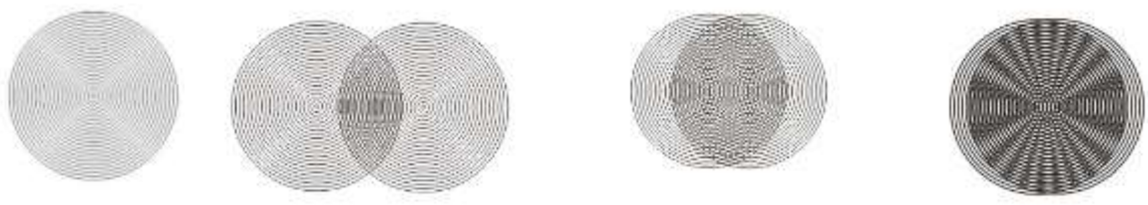
Some theoretical and practical explanations..

Here, we provide a more detailed description of the experiments, for those who wish to understand them technically, and possibly for those who wish to redo them themselves. First of all, let us look a little deeper into the subject of optical interference.

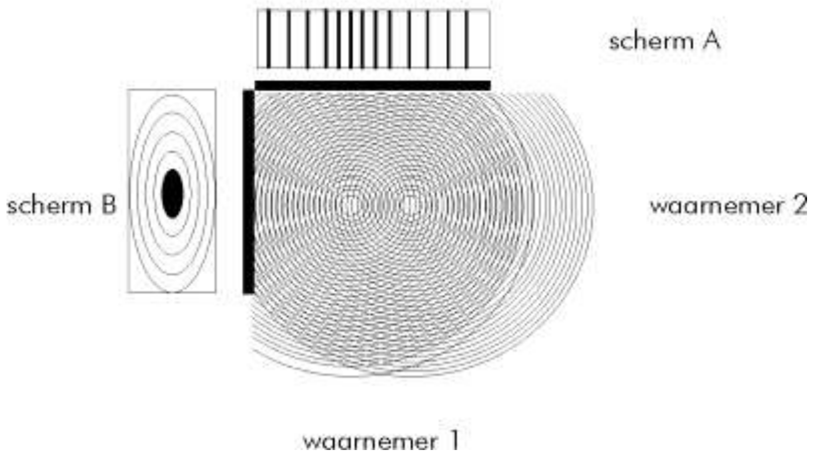
Optical interference

Two coherent light points that are very close to each other generate light waves that, like many concentric spheres, keep on expanding and mixing with each other.

We illustrate this with two transparent sheets on which a number of concentric circles are printed. We gradually slide these sheets over each other. They seem to form a kind of moiré pattern.



The paper shows all this in a flat plane, in two dimensions. In essence, however, they are not circles, but expanding spheres that still have a spatial and a temporal dimension.



Above, we see a top view of two coherent monochromatic point light sources, we call them A and B, which are very close to each other. The horizontal and vertical black strip each represent the top view of a projection screen. The screens A and B, are the same screens, but now slightly unfolded, we say at 45°, allowing us to see what is being projected onto them.

From the point of view of observer 1, the light sources A and B lie side by side. On the screen A there will be a number of parallel interference lines, which brings us to the interference experiments of Young and Fresnel.

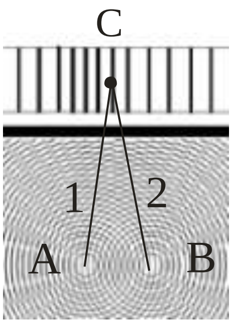
However, from the point of view of observer 2, the light sources A and B lie behind each other. On the projection screen B, some concentric circles will be visible, referring to Newton rings.

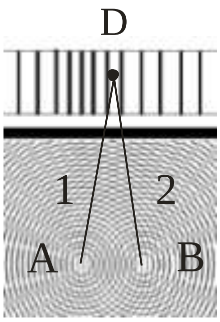
Let us try to clarify this. The images below are details of the images just given.

Let us first look at screen A.

At the top in the middle we see a dark line, the line of destructive interference. Point C falls on that line. All light rays from A and B that form the line in which C is situated, such as light rays 1 and 2, have an opposite phase and extinguish each other.

Point D in the illustration on the right falls on a wider band of light, a line of constructive interference. All light rays from A and B that form the line in which D is situated, such as light rays 1 and 2, have the same phase and reinforce each other. The light is more intense there.

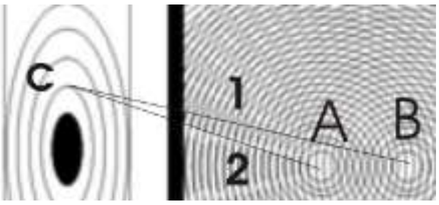


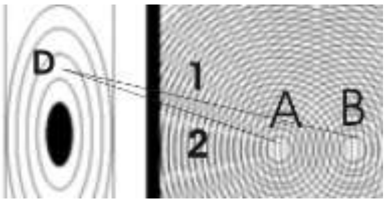


Next, let us look at screen B.

Point C on the image on the left falls on a dark circle, a circle of destructive interference. All light rays from A and B that form the circle C, such as light rays 1 and 2, have an opposite phase and extinguish each other.

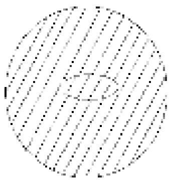
Point D in the picture on the right is falling on a wider circle of light, a circle of constructive interference. All light rays from A and B that form the circle D, such as light rays 1 and 2, have the same phase and reinforce each other. The light is more intense there.





If one now gradually moves from the position of observer 1 to that of observer 2, theoretically, these lines, which were at first parallel, will gradually transform into curves, until they finally turn into concentric circles.

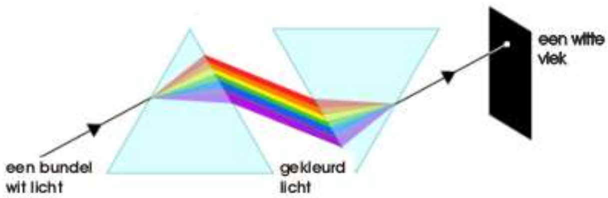
In a certain form of interference microscopy (53), the field of view is adjusted so that it is filled with many lines of destructive interference. A transparent bacterium brought into the light path will slow down the light causing these lines to be slightly distorted and shifted. This then provides some information about the location, shape and thickness of the bacterium.



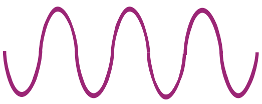
If the two light sources are brought even closer together, these circles on screen B will become larger and larger. Eventually, the central ring will be so large that it fills the observer's entire field of vision. This is called an 'infinite fringe width' in Anglo-Saxon. In what follows we will shorten this to 'IFW'.

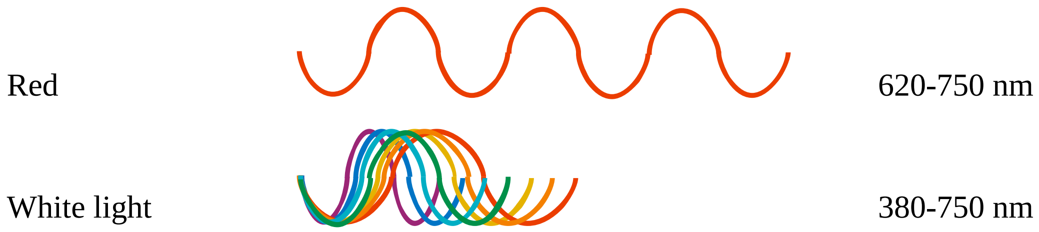
Something about colors

The brilliant English physicist Isaac Newton (1643/1727) demonstrated that sunlight passing through a prism is broken down into its constituent colors. A second prism can bring these colors back together again to form white light.

