Mother Son Dialogues:
Light and Vision 6-9

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Dialogue 6: Independent Evidence

R: Mom, you were asking me yesterday about independence evidence for light traveling in straight lines. I have an idea. If you go out in the morning when it is foggy, and you look at the light streaming in through the leaves and branches of trees, they are all totally straight.

M: Look at the light? Can you see light?

R: Of course I can. Everybody can. Haven't you seen light rays coming in through leaves and branches in the morning?

M. No. And I don't think you haven't seen light either.

R: Mom, are you just being difficult or is there a point to all this?

M: Doesn't the theory that you proposed yesterday say that you see an object when light coming from that object hits your eye?

R: Yes.

M: So, if you have to ***see*** light, the light coming from that light must hit your eye, right?

R: Light coming from light… What are you saying, Mom? That is goobledigook.

M: I am just asking you take your own theory seriously.

> We see X when light coming from X hits our eye.
> We see light.
> Hence light coming from light hits our eye.

R: Oh, oh! … I understand what you mean. But there is something that we do see streaming through the trees and coming in straight lines. It looks like light. If it is not light, what is it?

M: Do we see those bright straight patches when there is no fog, like later in the day?

R: No.

M: So, what do you think you are seeing when you see those bright patches?

R: Oh, we are seeing fog lit by sunlight. And when there is no fog, we don't see anything. Oh, oh, Mom, I just thought of something. When there is smoke in the kitchen and there is light coming in through the window, the same thing happens. We can see smoke being lit up in a straight line. What we are seeing is the smoke, not the light.

M: Very good. Can you see light?

R: Hm! No, we can't see light. That is very strange. Light helps us see things, but we can't see light itself. Light is invisible.

M: So when you say that light travels in a straight line, you are making a statement about an invisible entity.

R: That is so cool. … Mom, what is light?

M: That's an excellent question, Rafa. I am not going to answer that question. It will take you a long time to answer that question. And you are likely to keep modifying your answers, but that is where all the fun lies.

R: So you are not going to give me even a hint?

M: No.

R: Okay, I will suffer in silence. Anyway, before you raised this can-you-see-light-and-what-is-light issue, I was going to say that what you see through the leaves and branches in the morning is independent evidence for light traveling in straight lines. Sure, what we are seeing is fog or dust particles. But it is still the case that we see the fog or dust particles lit up in a straight line, not in a zig zag or random curvy way. So it must be the case that light travels in a straight line.

M: Very good, Rafa. Can you design an experiment to show that light travels in a straight line?

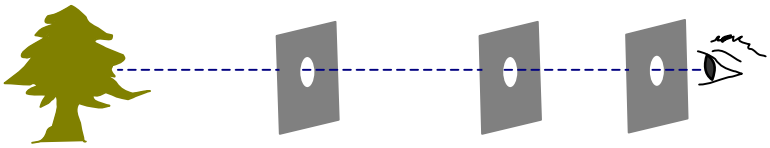
R: Oh, I don't know. That is hard. I can't draw a straight line and ask light to move partly on that line and then wander away from the line, can I? How do I…. wait a minute. … if… no that won't work… Mom, ..

M: Yes, Rafa, I am still here.

R: Suppose we… hm! …how would I know….. YES! Mom, here it is. Suppose I make a small hole in a piece of cardboard and look at a tree through that whole, like this:

M: Okay, what next?

R: Now I put two more pieces of card board with wholes in front of the first one. I will see the tree only if the three holes are perfectly aligned in a straight line.



R: If I move any one of the holes away from the line, I will not be able to see the tree through the first whole

M: How would you be able to tell if they are in a straight line?

R: I can put a string through the wholes and pull them from both sides, so that they are in a line.

M: Very good, Rafa. Now, this is a ***thought experiment***, not a real experiment yet.

R: Huh? What is a thought experiment?

M: You are just saying, imagine doing such and such. If we do that, don't you think the results would be such and such? You are doing that in your head, and concluding, on the basis of your current knowledge and intuition, that if you did it, you will be able to see the tree only if the holes are in a straight line.

R: And what will make it a real experiment?

M: For that, you actually have to get three cardboards, make holes, and look through them with and without aligning the holes in a straight line. Instead of your intuition to infer or guess what the results would be if you perform the experiment, you need to *observe* that the results after conducting the experiment.

R: Oh, I see. I will do the real experiment tomorrow. I am too sleepy now.

M: Good night, Rafa.

R: Good night, Mom. Are you going to tell dad about my experiment to show independent evidence for light traveling in straight lines?

