Study Guide: Total Internal Reflection and Albedo

Term	**Description**
Refractive Index	The ratio of the speed of light in a vacuum to its speed in a particular substance.
Total Internal Reflection (TiR)	The complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium.
Critical Angle	The critical angle is the smallest angle of incidence that yields total reflection, or equivalently the largest angle for which a refracted ray exists.
Mirage	The deceptive appearance of distant objects caused by the bending of light rays (refraction) in layers of air of varying density.
Albedo	A non-dimensional, unitless quantity between 0 and 1 that indicates how well a surface reflects light energy, with 0 meaning a "perfect absorber" that absorbs all incoming energy, and 1 meaning a "perfect reflector" that reflects all incoming energy.

Total Internal Reflection

Total Internal Reflection occurs if the **angle of incidence** is greater than a certain limiting angle, called the **critical angle**. In general, total internal reflection takes place at the boundary between two transparent media when a ray of light in a **medium of higher index of refraction** approaches the other medium at an angle of incidence greater than the critical angle.

For a water-air surface the critical angle is 48.5°. Because indices of refraction depend on wavelength, the critical angle (and hence the angle of total internal reflection) will vary slightly with wavelength and, therefore, with color. At all angles less than the critical angle, both refraction and reflection occur in varying proportions.

Both refraction and reflection can occur at the same time if the angle of incidences is less than the critical angle for a particular medium.

Critical Angle

The critical angle is the smallest angle of incidence that yields total reflection, or equivalently the largest angle for which a refracted ray exists. For light waves incident from an "internal" medium with a single refractive index n_1, to an "external" medium with a single refractive index n_2, the critical angle is given by $\theta_c = arcsin\frac{n_2}{n_1}$, and is defined if $n_2 \leq n_1$.

TiR in a Mirage

Under certain conditions, such as over a stretch of hot pavement or desert air heated by intense sunshine, the air rapidly cools with elevation and therefore increases in density and refractive power.

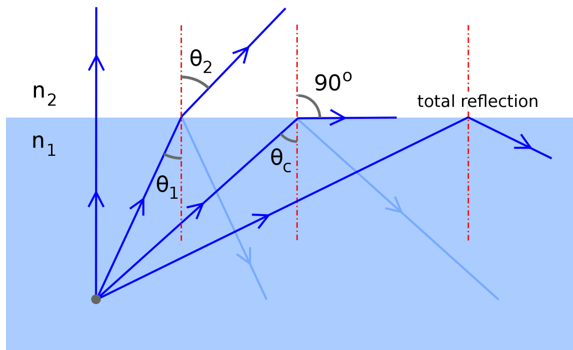

Figure 1: Total Internal Reflection Angles

Sunlight reflected downward from the upper portion of an object——for example, the top of a camel in the desert——will be directed through the cool air in the normal way. Although the light would not be seen ordinarily because of the angle, it curves upward after it enters the rarefied hot air near the ground, thus being refracted to the observer's eye as though it originated below the heated surface.

A direct image of the camel is also seen because some of the reflected rays enter the eye in a straight line without being refracted. The double image seems to be that of the camel and its upside-down reflection in water. When the sky is the object of the mirage, the land can be mistaken for a lake or sheet of water.

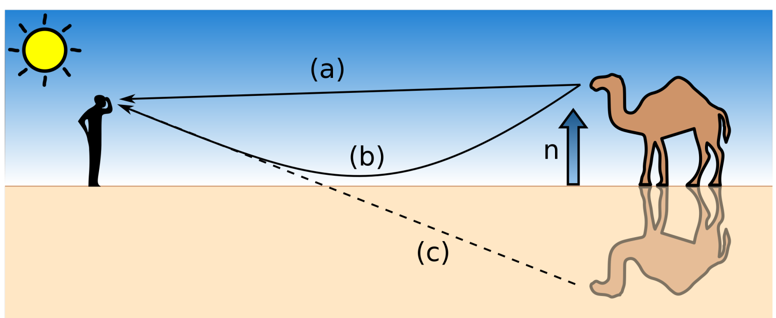

Figure 2: Total Internal Reflection in a Mirage

TiR in a Looming

Sometimes, as over a body of water, a cool, dense layer of air underlies a heated layer. An opposite phenomenon will then prevail, in which light rays will reach the eye that were originally directed above the line of sight. Thus, an object ordinarily out of view, like a boat below the horizon, will be apparently lifted into the sky. This phenomenon is called looming.