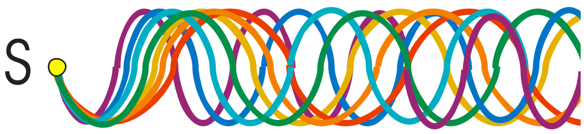


Each color has its own wavelength. The wavelength of red, for example, (between 620-750 nanometres) is much longer than the wavelength of violet (between 380-450 nanometres).

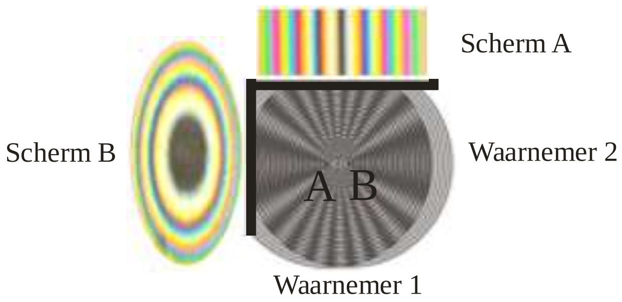
Violet  380-450 nm



The 'white' point light source S below generates all the colors of the rainbow. As there are about two thousand (!) waves in a single millimeter, the different colors overlap very quickly and white light is produced again fairly quickly.

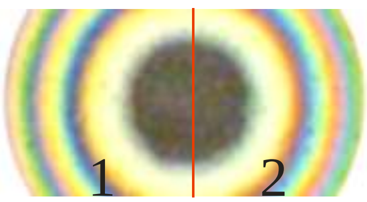


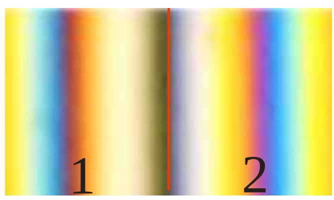
We work with white light in our experiments. So the interference lines and the Newton rings on our two projection screens will look quite colorful. We get:



What were black lines or circles in the images with our monochromatic light source are now lines and circles with the colors of the rainbow.

Below is a detail of both screen B and screen A and a red line is added centrally in each image. We see that in both screens the halves are each other's mirror image.





If we zoom in on the blue color of interference line 1, we will find the red color to the left of it. If we zoom in on line 2, we find the red color to the right of it.

Let's reason a step further. We adjust so that the whole surface of our main mirror is filled with a single color of the spectrum. If we then disturb the light path by, for example, holding our hand just in front of the mirror, the heating/ evaporation emanating from our hand will slow down the light path at that point and lead to a shift in the interference colors. It is then obvious that this shift will be in function of the interference line or circle left or right of the line or circle of destructive interference. In other words, it depends on whether we are in interference area 1 or 2

A disturbance in an interference setup, caused by monochromatic light, will cause a shift of the interference lines. We illustrate this with the example of the bacterium in the microscope.

If we work with white light, such a line is a series of colors. If we could adjust our set-up so that the mirror surface is filled with a single color of a single line, we would have good reason to believe that we would obtain a much more sensitive instrument. This is ultimately the basic idea behind all the subsequent experiments we want to perform.

Something about interferometers

As already mentioned, in an interferometer the light is split into two partial beams that are disturbed in one way or another and then rejoin, giving rise to interference and perceptible color shifts.

Abbreviations used

S = Source, point light source.
M = Mirror, concave mirror, 155 mm diameter, f = +/- 1250 mm
m = mirror, small flat mirror, with reflective layer on top
Bs = Beam splitter cube for visual light, 50/50, 20 mm
E = Eye, location of the observer
v = Object distance
b = image distance
B = image point
K (the upper case letter) = center of curvature
k (the lower case letter) = fulcrum point distance

La = Green laser, necessary to align the components. La is placed behind E, so that when looking, the head is between La and E, reducing the danger of being blinded by the laser. It is still recommended to turn off the laser when looking.

IFW: Infinite fringe width: An image where the mirror surface has only one color of the spectrum. In other words, a single line of interference is spread so wide that M is filled with a single color.

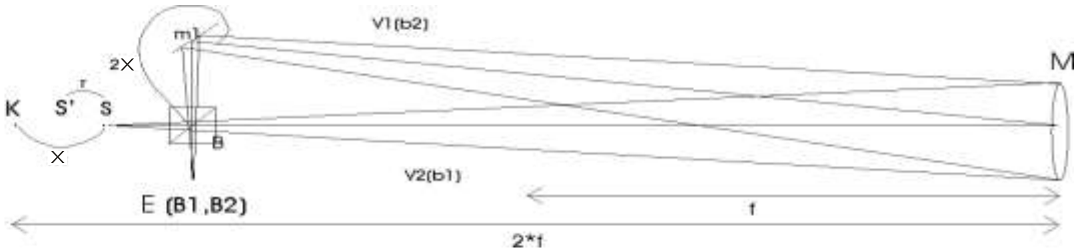
A radial interferometer.

1. Algebraic approach

For the arrangement below

a = light path from S to M in clockwise direction
b = light path from S to M in counterclockwise direction
x = distance a - b

r = sqr $(x^2 + f^2) - f$



We call this setup the 'basic setup'. We think of the point light source as being in S' and we try to define the two object distances algebraically.

We get:

v1, the anticlockwise object distance, is equal to the distance from S' to S, then to B, m1 and M, or: v1 = 2*f - (x - r) + 2*x = 2*f + x + r. (1)

v2, the anticlockwise distance, is equal to the distance from S' to S and further via B to M or: v2 = 2*f - (x - r) = 2*f - x + r (2)

Via the mirror formula 1/f= 1/b+1/v we find: b=(v*f) /(v-f), so that b1, the first image distance, belonging to v1, and going from M via B in the direction of E, is equal to

b1 = (2*f-x+r)*f / (2*f-x-r-f) (3)

For b2, the second image distance, belonging to v2, and going from M via m1 and B in the direction of E, we find

b2 = (2*f+x+r)*f / (2*f+x+r-f) (4)

If we then see in the drawing where b1 is located, we notice that the available path for b1 is equal to v2. So the image point B1 (the capital letter to distinguish it from the lower case b1, the image distance) will be at b1-v2 from E, or:

B1 = b1 - v2

If we look analogously at the location of b2, we see that the available path is equal to v1. Therefore, point B2 will be at b2-v1 distance from E.

B2 = b2 - v1

We find the distance D between both image points B1 and B2 by making the difference between these two.

We get:

D = B2 - B1 =(b2-v1)-(b1-v2) = (b2-b1) - (v1-v2) (5)

From (1) and (2) we find:

(v1-v2)= 2*f-x+r-2*f-x-r= -2*x (6)

so we can rewrite (5) as: D = (b2-b1)+2*x (7)

Now we substitute in (7) for b2 and b1 the values obtained in (3) and (4):

$D = ((2*f-x+r)*f/(f-x+r)) - ((2*f+x+r)*f/(f+x+r)) + 2*x$

Now we work out this equation.

$=(((2f^2-fx+fr)*(f+x+r)-(2f^2+fx+fr)*(f-x+r))/(f-x+r)*(f+x+r)) +2x$
$= (2f^3+2f^2x+2f^2r-fx^2-fxr+f^2r+fxr+fr^2)/(f+x+r)*(f-x+r) -$
$(2f^3-2f^2x+2f^2r+f^2x-fx^2+fxr-f^2r-fxr+fr^2)/(f+x+r)*(f-x-r) -2x$
$= (2f^2x/(f+x+r)*(f-x-r)) -2x$
$= (2f^2x/(f^2-fx+fr+fx-xr+r^2)) -2x$
$= (2f^2x/(f^2+2fr+r^2-x^2)) - 2x$
or $D = (2f^2x/((f+r)^2 - x^2)) - 2x$ (8)

With this last expression we now have a formula that tells us at what distance the two image points B1 and B2 are from each other in our setup, and this as a function of the focal length f of our mirror M, of the value for x and of the radial shift r of our point light source.

