Light Science & Magic

Chapter 3 – The Family of Angles

In the last chapter we took a close look at light and how it behaves. We saw that the three most important qualities of any light source are its brightness, color, and contrast. We also saw that the subject, not just the light, has a major influence on lighting. A subject can transmit, absorb, or reflect the light that strikes it.

Of the three ways the subject can affect the lighting, reflection is the most visible. Highly transparent subjects have minimal effect on light, so tend to be invisible. Highly absorbent subjects may also be invisible because they convert light into other forms of energy, such as heat, which we cannot see.

Photographic lighting, therefore, is primarily an exercise in reflection management. Understanding and managing reflection, for the result the photographer wants, is good lighting. In this section, we will look at how subjects reflect light and how to capitalize on those reflections to your advantage.

We will begin our discussion of reflection with a "thought experiment". We would like you to create three different images in your mind. First, on a desk top, imagine a piece of very thick, perfectly smooth, gray paper. The gray should be a medium one, light enough to write on, but dark enough that no one would confuse it with white. Next, visualize a piece of metal of the same size as the paper. We suggest old pewter. The metal should also be smooth and exactly the same gray as the paper. Third, make a mental ceramic tile, very glossy and the same shade of gray as the other two subjects. Finally, put the three mental images together on the same desk and examine the differences you see in the three subjects.

Notice that none of the subjects transmits any light. (That is why we made the paper thick.) Furthermore, they all appear to absorb the same amount of light (because they are all the same gray). Yet, the difference in the three subjects is apparent. You have seen it. (If not, try again, and you will, now that you know we expect you to do so!)

The reason that these subjects, with identical transmission and absorption, appear different is that *the subjects reflect the light differently*. The reason you can see the differences without looking at examples on this page is that they are part of that visual knowledge you already have in the occipital lobe of your brain!

In this chapter, we are not going to tell you very many things your brain does not already know. We will, however, put some of that knowledge into words. This will make it easy for us to talk about reflection for the rest of this book.

TYPES OF REFLECTION

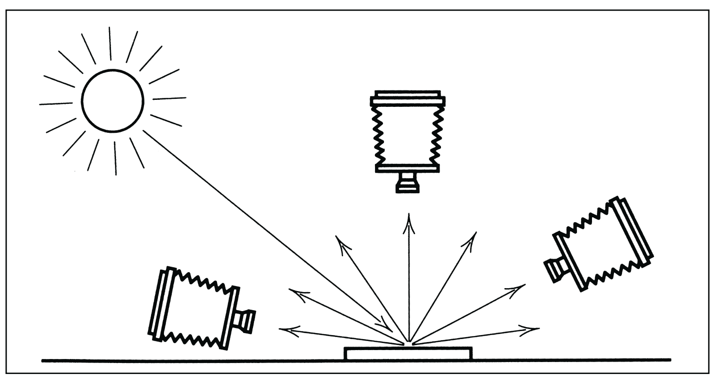
Light can reflect from a subject as either *diffuse reflection, direct reflection,* or *glare*. Most surfaces cause some of each of these three types. The proportions of each type of reflection vary with the subject, and it is the proportion of each reflection in the mix that makes one surface look different from another.

We are going to examine each of these types of reflections in some detail. In each case, we will assume that the reflection is a perfect example, uncontaminated by either of the other two. This will make it easier to analyze each of them. (Events in nature sometimes offer nearly perfect examples, but not quite.)

For now, we do not care what type of light source might be producing any of the following examples. Only the reflecting surface matters. Any sort of light could work.

DIFFUSE REFLECTION

Diffuse reflections are the same brightness regardless of the angle from which we view them. This is because the light from the sources is reflected equally in all directions by the surface it strikes. Figure 3.1 shows a diffuse reflection. In it we see light falling on a small white card. Three people are pointing their cameras at it.

