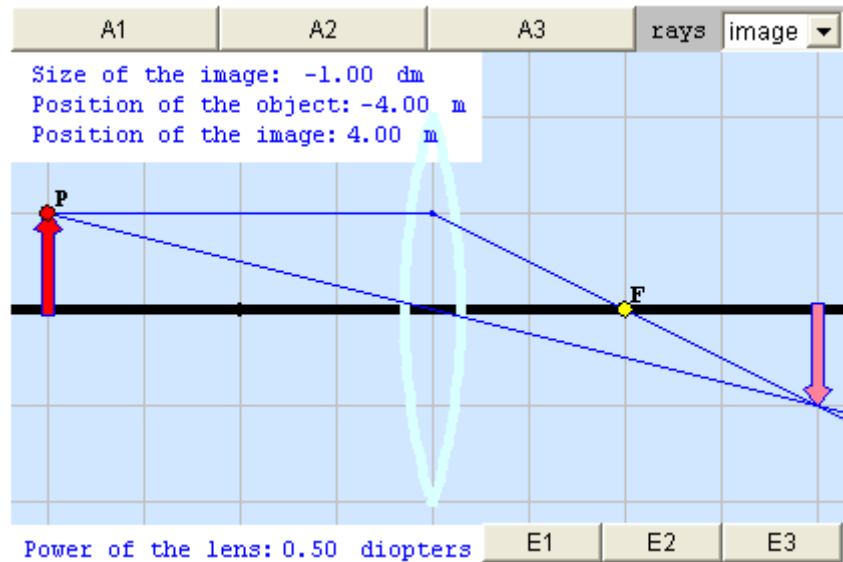
By moving the slide you can see how light behaves when it passes through a biconcave and a biconvex lens





### 3.3.1 Converging lenses

#### Converging lenses



A1: Drag the red dot to a different position.

A2: Drag the yellow dot to a different position.

A3: Click on any point on the visual to see its coordinates. On the optic axis, the y coordinate is equal to 0. In the middle of the lens, the x coordinate is 0.

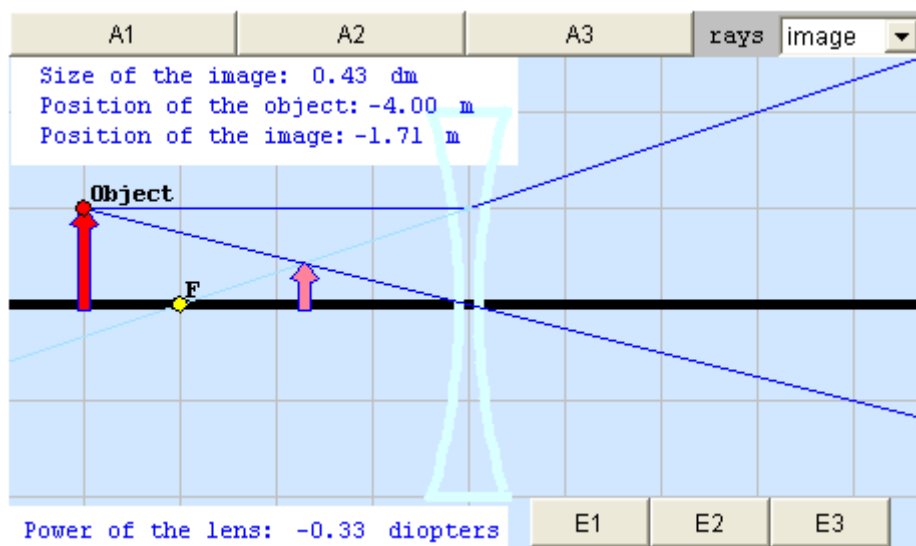
E1: Is the image formed by a converging lens always real? Can it be virtual?

E2: Is the image formed by a converging lens always smaller than the object or can it be bigger?

E3: When we increase the power of a lens, are the images nearer or further away from the object?

### 3.4 Diverging lenses

How do images form in diverging lenses?



A1: Drag the red dot to a new position.

A2: Drag the yellow dot to a new position.

A3: Click on any part of the visual to see its coordinates. The y coordinate is equal to 0 along the optic axis. The centre of the lens is at (0,0).

E1: Are images formed by diverging lenses always real, or can they also be virtual?

E2: Are images formed by diverging lenses always larger than the object, or can they also be smaller?

E3: If the power of the lens increases is the size of the image greater?

## 4.1 The telescope: How does it work?

It is said that Nero used a ruby as a magnifying glass. During the Middle Ages it was quite usual for short-sighted scholars to use spectacles for reading. In about 1600, a Dutchman called Liepperhey built the first telescope worthy of the name. Later, Galileo built others for himself and pointed them at the sky. The era of modern Science had begun.