Let us aim for 0 in this expression r, and if we work out further we obtain

$D = (2f^2x/(f^2 - x^2)) - 2x$
$D = (2f^2x - 2x (f^2-x^2)) / (f^2 - x^2)$
$D = (2f^2x - 2xf^2 +2x^3) / ((f^2 -x^2)$
$D = 2x^3/(f^2-x^2)$

We see that the value of D becomes smaller as the value of x decreases and /or the value of f increases. If, at r = 0, we want to bring the image points B1 and B2 closer together, we will have to make the object distances v1 and v2 as equal as possible and work with mirrors with long(er) foci. The importance of a small D-value will become clear in the following, where it will be shown that we then have more mechanical leeway when adjusting our setup.

The obvious question now is when the two image points really coincide, or when the value for D becomes 0. We will calculate this as a function of the distance r, because this value can most easily be changed in a set-up by moving the light source forwards or backwards. If we work this out, starting from the equation given in (8), we find:

$D = (2f^2x / ((f+r)^2 - x^2)) - 2x$, or:
$(2f^2x / ((f+r)^2 - x^2)) - 2x = 0$

and we work out further:

$2f^2x/ ((f+r)^2 - x^2) = 2x$, or
$(f+r)^2 - x^2 = 2f^2x/2x$
$(f+r)^2 = f^2 + x^2$
$f + r = sqr(x^2 + f^2)$, or

$$\mathbf{r = (sqr (x^2 + f^2)) - f}$$

With this last formula we have what we need; a zero value for D as a function of r. So if r satisfies the condition described above, both image points B1 and B2 must theoretically coincide.

2. Mathematical approach.

Let's check this with some concrete values.
Diameter M = 155 mm, f = 1250 mm, Bs = $10mm^3$,
Distance m1 to center Bs = 10, then 2x = 10mm and x = 5mm.
If B1 and B2 are to coincide then r must satisfy:

$$r = sqr (f^2 + x^2) - f, \text{ or}$$
$$r = sqr (1250^2 + 5^2) - 1250 = 0.01mm.$$

At r = 0.01, D = 0. Let us check:

$$D = (2f^2x/((f+r)^2 - x^2)) - 2x, \text{ or}$$
$$D = (2*1250^2*5 / ((1250+0.01)^2 -5^2) -2*5 = 0 \text{ mm.}$$

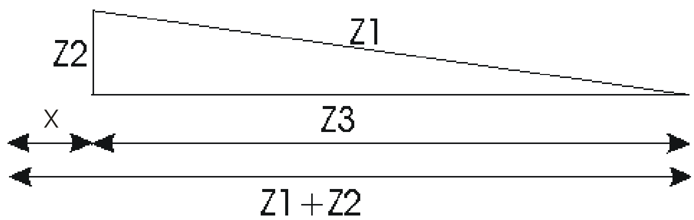
We get further:
v1 = 2f + x + r or 2*1250 + 5 + 0.01 = 2505.01
v2 = 2f - x + r or 2*1250 - 5 + 0.01 = 2495.01

Via 1/f = 1/v + 1/b we get
b1= (v1*f)/(v1-f) or (2505.01 * 1250)/(2505.01 - 1250) = 2495.01
b2= (v2*f)/(v2-f) or (2495.01 * 1250)/(2495.01 - 1250) = 2505.01

Let's check where in E the points B1 and B2 lie:
b2-v1= 2505.01 - 2505.01 = 0
b1-v2= 2495.01 - 2495.01 = 0

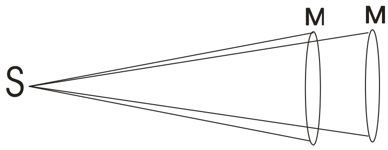
D is then also 0, so that theoretically B1 and B2 coincide exactly.

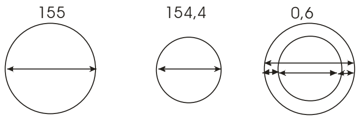
The basic idea behind this type of radial interferometer is very simple.
On the one hand: in the rectangular triangle, z1 + z2 > z3 and z1 + z2 -z3 = x.



And on the other hand: if v < k , then b > k and then v - b = x.

In summary, we described and calculated a type of radial interferometer. It is an interferometer because two light paths - clockwise and counterclockwise - unite in E, and because these images do not have the same size. The light path M, Bs, E is indeed shorter than the light path M, m1, Bs, E. And yet, with the given values, theoretically, both image points coincide.





3. Three distinct situations

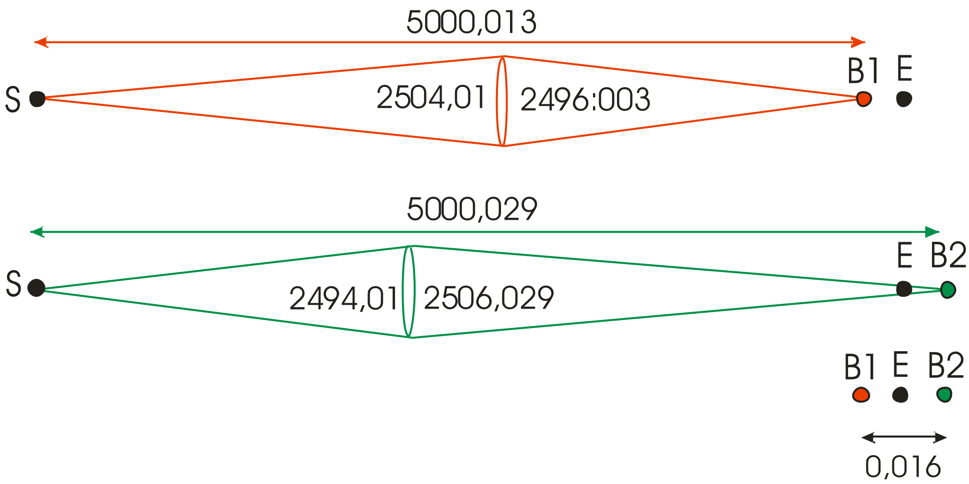
Let us consider below what the consequences would be for values that differ slightly from those calculated in theory. In other words: let's ask ourselves whether our set-up is practically feasible. Suppose, for example, that we make an error of one millimeter. We calculate our setup when the distances are 1 millimeter too short, we compare this with the distances that are exactly according to the theory, and finally when they are 1 millimeter too long. In order not to mix up the object and image distances, we replace the hollow mirror by a lens in the drawing below.

