REFLECTION

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REFLECTING SURFACES

A ray of light may be turned through an angle by being reflected at a suitable surface. (Bear in mind that some reflection occurs together with any refraction.) Highly polished glass will reflect only approximately 4% of the incident light near to normal incidence, whereas highly polished silver reflects about 95% of the incident light. Many other reflecting surfaces may be used (even obsidian!), but in all cases, some loss of energy occurs.

The original optical reflecting surface was a chemical deposit of silver on glass. The silver was on the front surface (front-reflecting mirror), in contrast to reflectors produced by depositing a layer of aluminium or tin amalgam on the back of a sheet of glass (back-reflecting mirror).

One of the main drawbacks to using such back-reflecting mirrors is the formation of multiple images. For this reason, back-reflecting mirrors are never used in high-grade optical equipment and instruments.

The glass used for front-reflecting mirrors need not be of the best quality because the light does not actually pass through it. The glass is simply a carrier for the reflecting surface. However, the deposit may not be able to be protected against corrosion and may have to be renewed at frequent intervals.

REFLECTION AT PLANE SURFACES

All real objects reflect a certain proportion of the light falling upon them, and it is this reflected light that enables us to see them. In most cases, the surface of the object has irregularities that spread out an initially parallel beam of light in all directions to produce *diffuse* reflection.

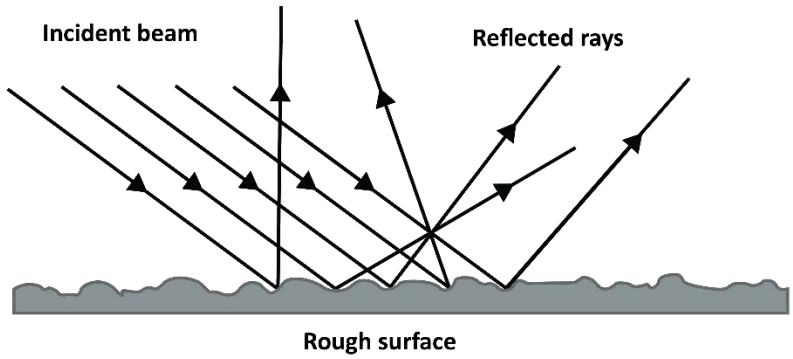

Figure 6.1: *Irregular surface causing diffuse reflection*

A surface so smooth that any irregularities in it are small relative to the wavelength of light falling on it behaves differently. When a parallel pencil of rays of light is incident on such a surface, it is reflected in a single definite direction. Such reflection in one definite direction is termed *regular* or *specular* reflection.

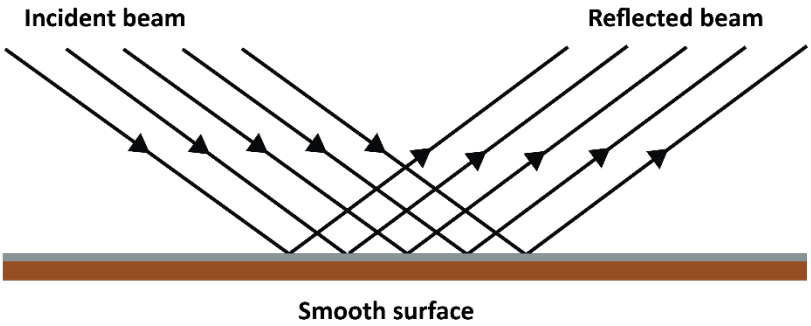

Figure 6.2: *Regular surface causing specular reflection*

For instance, consider the two types of reflection from a road surface that one sees while driving at night. When the road is dry, light from oncoming vehicles is scattered off the road in different directions (diffuse) and the road is quite visible. This diffuse reflection is also responsible for the perception of depth which makes the raised road markings visible.

On a rainy night, when the road is wet, the road irregularities are filled with water. Because the wet surface is quite smooth, the light undergoes specular reflection. This means that the light is reflected straight ahead and the driver only sees what is directly in front.

Our concern in this course is only with this specular reflection.