### ELEMENTS OF A TELESCOPE



**EYEPIECE**

This is another convergent lens with a much shorter focal distance than the main lens, where the observer places their eye. It acts as a magnifying glass on the image formed by the main lens. Modern eyepieces can be made up of many simple lenses.

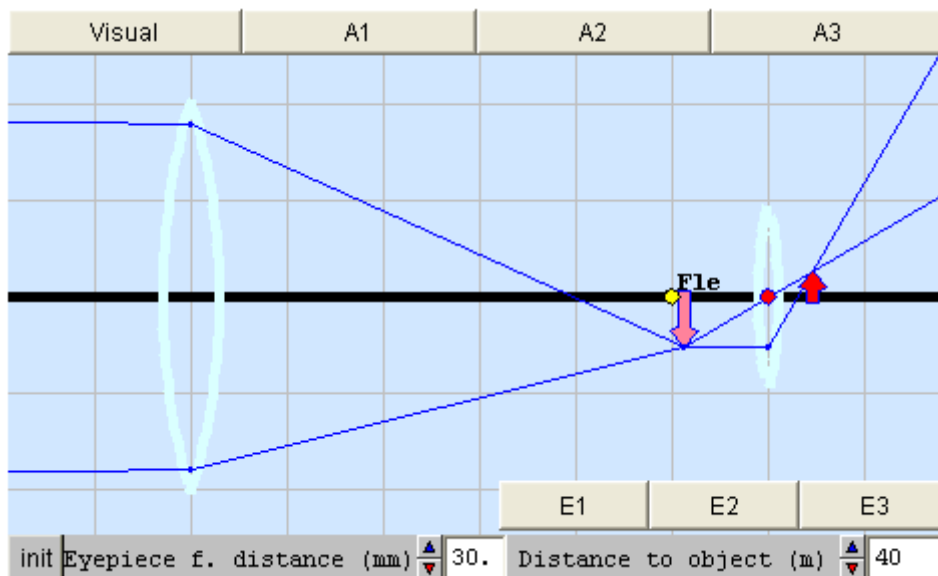


It is the convergent lens where light enters the instrument. In modern telescopes there is a combination of two or more lenses. There are also telescopes which use a concave mirror. The lens serves to produce a tiny inverted real image of the distant object we are viewing.

## LENS

### 4.1.1 The telescope: How does it work?

How does a telescope work?



Visual: ...We can modify the distance of the object we are looking at and the focal distance of the eye piece with the lower controls. By moving the yellow dot ( $F_{ob}$ ) we change the focal distance of the lens. We can then move the red dot to try to focus the eye piece. The eye piece is focussed when we manage to make the rays leaving it parallel. It is then that our eyes see a clear image. When you have managed this the computer will inform you of the magnification of the telescope. The magnification will tell you the amount by which the telescope has

A1: Keep the distance of the object and the focal point of the lens fixed, focus the telescope with different values of the eyepiece

A2: Set the eyepiece to 30mm. Gradually change the focal distance of the lens and and focus. Copy down the values of magnification that you get in each trial. How does the magnification change? Repeat the process for 20mm eyepieces. Can you see a relation between the focal distances of the lens and the eyepiece?

A3: Keep the values of the focal distances of the lens and the eyepiece constant. Change the distance to the object and focus the telescope for each new distance. Does the magnification change much?

E1: Focus the telescope with different values of the focal distance of the eyepiece. How does the magnification change? Is there a relation of proportionality?

E2: Carry out the exercises in A.30. Is there any relation between the focal distances of the lens and the eyepiece?

E3: Now modify the distance to the lens and focus the telescope for each new distance. Does the magnification change much?

## 4.1 The telescope: How does it work?

Amateur Astronomy is an enjoyable and educational activity. If you ever want to acquire an astronomical telescope you should first find out about its possibilities. Bear in mind that the information provided in some shops that sell telescopes is not always complete.

The important factors in an astronomical telescope are the range, the resolution and the [magnification](#). We have already talked about the latter, if you want to know more about the range and resolution, click on the corresponding word.



### RANGE

It is the weakest stellar magnitude that we can observe with the telescope. A bright star can have a magnitude of 1 (a few are even brighter). The weakest that we can see with the naked eye have a magnitude of 6. A telescope can let you view much weaker stars. In some cases up to a magnitude of 21 or more. In order for you to compare, we can say that a heavenly body is 100 times brighter than another which is 5 magnitudes weaker (a star with a magnitude of 6 is 100 times weaker than one with a magnitude of 1).

