Introduction:
Believe, Know, Understand

Our **comprehension** about a physical phenomenon could derive from three different approaches:

- to believe
- to know
- to understand

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To ***believe*** has little to do with science, it is related to our confidence on some-one: our parents, our friends, our teachers and so on.

To ***know,*** is generally related to our direct experience. However if experience can give a stronger support to our comprehension about a phenomenon, our interpretation could be biased due to

limited experience: If we witness a rare event we are prone to give a high probability to it;

selective attention: focusing on selected aspect of a phenomenon, neglecting others, this may give a distorted view of a phenomenon.

measurement uncertainty: experimental results maybe spread due to the stochastic nature of the observed phenomena, we need a way to deal with uncertainty and evaluate the risk of failure;

experimental errors: errors in the experimental set-up, interpretation of the data, may bring wrong conclusions.

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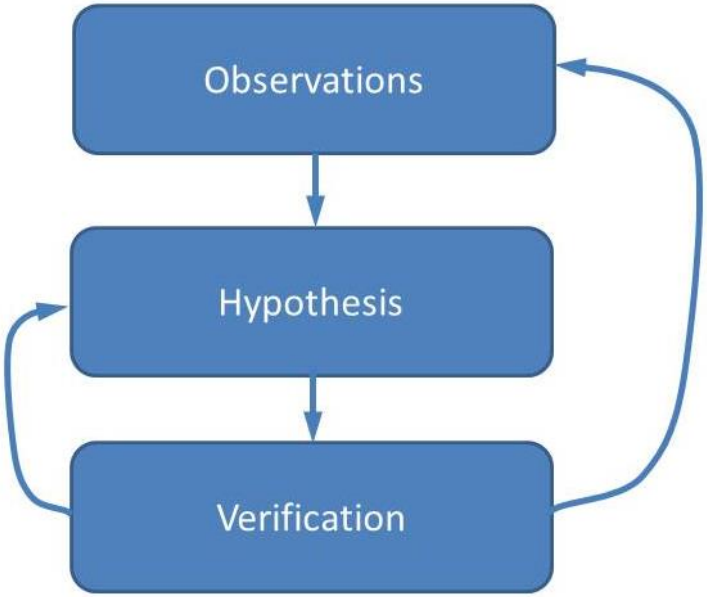
To Understand is different from *believe* or simply *know:* it means we understand the **causes** of a phenomenon, so we can make **previsions** and **estimate** the risk of failure.

The **scientific method** is the way we can achieve such **understanding**: it proceeds through three steps:

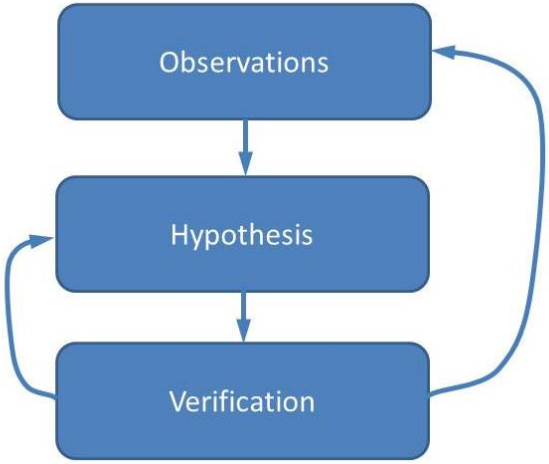
- observing,
- making hypothesis and
- verifying

This is an always ongoing process running in a continuous cycle with which science continually tests its laws, revises a theory, reviews his results.



In this process **make hypothesis** represents the fascinating and creative part of the Science.
Often this steps is skipped when we propose to students to verify the value of a physical constant, to apply a physical law (also if derived by a rigorous mathematical reasoning) to solve an exercise.
Verify and apply alone may results in a trivial exercise far from Science

Make Hypothesis relying on a solid deductive or inductive basis is a prerequisite for scientific reasoning.



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Deductive or Inductive?

Deduction:

If the hypothesis are true

then

Conclusions are true

False conclusions may point out false hypothesis: this is the basis of *ad absurdum* proofs and Hypothesis rejection tests.

Induction:

On the basis of evidences, inductive reasoning formulates hypotheses containing statements being not implicit in the premises and going beyond them.