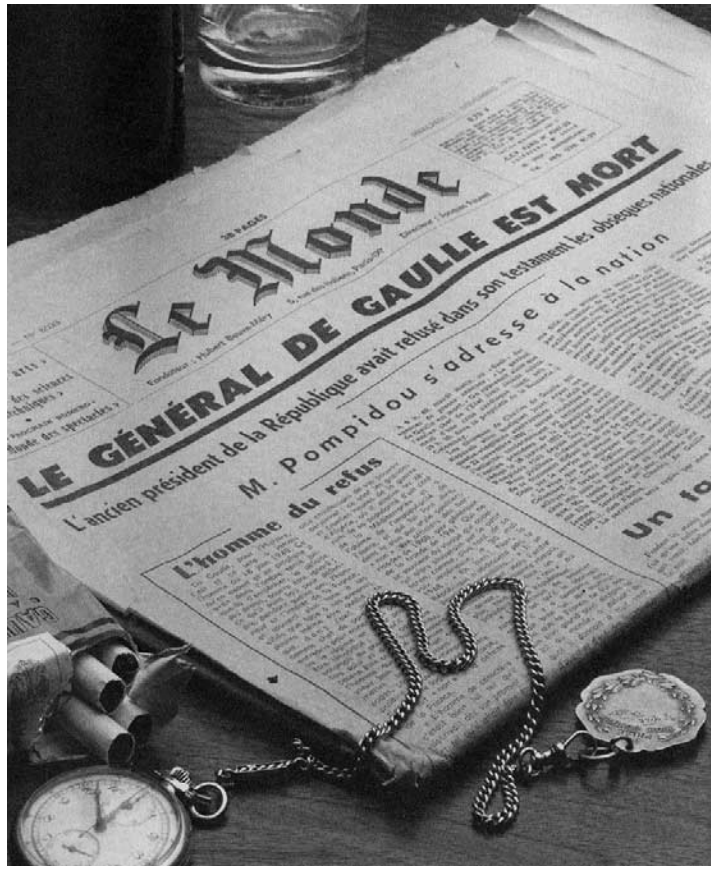


3.1 *A white card gives off almost nothing but diffuse reflection. Because diffuse reflection from a light source is reflected equally in all directions from the surface, all three cameras see the card as having the same brightness.*

If each of these individuals were to photograph the white card, each of their pictures would record the subject as the *same brightness.* The the card would have the same grayscale value in each picture. Neither the angle of illumination of the light source nor the camera's angle of view would affect the brightness of the subject in such a picture.

Hunter, Fil, and Paul Fuqua. **Light – Science & Magic, 3rd Edition.** Boston: Butterworth-Heinemann, 2005.

3.2 *The newspaper in this scene gives off primarily diffuse reflection. It would appear white from any angle.*



3.3 *The soft shadows prove we used a large light. The highlights in the newspaper look the same because the size of the light source does not alter the appearance of diffuse reflection.*

Other than in lighting textbooks, no surfaces reflect light in a perfectly diffuse manner. However, white paper sometimes approximates such a surface. Now look at Figure 3.2. Notice that the scene contains a mostly white sheet of newspaper.

There is a reason that we choose to put the white newsprint in this particular example. All white things produce a great deal of diffuse reflection. We know this because they appear white regardless of the angle from which we view them. (Walk around the room you are in now. Look at the white objects and the black objects from different angles. Notice that the apparent brightness of the black objects may change with viewpoint, but the white objects stay about the same!)

The contrast of the light source does not affect the appearance of a diffuse reflection. It is worth proving this with one more picture of the same scene. The earlier photograph was lit by a small light. We could see that by the hard shadows cast by the objects in it. Now look at Figure 3.3 to see what happens when we use a large light instead.

Diffusion Confusion

In Appendix 1, we discuss diffusion of the light source by reflecting the light from an umbrella or by covering it with a translucent material. We call light passing through translucent material *diffuse transmission*. Now we speak of *diffuse reflection.* The two concepts have enough in common that we should pay special attention to the differences between them.

Diffusing the light source has no effect on whether the reflection is diffuse. Remember that small light sources are always “hard” (undiffused) and that large light sources are almost always “soft” (diffused). Then notice that Figures 3.2 and 3.3 show diffuse reflections produced by both diffused and undiffused light sources. Similarly, Figures 3.5 and 3.6 show direct reflections produced by diffused and undiffused light sources.