Situation 1: the distances are 1 millimeter too short.

v1 = 2 * f + x + r - 1
v2 = 2 * f - x + r - 1

v1 = 2504.01 b1 = (2504.01 * 1250) / (2504.01 - 1250) = 2496.003
v2 = 2494,01 b2 = (2194,01 * 1250) / (2494,01 - 1250) = 2506,019

v1 + b1 = 2504.01 + 2496.003 = 5000.013
v2 + b2 = 2494.01 + 2506.019 = 5000.029
5000,029 - 5000,013 = 0,016



Because b1 = 2496.003, but v2 = 2494.01,
B1 falls on v2-b1 or 2494.01-2496.003 = - 1.993 past E

Since b2 = 2506.019, but v1 = 2504.01,
B2 falls on v1-b2 or 2504.01-2506.019 = - 2.009 past E

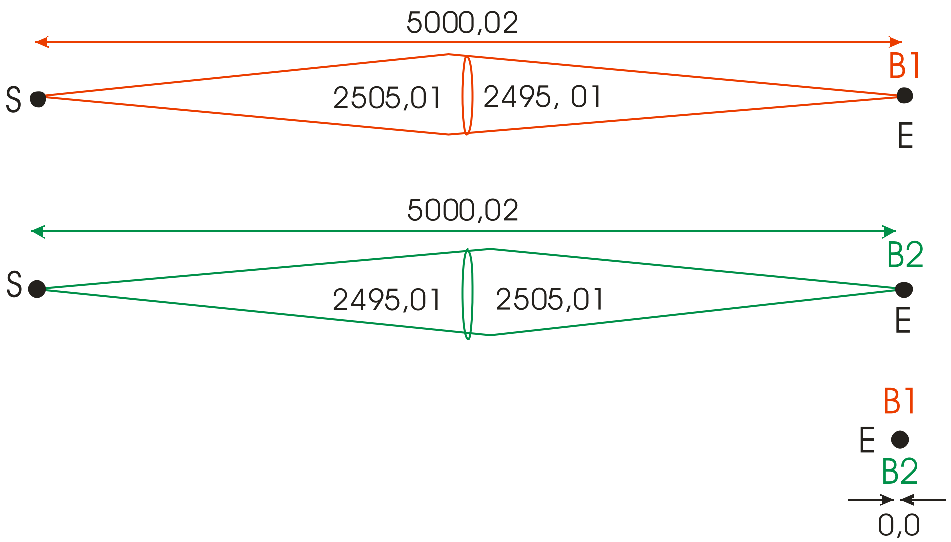
So B2 is further from E than B1,
their mutual difference is B2-B1 = 2.009 - 1.993 = + 0.016,

Situation 2: the distances are equal.

v1 = 2 * f + x + r
v2 = 2 * f - x + r

v1 = 2505.01 b1 = (2505.01 * 1250) / (2505.01 - 1250) = 2495.01
v2 = 2495,01 b2 = (2495,01 * 1250) / (2495,01 - 1250) = 2505,01

v1 + b1 = 2505.01 + 2495.01 = 5000.02
v2 + b2 = 2495.01 + 2505.01 = 5000.02
5000,02 - 5000,02 = 0,0



Since b1 = 2495.01, and v2 = 2495.01,
B1 falls on v2-b1 or 2495.01-2495.01 = 0 B1 falls in E

Because b2 = 2505.01, and v1 = 2505.01
B2 falls on v1-b2 or 2505.01-2505.01 = 0 falls on B2 in E

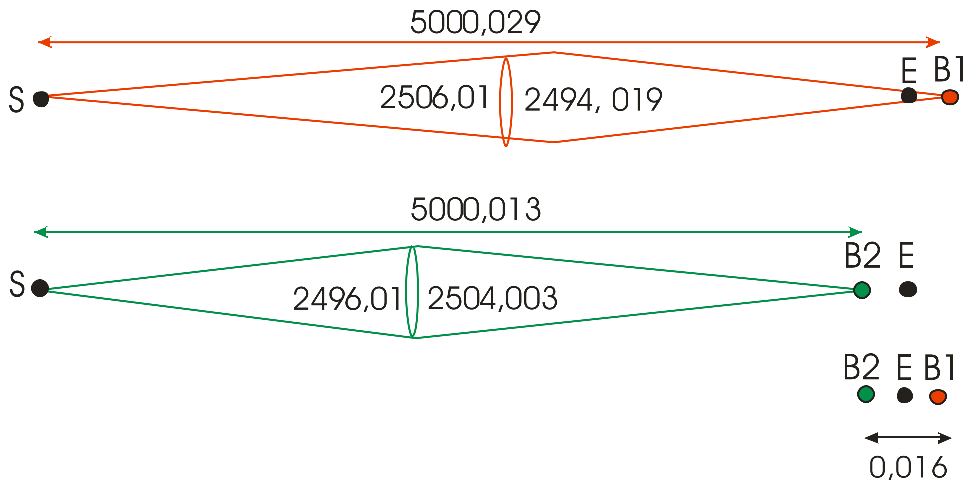
So B2 and B1 coincide,
their mutual difference is B2-B1 = 0

Situation 3: the distances are 1 millimeter too long.

v1 = 2 * f + x + r + 1
v2 = 2 * f - x + r + 1

v1 = 2506,01 b1 = (2506,01 * 1250) / (2506,01 - 1250) = 2494,019
v2 = 2496,01 b2 = (2496,01 * 1250) / (2496,01 - 1250) = 2504,003

v1 + b1 = 2506.01 + 2494.019 = 5000.029
v2 + b2 = 2496.01 + 2504.003 = 5000.013
5000,029 - 5000,013 = - 0,016



Since b1 = 2494.019, but v2 = 2496.01,
B1 falls on v2-b1 or 2496.01-2494.019 = 1.991 for E

Since b2 = 2504.003, but v1 = 2506.01,
B2 falls on v1-b2 or 2506.01-2504.003 = 2.007 for E

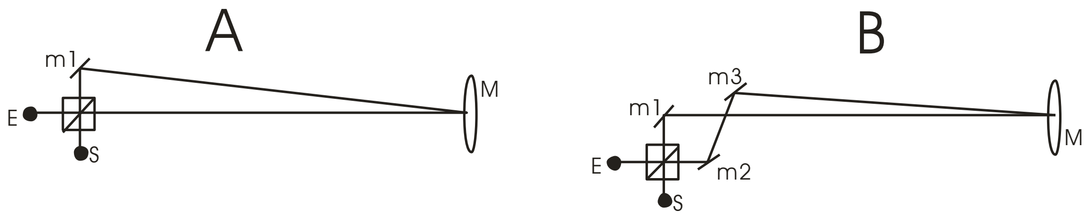
So B2 is further from E than B1,
their mutual difference is B2-B1= 1.991 - 2.007 = - 0.016,

We generalize: In the basic setup, variables can be chosen such that relative to the mirror M, B2 comes exceptionally close after B1 (1), that both coincide (2), or that B2 comes exceptionally close before B1 (3). In other words: theoretically, we have a way to bring two image points incredibly close together or even make them coincide exactly.

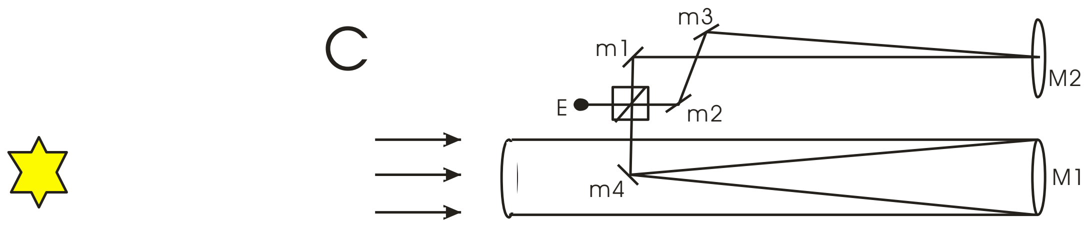
The two image points can thus be brought much closer together than is thought possible in Young's classic two-slit experiment.

We will see that this opens the door for the creation of very broad interference lines.

And another thing: In the image below, under A we see the basic setup schematically represented: the radial interferometer. Under B we see again the basic setup, but now with equal light path, so that the radiality strives for 0. Thus it became possible to achieve destructive interference.



One may wonder if other applications are conceivable. For example, under C we have coupled the arrangement B to a newton scope. The question arises whether destructive interference can also be obtained from the image captured in the viewer. In that case, however, we are at the professional level, which reaches much further than what is possible for an amateur.