Conjecture (in mathematics) as well Theories in science, derives from Inductive reasoning

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Chapter 1
A look into the mirrors

The reflection law is presented as a result of a deductive reasoning based on symmetry reasons motivated by the observation.

Objective: recognize the differences between real and mirror worlds

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Unit 2

Looking into a mirror is a quite common activity but thinking about the characteristics of the image could be a stimulating discussion.

Stand in front of a mirror, look at your image and describe the image characteristics

Questions	aims
Where is the image?	Recognize the image located behind the mirror
At which distance?	Recognize your and your image distances from the mirror surface are similar
Can you touch your image?	Recognize the image is virtual
Do you know Real images?	Images from a slide projector are real: on the screen
If you move the right arm your image move the left image. Is it is correct that mirror exchange left and right?	Recognize the reflection symmetry changes back/front directions, i.e. comparing with a figure drawn on a transparent sheet
Can you drawn a schema of the reflection geometry?	

Unit 2

Recognize differences between the real word and the specular one (the Alice's word)

Problem: You are looking inside a box, there is a screw inside, can you distinguish if it is real screw or an image from a mirror surface?

The image of the screw advances turning anti-clockwise. Notice that clockwise is reversed in the mirror word

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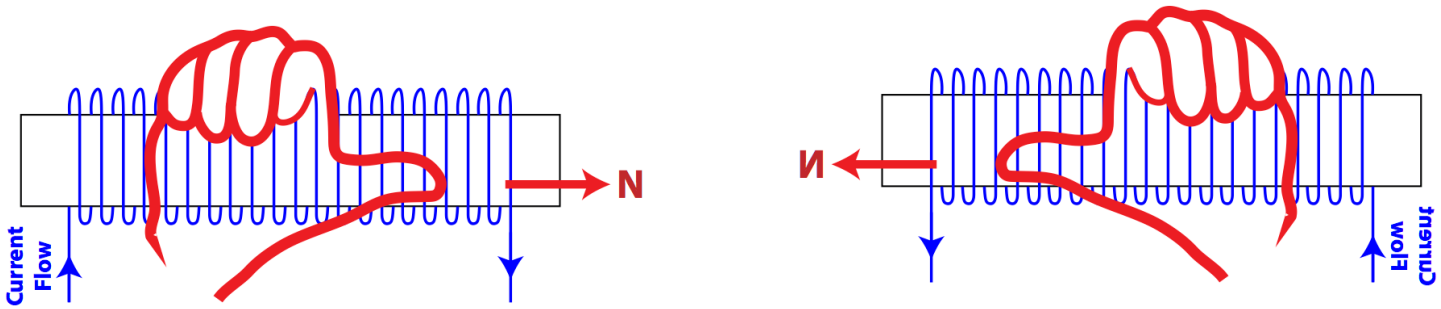
Unit 2

Problem: Can you find **physical** reasons why the Alice's word cannot be real?

Es.: The electric current-magnetism relationships are reversed in the mirror word



Notice: this could be a question for advanced students knowing about electromagnetism. But it is indeed an important question that allows understanding why chiral molecules are indeed different object with different properties, such a difference is not only a topological difference but imply difference of their physical, chemical and biological behavior.