Figure 3: Total Internal Reflection on the Sea

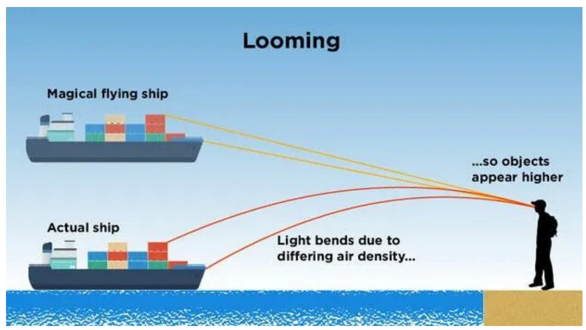

Figure 4: Total Internal Reflection in Looming

TiR in a Cut Diamond

Diamonds (with a high refractive index of about 2.42) are often cut so that as light penetrates, it is subjected to TiR on multiple faces (or facets). The critical angle of diamond to air is 24°. When the angle of incidence at any face is less than 24 degrees, light shines through again, making the diamond on that face seem more brilliant.

Tir in Optical Fibers

The design of optical fibers makes use TiR. An optical fibre is made up of an inner core (glass or plastic) with a high refractive index, and an outer cladding (glass or plastic) with a lower refractive index.

TiR in Water

When standing beside an aquarium with our eyes below the water level, we are likely to see fish or submerged objects reflected in the water-air barrier. The brightness of the reflected image—often just as bright as the "direct" view—can be startling.

A similar effect can be observed by opening our eyes while swimming just below the water's surface. If the water is calm, the surface outside the critical angle (measured from the vertical) appears mirror-like, reflecting objects below.

At such angles, the region above the waterline cannot be seen, where the hemispherical field of view is compressed into a conical field known as **Snell's Window**, whose angular diameter is twice the critical angle.

The field of view above the water is theoretically 180° across, but seems less because as we look closer to the horizon, the vertical dimension is more strongly compressed by the refraction; e.g., by Eq. (3), for air-to-water incident angles of 90°, 80°, and 70°, the corresponding angles of refraction are 48.6° (cr in Fig. 6), 47.6°, and 44.8°, indicating that the image of a point 20° above the horizon is 3.8° from the edge of Snell's window while the image of a point 10° above the horizon is only 1° from the edge.[13]

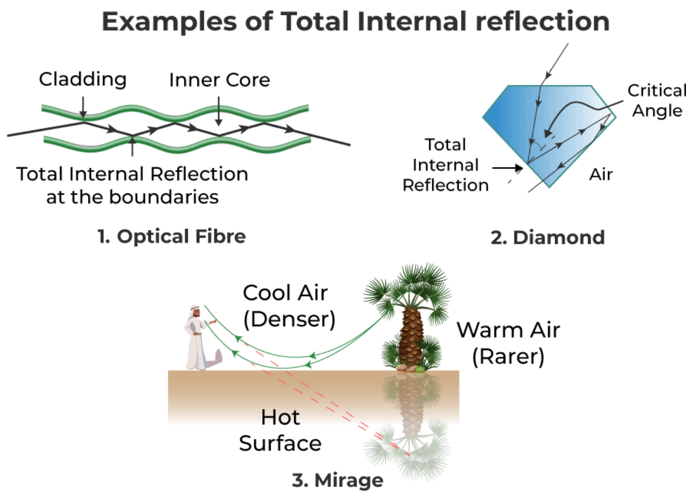

Figure 5: Examples of Total Internal Reflection

Earth's albedo

Albedo is usually differentiated into two general types: **normal albedo** and **Bond albedo**.

Normal albedo

Normal albedo (also called normal reflectance), is a measure of a surface's relative brightness when illuminated and observed vertically. The normal albedo of snow, for example, is nearly 1.0, whereas that of charcoal is about 0.04. Albedo generally refers to visible light, although it may involve some infrared. than concrete because the black surface absorbs more energy and reflects very little energy.

