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College: College of Science

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Stage: Third stage

Subject: Optics 1

Lecture title: Reflection

1.3 Reflection

When a beam of light impinges on the surface of a transparent material, such as a sheet of glass, the wave will be scattered by a vast array of closely spaced atoms. Remember that the wave may be ≈500 nm long, whereas the atoms and their separations (≈0.2 nm) are thousands of times smaller. In the case of transmission through a dense medium, the scattered wavelets cancel each other in all but the forward direction, and just the ongoing beam is sustained. This is not the case at an interface between two different transparent media (such as air and glass), which is a jolting discontinuity. When a beam of light strikes such an interface, some light is always scattered backward, and we call this phenomenon ***reflection***.

1.3.1 The Law of Reflection

Assume that the surrounding environment is vacuum. One wavefront as it sweeps in and across the molecules on the surface (Fig. 1.7a). For the sake of simplicity, in Fig. 1.7b, assume that the interface is only a few molecular layers. Because the wavelength is so much greater than the separation between the molecules, the wavelets emitted back into the incident medium advance together and add constructively in only one direction, and there is one well-defined *reflected* beam. The direction of the reflected beam is determined by the constant phase difference between the atomic scatterers. That, in turn, is determined by the angle made by the incident wave and the surface, the so-called ***angle-of-incidence***. In Fig. 1.8, the line AB lies along an incoming wavefront, while CD lies on an outgoing wavefront—in effect, AB transforms on reflection into CD.

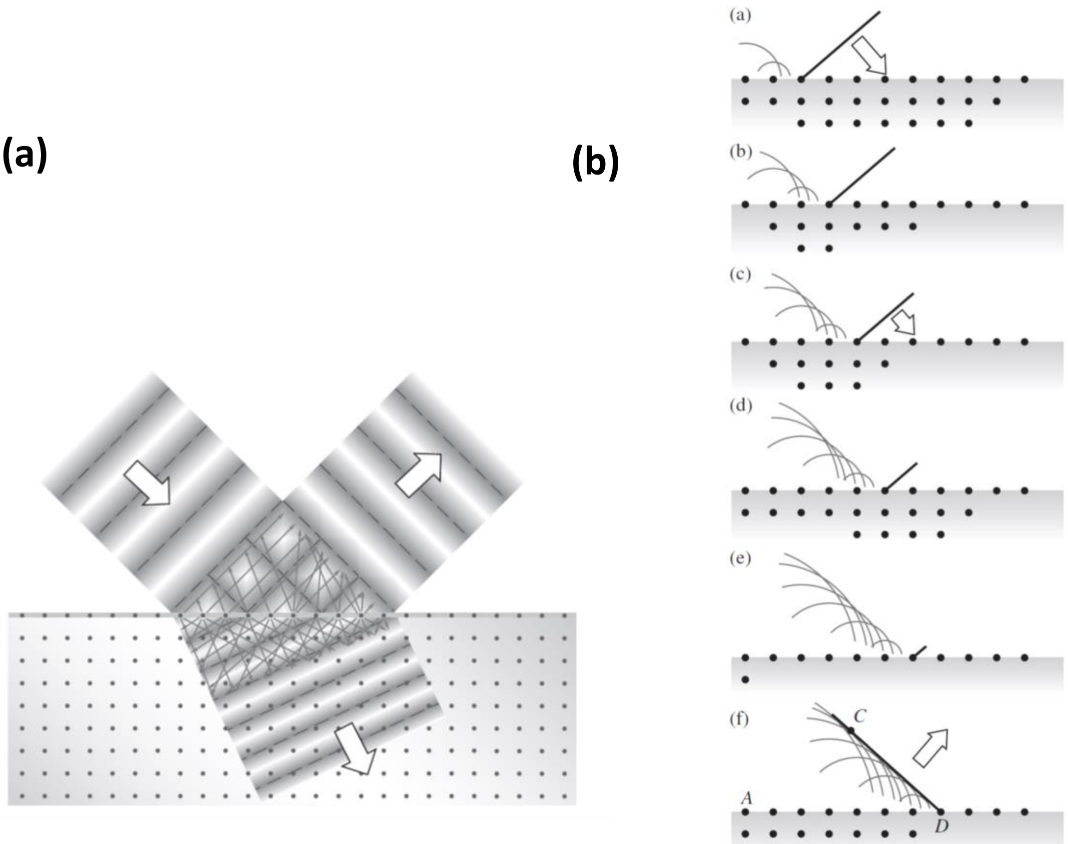

Figure 1. 1. (a) A plane wave sweeps in stimulating atoms across the interface. These radiate and reradiate, thereby giving rise to both the reflected and transmitted waves. The wavelength of light is several thousand times the atomic size and spacing. (b) The reflection of a wave as the result of scattering.