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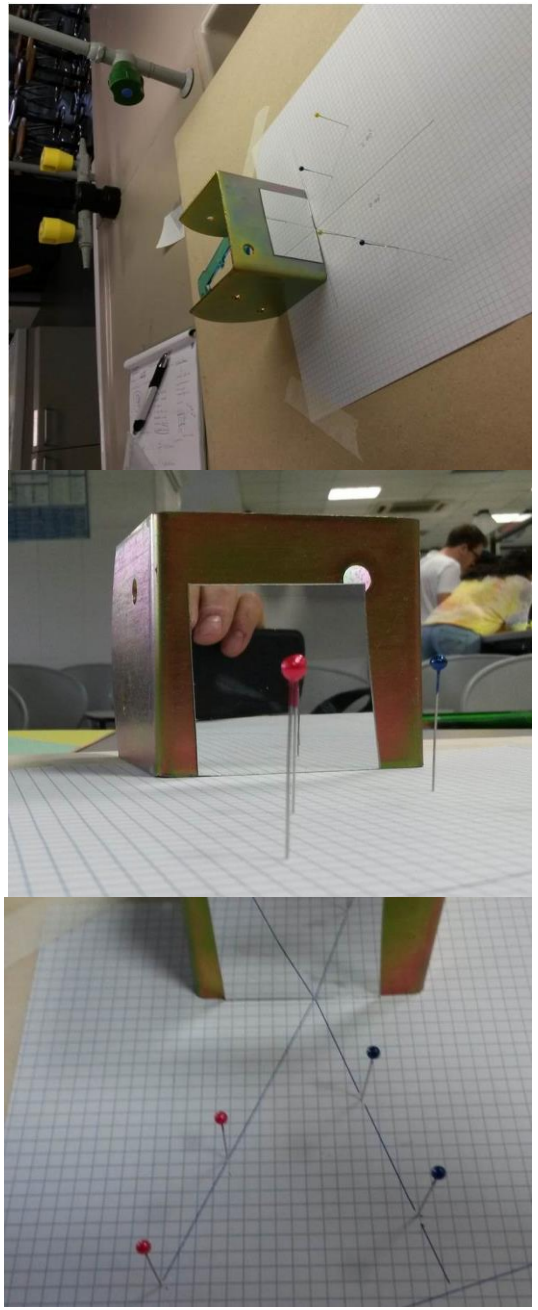
Chapter 2
Observing and Measuring reflection

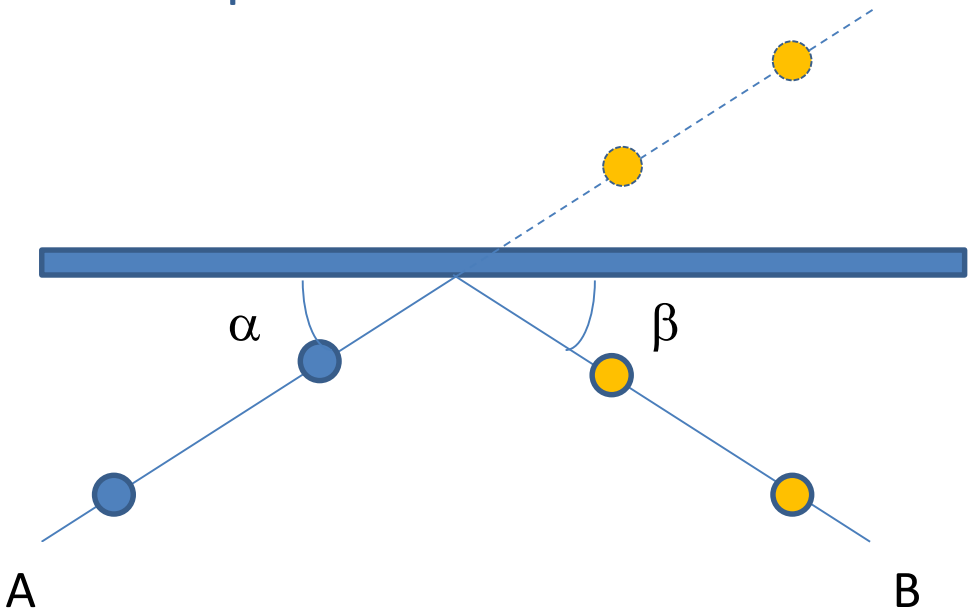


Align four pins in front of a mirror (see Experimental sheet) so that two pins are aligned with the image of the other two (figure)

Objective: observe, measure and schematize the reflection

Draw a schema of the observed phenomenon

A schema is always useful to discuss the phenomenon: it allows to select the main **parameters** (angles, point of view) and **components** (mirror surface, pins, images) allows a simple representation of the phenomenon



Observe and describe

Stimulate to describe "what you observe" to individuate and interpret the characteristics of the phenomenon.

