PHYSICS IN ANAESTHESIA: THE FIBREOPTIC INTUBATING LARYNGOSCOPE

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Light normally travels in straight lines but there are circumstances in which the light-path is not straight. When we look in a mirror the light rays from our face hit the mirror and bounce back - this is called **reflection**. Reflection of light from shiny surfaces is seen everyday and is the first example of light not traveling in a straight line. The other is a bit more complicated. If you stand by a pond or river holding a stick and dip the end of the stick in the water, the stick appears to bend a little at the surface of the water. Of course the stick is still straight, and it is the light rays that have been bent. This type of light bending is called **refraction**.

Being able to bend light in these two ways means that it is possible to build a glass rod and force the light to travel down the inside of the rod. If the rod is very thin (called a fibre) it can be bent to go round a corner and the light will still travel in the rod even going round a fairly sharp bend. It is possible to build an instrument which contains a lot of these fibres and use the instrument to look round corners inside the body. The instrument is called a flexible fibrescope and this chapter looks at the physics of light bending and how a fibrescope works. Anaesthetists use flexible fibrescopes to look into the trachea and lungs and also to help put tracheal tubes in the right place.

Physics of Fibreoptic Light Transmission

● **Reflection**. When light hits a surface it bounces off it. The angle at which light bounces off is exactly the same as the angle at which it hits the surface. Put another way, the law of reflection state that 'the angle of reflection is the same as the angle of incidence' and this can be seen in figure 1.

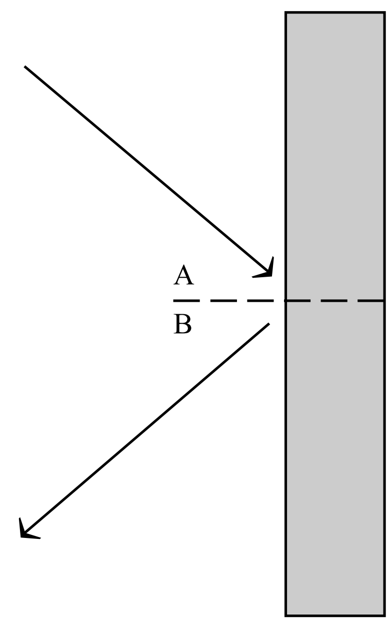


Figure 1: The angle at which the light hits the mirror is the same as the angle of the reflected light. Angle A is the same as Angle B.

- **Refraction (Snell's Law)**. Refraction is more complicated and concerns what happens to light when it is travelling in one substance (or medium) and hits another medium. The light can bend at the junction or interface of the two substances. When light passes from one medium, for example air, to another, for example glass or water, the direction that the light is traveling in changes. This is known as refraction. It happens because the speed of light varies in different mediums.

The law that describes how refraction of light occurs is named after a Dutch mathematician, Willebrord van Roijen Snell, who made it known in 1621. Rene Descartes, a French mathematician and philosopher, also described refraction in 1637, calling it the Law of Sines. They both realized there are two factors that determine how much the light bends at the junction between the two substances:

1. The nature of the substances. The speed of light is very fast but is different in different mediums. Each substance has a measure of this called the index of refraction. The **index of refraction** is the ratio of the speed of light in a vacuum to the speed of light in a given medium. Note that when we refer to the speed of light in general terms, what we are talking about is the speed in a vacuum such as space. The speed of light changes when it passes from one medium to another, for example from air to glass, causing it to change direction. The index of refraction for air is 1.0, for water 1.3 and for normal glass 1.6.

2. The **angle of incidence of the incoming ray of light** (shown by the symbol (θ in figure 2). In other words, the angle at which the light strikes the junction between two media, taken from a line that is at right angles to the junction.

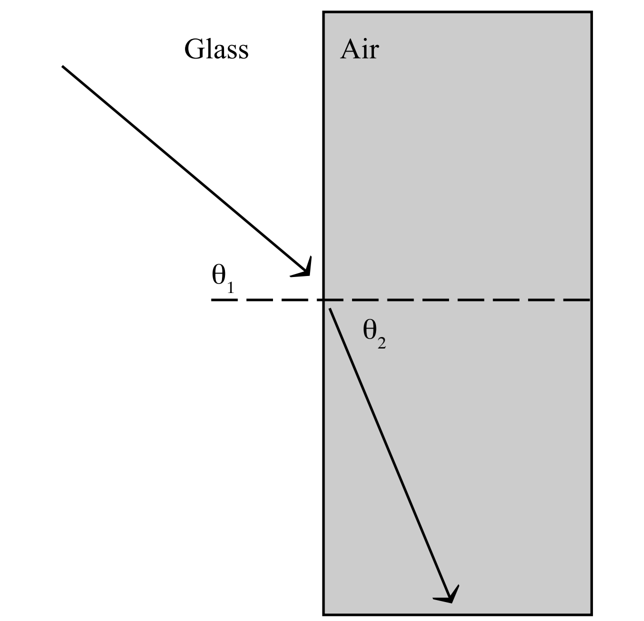


Figure 2. This demonstrates Snell's Law. In this example medium 1 has a refractive index greater than medium 2, such as is the case when light passes from glass to air.