4. Getting started

A few practical remarks beforehand.

A whole room.

Please note that a set-up requires a whole room, which we can also darken.

The point light source.

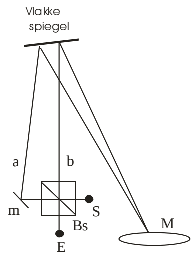
For S we used a point light source with a diameter of 0.3 mm. We mounted one end of a glass fiber cable in a piece of plastic electricity tube that we closed with a metal plate (e.g. of a soda can) and punctured it with a 0.3 mm acupuncture needle. Then carefully sand away all the burr and check it with a microscope. The other end of the glass fiber was held at some distance (+/- 200 mm) from a lamp (+/- 50 Watt). This was to avoid burning the plastic holder of the fiber. We did not use a fan because it causes disturbing air turbulences. And for the same reason, the lamp was not placed in the light path. We also fitted the lamp near E with a dimmer so that we could increase or decrease the light intensity. We also made the light source lightproof in order to keep the room dark.

A laser

The alignment of each setup is done with a laser. It must be powerful enough, because in some setups the light path is up to 15 meters. The longer the light path, the wider and weaker the laser spot becomes and the more difficult the alignment. We place the laser behind E, so that when we look from E, the laser light shines on the back of our head. We studiously avoid any laser light in the eye. Yes, with a switch at hand, we turn off the laser before looking into the setup.

An additional flat mirror.

We want to find out what will be seen of our hand when it is placed in such an arrangement just before M. With an f-value of +/- 1250 mm and a k-value of +/- 2500 mm, this is obviously not possible. To avoid being dependent on others for viewing the hand, we place an extra flat mirror (diameter +/- 100 mm) halfway along the light path so that, looking from E, the observer can still hold the hand in front of M and see for himself what is revealed.



The main mirror

We used a mirror that we had grinded ourselves with a diameter of 155 mm, which is about the standard value for those who take a mirror grinding course at some popular observatory with a view to building a Newtonian telescope.

Some small mirrors

In addition, we will need some mirrors with the reflective layer on top, to avoid errors that could occur because the light has to pass through the glass differently. Their size depends on their position in the set-up. If they are close to Bs, 15*15 mm is sufficient. We ourselves needed some mirrors of 15*100 mm. This will be explained later.

Three larger auxiliary mirrors (H1,H2 and H3)

These ordinary mirrors will help us with the alignment of more difficult setups. We used mirrors of about 100 mm * 900 mm, with the reflective layer on the back. They are attached to a beam that is not slightly longer. We took them from old mirror cabinets that one places, for example, above washbasins or on doors of wardrobes. Although not really 'flat' according to high optical standards, they usually suit our purpose.

4.1. The basic setup

The basic set-up was already explained under 1. The use of an extra plane mirror was also mentioned.

Because all parts are in the same 'plane', this setup is relatively easy to build and to adjust with a laser. For example, in this setup it does not matter if the light path Bs-m is parallel to the optical bench or not. If, for example, two splitters or several small mirrors are used, then, as we shall see, the adjustment becomes much more difficult.

If you build this basic setup, you will soon notice a number of interference lines or concentric circles. One can experiment by increasing or decreasing the difference between the two light paths (s-Bs-m-M and s-Bs-M). Disturbances, distortions of the interference lines by, for example, bringing a burning candle, a burning cigarette or the hand into the path of light, become perceptible when the path difference is kept as small as possible, i.e. when m and Bs are very close to each other and the distance to M strictly complies with the calculation. We ourselves always used the Foucault Knife test for this. The difference, however, was that the knife in E had a fixed position, and we could accurately change the distance to M and m.

Changing the distance from m to Bs is done with the adjusting screws. Changing the distance from M to E is somewhat more difficult. We placed M on a trolley with 4 wheels and connected it to a longer beam that went under the optical bench until it was within reach of the observer in E. To prevent the beam from bending, a metal beam +/- 15 mm thick was placed against it. In the other end of the beam (at E) an Hb and a Vb were placed, together with a bolt that can move the mirror M a little closer or further away from E.

Note that a radial interferometer brings together two similarly perturbed waves that are slightly different in size. Let us try to illustrate this with the drawing below on the left. Where the two waves 'intersect', they mix and there are color differences that can be seen by the eye.

Please note the picture (the second image below) which schematically shows part of the basic setup. With simple angle irons, m1 and Bs can be moved roughly along the required axes: the mirror m1 along the x and y axes, Bs along the x, y and z axes. The aluminum rods (diameter: 10 mm²) can then be used to fine tune the parts required. The green line in the photograph was applied later and is intended to indicate the path of the laser light. M is however outside the photograph in view of its large f-value.

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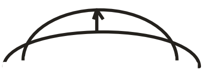
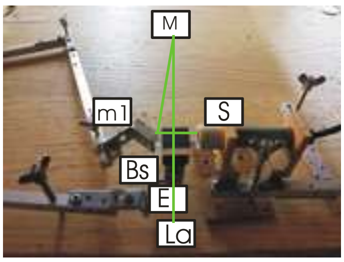
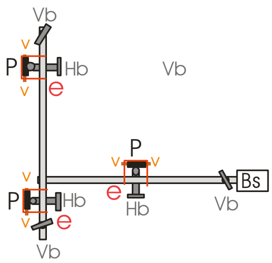
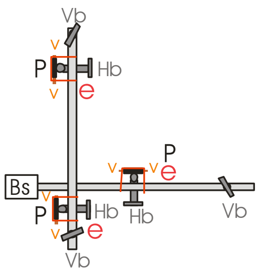




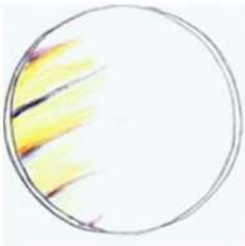


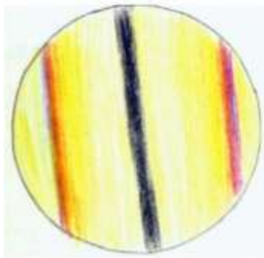


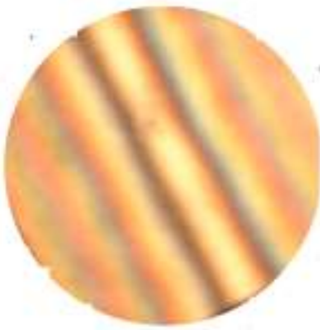
The third image above on the right shows e.g. Bs in a modified holder. Both 'levers' are made of aluminum, have a diameter of 10 mm² and are approximately 400 mm long. 'Hb' stands for 'Horizontal bolt', 'Vb' for 'Vertical bolt'. These bolts have a wing nut at the top and were drilled out conically. A ball was glued into the resulting hole to minimize friction between the bolt and the optical bench when the bolt was rotated. The letter 'P' stands for a fixed upright board against which the bolt can settle when tightened. The letter 'e' stands for a stretcher that presses the bolt against the shelf, and the letter 'v' stands for a small screw to which the stretcher can be attached. You can see that by the interplay of the 6 bolts, Bs can move according to its

3 axes, but also to the left, right, up, down, forwards or backwards. These are all movements that we will need.