Examples:

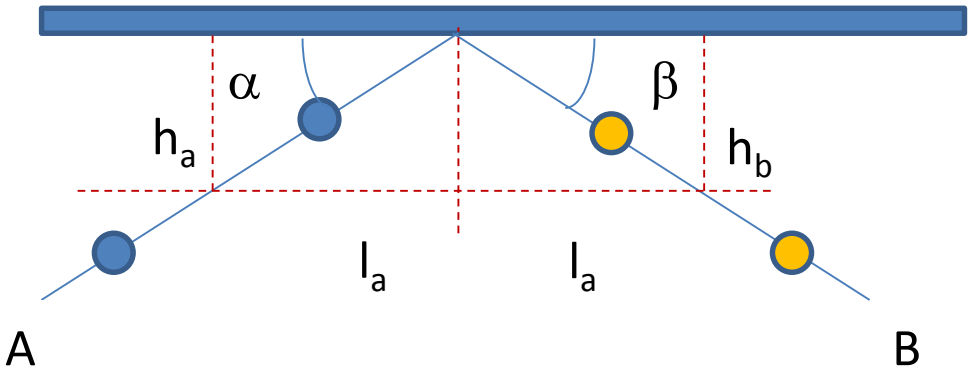
- the image of pins behind the mirror is aligned with my pins
- I see the "light" from pins B as coming from behind the mirror, aligned with my pins
- **the pins appear aligned either looking from A or B**;
- **When the pins are aligned the angles a and b are equal**

The last two are important answers for the next discussion

Measure the angles or the geometry

Drawn the lines across the pin points to the mirror surface and measure the reflection geometry parameters:

1. Measure α and β with a goniometer
2. Drawn a line parallel to the mirror plane and measureh_a, h_b l_a, l_b
3. Etc…



Activity

Insert here experimental results:

- Measure angles
- Measure h and l and calculate angles
- …

The data will be available for further comparison and discussion

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The reflection law states that $\alpha = \beta$

Discussion: can you really demonstrate the α and β angles are equal?

This is not necessarily true by at least two reasons:

1. You may do mistakes in the measurement (it can happen with this rough set-up: check the database).
2. the difference between α and β could be less than the accuracy of your measurements (your accuracy is definitively poor with this set-up).

The reflection law states that

$$\alpha = \beta$$

What your attitude about this law?

Believe: you trust on your physics book or your teacher about the reflection law

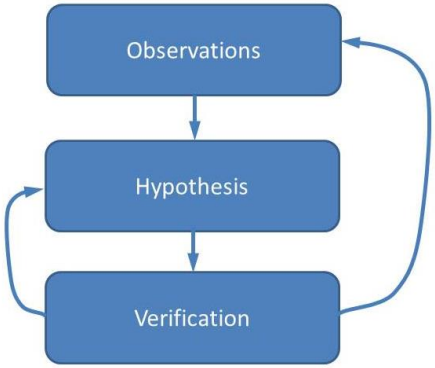
Known: your experiment suggests $\alpha = \beta$ but **what if α not equal β for some reason?**

Understanding Can you find a reason why the two angles are to be equal or against their difference?

Unit 4

Takes the reflection law ($\alpha=\beta$) as hypothesis (it is reasonable from the observations), but hypothesis must relies on a solid arguments to became a **Law** and cope with experimental errors, measurement uncertainty, etc….

Searching, **reasoning** and **discussing** represents the creative part of the scientific method giving to the **make hypothesis** step a creative and fascinating role.



Objective: base the reflection law on symmetry reasoning

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Make hypothesis Can you find a reason why the two angles are to be equal or against their difference?