The Critical Angle and Total Internal Reflection

Sometimes the bending of the light at the junction or interface is so great that the light appears to be reflected from the interface. The light has bounced back at the junction and doesn't pass through. This is called **total internal reflection** (figure 3).

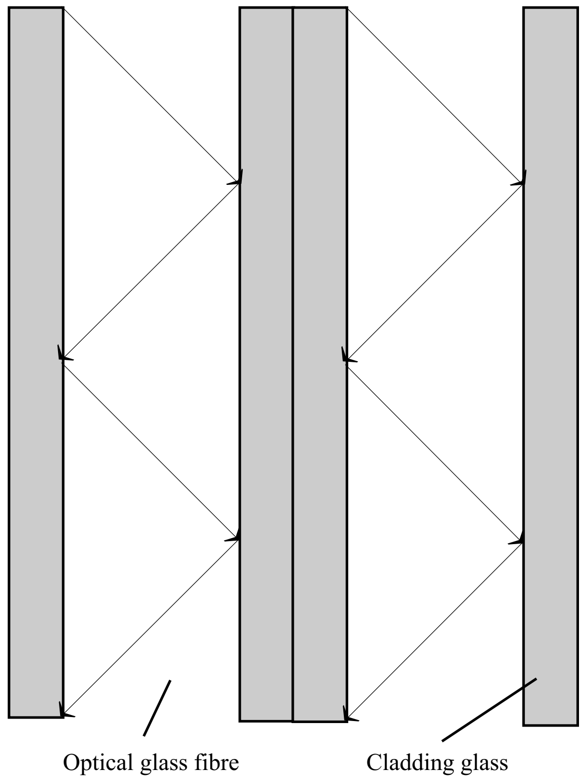


Figure 3. Light transmission, by total internal reflection, along parallel glass fibres.

Structure of The Glass Bundles Used in a Fibrescope

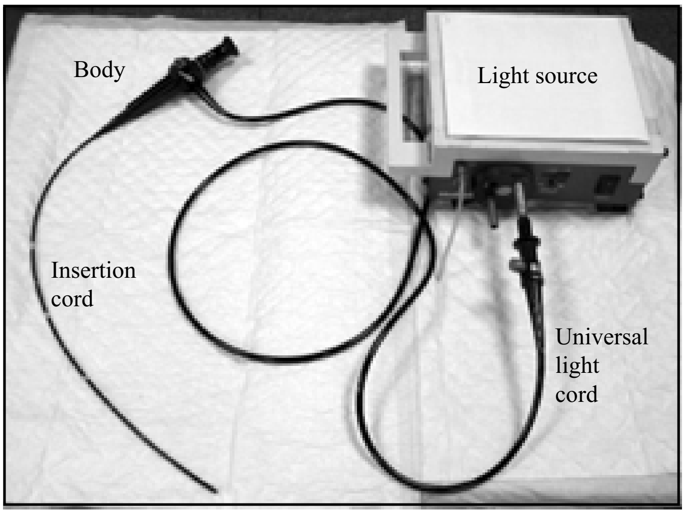
The glass fibres used inside fibrescopes are constructed so that light is able to pass within the glass fibre from one end to the other by total internal reflection.

During manufacture glass is heated and stretched into very thin fibres. These are only 8-10μm in diameter. Each fibre is coated, or cladded, with a thin layer of glass (only about 1μm thick) which has a much lower index of refraction, ensuring that only total internal reflection of light takes place and preventing light passing between fibres (figure 3). These fibres are grouped together into flexible bundles containing several thousand fibres. Several bundles are then placed together to form the **image transmitting bundle**. This is also called the **viewing bundle**.

The total number of fibres in the viewing bundles varies from 36,000 to 85,000, depending on the size of the scope. The greater the number of fibres, the larger and clearer the image will appear. This is because each fibre, being very thin, will only transmit a small image. The final image is made up of all these small images added together, similar to the way an image appears on a television screen or digital camera. This explains why black dots appear on the image when individual fibres or groups of fibres are broken.

Each fibre within the viewing bundle is arranged in a specific position, relative to the other fibres, throughout the length of the bundle. If the fibres were all jumbled up, so would be the image. A **coherent** bundle is one which will transmit an accurate and clear image and this is necessary for the **viewing** bundle.

If the fibres are not specifically arranged, then there will be just a random array of light seen at the eyepiece. The fibreoptic bundles that transmit light from the light source to the object, in order to illuminate it, are like this. That is because these bundles, known as the **light transmission bundles**, or **incoherent bundles**, only need to transmit white light. The fibres in the light transmission bundle are thicker than those in the viewing bundle, approximately 10-15 μm in diameter. There are also only about 6000 fibres in these bundles.



Basic Structure of the Fibrescope

Since the 1980's, manufacturers have made available sophisticated, well-constructed fibreoptic intubating laryngoscopes with a standard insertion cord length of 60 cm and a standard thickness of 4mm for adults, down to 2 mm thickness for small children. These allow narrow diameter tubes to be passed over the scope into the trachea.

