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Making a cat's eye in a classroom

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Making a cat's eye in a classroom

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Abstract

Three plain mirrors, perpendicular to each other, reflect a beam of light back into the direction it came from. An activity is suggested where pupils can employ this feature of perpendicular mirrors and make their own corner cube retroreflector—a kind of cat's eye.

Introduction

A child is taught to behave and act from early childhood in a way that is safe. An important part of safety training is teaching him the proper conduct when involved in traffic. For example, when walking in the dark by the side of the road, one should carry visible marks—reflectors—on clothing. If marks are not stitched on clothes, one should carry reflectors separately. What is so special about the reflector, that makes it visible in the dark?

Even the simplest natural laws have some employable properties from which young students can discover both the law and its application by themselves. We shall present an example, a simple application of the law of reflection. We shall start with the law and proceed, step by step, until we finally make a corner cube retroreflector, a model of the cat's eye[1]. The activity was designed as a part of the project Pollen, Seed Cities of Science, in Slovenia [1]. It encourages the first steps of primary school pupils into science with hands-on activities.

The law of reflection

First we should clarify the fact that the reflector is not a light source. It acts selectively—it makes the bearer visible only if he or she is illuminated by some other light source. The reflector reflects light strongly back into the direction it came from. How does this happen? Can we construct some kind of reflector?

One plane mirror reflects light, but generally not back in the direction the light came from. Therefore it cannot be used as a reflector. Nevertheless we first investigate light reflection on plane surfaces of mirrors.

The law of reflection is fairly obvious. Pupils can explore the reflection of a beam of light on a smooth surface of a plane mirror if they have a mirror, a torch, some cardboard, scissors and a dark classroom. They cut a narrow slit into the cardboard and fold it so it can stand perpendicularly on a flat surface, as shown in figure 1(a). They light it with a torch directed through the slit towards the plane mirror, which

[1] Here we use the name *cat's eye* a bit carelessly. We actually mean the *corner cube retroreflector*, which works as we explain herein. A *cat's eye* is a patented road reflector, a safety device [5], which also reflects light back to where it came from but it exploits another phenomenon. The light enters the refractive medium through a curved, usually spherical exterior surface S_1, then it reflects on the curved mirror S_2, which coincides with the focal surface S_2 of the exterior refracting surface S_1, and exits through the same exterior surface S_1 again. After refraction, reflection and another refraction, the direction of the light is inverted. The cat's eye device gets its name from the eyes of animals that are nocturnal, or are adapted to the low-light conditions of the deep sea. After reflection on a thin layer of tissue (by thin film interference) behind or within retina, the light passes the retina again and increases exposure of photoreceptors to light. In the dark the cat's eyes seem to *shine back* when they are exposed to light, due to refraction and reflection of incident light in the cat's eye.

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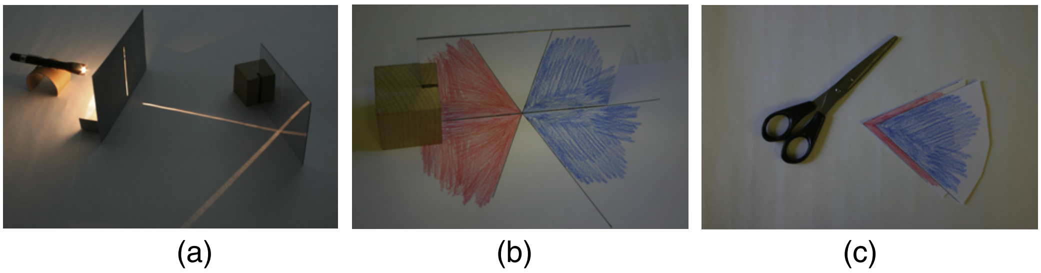


Figure 1. The law of reflection (a) demonstrated by coloured corners (b) which are compared and found equal (c).

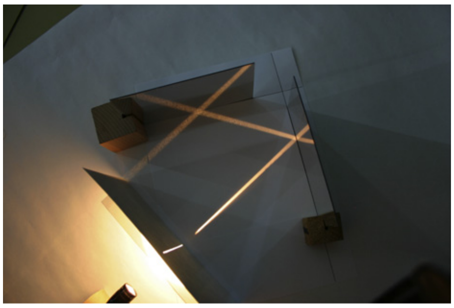


Figure 2. Two perpendicular plane mirrors invert the direction of the light beam.