I found at least three way for that

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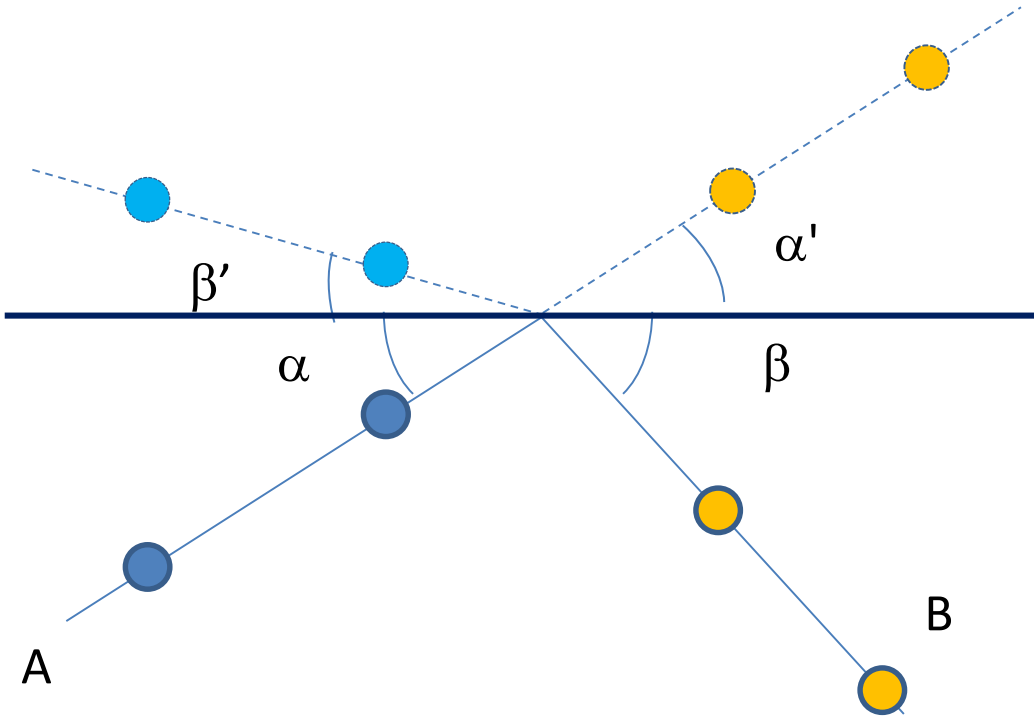
Argument A:

Suppose that in order to have $\alpha=\alpha'$, it is $\beta>\alpha$

It must be $\beta>\alpha'$: the angles of virtual rays are less than the real one.

Therefore it must be $\alpha>\beta'$ so that the pins aligned looking from A could not be seen aligned from B and this is impossible as the pins appear aligned either looking from A or B.

Note: An argument against this is that the difference is so small that we cannot appreciate it.



Argument B:

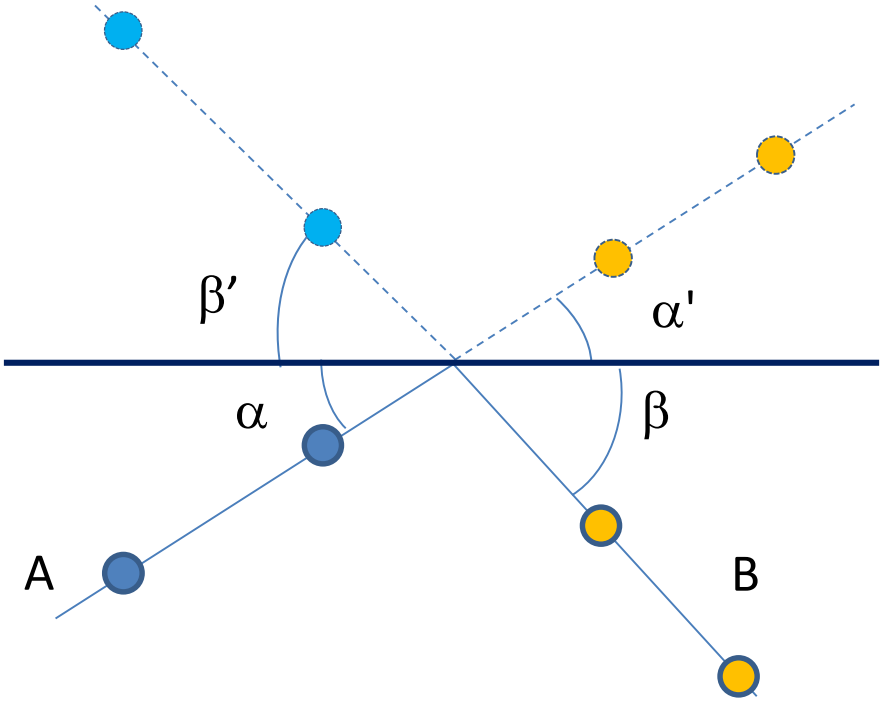
Suppose that $\alpha=\alpha'$ and $\beta=\beta'$, in order to see aligned the real and virtual rays, but $\beta>\alpha$.

This implies that $\beta>\alpha'$ but $\alpha<\beta'$. Why not the contrary, i.e.: $\beta<\alpha$ so all the inequalities are reversed?

Because there is no reason for such asymmetry, it would be likely $\beta=\alpha$ and $\alpha'=\beta'$.

This is the so called *Principle of Sufficient Reason*: for every fact there must be an explanation why fact is that and not other.