With Fig. 1.7, we see that the wavelet emitted from A will arrive at C in-phase with the wavelet just being emitted from D, as long as the distances AC and BD are equal. In other words, if all the wavelets emitted from all the surface scatterers are to overlap in-phase and form a single reflected plane wave, it must be that AC = BD. Then, since the two triangles have a common hypotenuse

$$\frac{sin\theta_i}{\overline{BD}} = \frac{sin\theta_r}{\overline{AC}} \qquad (1.2)$$

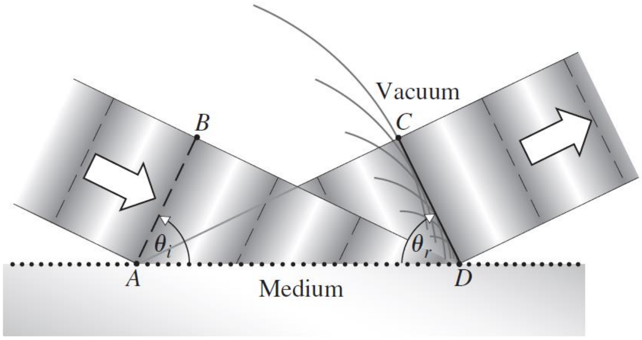

Figure 1. 2. Plane waves enter from the left and are reflected off to the right. The reflected wavefront CD is formed of waves scattered by the atoms on the surface from A to D. Just as the first wavelet arrives at C from A, the atom at D emits, and the wavefront along CD is completed.

All the waves travel in the incident medium with the same speed v_i. It follows that in the time (Δt) it takes for point B on the wavefront to reach point D on the surface, the wavelet emitted from A reaches point C. In other words, $\overline{BD}$= $v_i\Delta t$ = $\overline{AC}$ and so from the above equation, $sin\theta_i$= $sin\theta_r$, which means that

$$\boldsymbol{\theta_i=\theta_r} \qquad (1.3)$$

The angle-of-incidence equals the angle-of-reflection. This equation is the first part of the **Law of Reflection**.

Rays

A ray is a line drawn in space corresponding to the direction of flow of radiant energy. In a medium that is uniform (homogeneous), rays are straight. If the medium behaves in the same manner in every direction (isotropic), the rays are perpendicular to the wavefronts. We can simply draw one incident ray and one reflected ray (Fig. 1.9a). All the angles are now measured from the perpendicular (or normal) to the surface, and θ_i and θ_r have the same numerical values as before (Fig. 1.8). The second part of the Law of Reflection maintains that ***the incident ray, the perpendicular to the surface, and the reflected ray all lie in a plane*** called the **plane-of-incidence** (Fig.1.9b). Figure 4.18a shows a beam of light incident upon a reflecting surface that is smooth (one for which any irregularities are small compared to a wavelength). In that case, the light re-emitted by millions upon millions of atoms will combine to form a single well-defined beam in a process called **specular reflection**. Provided the ridges and valleys are small compared to l, the scattered wavelets will still arrive more or less in-phase when θ_i=θ_r.

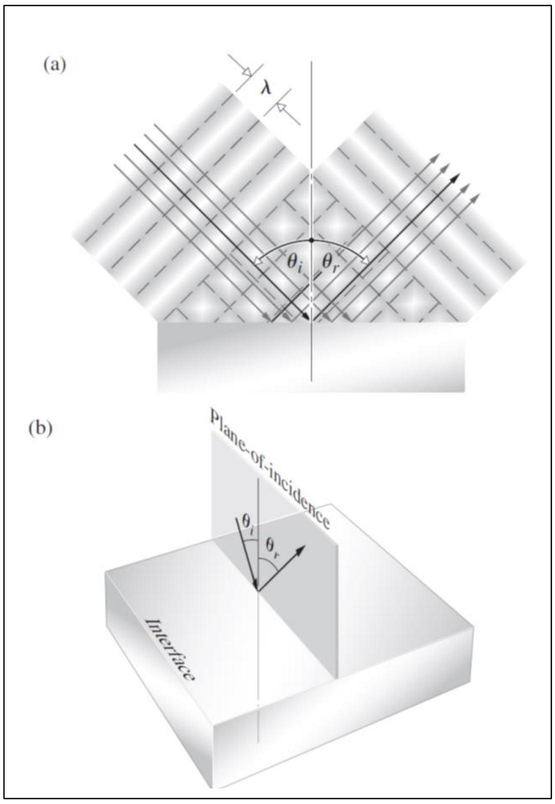

Figure 1. 4. (a) Select one ray to represent the beam of plane waves. Both the angle-of-incidence θ_i and the angle-of-reflection θ_r from a perpendicular drawn to the reflecting surface. (b) The incident ray and the reflected ray define the plane-of-incidence, perpendicular to the reflecting surface.

