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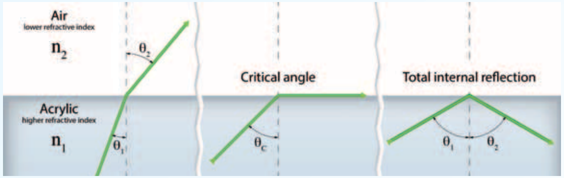
SUPER SIGHT

Developing lightweight optical technology with the help of mathematics



The bending of the light is described by Snell's Law. This equation relates the angle the light beam makes with the boundary between the two materials to the refractive index of the materials.

NPL and Colour Holographic Ltd. have developed a lightweight optical technology that allows digital images to overlay human vision, facilitating eye tracking, medical diagnostics, distance measurement and hands free interaction with the internet and environment. A critical component of this device is the waveguide. This carries the light from a microdisplay on the side of the head until it can be directed into the user's eye. The light travels through the waveguide via *total internal reflection*. This phenomenon is also used in fibre optic telecommunication applications. To understand this we need to look at how light travels through different materials.

Light travels at different speeds in different materials. The *refractive index* of a material is the ratio of the speed of light in free space to that in the material – the larger the refractive index, the slower light travels. When light moves between two materials with different refractive indices the change in speed causes the direction the light is travelling in to change: this is called refraction. You can see light refracting when you place a straw in a glass of water: the straw will appear to bend where it enters the water. The amount that the direction of light bends when moving from one material to another depends on the refractive indices of the materials.

The bending of the light is described by Snell's Law. This equation relates the *angle of incidence* θ_1 that the light beam makes with the boundary between the two materials, and the *angle of refraction* θ_2 to the refractive indices, n_1 and n_2, of the two materials.

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

This equation makes it easy to calculate the change in angle that occurs when a beam of light passes from one medium to another. So, what is total internal reflection?

Total internal reflection can occur when light tries to pass from a material with high refractive index into a material with lower refractive index. At some angles the change in direction is so great that instead of passing into the new material the light bounces back into the original material. This happens when the light hits the boundary at an angle greater than the so-called *critical angle* (θ_c).

The critical angle occurs when the refracted ray travels parallel to the boundary, *ie* when $\theta_2 = 90^\circ$. When this happens $\sin \theta_2 = \sin 90^\circ = 1$. We can rearrange Snell's Law to get $\sin \theta_c = n_2/n_1$. So the critical angle can be calculated from the refractive indices as $\theta_c = \arcsin n_2/n_1$. Inside the waveguide the light always hits the boundary of the Perspex strip at an angle greater than the critical angle θ_c and so reflects internally along the length of the waveguide. This carries the light from the microdisplay into your eye and gives the impression that the image is hovering in front of you at a controllable distance which could be from a few centimetres to the far distance.

www.npl.co.uk/adaptive-optics

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