The instrument has 3 main components:

The Body which has the following features:

- The **eyepiece**.
- The diopter ring, part of the eyepiece, which is used to focus the image.
- The lever, which controls the angulation near the tip of the scope.
- The working channel access port.

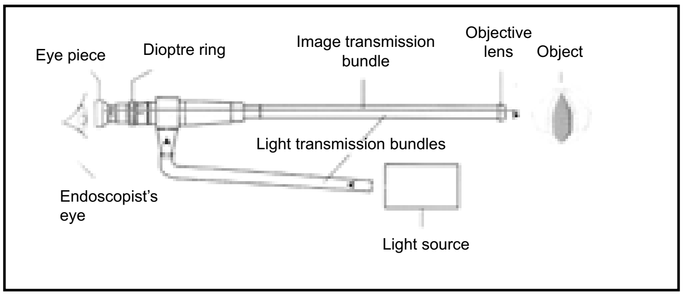
The Insertion Cord which contains

- The light transmission (viewing) bundle.
- The **objective lens**, situated at the tip of the scope, over the distal end of the viewing bundle.
- The light transmission bundles. There are usually two.
- The working channel: this can be used for suctioning secretions, injecting drugs, insufflating oxygen, to pass guide wires or biopsy instruments.
- The control wires. There are two of these. They extend from the lever on the handle to the tip of the scope.

All the components of the insertion cord are enclosed in a wire mesh. This is then covered by a waterproof plastic coating. Note that as the diameter of the insertion cord is reduced, so the size of the working channel is reduced, making it less useful, especially with regards suctioning of airway secretions.

The Universal Light Cord contains light transmission bundles, which transmit light from a **light-source** to the light transmission bundles in the insertion cord. The universal cord has a connector which plugs into the light-source. The light-source is a separate box that is operated by electricity. To make this system more portable, and for use in areas where electricity is not available, the universal cord can be replaced by a handle-shaped, battery operated light-source, attached to the body of the scope, as shown in the photograph. Often the ETO (ethylene oxide) cap is present on the ULC. This port does not need to be used normally.

Pathway of Light



- White light is transmitted from the light-source through the incoherent, light transmission bundles to the distal end of the instrument.
- This illuminates the object.
- Light from the object is reflected onto the objective lens.
- The objective lens focuses the light onto the distal end of the coherent, image transmitting bundle.
- Light travels by total internal reflection up the image transmitting bundle to the to the lens in the eyepiece.
- The image is focused onto the retina of the viewer's eye using the diopter ring, so that the image is clear.

Note: A camera can be attached to the eyepiece of the fibreoptic intubating laryngoscope, enabling the image to be seen on a television screen. This is a very useful aid to teaching fibreoptic technique and for demonstrating pathology of the upper airways to colleagues.

Practical Care of Fibrescopes

A flexible fibrescope is expensive and can be broken by poor handling. Handle it gently and do not knock, twist or bend the insertion cord or catch it in the door. The commonest cause of damage is catching the fibrescope between the lids of the carrying case. The fibrescope should not be tightly coiled, and the distal bending section should not be bent by hand. After cleaning, the fibrescope should be kept in a cupboard supported by the control section so that the insertion tube is hanging straight down. This keeps it clean, allows it to dry out and keeps the insertion tube straight. It should not be stored in the travelling case.

After use in a patient, the fibrescope must be cleaned. The most important point is to immerse the whole scope in a bowl of warm water with a splash of detergent. Using a syringe, flush the working channel with 40-60 ml of this warm water to force out any blood or mucus. If possible, use a long channel cleaning brush passing this down from the control section until it emerges at the tip of the scope. The brushes are very narrow and prone to damage. Scrub the whole outer surface with a soft scrubbing brush to remove all mucus or blood from the external surface. Rinse off the detergent with ordinary water. It is much more important to wash the fibrescope in detergent than to place it in disinfectant.

The fibrescope must NOT be autoclaved or boiled. Heating above 50-60^{o}C will destroy the fibrescope. After manual cleaning with detergent, the fibrescope can be disinfected by placing in a cold chemical disinfectant solution for the appropriate time. The cheapest disinfectant is 2% activated glutaraldehyde and an immersion time of 20 minutes should kill most bacteria and viruses. Spores require much longer - possibly 2 hours. The fibrescope should not be immersed in any fluid for longer than 6 hours. After immersion, the fibrescope should be rinsed in sterile water before being hung up to dry. If no cold chemical disinfectant is available, wiping the outside and flushing the working channel with 70% alcohol will kill some viruses. The fibrescope should not be immersed in alcohol.

Further Reading

1. Airway Management, Principles and Practice. Benumof J L, Mosby-Year Book, 1996

2. Handbook of Difficult Airway Management. Hagberg C A, Churchill Livingstone, 2000

3. Practical Fibreoptic Intubation. Popat M, Butterworth Heinemann, Oxford, 2001

4. Fibreoptic Intubation. Hawkins N. Greenwich Medical Media, London, 2000