LAWS OF SPECULAR REFLECTION

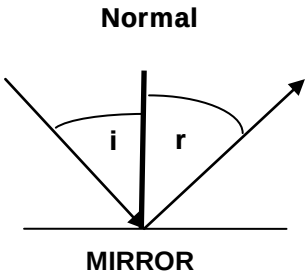

Figure 6.3: *Incident and reflected angle on a mirror surface*

This diagram shows light being reflected from the surface of a smooth plane mirror. Note, once again, that the angles are measured between the ray and the normal.

Law 1: The angle of incidence is equal to the angle of reflection.

Law 2: The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

One of the consequences of these laws is a common occurrence in photographs of individuals – their eyes appear to be glowing red. This occurs when a flash unit is used and the unit is very close to the camera lens. The light from the flash unit will enter the eye normally and will thus be reflected back along its original path from the retina. This reflected light can enter the lens. Most of the light reflected from the retina is red, mainly due to the blood vessels at the back of the eye, giving the “red-eye effect”.

IMAGE FORMED BY A PLANE MIRROR

The image formed by a plane mirror can be analyzed by graphical construction in a similar fashion to what we did with lenses. The results of this analysis give the *characteristics of the image formed by a plane mirror.*

The image is:

1. as far behind the mirror as the object is in front.
2. the same size as the object.
3. virtual.
4. erect.
5. laterally inverted.

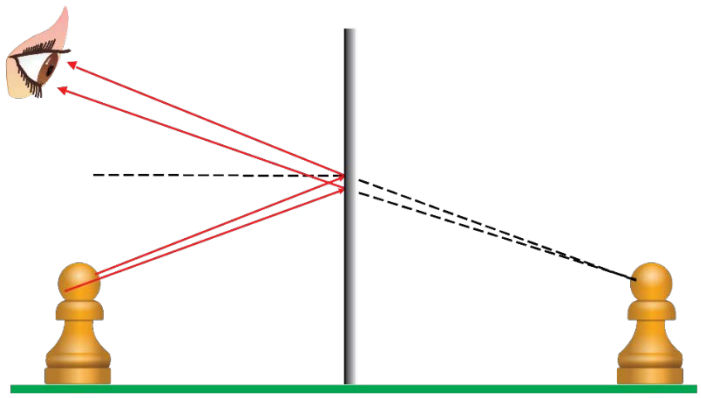

Figure 6.4: *Image formed by a plane mirror*

Lateral inversion refers to the phenomenon that the image is reversed from left to right in comparison to the object. For example, when you look in a mirror and touch your right ear, it is the left ear being touched in the image.

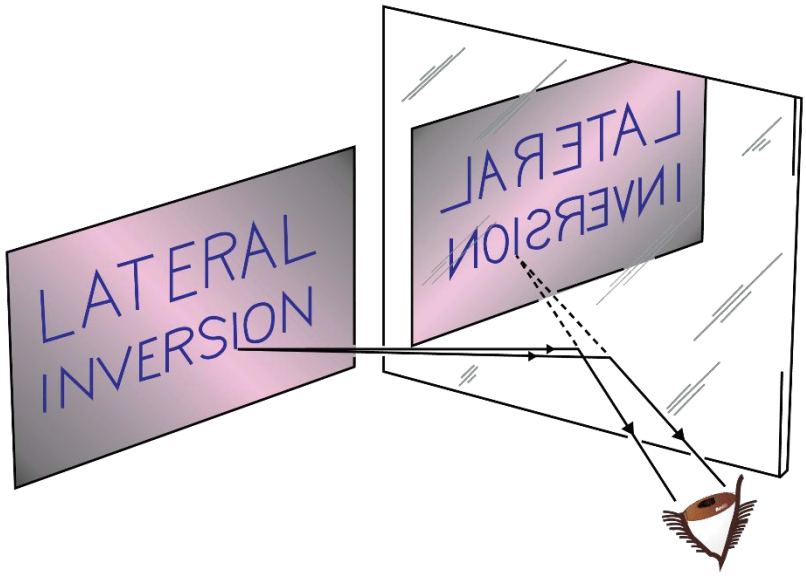

Figure 6.5: *Lateral inversion in mirrors*

ROTATION OF REFLECTED RAY

If a ray is incident on a plane mirror at an angle ***i,*** the angle of reflection is also equal to ***i.*** The angle between the two rays will thus be 2***i***.