M: Yes, I am. He will be pleased.

Dialogue 7: Reflection

R: There is something very strange about reflections, Mom.

M: What's strange about them?

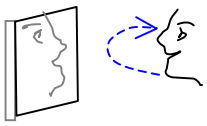
R: We see something because light from that object hits our eye, right?

M: Yes. You had a mock debate with Empedocles and demonstrated that.

R: But what makes us see a reflection? When stand in front of a mirror, I can see my face behind the glass, but I know there is no me behind the mirror. So if it is true that we see an object when light from an object hits our eye, then light from my face must be hitting my eye.

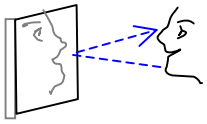
M: That is an excellent inference, Rafa.

R: But we also showed that light travels in a straight line. There is no way for light from my face, say, from my chin, to travel in a straight line and hit my eye.



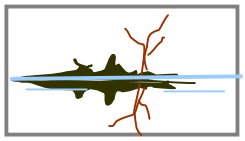
M: Correct.

R: So it must be the case that light from my face travels to the mirror in a straight line, hits the mirror, turns around, and comes back in a straight line, and hits my eye.



M: I am speechless.

R: So far so good. This is what puzzles me. Suppose I am looking at a tree at the edge of water. The reflection is upside down. For the real tree, the base is at the bottom of the branches, but for the reflection, the base is on top of the branches:



M: That's right. That is how reflections are. So?

R: But that is not how reflections are in the mirror. Come stand here, in front of this mirror.

M: Okay.

R: Are you upside down?

M: No.

R: So why is the tree's reflection upside down in the water?

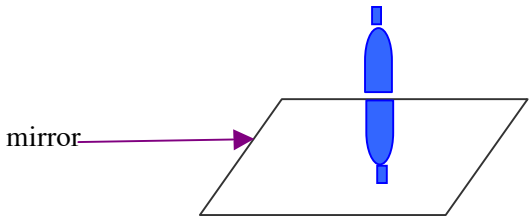
M: That is a very good question, Rafa.

R: Aaargh! I should have known. You are not going to give me an explanation, right?

M Nope. I want you to come up with an explanation.

R: It may have something to do with liquids and solids. Water reflections are reflections on liquid surfaces, but mirror reflections are reflections on solid surfaces. Okay, here is my principle to explain this: reflections on solid surfaces are not upside down.

M: Let us see if it works. Let us put a mirror on this table, and put a blue bottle next to it on the table, like this. And look at the reflection of the bottle in the mirror. Isn't that upside down?



R: Oh! Yes, it is upside down. So the reflection difference is not because of the difference between solid surfaces and liquid surfaces. My theory doesn't work.

M: How would you explain the difference then?

R: When you put the bottle on the mirror, the bottle is perpendicular to the mirror. But if the bottle is parallel to the mirror, like now, see, I am looking at the mirror and holding the bottle in front of the mirror, the bottle is not upside down. So that means it must be the angle at which the light from the bottle hits the mirror.

M: Good point, Rafa.

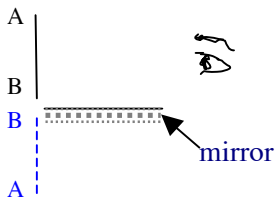
R: The image of a bottle is inverted when the bottle is perpendicular to the mirror but not inverted if it is parallel to the mirror. I can't figure out why this is so.

M: I'll give you a clue though.

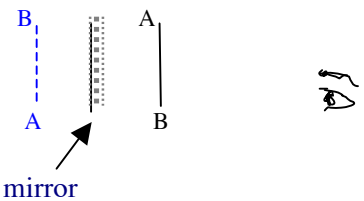
R: A clue? A clue? Wow! Aren't we generous today?

M: You deserve it. You did a fair amount of careful thinking. In science, we approach complicated problems by considering the bare essentials and eliminating the irrelevant details. One way of doing this is to take just the top point and the bottom point of the bottles, call them A and B, and find out what happens in the reflection.

R Ah, that's good. When the mirror is perpendicular, it looks like this:



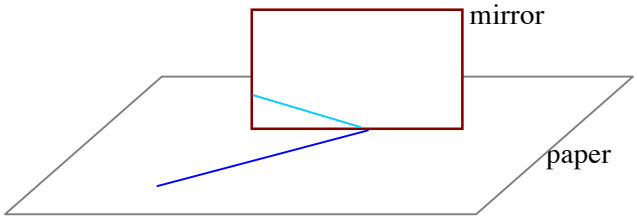
But if the mirror is parallel, the image is not inverted.



first constructing solutions for uncomplicated straightforward ones and then gradually tackling the complicated ones. Look for a simple problem of reflection first.