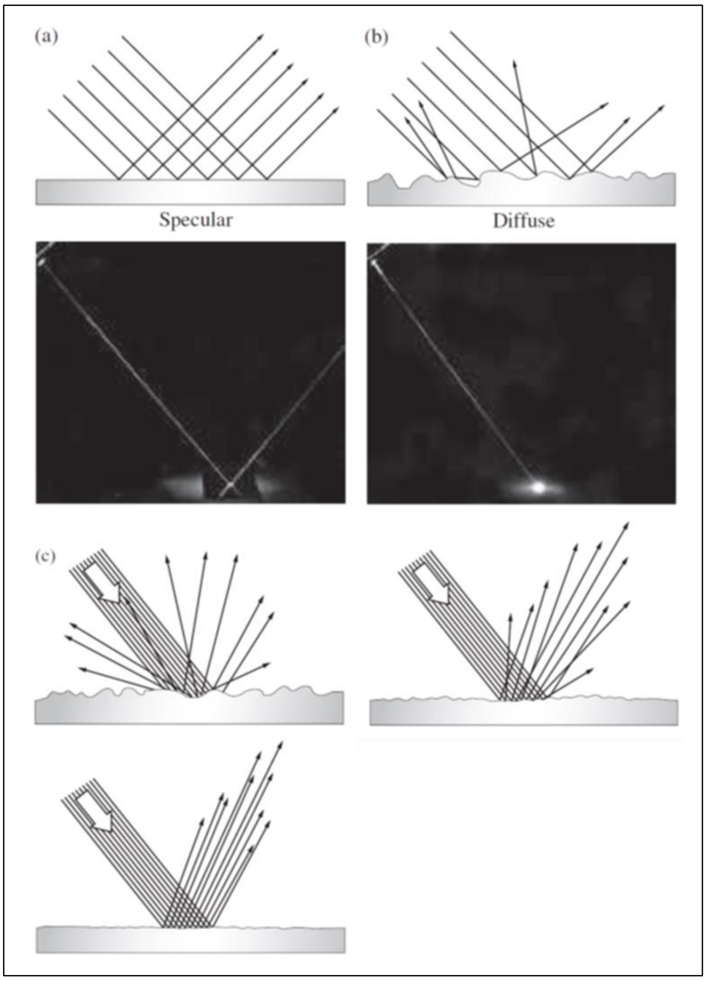

Figure 1. 3. (a) Specular reflection. (b) Diffuse reflection. (Donald Dunitz) (c) Specular and diffuse are the extremes of reflection. This schematic drawing represents a range of reflections between the two that are likely to be encountered.

On the other hand, when the surface is rough in comparison to l, although the angle-of-incidence will equal the angle of- reflection for each ray, the whole lot of rays will emerge every which way, constituting what is called **diffuse reflection**. Both of these conditions are extremes; the reflecting behaviour of most surfaces lies somewhere between them.

The F-117A fighter has an extremely small radar profile, that is, it returns very little of the incoming microwaves back to the station that sent them. Explain what is the principle behind that?

HMW

1.4 Refraction

In some cases, a beam of light impinging on an interface at some angle ($\theta_i \neq 0$). The interface corresponds to a major inhomogeneity, and the atoms that compose it scatter light both backward (reflected beam) and forward (the transmitted beam). The fact that the incident rays are bent or “turned out of their way,” as Newton put it, is called **refraction**.

1.4.1 The Law of Refraction

Fig 1.11 illustrates several wavefronts, all shown at a single instant in time. The wavefronts “bend” as they cross the boundary because of the speed change. Notice that in the time Δt, which it takes for point ***B*** on a wavefront (traveling at speed v_t) to reach point ***D***, the transmitted portion of that same wavefront (traveling at speed vt) has reached point ***E***. If the glass (n_t = 1.5) is immersed in an incident medium that is vacuum (n_i = 1) or air (n_i = 1.000 3) or anything else where $n_t > n_i$, $v_t < v_i$, and $\overline{AE} < \overline{BD}$, the wavefront bends. The refracted wavefront extends from ***E*** to ***D***, making an angle with the interface of θ_t. As before, the two triangles *ABD* and *AED* in Fig. 1.11 share a common hypotenuse $\overline{AD}$, and so