Suppose now that the mirror is rotated through an angle **θ**. The angle of incidence will increase by **θ** and so will the angle of reflection. The total angle between the two rays is now 2***i***+ 2**θ**. Consequently, the angle of reflection will rotate through an angle of 2**θ**. Thus, *the reflected ray rotates through twice the angle through which the mirror rotates.*

This important effect may be used as a magnifying device for small rotations in applications known as **optical levers**.

MULTIPLE IMAGES

With a thick back-silvered plane mirror, some light is always reflected at the front surface. The amount of reflected light is greater if the incident angle is large. When a brightly illuminated object is viewed at fairly large angles of incidence a series of “ghost images” may be observed in addition to the main bright image.

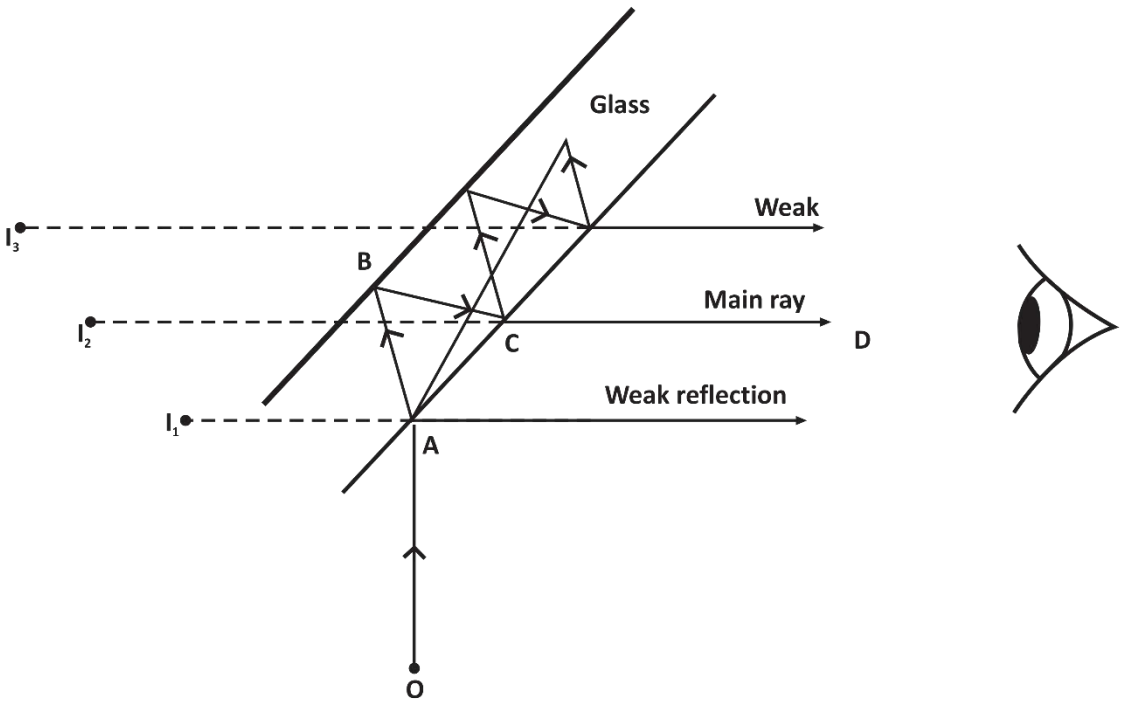

Figure 6.6: *Ghost images in thick back silvered mirror*

This phenomenon is applied in the rearview mirrors of cars that have a day setting and a night setting. The night setting greatly diminishes the intensity of the image so that lights from trailing cars will not blind the driver. To understand how such a mirror works, consider the figure. The mirror is a wedge of glass with a reflecting metallic coating on the back surface. When the mirror is in the *day* setting, as in (a, below), light from an object behind the car strikes the mirror at point 1. Most of the light enters the wedge, is refracted, and reflects from the back of the mirror to return to the front surface, where it is refracted again as it re-enters the air as ray B (for *bright).* In addition, a small portion of the light is reflected at the front surface, as indicated by ray D (for *dim*).