R: I don't know what simple problem I should begin with.

M: Try this. Draw a straight line on a piece of paper and put it on the table. Then put a mirror on the straight line and look at the reflection, Do you see the reflection as a straightline continuing the actual line on the piece of paper?



R: That is interesting. No, it is not a continuation. The reflected line is at an angle.

M: At what angle?

R: How do I know? I can't go inside the mirror and measure the angle.

M: You don't have to go inside the mirror. You can invent a way of deducing the angle from outside the mirror.

R: Hm! Invent a way of deducing the angle? Mom, my head is all heated up. I don't think I can do any invention today. I'll think of something tomorrow.

Dialogue 8: Reflection contd.

R: Mom, mom! Where are you? Mom!

M: Don't scream, Rafa, you will bring down the fire brigade. I am in the bathroom.

R: Can you come out quick? I have an idea.

M: Rafa, your idea can wait. Can I have a moment of peace in the bathroom, please?

R: Okay, I'll wait.

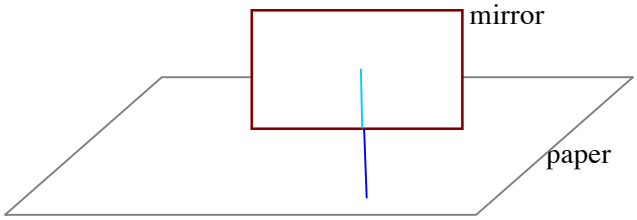
……

M: Alright, Rafa. What is it? What was the brilliant idea you are going to get a Nobel prize for?

R: I was playing with the mirror reflections of lines on paper. Remember in the reflection you showed me yesterday, the mirror reflection was at an angle to the paper line, not a continuation?

M: Yes?

R: I found a way of joining the two into one continuous straight line. Here, look:



M: Very good, Rafa. So how come the paper line and the reflection line make a single straight line in this case, but not in what we did yesterday?

R: I was coming to that. I measured the angle between the paper line and the mirror. And you know what, it is exactly 90 degrees. So here is my law of reflection:

> *If the angle between the paper line and the mirror is 90 degrees, then the paper line and the reflection line form a single straight line.*

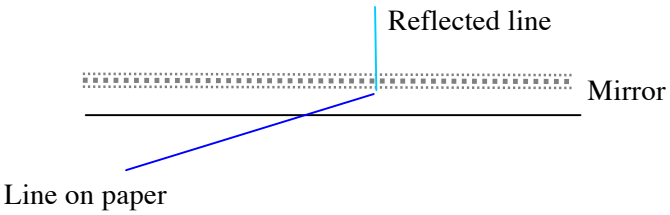
M: And what happens when it is not 90 degrees?

R: Then it doesn't make a single straight line.

M: Yes, but can you predict what kind of line the reflection would make?

R: Er… I don't know.

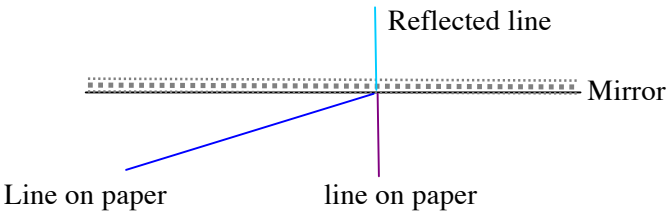
M: Try this. Suppose the angle between the mirror and the paper line is 30 degrees. Do you expect the reflection to be 90 degrees to the mirror, like this:



R: No. That is no possible.

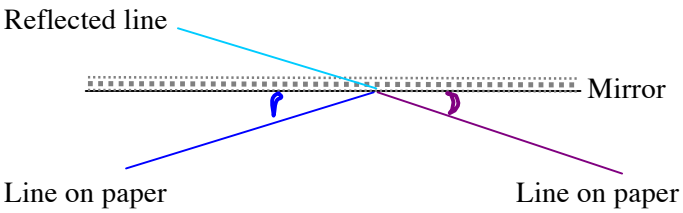
M: Ah, but you said yesterday that you can't measure the angle of the reflected line, didn't you? So how can you tell it is not going to be 90 degrees if the angle of the paper line is not 90 degrees?

R: I can draw a 90 degrees line on paper, and show that the reflected line does not form a single straight line with the line I draw.