The word *diffusion* is a good one because its meaning is perfectly consistent in both uses. In each case, it means a scattering of the light. But *what* does the scattering, the light or the subject? The source determines the type of light and the surface determines the type of reflection. Any light can produce any reflection, depending on the subject.

Predictably, the large light source has softened the shadows in the scene. But notice that the highlights on the paper look about the same. The diffuse reflection from the surface of the paper is identical to that in Figure 3.2.

So we now have seen that neither the angle nor the size of the light source affects the appearance of a diffuse reflection. However, the distance from the light to the surface of the subject does matter. The closer the light gets to the subject, the brighter the subject becomes, and, at a given exposure setting, the lighter the subject appears in the finished picture.

The Inverse Square Law

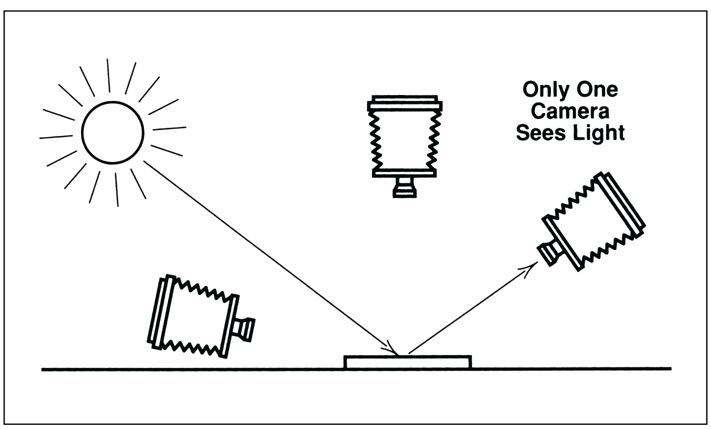
A diffuse reflection gets brighter if we move the light source closer to the subject. If we needed, we could calculate this change in brightness with the *inverse square law*. The inverse square law says that intensity is inversely proportional to the square of the distance. Thus, a light at any particular distance from the subject will light the subject with an intensity four times as bright as the same light twice as far away. Similarly, a light will have nine times the intensity of the same light moved three times as far from the subject. As the intensity of the light falling on the subject varies, so does that of the diffuse reflection.

Ignoring the math, this simply means that reflection from a surface gets brighter if we move the light closer and dimmer if we move the light farther away. Intuitively, this seems immediately obvious. Why even bother to mention it? Because such intuition is often misleading. Some subjects, as we shall soon see, do not produce brighter reflections as the light moves closer to them!

DIRECT REFLECTION

Direct reflections are a mirror image of the light source that produces them. They are also called *specular* reflections.

Figure 3.4 is similar to Figure 3.1, but this time we have replaced the white card with a small mirror. Both the light source and the observers are in the same positions as they were earlier. Notice what happens. This time one of the three cameras now sees



***3.4** Direct reflection. Looking at the mirror, one of the cameras sees a blinding reflection of the light source, while the others see no reflection at all.*

a blindingly bright reflection, while the others see no reflection at all in the mirror.

This diagram illustrates the direct reflection produced when a light is directed at a polished surface such as glass. The light rays bounce from the smooth surface at the same angle at which they hit it. More precisely stated: *the angle of incidence equals the angle of reflectance*. This means that the point at which direct reflections can be seen is exactly determined by the angles between the light source, the subject, and the camera viewpoint.

So, with all that in mind, it is easy to see why the three cameras see such a difference in the brightness of the mirror. Those positioned on each side receive no reflected light rays. From their viewpoint the mirror appears black. None of the rays from the light source is reflected in their direction because they are not viewing the mirror from the one (and *only*) angle in which the direct reflection of the light source can happen.

However, the camera that is directly in line with the reflection sees a spot in the mirror as bright as the light source itself. That is because the angle from its position to the glass surface is the same as the angle from the light source to the glass surface. Again, no real subject produces a perfect direct reflection. But brightly polished metal, water, or glass may nearly do so.