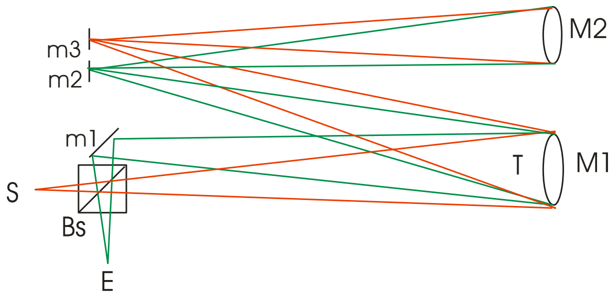
The fourth illustration shows a variation of a Bs holder. Here, the Bs is more central. For each arrangement, one obviously chooses the most feasible variant. Every small mirror that is part of an arrangement should also be placed in such a holder.
If a setup has only a few parts, such as the basic setup, then such a setup is relatively easy to build. If, however, a set-up requires several parts, the optical bench is filled with many aluminum rods that often seem to get in each other's way. It then requires some ingenuity to arrange everything in a user-friendly way. Remember that we want to operate the main adjusting screws from E. This means that they must be within arm's length. Setups with more than 1 Bs or m also require additional flat auxiliary mirrors. When aligning, all laser beams must lie accurately in one plane. We will come back to this in a moment.





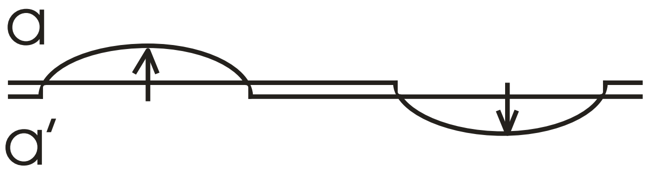




A variation on this setup (and some subsequent ones) is to let the light pass through the disturbance 'T', 'T' of 'turbulence', here usually our hand, a second time. The drawing below does show a large parallax but in practice this does not play a major role. The mirror M1 is at 2500 mm from Bs and m2 and m3 are just next to m1. So the drawing is not at all in proportion. We found that the image quality became less good because of this. The light does indeed travel a distance of 15 meters here. In principle, this cannot be a problem. We have been using our mirrors for 25 years and they have never been re-coated. Perhaps that also plays a role.



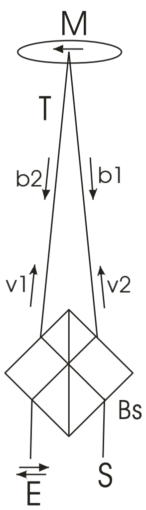
4.2. A reversal interferometer

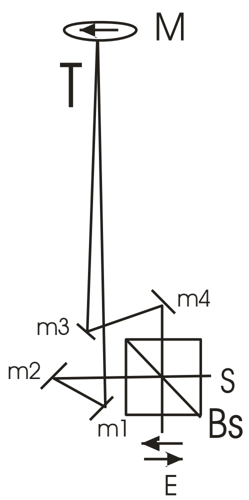
As already mentioned, in a reversal interferometer, one half of the image is merged with the mirror image of the other half. If we do not go past the centre line of the mirror by hand, a disturbed wave interferes with an undisturbed one. Their mutual difference, each time indicated by the arrow below, is much larger than in a radial interferometer. We therefore see a much more intense colour shift. The drawing of this in the first text confirms this indeed: we see that the evaporation/ heating of hand brings up two interference lines.



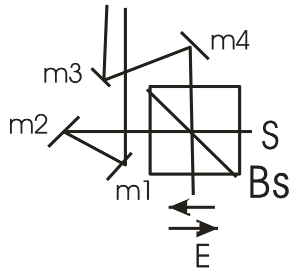
The setup in the image below on the left shows us a reversal with one Bs, as described in the literature. We did not succeed in generating a broad interference with this. The light beams fall too obliquely on Bs, which makes the IFW very difficult.

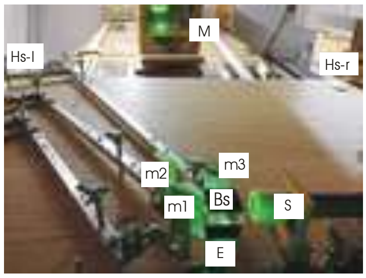
So we circumvented this problem with the setup shown in the center image. In order to make the different light paths as similar as possible, we used a card (image on the right) in which the two light paths could be accurately made almost equal in length, to less than 1 mm difference in distance. Mirrors m1 to m4 could thus - again via the fixed foucault test - be positioned very precisely.





The photo below shows a detail of the set-up on the left. In the middle of the photo, pay attention to m4. It shows the mirror image of the lines drawn on the cardboard. If we adjust the mirror m4 in such a way that we see the drawn line and its mirror image in each other's extension, then we know that the adjustment is already quite accurate. This of course applies to all mirrors.



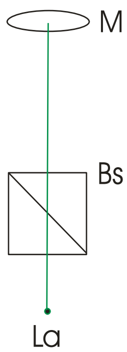


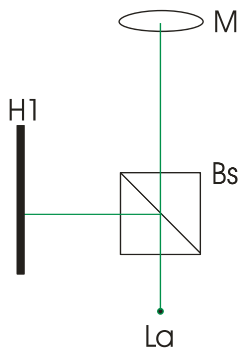
Since all parts must lie precisely in the same plane, this setup is much more difficult to build. Laser alignment requires a well thought-out algorithm. We did it as follows.

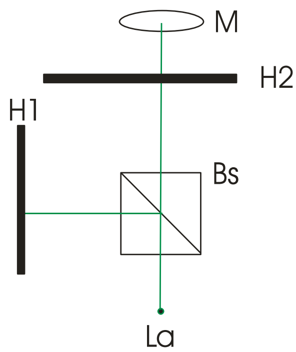
1. Left image. The laser is aimed at the main mirror M. We adjust M so that the light is reflected back to the laser. The splitter Bs is placed in the light path in such a way that the previously weak light beam reflected from the front exactly coincides with the laser.

2. Picture in the middle. H1, the first auxiliary mirror is placed. It is set up so that it can move along its two axes and so that it reflects the light coming from Bs exactly back to Bs.

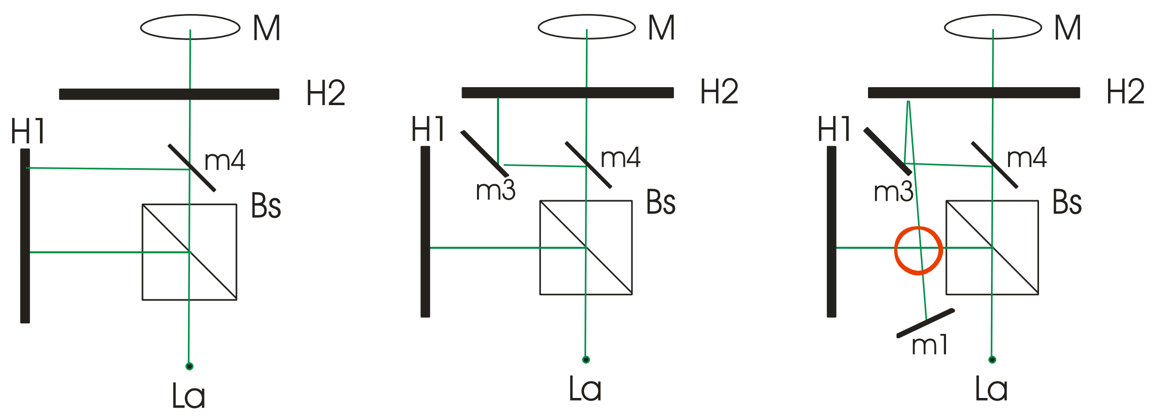
3. Picture on the right. H2, the second auxiliary mirror is placed. It can move along its two axes and reflects the light coming from Bs exactly back to Bs. This mirror will be removed after the adjustment is completed.