When sunlight reaches the Earth's surface, some is absorbed and some reflected. A surface with a high albedo will reflect more sunlight than a surface with low albedo. Surfaces with high albedos include sand, snow and ice, and some urban surfaces, such as concrete or light-colored stone. Surfaces with low albedos include forests, the ocean, and some urban surfaces, such as asphalt.

Albedo generally applies to visible light, although it may involve some of the infrared region of the electromagnetic spectrum. You understand the concept of low albedo intuitively when you avoid walking barefoot on blacktop on a hot summer day. Blacktop has a much lower albedo than concrete because the black surface absorbs more energy and reflects very little energy.

Albedo is important to Earth scientists because it plays a significant role in our planet's average surface temperature. When a surface reflects incoming sunlight, it sends the energy back to space, where it doesn't affect temperature or climate.

Bond albedo

Bond albedo is defined as the fraction of the total incident solar radiation reflected by a planet back to space. It is a measure of the planet's energy balance. (It is named for the American astronomer George P. Bond, who in 1861 published a comparison of the brightness of the Sun, the Moon, and Jupiter.)

The value of Bond albedo depends on the spectrum of the incident radiation because such albedo is defined over the entire range of wavelengths. Earth-orbiting satellites have been used to measure Earth's Bond albedo. The most recent values obtained are approximately 0.29. The Moon, which has a very tenuous atmosphere and no clouds, has an albedo of 0.12. By contrast, that of Venus, which is covered by dense clouds, is 0.75.

Albedo and Astronomy

Measurements of albedo are commonly used in astronomy to describe the reflective properties of planets, satellites, and asteroids. Investigators often rely on observations of normal albedo to determine the surface compositions of satellites and asteroids. The albedo, diameter, and distance of such objects together determine their brightness.

If the asteroids Ceres and Vesta, for example, could be observed at the same distance, Vesta would be the brighter of the two by roughly 10 percent. Though Vesta's diameter measures less than half that of Ceres, Vesta appears brighter because its albedo is about 0.35, whereas that of Ceres is only 0.09.

Albedo and Climatology

The Earth's albedo plays a significant role in our planet's average surface temperature. When sunlight reaches the Earth's surface, some of it is absorbed and some is reflected. The relative amount (ratio) of light that a surface reflects compared to the total incoming sunlight is called albedo. A surface with a high albedo will reflect more sunlight than a surface with low albedo. Surfaces with high albedos include sand, snow and ice, concrete and light-colored stone. Surfaces with low albedos include forests, the ocean, and asphalt. When a surface reflects incoming sunlight, it sends the energy back to space, where it has little direct affect on surface temperatures or climate.

Changes in the Earth's **global albedo** can affect the global climate. Sea-ice loss in the Arctic since the end of the 20th century has lowered the region's albedo, decreasing the region's ability to reflect incoming sunlight while increasing its ability to absorb energy from sunlight. Researchers note that the Arctic's falling albedo is producing a **positive temperature feedback loop**——in which greater energy absorption at the surface leads to increases in available heat, which in turn melt additional ice, thereby further decreasing the region's albedo...

Some Practical Applications

1. **Optical Instruments:** The development of specially shaped glass prisms to produce total internal reflection in binoculars, periscopes, telescopes, and other optical instruments.
2. **Fiber Optics:** The development of low-consumption and near speed of light communications using long, twisted paths of glass or plastic rods or fibers that allow rays of light tn travel by **multiple total internal reflection**.
3. **Climatology:** Research into the effects of a changing planetary surface on global climate patterns.
4. **Astronomy:** Research into the makeup of distant planets.

Questions

1. What is the difference between Normal and Bond albedo?
2. What causes a mirage?
3. Does the open ocean have a low or high albedo?
4. Does asphalt have a low or high albedo?
5. Do ice and snow have a low or high albedo?
6. Do clouds have a low or high albedo?
7. How can observations of the albedo of distant planets help us understand their surface composition?
8. When analyzing a planet's brightness, why is it important to know it's size, distance from Earth and albedo?
9. How does melting snow and ice at the poles affect global climate patterns?

Sources

- Wikipedia: https://en.wikipedia.org/wiki/Total_internal_reflection
- Wikipedia: https://en.wikipedia.org/wiki/Mirage
- Britannica: https://www.britannica.com/science/total-internal-reflection
- Britannica: https://www.britannica.com/topic/mirage-optical-illusion