Specular Reflection and Specular Light

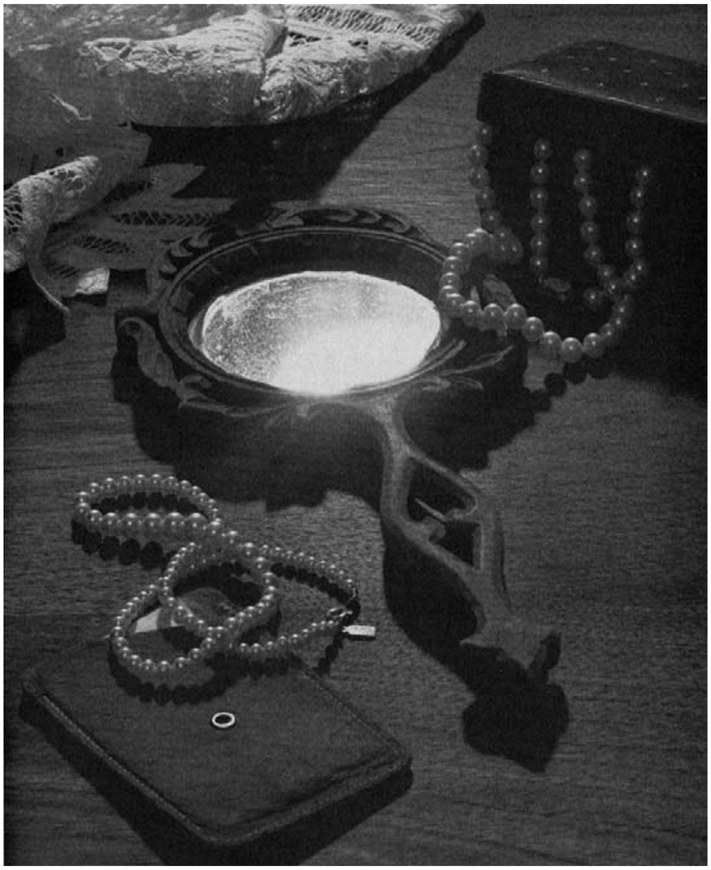
Photographers sometimes call direct reflection *specular reflection.* As a synonym for direct reflection this is a perfectly good term. If you use the word specular in this way, please feel free to substitute the words as you read *direct reflection*.

However, some photographers also use specular to mean smaller, brighter highlights within a large one; others mean highlights created by a small light source. *Direct reflection* does not necessarily imply either of these. Because *specular reflection* has different meanings to different people, we will not use the term in this book.

Modern usage adds further inconsistency. Originally *specular* was used only to describe the reflection, not the source of the light. (The Greek root means “mirror”.) Today, some photographers use specular light as a synonym for hard light, but a “specular” light source does not necessarily produce a “specular” reflection! A hard light is always hard, but the way it reflects depends on the surface of the subject. So we will always call specular lights *hard* in order to make it clear that we are talking about the light, not the reflection.

Breaking the Inverse Square Law?

Did it alarm you to read that the camera that sees the direct reflection will record an image “as bright as the light source”?



***3.5** Two clues tell us this picture was made with a small light source: hard shadows and the size of the reflection in the mirror.*

***3.6** A larger light softens the shadow. More importantly, the reflection of the light now completely fills the mirror. This is because the light we used this time was large enough to fill the family of angles that causes direct reflection.*

How do we know how bright the direct reflection will be if we do not even know how far away the light source is?

We do not need to know how far away the source is. The brightness of the image of a direct reflection is the same regardless of the distance from the source. This principle seems to stand in flagrant defiance of the inverse square law, but an easy experiment will show why it does not.

You can prove this to yourself, if you like, by positioning a mirror so that you can see a lamp reflected in it. If you move the mirror closer to the lamp, it will be apparent to your eye that the brightness of the lamp remains constant.