Add a link

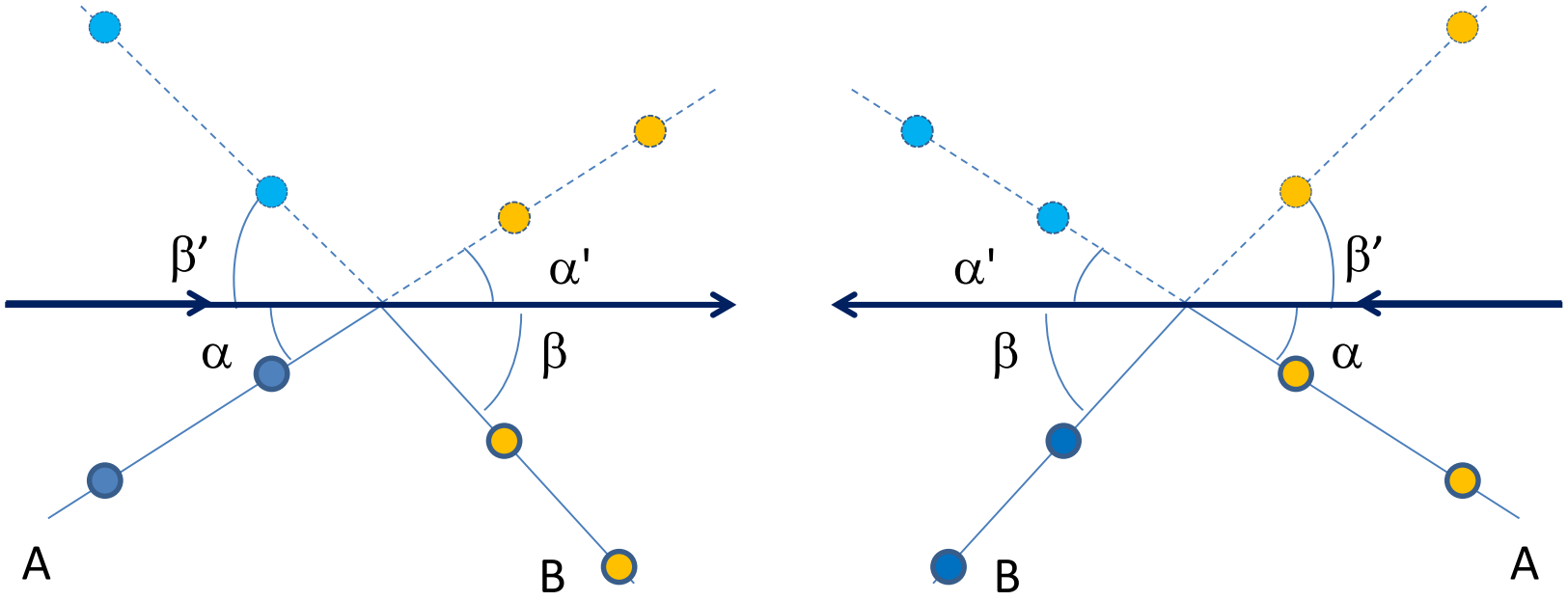


Argument C:

Let be $\alpha=\alpha'$ and $\beta=\beta'$, in order to see aligned the real and virtual rays, but $\beta>\alpha$.

This implies that $\beta>\alpha'$ and $\alpha<\beta'$.

If you rotate the mirror by π around the normal to its surface, you should have an opposite situation with $\beta<\alpha'$ and $\alpha<\beta'$ but there is **no reason** why the mirror can distinguish the two situations, therefore we must assume $\beta=\alpha$ (see **Argument B**)



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Discussion

Looks at the experimental values for α and β

Case $\alpha=\beta$ within the experimental uncertainty: you verify the reflection law

Case $\alpha \neq \beta$?

Notice that errors and mistakes may occur in the experimental practice. If your argument is strong and well based you will firstly carefully check all possible reasons of mistakes instead of deny the hypothesis.

Debugging the experimental set-up is a stimulating discussion:

- errors in drawing A and B lines,
- errors in positioning the pins,
- errors on the mirror plane line,
- etc…

Activity

Do you find other laws can be discussed?

Hints:

- Third law of dynamics: $F_{12}=F_{21}$

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