$$\frac{sin\theta_i}{\overline{BD}} = \frac{sin\theta_t}{\overline{AE}}$$

Where $\overline{BD}$=$v_i\Delta t$ and $\overline{AE}$=$v_t\Delta t$. Hence

$$\frac{sin\theta_i}{v_i} = \frac{sin\theta_t}{v_t}$$

Multiply both sides by c, and since $n_i = c/v_i$ and $n_t = c/v_t$

$$n_i sin\theta_i = n_t sin\theta_t \qquad (1.4)$$

This equation works for every frequency, but each will “bend” differently. This expression is the first portion of the ***Law of Refraction***, also known as **Snell’s Law**.

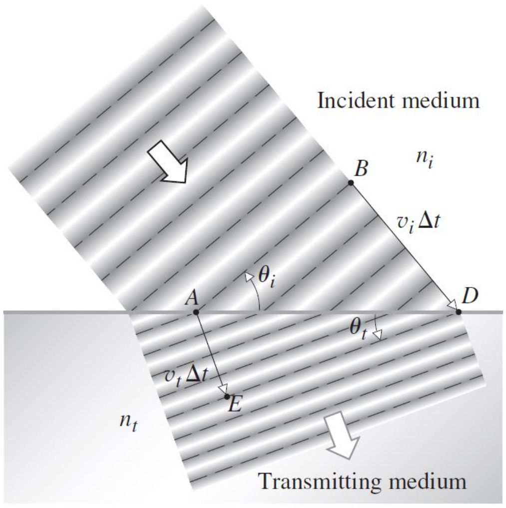

Figure 1. 5. The refraction of waves. The atoms in the region of the surface of the transmitting medium reradiate wavelets that combine constructively to form a refracted beam. For simplicity the reflected wave has not been drawn.

What was found through observation was that the bending of the rays could be quantified via the ratio of $x_i$to x_t which was constant for all θ_i. That constant was naturally enough called the *index of refraction*.

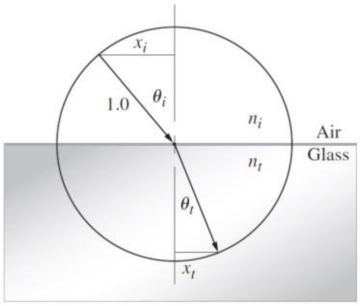

Figure 1. 6. Descartes's arrangement for deriving the Law of Refraction. The circle is drawn with a radius of 1.0.

Snell's Law can be rewritten in the form

$$\frac{sin\theta_i}{sin\theta_t} = n_{ti} \qquad (1.5)$$

where $n_{ti} = n_t/n_i$ is the relative index of refraction of the two media. Note that $n_{ti} = v_i/v_t$; moreover, $n_{ti} = 1/n_{it}$. For air-towater $n_{wa} \approx 4/3$, and for air-to-glass $n_{ga} \approx 3/2$. As a mnemonic think of $n_{ga} = n_g/n_a$ as dividing "air into glass," just as light goes from "air into glass

-Drive the Law of Refraction (Snell's Law)?

HMD

EXAMPLE 1.1

A ray of light in air having a specific frequency is incident on a sheet of glass. The glass has an index of refraction at that frequency of 1.52. If the transmitted ray makes an angle of 19.2° with the normal, find the angle at which the light impinges on the interface.

SOLUTION

From Snell's Law

$$sin\theta_i = \frac{n_t}{n_i}\ sin\theta_t$$

$$sin\theta_i = \frac{1.52}{1.00}\ sin19.2°$$

$$\theta_i = 30°$$

EXAMPLE 1.2

A narrow laserbeam traveling in water having an index of 1.33 impinges at 40.0°with respect to the normal on a water–glass interface. If the glass has an index of 1.65 (a) determine the relative index of refraction. (b) What is the beam's transmission angle in the glass?

SOLUTION

(a) From the defining equation

$$n_{ti} = \frac{n_t}{n_i}$$

$$n_{GW} = \frac{n_G}{n_W} = \frac{1.65}{1.33} = 1.24$$

(b) Using Snell's Law

$$\sin\theta_t = \sin\theta_i / n_{ti}$$

$$\sin\theta_t = \sin 40.0^\circ \;\; /1.24 = 0.5184$$

$$\theta_t = 31.2^\circ$$

References:

1-Principles of optics-Max Born

2-Optics,-Eugene-Hecht

3-Optics and photonics an introduction