M: Very good. So you have found a way of measuring the angle of the reflected line.

R: Huh? I have found a way of … Oh! …… Oh! Oh, yes! That is the way. And … Oh, oh! You know what? I can draw a line on paper such that it forms a single straight line with the reflected line, and that way I can measure the angle of any reflected line.



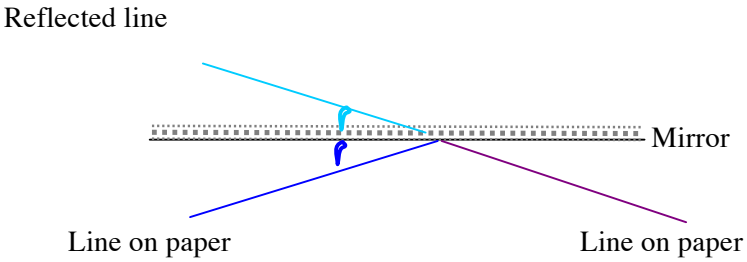
M: Now you are talking, kiddo.

S; And I bet the two angles would be the same.

M: Which two angles?

R: The angle between the mirror and the line on paper (the purple angle) and the angle between the mirror and the line we draw to extend the reflection on to paper (the purple line.) Oh, another thing. Since this angle and the angle between the mirror and the reflected line are opposite angels, I can actually state it as a law:

> *The angle between a mirror and a straight line that meets the mirror is equal to the angle between the reflected line and the mirror.*



And another thing. Mom, this is really good. My earlier law about perpendiculars follows from this news law. If the angle between the line and mirror is 90 degrees, the angle between the reflected line and mirror would also be 90 degrees, so it follows that the line and the reflected line would make a single straight line.

M: Good thinking. Now for the next step. Have you actually done the measurements?

R: No, but I am pretty sure that it will be the same.

M: Don't go by your guesses. Draw a number of sample lines with mirror and check if your hypothesis is correct. Remember, if you are doing science, you need to move from thought experiments to real experiments.

R: Will do that tomorrow.

Dialogue 9: Laws of Reflection

R: Hello, Sandy! Haven't seen you for a long time. Are you and Rafa going to do some homework together?

S: Well, er … not really. I came because …

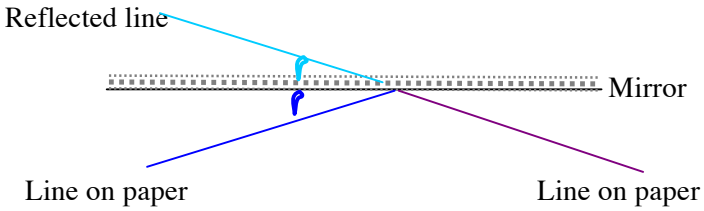
R: Mom, I told Sandy about what we have been doing with light and reflection. And we tested the reflection law with lots of cases. It is correct. And then Sandy had an idea. Tell her, Sandy.

S: Well, Mrs Zin, what Rafa's law says is that if a mirror is kept on a straight line on a paper, the line and its reflection are symmetric along the axis of the mirror.

S: Rafa and I did an experiment with a laser pointer, using the line and reflection diagram that Rafa used when he discovered his reflection law.

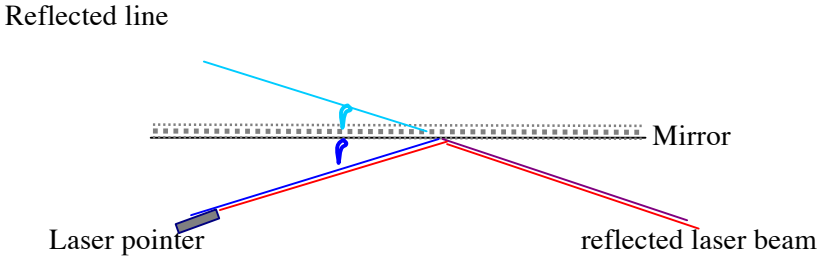
> *The angle between a mirror and a straight line that meets the mirror is equal to the angle between the reflected line and the mirror.*

You remember the diagram, don't you?



S: We pointed the beam of the laser pointer along the line on paper, and imagine what we

found! The reflection of the laser beam coincides with the line on paper that extends the image reflected in the mirror!



R: You know. Mom, that suggests that the way light rays are reflected from the mirror is responsible for the image being symmetric. The angle at which a light ray falls on a mirror is the angle at which it is reflected. So my law should be stated not as a law about reflected images, but about light. Isn't that awesome?