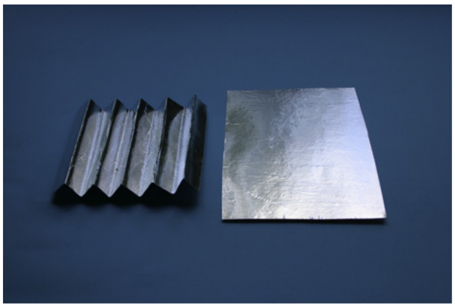


Figure 3. A planar ribbing construction of plane mirrors, which acts in the same way as two perpendicular mirrors.

also stands on a flat surface, and observe the reflected beam. They mark the position of the mirror and both incident and reflected beams on a piece of paper placed underneath, colour both corners (as shown in figure 1(b)) cut them out from the paper and compare them (see figure 1(c)). They find that both corners are the same and thus discover the law of reflection.

There is no law prohibiting subsequent reflections of our beam. It can reflect again, if we put another mirror in its way. At its second reflection the same law of equal corner angles holds.

Here comes the challenge: how should we place the two mirrors so the course of the beam is exactly inverted? The children can play and test different set-ups and they eventually come up with a solution—the two plain mirrors should be standing perpendicularly to each other. They can test different directions of the incident beam and discover that the beam is in all cases exactly inverted, as shown in figure 2. Two perpendicular plane mirrors already act as a simple reflector.

Simple and improved models of the reflector

It would be a bit awkward to walk around in the dark equipped with two large perpendicular plane mirrors, which extend into three dimensions. A more planar construction has advantages over an extended three-dimensional one. The pupils proceed as follows. From cardboard they cut a rectangle with sides approximately 10 and 15 cm long. Kitchen aluminum foil is stuck on the rectangle with its shiny side on the outside. The rectangle is then folded into a ribbing with approximately 1 cm wide ribs, as shown in figure 3. If the angles between the sides of the ribs are around 90°, the ribbing covered with shiny aluminum foil acts upon the light beam in just the same way as two perpendicular mirrors.

However, the ribbed reflector has its faults. It works properly only if the incident light beam lies in a plane perpendicular to the ribs. When a walking child is carrying such a reflector, it swings in all directions. In its general orientation it does not reflect light back towards the driver of the approaching car. So, the work is not finished yet.

(*a*) (*b*)

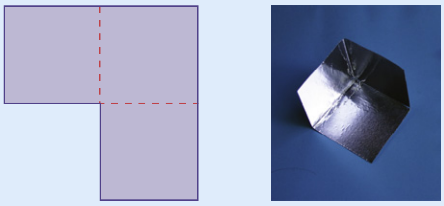


Figure 4. (*a*) A scheme for the cube corner and (*b*) internal side of the corner covered in aluminum foil.

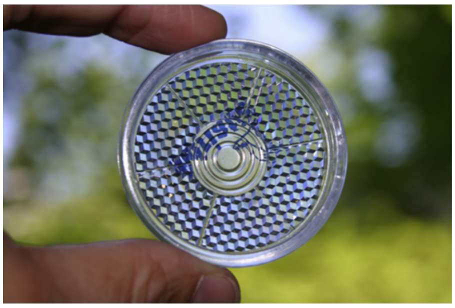


Figure 6. A close-up view of the surface of a 'real' reflector. It is composed of many small plastic cubes. The light enters the transparent plastic, experiences three total internal reflections on the corner surfaces and exits in the opposite direction on the same side as it entered.

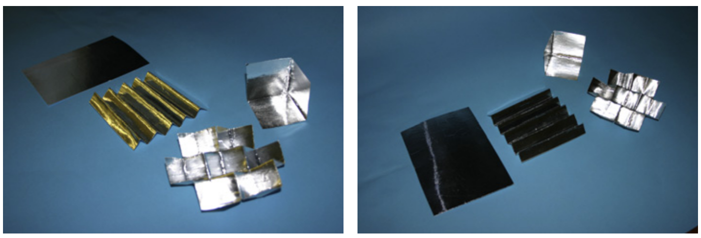
If we have already used two perpendicular plane mirrors, why do we not use three? Here is the next challenge—how should we put the third mirror against the first two? There is, of course, the third perpendicular plane. The three mirrors make the internal corner of a cube. The corner retroreflector was invented as part of the interferometer [2], and is nicely explained in many introductory textbooks on physics, for example in [3].