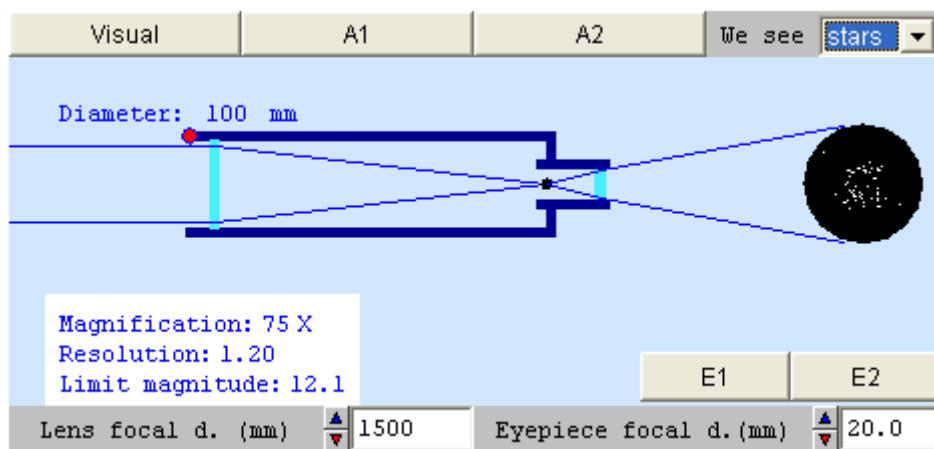
### RESOLUTION

It is the smallest angle at which we can observe two stars of the same magnitude as distinct. If we are observing stars S1 and S2 from point O, then the resolution would be the minimum angle  $\angle S_1OS_2$  at which they do not look like a single

star. This magnitude is very important in order to distinguish objects on planets, the sun (always use an adequate filter) or the moon.

#### 4.2.1 The telescope: What type should I buy?

Is it better to have a long telescope or a short one? Is a wide telescope better than a narrow one?. The following visual may help you to answer these questions.



Visual: The lower controls allow us to change the focal distance of the lens and the eyepiece. The upper control allows you to choose the type of object: planets or stars. The red dot can be dragged to change the diameter of the lens. The visual will constantly inform us of the magnification, resolution and range of each telescope.

A1: Which is better: a long telescope or a short one? 1) Use the upper control to choose planets and set the focal distance of the lens to 10 mm. 2) Keep the other variables constant and change the focal distance of the lens and observe how the resolution of the telescope and the image of the planet are modified. When can you see the planet more clearly? 3) Change the upper control to stars and repeat the changes for the lens. What is the limit magnitude for the telescope? In which case are more stars observed? Can you explain your observations?

A2: We will first examine the problem of resolution. 1) Give the telescope the largest possible focal distance for the lens and the thinnest diameter. 2) Gradually reduce the focal distance from 30 to 10 mm. How does the resolution change? 3) Repeat the experience for greater diameters of the lens. What is your conclusion? 4) Now observe the limit magnitude for each diameter. What can you observe?

E1: In order to observe a planet the best telescopes are...

E2: The width of a telescope is related to a) its magnifying power, b) its resolution.

## 5.1 Light as a particle

What is the nature of light?

Throughout history philosophers and scientists have developed many hypotheses about light. It was not until 1924 that a satisfactory answer could be given to the question.

Is it in the form of waves or particles?

Light behaves as if it were formed by waves emitted by a source.

All the properties studied in the topic WAVES can be applied to light.

### Then is light formed by waves or particles?

In 1924 Louis de Broglie put an end to the controversy when he made the following hypothesis:

All moving particles are associated with an electromagnetic wave.

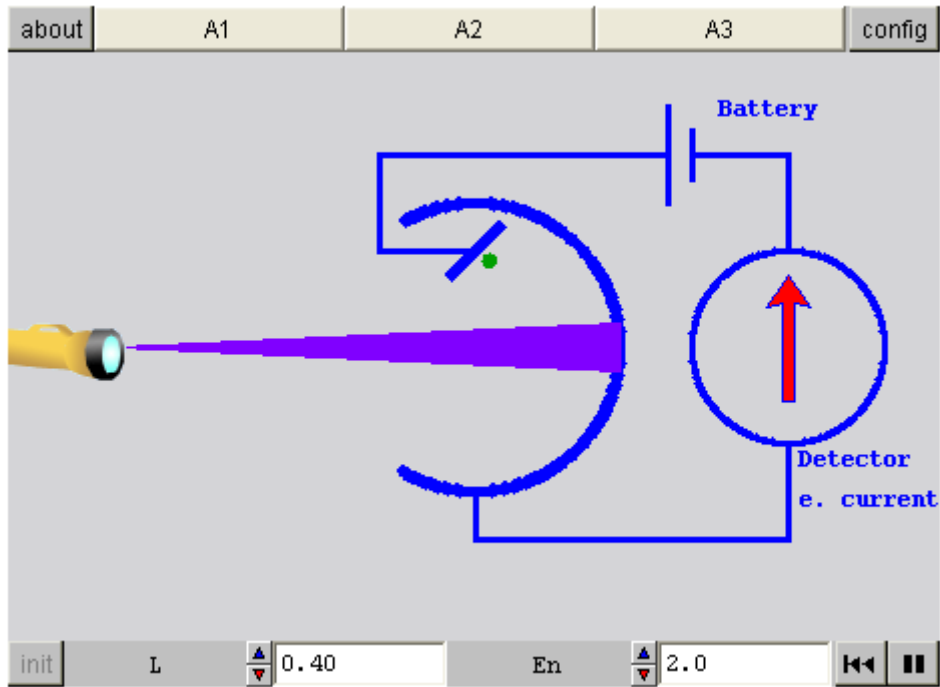
That is to say that light has a "double" nature: it is formed by waves and particles at the same time.