Notice, however, that the *size* of the reflection of the lamp *does* change. This change in size keeps the inverse square law from being violated. If we move the lamp to half the distance, the mirror will reflect four times as much light, just as the inverse square law predicts. But the *image* of the reflection covers four times the area, so this image still has the same density on the negative (or brightness, at the CCD). In plainer words, if we spread four times the butter on a piece of bread of four times the area, the thickness of the butter stays the same.

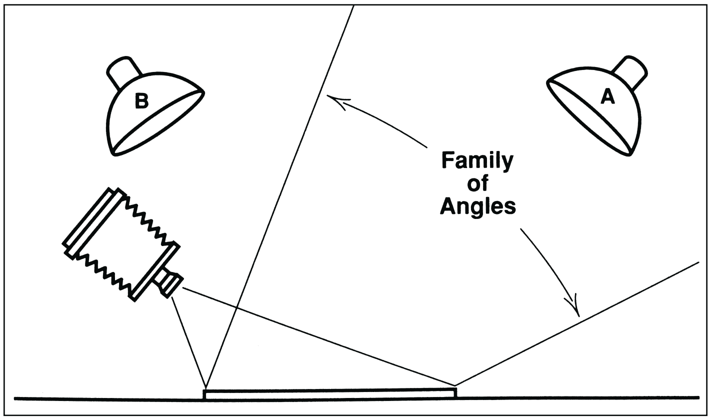
Now we will look at a photograph of the scene in the previous diagram. Once again, we will begin with a high-contrast light source. Figure 3.5 has a mirror in place of the earlier newspaper. Here we see two indications that the light source is small. Once again, the shadows are hard. Also, we can tell that the source is small because we can see it! It is reflected in the mirror. Because the image of the light source is visible, we can easily anticipate the effect of an increase in the size of the light. This allows us to plan the size of the highlights on polished surfaces.

Now look at Figure 3.6. Once again, the large, low-contrast light source produces softer shadows. The picture is more pleasing, but that is not the important aspect. More important is the fact the reflected image of the large light source completely fills the mirror. In other words, the larger light source fills the *family of angles that cause direct reflection*. This family of angles is one of the most useful concepts in photographic lighting. We will discuss that family in detail.

THE FAMILY OF ANGLES

Our previous diagrams have been concerned with only a single point on a reflective surface. In reality, however, each surface is made up of an infinite number of points. A viewer looking at a surface sees each of these points at a slightly different angle. Taken together, these different angles make up the family of angles that produce direct reflection.

In theory, we could also talk about the family of angles that produce diffuse reflection. However, such an idea would be meaningless because diffuse reflection can come from a light source at *any* angle. Therefore, when we use the phrase *family of angles* we always mean those angles that produce direct reflection.



3.7 *Light A, positioned within the family of angles, will produce a direct reflection. Light B, outside the family of angles, will not.*

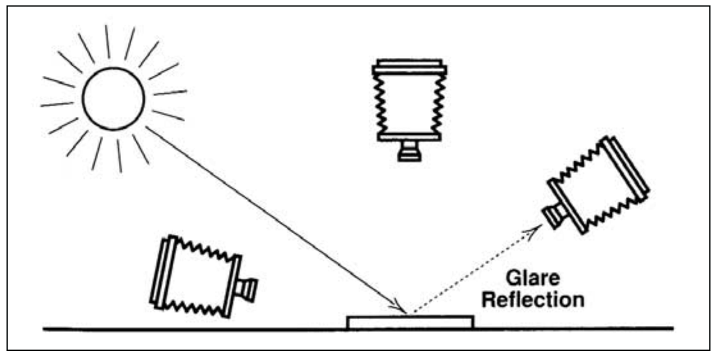
This family of angles is important to photographers because it determines where we should place our lights. We know that light rays will always reflect from a polished surface, such as metal or glass, at the *same* angle as that at which they strike it. So we can easily determine where the family of angles is located, relative to the camera and the light source. This allows us to control if and where any direct reflection will appear in our picture. Figure 3.7 shows the effect of lights located both inside and outside this family of angles. As you can see from Figure 3.7, any light positioned *within* the family of angles will produce a direct reflection. A light placed anywhere else will not. Consequently, any light positioned *outside* of the family of angles will not light a mirror-like subject at all, at least as far as the camera can see.