A sheet of aluminum foil is stuck on a scheme of a cube corner (shown in figure 4(*a*)) made of cardboard. The cube corner is obtained when the cut-out scheme is folded and the sides stuck together. The shiny aluminum side should be on the internal side of the corner, as shown in figure 4(*b*). When the corner reflector is put on trial in a dark room, illuminated by light from a torch, it is recognized as a perfect reflector. The photographs in figures 5(a) and (b) were made in darkness, and the light source was the flashlight of a camera. A 'driver' (a photographer) was behind his 'headlamps' (flashlight). The plane mirror appears dark, the ribbing reflector is somewhat brighter and the corner is clearly visible. These observations are independent of the photographing direction, as can be concluded when figures 5(a) and (b) are compared.

To avoid extended three-dimensional construction of the cube corner, the reflector can be made more planar. An array of small cube corners acts as one large cube corner. Some (but not all) real retroreflectors are made exactly like that, from many small internal cube corners compounded together, as shown in figure 6. Pupils can make their own compound retroreflectors from the scheme in figure 7(*a*). They need only some aluminum foil, cardboard, glue and scissors. One large cube corner or an array of many small cube corners work excellently as a reflector, as can be seen in figures 5(a) and (b).

Summary

We have presented an example of an activity for pupils where they gradually discover and implement the law of reflection by themselves. The motivation is clear from the beginning. By the end pupils should be able to understand how the simple corner cube reflector 'works'



(a) (b)

Figure 5. Candidates for the reflectors are photographed in darkness from two different viewing angles, (a) and (b). The flashlight simulates the car's headlamps.

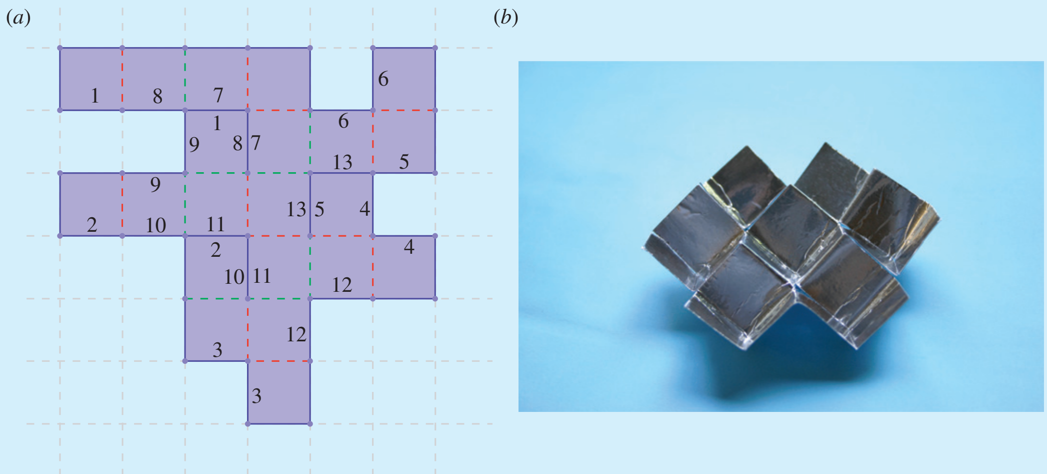


Figure 7. (*a*) A scheme for an array of seven cube corners. (*b*) The completed array. The scheme should be covered by aluminum foil, cut out and stuck together at edges with the same numbers. Black lines should be cut through. Green dashed lines indicate folding in one direction and red dashed lines indicate folding in the opposite direction.

and even to construct one by themselves. It is also interesting to know that such a simple device as a corner reflector can be found in a variety of applications—from taillights on cars and bicycles and radar markers on ships, to parts in interferometers or even in NASA projects. Several arrays of corner reflectors were installed on the Moon to measure its distance from Earth by measuring the time that a laser signal took to travel from Earth to the Moon and back again [4].

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