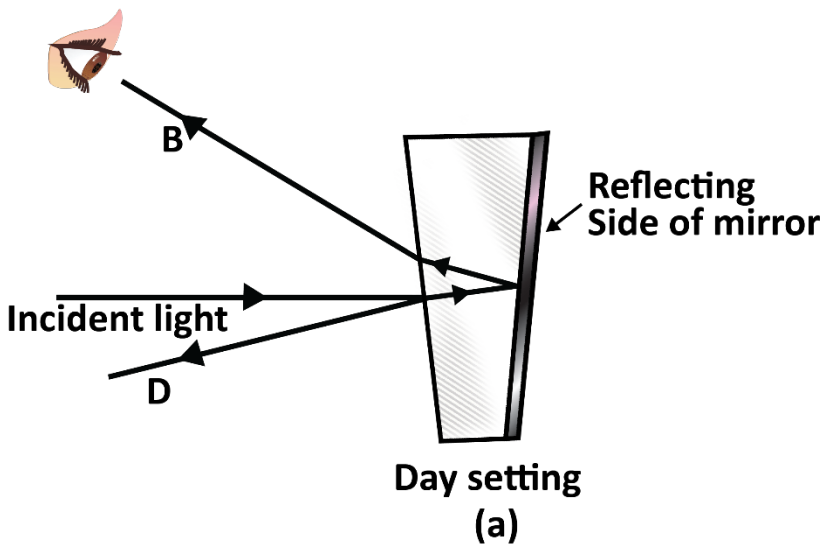

Figure 6.7: *Day setting in a rearview mirror*

This dim reflected light is responsible for the image observed when the mirror is in the night setting, as in (b). In this case, the wedge is rotated so that the path followed by the bright light (ray B) does not lead to the eye. Instead, the

dim light reflected from the front surface travels to the eye, and the brightness of trailing headlights does not become a hazard.

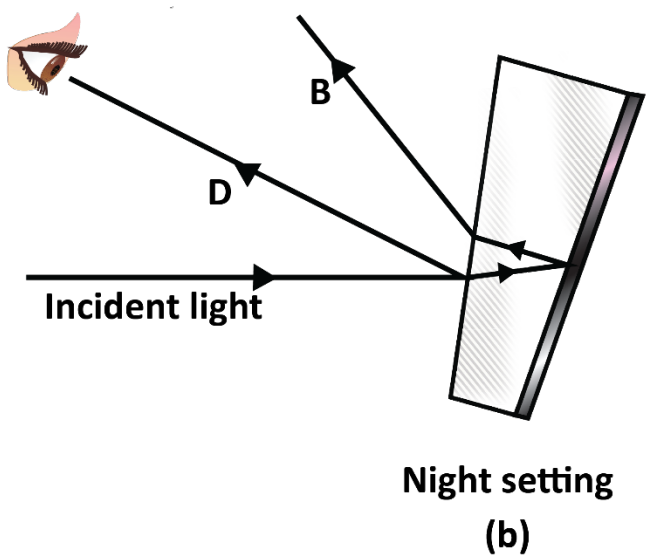

Figure 6.8: *Night setting in a rearview mirror*

REFLECTION AT CURVED MIRRORS

Curved mirrors are reputed to have been in use since the time of the ancient Greeks. Euclid, in his writings, referred to both concave and convex mirrors. Curved mirrors may sometimes be used as alternatives to lenses to form images of objects. They are not as widely used as lenses, but find application as car driving mirrors, in reflecting telescopes, cinema projectors, and slide projectors.

The optical properties of spherical mirrors, where each mirror is part of the surface of a sphere, will now be considered. The type of mirror may be classified as **concave** or **convex** dependent on which surface is coated with a reflecting layer.