Photographers sometimes want to see direct reflection from most of the surface of a mirror-like subject. This requires that they use (or find in nature) a light large enough to fill the family of angles. In other scenes, they do not want to see any direct reflection at all on the subject. In those instances, they must place both the camera and the light so that the light source is not located within the family of angles. We will use this principle repeatedly in the coming chapters.

> **Increasing Glare**
>
> Most photographers know that polarizers can eliminate glare they do not want. But in some scenes we may like the glare and even want more of it. In such cases we can use the polarizer to effectively *increase* glare. We do this by rotating the polarizing filter ninety degrees from the orientation that reduces glare. The glare then passes through easily.
>
> It is important to understand that a polarizer always blocks some unpolarized light. By doing this, in effect, it becomes a neutral density filter that affects everything except direct reflection. Thus, when we increase the exposure to compensate for the neutral density, the direct reflection is increased even more.

GLARE REFLECTION

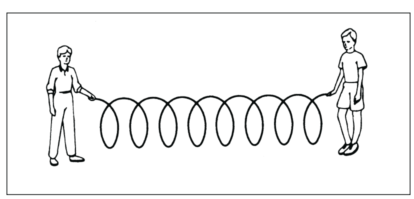
A *glare reflection* is a *polarized* direct reflection. In every other way, it is so similar to an simple direct reflection that we could treat them as the same. However, polarization of glare reflections gives photographers several specialized techniques and tools for dealing with them.



3.8 *Polarized direct reflection is called* glare reflection, *or* glare *for short. It looks like unpolarized direct reflection, only dimmer.*

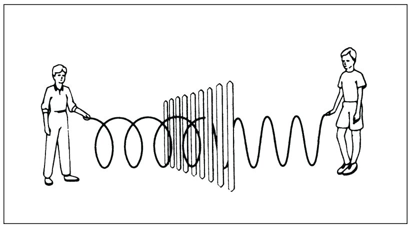
Like the direct reflection, only one viewer in Figure 3.8 will see the reflection. Unlike the direct reflection, an image of the glare is always substantially dimmer than a photograph of the light source itself. A *perfectly* polarized direct reflection is exactly half as bright as an unpolarized one (provided the light source itself is not polarized). However, since polarization is inevitably accompanied by absorption, the reflections we see in the scene are more likely to be much dimmer than that. To see why polarized reflection cannot be as bright as an unpolarized direct reflection, we need to know a bit about polarized light.

We have seen that the electromagnetic field fluctuates around a moving photon. In Figure 3.9 we have represented this fluctuating field as a jump rope being swung between two children. One child is spinning the rope while the other simply holds it.



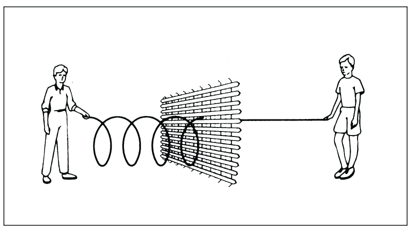
3.9 *An oscillating electromagnetic field around a photon represented as a jump rope. The child on the left is spinning the rope while the one on the right holds on.*

Now, let us imagine that a neighbor quickly puts up a picket fence between the children, as shown in Figure 3.10. The rope now bounces up and down instead of swinging in an arc. This bouncing rope resembles the electromagnetic field along the path of a photon of polarized light.