The following visual constitutes the proof that **light is formed by particles**.

### 5.1.1 Light as a particle. The photoelectric cell

The way a photoelectric cell works cannot be explained if we suppose that light is electromagnetic radiation.





A1: Click on play. Note that an electron jumps after the ray of light hits the cell. Explain why the galvanometer subsequently measures a current.

A2: See if, by varying the wavelength, there are wavelengths that do not produce the photoelectric effect.

A3: Test all the possible values of the energy and copy down in each case the maximum wavelength that produces the photoelectric effect. What can you deduce about the photons of each wavelength?

## 5.2 What consequences can be reached from the way the photoelectric cell works?

The photoelectric effect in the previous visual cannot be explained if we suppose that light is formed by waves. Thus it cannot explain why::

- it occurs with some radiations and not with others
- the photoelectric effect is instantaneous
- the intensity of the radiation does not influence either the speed with which the emission is produced or the energy of the electrons which are released

In 1905 Einstein maintained that when light interacts momentarily with matter, it behaves as if it were formed by particles. He called the minimal quantity of these particles photons and their energy is defined as follows:

$$E = h \cdot \nu$$

where  $h$  is the Planck constant and  $\nu$  is the frequency of radiation.

When a photon hits a metal, it is absorbed and the energy of the photon passes integrally to the electrons in the metal. If this energy is greater than that which keeps the electron joined to the nucleus, it becomes ionized. This minimal amount of energy needed to "release the electron from the metal" is called threshold energy, which is different for each metal.

This interpretation explains what cannot be explained using the electromagnetic theory of light.

## Evaluation

Have you learnt everything, ...a lot, ...something? Do you understand the topic?

- Can you distinguish between when light behaves like a particle and when it behaves like a wave?
- Do you know what reflection is and how a ray of light behaves when it hits a flat mirror and a convex one?
- Do you know the phenomenon of refraction and how a ray of light behaves when it passes through a converging lens and a diverging one?
- Do you understand the basics of a telescope and what you should look for if you went to buy one?
- Do you know how a photoelectric cell works and what consequences can be drawn from the experiment that you have simulated? This interpretation explains what cannot be explained using the electromagnetic theory of light.

1. Diverging lenses

- A always form images larger than the object
- B Always form images smaller than the object
- C only form virtual images.

2. The current created in a photoelectric cell:

- A is only related to the wavelength of the light incident on the metal
- B Is related to the ionization energy of the metal, but not to the wavelength of the light.
- C It is related to both the wavelength of the incident light and to the ionization energy of the metal

3. The prism

- A bends light rays of all colours equally
- B bends red rays further
- C bends blue rays further

4. In order to explain the photoelectric effect

- A we must assume that light is a wave.
- B we must assume that light is a transversal vibration.
- C we must assume that light behaves in a particle-like manner.

5. The power of converging lenses

- A is related to the size of the images they form
- B is not related to the size of the images they form

6. The reflection of light is an example of:

- A its undulatory behaviour
- B its corpuscular behaviour

7. The angle of the incident ray and the angle of the reflected ray

- A always sum 90 degrees
- B depend on the speed of the wave
- C are always the same

8. In transversal waves, the vibration is

- A perpendicular to the propagation.
- B parallel to the propagation
- C in the same direction as the propagation

9. Light travels

- A faster in water than in air
- B always at the same speed
- C faster in air than in water

10. The image in a concave mirror:

- A May be larger or smaller than the object
- B Is larger than the object
- C Is always smaller than the object

11. In a spherical mirror the focal distance is:

- A equal to the length of the circumference
- B equal to half the radius
- C equal to the radius of the sphere

12. Which of the following is true?

- A biconvex lenses diverge rays of light
- B biconcave lenses converge rays of light
- C biconvex lenses converge rays of light

13. The eyepiece of a telescope:

- A is the lens through which the light goes into the telescope.
- B it is the convergent lens where the eye is placed
- C it is the divergent lens where the eye is placed

14. The image in a convex mirror:

- A Might be larger or smaller than the object
- B Is always smaller than the object
- C Is always larger than the object

15. What is the relation between the wavelength and the frequency?

- A Their sum is constant
- B They are inversely proportional
- C They are proportional