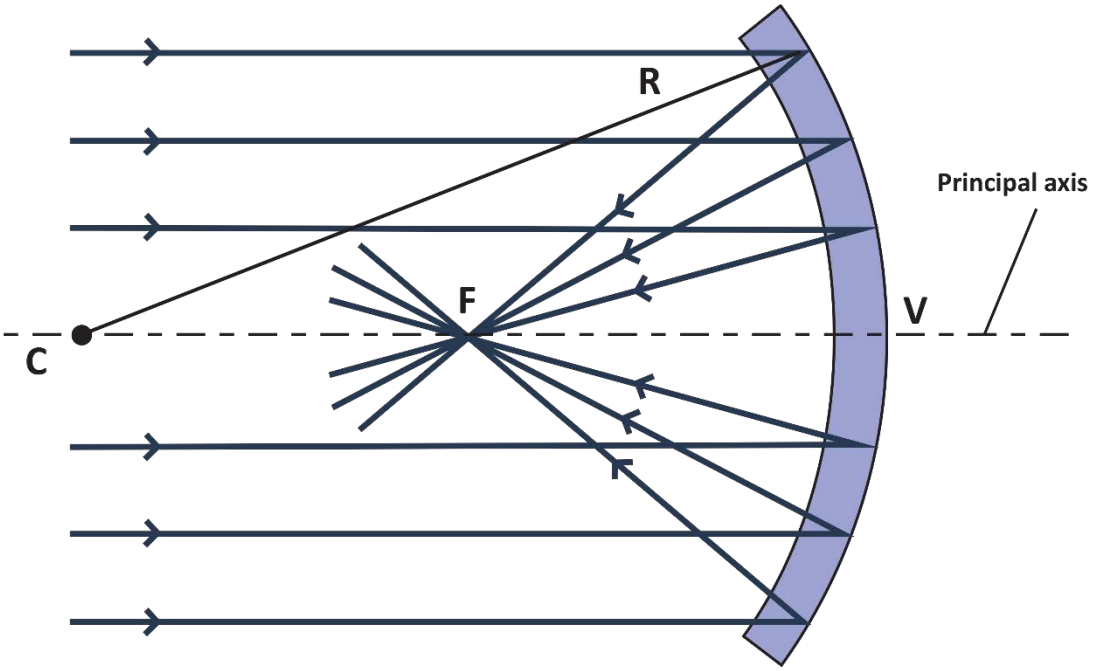

Figure 6.9: *Concave mirror*

The *principal axis* of a spherical mirror is the line passing through the *vertex* or *pole* (the centre of the mirror) and the *centre of curvature* which is the centre of the sphere of which the mirror forms a part. The *radius of curvature* r is the distance from the vertex to the centre of curvature. In the case of a concave mirror, the centre of curvature is in front of the mirror; in a convex mirror it is behind.

When a parallel beam of light falls on a plane mirror it is reflected as a parallel beam; but in the case of a **concave** mirror the rays in a parallel beam are all reflected so as to converge to a point called a *focus* or *focal point.* If the incident rays are parallel to the principal axis, the point through which all the reflected rays pass is on the principal axis just midway between the pole and the centre of curvature and is called the *principal focus*, F.