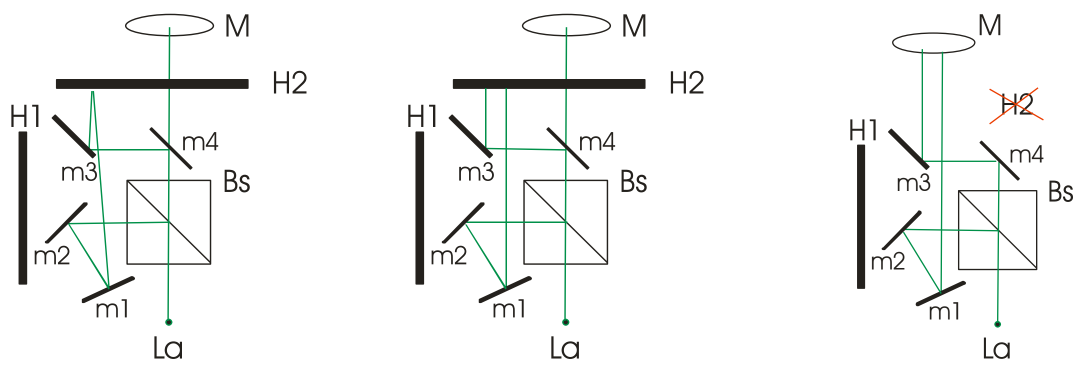
1. Picture left. The mirror m4 is placed so that the light goes to H1 and reflects back to m4.
2. Image in the middle. The small mirror m3 is placed so that the light goes to H2 and is reflected back to H2.
3. Picture on the right. The small mirror m1 is placed. We turn m3 slightly so that the reflected light falls on m1. Notice the two laser lines crossing in the red circle. In top view, they seem to intersect. To be sure of this, we bring a piece of transparent glass or plastic at that place in the light path. On this transparent plate we see two dots, one for each laser path. The intention is that these two points intersect at the point of intersection, that they coincide. If this is not the case, m3 and only m3 must be aimed more accurately. This way we can be sure that all laser light is still in the same plane.



4. Picture left. The mirror m2 is placed in such a way that the light coming from Bs falls on m1, at the very place where the laser light coming from H2 already falls on m1. Now the mirror m1 can be adjusted in such a way that the light coming from H2 falls on m2 via m1, and the light coming from m2 via m1 on H2.

5. Image in the middle. The mirrors m3 and m1 are lifted slightly so that the laser beam from m3 to H2, after reflection, falls back on m3, and the beam from m1, back on m1.

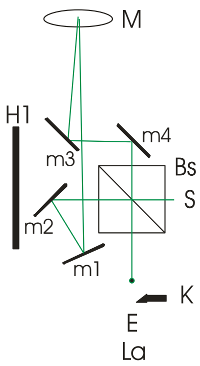
6. Right-hand side picture. H2, the second auxiliary mirror is removed. The main mirror M is moved a little to the left so that the laser beams from m3 and m1 fall nicely on this mirror next to its center.



7. The mirrors m3 and m1 are lifted a little so that their light falls neatly into the center of the mirror M. This mirror is adjusted so that the light goes from m3 to M, after reflection to m1, and the light from m1 to M, after reflection to m3.

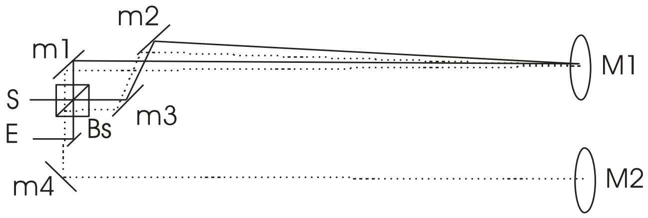
The point light source S (the glass fiber) is also placed so that the laser light from Bs falls exactly on the 0.3 mm hole. S is of course placed in a holder so that it can be accurately moved along its axes. At E, we also provide room for 'K', from 'Knife', the knife of the foucault test, a test that we will need when adjusting the converging beams of white light.

And don't be surprised if we end up tightening about sixty bolts.



4.3. A multiple interference setup.

If M1 is lifted slightly, and we use a second and equally large hollow mirror M2, then the light can pass through the set-up twice and we get an interference of two interferences. We see in E that here vertical interference lines mix with oblique lines, which gives a nice and symmetrical color pattern.



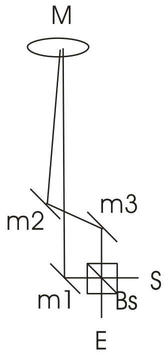
We will leave the tuning algorithm here. It is a variant of the previous detailed adjustment procedure.

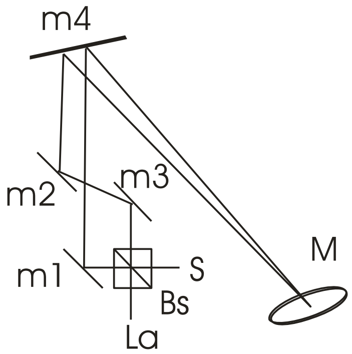
To get these interference lines wider, all light beams must fall perpendicular to Bs. However, since the main mirror M is slightly tilted, this is impossible: the dotted light paths fall obliquely on Bs. Indeed, on the splitter Bs we see two laser points: one spot of light going to M1, and to the left of it the slightly fainter point of light reflected from M1.

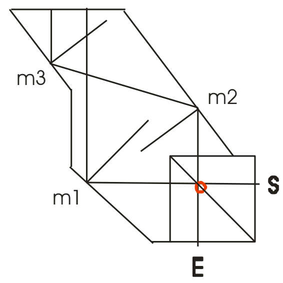
This set-up is therefore unsuitable for generating very broad interference lines or an IFW.

4.4. Nulling interferometry

We say that this type of interferometer is a 'limit' version of a radial interferometer, in which the path difference of the two partial beams aims at zero. We achieve this by adding the mirrors m2 and m3 to the basic setup.







The drawing in the middle shows us how M remains within reach from E.

The drawing on the right shows a detail of the setup. Again, we made a very accurate sketch in a drawing programme, which we then reduced, printed out, cut out and stuck onto a piece of cardboard. This is necessary to set the mirrors at the required distance and direction. If the adjustment is made very precisely, we will thus achieve destructive interference and see the faint band of light that surrounds the hand.

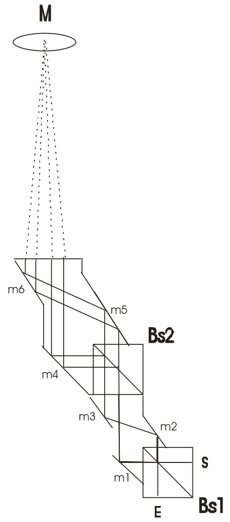
It can be seen that the adjustment algorithm is - mutatis mutandis - analogous to the previously described adjustment procedure.

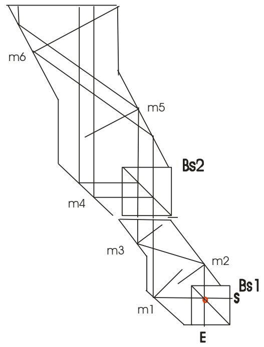
4.5. Multiple interference with 2 beamsplitters.

As indicated in the text above, this last experiment can be extended by allowing the light to pass through the set-up a second time. On the one hand, the finger can be illuminated a second time while maintaining one interference, but on the other hand, this can be done by allowing the light to undergo a second interference. A sketch of such a setup is shown below. Finally, an arrangement with a combination of the two preceding ones is also conceivable.

In practice, however, they are far from simple. However, after the laborious adjustment and alignment, which is a real test of our patience, it is worthwhile. The images are beautiful, but the set-up is so sensitive. Even the gentle touch of one of the adjusting screws results in a kaleidoscopic and changing color panorama, until one watches, almost with bated breath, as the image stabilizes. If one then holds one's hand in front of the mirror, one sees an IFW, and quite intense color turbulence, or, if one adjusts for the destructive line, the luminous band around the hand. The setup, mentioned above as a combination, we have not built. As mentioned before, we are really at the limits of what an amateur can achieve here.