M: How would you state the law?

R: *The angle at which a light ray falls on a reflecting surface is equal to the angle at which it is reflected*.

M: Do you know that in physics textbooks, these angles are called angle of incidence and angle of reflection? The standard formulation is: *the angle of incidence equals the angle of reflection*.

R: My law is already in textbooks?

M: Not *your* law, you MCP! You and Sandy discovered it together. Sandy was the brains behind seeing it in terms of light rays instead of images you see. I bet she was the one who suggested using the laser pointer as well.

R: Sorry, I didn't mean to steal the credit.

S: That's okay, Mrs Zin. I know Rafa, I don't mind the way he talks. So who discovered this law first?

M: Euclid. He proposed the idea of light traveling in a straight line. He also formulated the laws of reflection.

R: Mom, didn't you tell me the other day that it was Alhazen who formulated the laws of reflection?

M: Yes, I did. But I was wrong. I looked it up on Wikipedia yesterday, and found out it was Euclid.

R: But mom, haven't you been telling me not to trusted any printed sources or any authority? How come you trust Wikipedia now?

M: I didn't recommend total distrust, Rafa. You do need to rely on other people for your knowledge. What I warned you against was absolute blind trust in any authority. Yes, it is possible that the information given in Wikipeidia is wrong, but I think it is unlikely in this particular case.

R: Why?

M: We can find out if Euclid actually formulated the laws by going back to his work – you can do it yourself if you have the time – so if this was wrong, someone would have corrected it or raised on objection at least.

S: Talking about inaccuracies, Rafa was telling me about an email from his Dad that says that Plato, Aristotle and Euclid accepted Empidocles' theory of vision. I looked it up, Mrs Zin. Looks like there were two theories in ancient Greece, the emission theory that says that

light is emitted from the eyes and the intromission theory which says that light from an object falls on the eye. Empidocles proposed the emission theory, but Aristotle supported the intromission theory.

M: Oh, really? I am going to have a big bone to pick with that husband of mind who pretends to be a scholar.

R: But mom, haven't you been saying that it is okay to make mistakes? And you made a mistake about Alhazen, didn't you? So why are you picking on Dad?

M: Rafa, this is between me and my husband. Children don't but in.

R: Dictator!

S: To change the topic, Mrs Zin, did Euclid formulate the law exactly the way we did?

M: I don't really know the details. But there is something I want you to think about. If you look at the textbooks, you will find these laws of reflection.

> The incident ray, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane.
>
> The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal.

A "normal" is a line perpendicular to the surface of reflection. Why are they bringing in the normal when they say the angles are equal? Why do they say that the incident ray, the reflected ray and the normal are on the same plane? What do we need these specifications for?

R: I don't know.

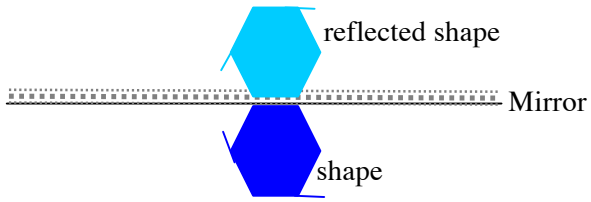
M: Rafa!

R: Okay, Mom, I'll think about it. Actually, Sandy and I will think about it and get back to you. Right, Sandy?

S: Yes, of course. Can I come back with Rafa tomorrow, Mrs Zin?

M: You are more than welcome, Sandy. I love discussing things with you.

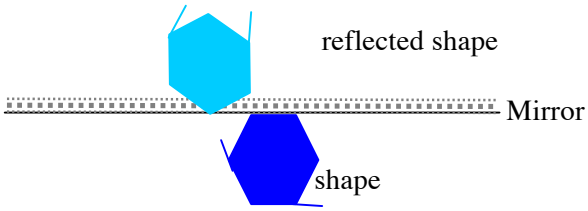
S. So I was thinking. Is this just a matter of a line? What if it is a two dimensional shape? The symmetry still holds, right?



M: Very good, Sandy. Rafa, do you know what symmetry is?

R: Yes, Sandy explained it to me. It is the same shape, but kind of flipped to the other side the along the axis of the mirror. Sandy is a math geek.

S: So I was thinking, what is the explanation for their symmetry, and that too, this particular symmetry? After all, it is logically possible that the image on the mirror is like this



M: Excellent question, kiddo. That is a future scientist talking. Do you have an explanation?

S: Well, not quite, but we have an idea.

M: I am all ears.