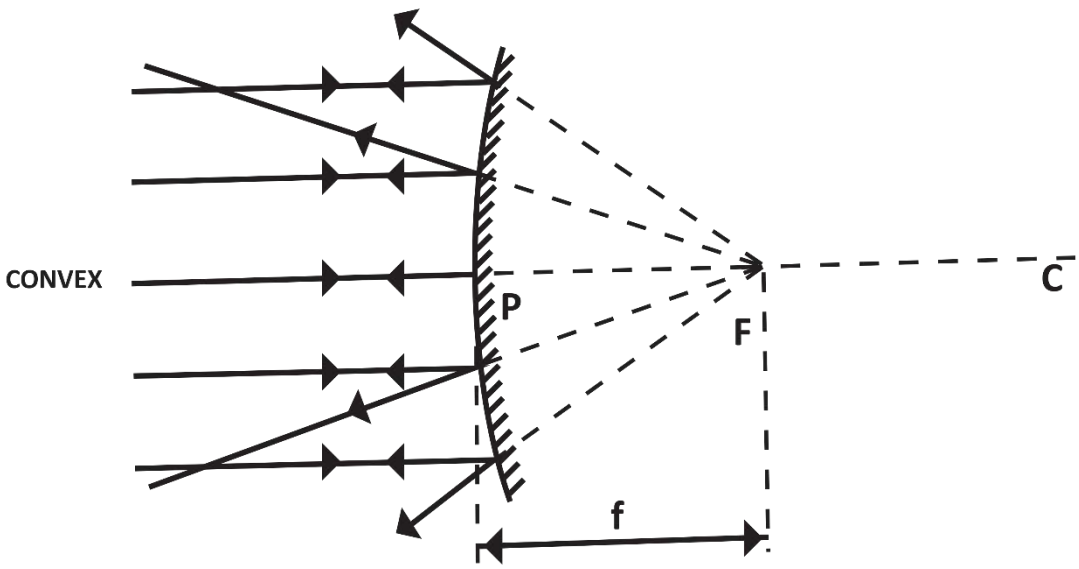

Figure 6.10: *Convex mirror*

The previous figure shows what happens when a beam of light parallel to the principal axis falls on a **convex** mirror. In this case the rays are reflected so that they all appear to be coming from a principal focus midway between the pole and centre of curvature *behind* the mirror. A concave mirror, therefore, has a real principal focus, while a convex mirror has a virtual one.

We can now state the following: **The principal focus of a spherical mirror is the point on the principal axis to which all parallel rays converge, or from which they appear to diverge, after reflection from the mirror.**

The focal length, f, of a spherical mirror is the distance between the pole of the mirror and the focal point.

We will not derive the following important relationship: **The focal length of a spherical mirror is half its radius of curvature.**

IMAGE FORMATION BY SPHERICAL MIRRORS

Concave Mirrors

In summary, concave mirrors form real and inverted images of objects located outside the principal focus. If the object is between the principal focus and the mirror, the image is virtual, erect and enlarged.

Convex Mirrors

Unlike the concave mirror, which can produce either real or virtual images according to the position of the object, the convex mirror gives virtual images only. These are always erect and smaller than the object and are formed between the principal focus and the pole of the mirror.

The previous statements are strictly only true for paraxial rays. For rays which are at larger angles to the principal axis, there is not a single focus. This is an inherent problem for any spherical mirror which is known as **spherical aberration**. The only way to avoid this problem in everyday situations is to use a parabolic (or paraboloidal) mirror.

THE MIRROR EQUATION

This has the same form as the lens equation for a mirror in air and uses the same sign convention.

$$L' - L = F$$

- L = object vergence
- L' = image vergence
- F = focal power of the mirror = -2R
- R is the curvature of the mirror

We also note that:

$$\mathbf{f = \frac{r}{2}}$$

Magnification and **Power** are defined exactly as we have done for lenses.

USES OF MIRRORS

The image-forming characteristics of curved mirrors obviously determine their uses. For example, suppose you want to use a mirror that will help people shave or apply cosmetics. Since we would need an enlarged, upright image, we need to use a concave mirror with the object inside the focal point. The same idea is used for the mirror used by a dentist to examine your teeth.

In other situations, the purpose of a mirror is to observe a large field of view. In this case we need a convex mirror. The diminished size of the image means that a fairly large field of view is seen in this mirror. They are used in stores to help employees watch for shoplifting.

This kind of mirror is often placed on the side of a motor vehicle and carries the warning “Objects are closer than they appear.” Without this warning, the driver might think she is looking into a flat mirror which does not alter the size of the image.

Keratometers use the first Purkinje image (the reflection of light occurring at the front surface of the cornea) to determine the curvature of the central cornea. Corneal topographers use the same principle to generate a map of the shape of the cornea at many individual points.

Many other clinical instruments use mirrors to direct light at the eye and to direct the reflected light from the eye to a viewing system or imaging sensor.