Let us have a look below at the set-up, at some preparatory work and at a detail of the set-up. .Zoals aangegeven in de tekst hierboven kan dit laatste experiment nog uitgebreid worden door het licht een tweede keer de opstelling te laten doorlopen. Enerzijds kan met behoud van één interferentie de vinger een tweede keer belicht worden, maar anderzijds kan dit door het licht een tweede interferentie te laten ondergaan. Een schets van zulk een opstelling zien we hieronder. Tenslotte is eveneens een opstelling denkbaar met een combinatie van beide vorige.



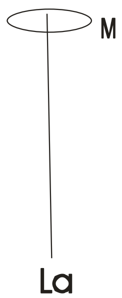
Because two beamsplitters are used, which have to be exactly in the same plane, this set-up requires even greater precision.

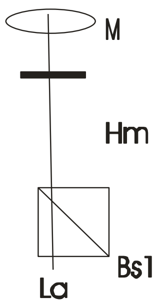
This is how we set up this setup.

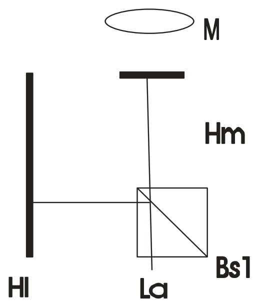
In the drawing below on the left, the laser is aimed at the main mirror M. The reflected rays fall back into the laser. The reflected rays fall back into the laser.

In the drawing in the middle, Bs1 is added, and the flat assisting mirror M is added so that the light reflected from M is now hindered. Bs1 is now adjusted so that the light reflected from its front side also goes back to La. Then Hm is adjusted so that the light reflected from it also falls on La. Hm is then perpendicular to the laser beam.

Hl, the auxiliary mirror on the left, has been added to the drawing on the right. It is 600 mm away from Bs1. This mirror should also reflect the light from Bs back to Bs.



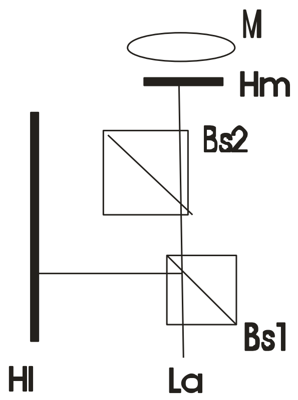


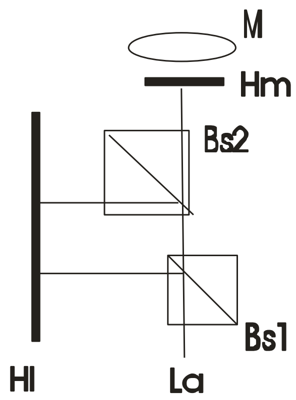


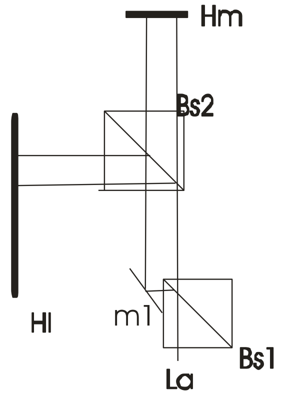
At the bottom left, Bs2 is added and adjusted so that the light reflected from the front of it falls back into the laser.

In the middle, Bs2 is adjusted so that the light reflected from Hl falls back on Bs2 exactly where the laser beam left Bs2 and entered Hl. These are time-consuming and difficult adjustments.

In the drawing on the right, m1 has been added and adjusted so that the light going to Hm and Hl falls back on m1.



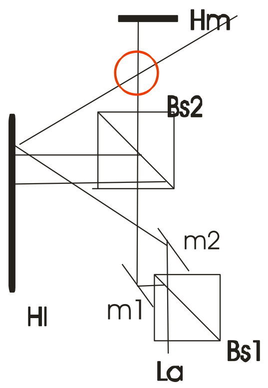


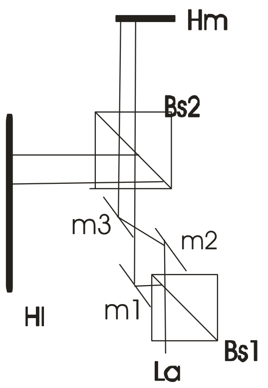


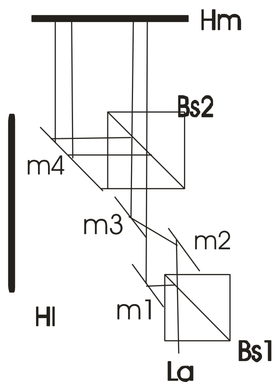
In the drawing below on the left, mirror m2 has been added. It is not at 45° because of the equal light path of both partial beams. Mirror m2 is obliquely placed on Hl which reflects the light obliquely. Now hold the translucent piece of plastic (or glass) in the place of the red circle. The light beam from Bs1 to Hm must intersect the light path of m2 that reflects on Hl. We adjust m2 in such a way that this is indeed achieved.

Then, in the middle, m3 is added and adjusted so that the light reflects from it to Hm, back to m3.

To the right m4 is added, such that the rays to Hm reflect on m4 again.





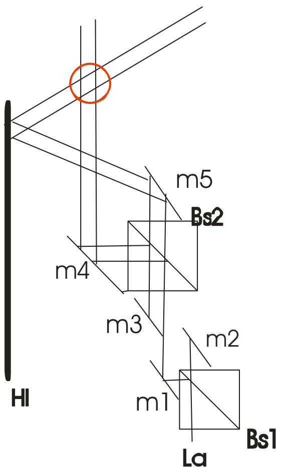


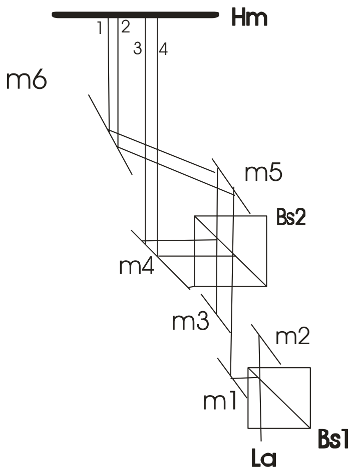
At the bottom left, m5 is added and adjusted so that the reflected rays from m4 intersect through m5- hl.

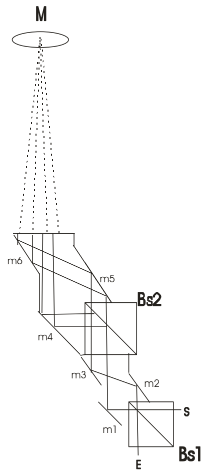
In the middle, m6 is added and adjusted so that the reflected rays from Hm, again fall on m6. Because of the divergence that will show itself when using white light, m6 is already much longer than e.g. m1. In our experiments m6 was already 80 mm long.

Finally, Hm is taken away, M is placed so that the beams 1, 2, 3 and 4 fall at equal distances from the center of M. The mirrors m1 and m4 (and only these) are gently wired so that the bundles 1, 2, 3 and 4 fall exactly in the center of M. If the whole procedure is exact, 1 will reflect to 4 and 2 to 3 and these 4 beams will all be of the same length.

In the end, they will show us an interference of two, making this arrangement exceptionally sensitive to turbulence.







With this whole set-up, we asked ourselves the question whether any of this fine dust could be demonstrated. Our experiments have strengthened our conviction and it seems to us that this question has been more than answered.

optical experiments
from 2000 to ...?