3.10 *When the children are forced to spin the rope through the picket fence, it bounces up and down instead of spinning in an arc. A* polarizing filter *blocks the oscillation of light energy the same way.*

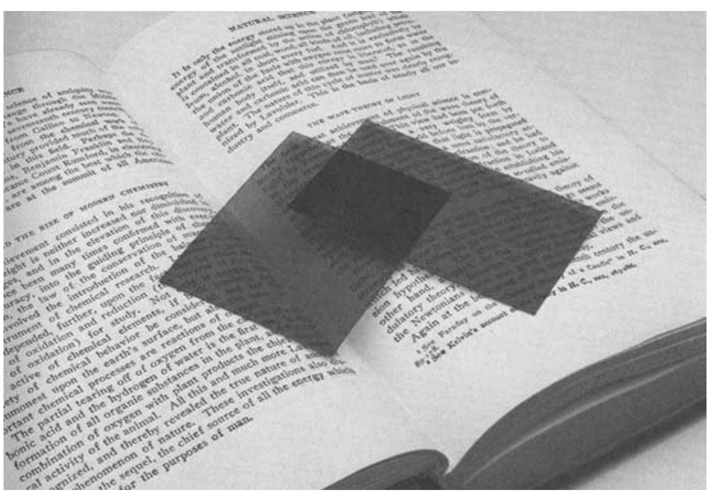
Molecules in a polarizing filter block the oscillation of the light energy in one direction, just as the picket fence does to the oscillating energy of the jump rope. The molecular structure of some reflecting surfaces also blocks part of the energy of the photon in still the same manner. We see such a photon as a polarized reflection or glare.



3.11 *This time the nasty neighbor has ruined the children's play by adding a horizontal fence to the first. Now, if one child spins the rope, the other will see no movement.*

Now suppose the same neighbor, not satisfied with eliminating just a part of the children's play, installs a horizontal fence in front of the first, as shown in Figure 3.11.

Now, with the second fence in place, if one child spins the rope, the other sees no rope movement at all. The crossed picket fences block the transmission of energy from one end of the rope to the other. Crossing the axes of two polarizing filters blocks the transmission of light, just as the two picket fences do with rope energy. Figure 3.12 shows the result. Where the polarizers overlap with their axes perpendicular, none of the type is invisible. The transmission of light reflected from the page to the camera has been completely blocked.



3.12 *The two overlapping polarizers have their axes perpendicular. They block light just as the two fences did with the energy of the jump rope.*

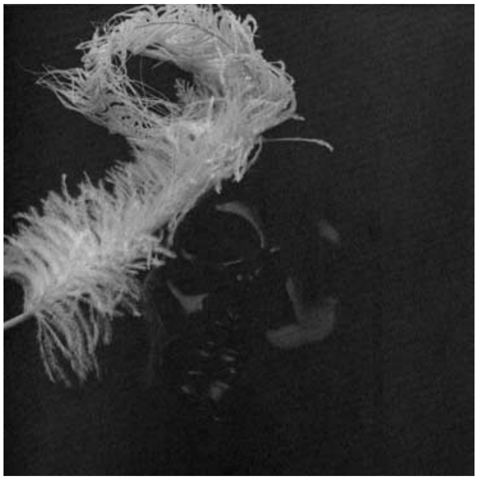
A lake, painted metal, glossy wood, or plastic can all produce glare reflection. Like the other types of reflection, the glare is not perfect. Some diffuse reflection and some unpolarized direct reflection are mixed with the glare. Glossy subjects produce the most glare.

Glare is more likely to be visible if the subject is black or transparent. Black and transparent subjects do not necessarily *produce* stronger direct reflections than white ones. Instead, they produce weaker diffuse reflection, making it easier to *see* the direct reflection. This is why you saw the change in apparent brightness of the black objects, but not of the white ones, when you walked around your room a while ago.

3.13 *The glossy black plastic sheet and mask give off almost nothing but polarized direct reflection. The feather gives off almost nothing but diffuse reflection.*

Glossy black plastic can show us enough glare reflection to make a good example. The scene in Figure 3.13 includes a black plastic mask and a feather. They are placed on a sheet of glossy black plastic. We used the same camera and light position as in the pictures of the newspaper and the makeup mirror. However, this time we begin with a large light source rather than a small one. Both the mask and the plastic sheet produce nearly perfect glare reflection. From this angle, glossy plastic produces almost no unpolarized direct reflection; and black things never produce much diffuse reflection. However, the feather behaves quite differently. It produces almost nothing but diffuse reflection.

The light source was large enough to fill the family of angles defined by the plastic sheet, creating glare over the entire surface. The same light was large enough to fill only part of the family of angles defined by the mask. We know this because of the highlights we see only on the front of the mask. Predictably, the glare reflection in this picture looks like unpolarized direct reflection, but it is far less bright.



3.14 *A polarizer over the camera lens blocks the polarized direct reflection. Only the feather, which gives off diffuse reflection, is easily visible.*

Now look at Figure 3.14. We made it with the same setup we used with the previous picture, only this time we placed a polarizing filter over the camera lens. Since glare was almost the only reflection from the black plastic in Figure 3.14, and since the polarizing filter blocks glare, little of the light reflected from them reached the camera. As a result, the plastic now looks black.

We did have to open our aperture by about two stops to compensate for the neutral density of the polarizing filter. How do you know that we did not accidentally miscalculate the exposure? (Maybe we did so deliberately, just to get the image dark enough to prove our point?) The feather proves that we did not. The polarizer did not block the diffuse reflection from the feather. So, with accurate exposure compensation, the feather is about the same gray in both pictures.

Is It Glare or Simple Direct Reflection?

Polarized and unpolarized direct reflections often have similar appearance. Photographers, out of need or curiosity, may want to distinguish one from the other.

We know that direct reflection appears as bright as the light source, while glare reflection appears dimmer. However, brightness alone will not tell us which is which. Remember that real subjects produce a mixture of reflection types. A surface that seems to have glare may actually have weak direct, plus some diffuse, reflection.

How do we know whether a reflection is polarized? We cannot always tell by immediate appearance, but here are a few guidelines that tend to indicate which it is:

- If the surface is made of a material that conducts electricity (metal is the most common example), its reflection is likely to be unpolarized. Electrical insulators, for example, plastic, glass, and ceramics, are more likely to produce polarized reflection.
- If the surface *looks* like a mirror, for example, bright metal, the reflection is likely to be simple direct reflection, not glare.
- If the surface does not have a mirror-like appearance, for example, polished wood or leather, the reflection is more likely to be glare if the camera is seeing it at an angle of forty to fifty degrees. (The exact angle depends on the subject material.) At other angles, the reflection is more likely to be unpolarized direct reflection.
- The conclusive test, however, is the appearance of the subject through a polarizing filter. If the polarizer eliminates the reflection, then it is glare. If, on the other hand, the polarizer has no effect on the suspect reflection, then it is simple direct reflection. If the polarizer reduces the reflection but does not eliminate it, then it is a mixed reflection.

Turning Simple Direct Reflection into Glare

Photographers often prefer that a reflection be glare so that they can manage it with a polarizing filter mounted on their camera lens. If the reflection is not glare, the polarizer on the lens will have no effect except to add neutral density.

However, placing a polarizing filter over the *light source* will turn a direct reflection into glare. A polarizer on the camera lens can then manage the reflection quite nicely.

Outdoor photographers who lack the luxury of studio lighting find that the open sky often serves as a beautifully functional polarized light source. Facing the subject from an angle that reflects the most polarized part of the sky can make the lens polarizing filter effective. This is why photographers sometimes find polarizing filters useful on subjects such as bright metal, even when the filter manufacturer has told them that polarizers have no effect on such subjects. In those cases, the subject is reflecting a polarized source.

APPLYING THE THEORY

Excellent recording of a subject requires more than focusing the camera properly and exposing the image accurately. The subject and the light have a relationship with each other. In a good photograph, the light is appropriate to the subject and the subject is appropriate to the light.

The meaning of *appropriate* is the creative decision of the photographer. Any decision the photographer makes is likely to be appropriate if it is guided by understanding and awareness of how the subject and the light *together* produce an image.

We must decide what type of reflection is important to the subject and then capitalize on it. In the studio, this means *manipulating* the light. Outside the studio, it often means getting the camera position, anticipating the movement of the sun and clouds, waiting for the right time of day, or otherwise *finding* the light that works. In either case, the job is easier for the photographer who has learned to see what the light is doing and to imagine what it could do.