12.5 TOTAL INTERNAL REFLECTION
Reflection & Refraction

When light travels from one medium into another, some of the light is reflected and some is refracted.
How Does Light Bend?

Remember...Light bends **away** from the normal when it speeds up at the boundary of two media.

Example: When light travels from acrylic into air.
There is a special phenomenon that can occur where the refracted ray \textit{disappears} and only a \textit{reflected} ray can be seen.

This is called \textit{total internal reflection}

This angle occurs once the incident ray goes past the \textit{critical angle}

Examples of critical angles:

- Water: 48.8°
- Diamond: 24.4°
- Glass: 41.1°
The angle of refraction continues to increase as the angle of incidence increases.

Eventually the **angle of refraction** will become 90°...
The angle of incidence at this point is called the **CRITICAL ANGLE**

The critical angle is the angle of incidence that produces a refracted angle of $90^\circ$ (**red line**). 

![Diagram showing critical angle](image)
CRITICAL ANGLE

Occurs when light passes into a medium with a lower index of refraction.

Reflected ray does not exit the medium - travels along the boundary.
If you increase the angle of incidence past the critical angle, the refracted ray no longer exits the medium.

Instead, it will reflect back into the medium... *(Blue line)*
Total Internal Reflection

When the *angle of incidence* is greater than the *critical angle*...
The refracted ray disappears; only a *reflected* ray is visible
Total Internal Reflection

In order for this to happen, **two conditions** must be met:

1. Light must **speed up** from medium 1 into medium 2
2. The angle of incidence must be **large** enough to cause no refraction
Total Internal Reflection

The cut of the diamond faces along with the high index of refraction for diamonds (2.42) results in the total internal reflection of light.

Diamonds have a very small critical angle: 24.4°

So a lot of incident light undergoes total internal reflection inside the diamond
A light ray can bounce around several times inside the diamond before eventually exiting through a top face of the diamond. This is what causes the “sparkling” effect that makes diamonds so appealing.
APPLICATIONS OF TOTAL INTERNAL REFLECTION

Reflecting light under the surface of water

Fiber Optics

Well cut Diamonds

Shallow  Ideal  Deep
APPLICATIONS OF TOTAL INTERNAL REFLECTION

**Fiber-optic cables** are used for phones, computers, and TVs. They are also found in the endoscope that surgeons use to see internal organs during surgery.

These cables are made of glass or lucite (a plastic) and are used to transmit light.

The cable has a small critical angle so that the light entering it will have an angle of incidence greater than the critical angle and will undergo *total internal reflection*. The light bounces back and forth and is transmitted very quickly.
Diamond cutters cut the faces of diamonds so that the light entering the diamond undergoes *total internal reflection* and the light rays bounce around many times inside the diamond.

A well-cut diamond will sparkle more than a poorly cut diamond.

Diamonds also sparkle because their index of refraction is very high \( n = 2.42 \)
DEVICES THAT USE TOTAL INTERNAL REFLECTION

A periscope uses triangular prisms to change the direction of light by $90^\circ$ twice.

Binoculars use two triangular prisms to change the path of light.
DO YOUR HOMEWORK

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1. The speed of light in the medium containing the incident ray must be slower than in the second medium. The angle of incidence must exceed the critical angle.
2. Light has to travel faster in the second medium because as it speeds up, it bends away from the normal (ray 1). If it bends far enough away from the normal, total internal reflection occurs (ray 2).
If the light were to travel more slowly in the second medium, it would bend toward the normal (rays 3 and 4), which is in the direction opposite to what would allow total internal reflection.
3.a) No
b) Yes
c) Yes
d) No
5. A smaller critical angle results in more total internal reflection because any angle of incidence that exceeds the critical angle produces total internal reflection.
7. Diamonds are cut so that much of the light that enters the sides undergoes total internal reflection and exits the top, making the diamond sparkle. Optical fibre cables use total internal reflection to carry communications encoded in light rays. Triangular prisms use total internal reflection to redirect light in periscopes and binoculars.
9. Total internal reflection is only possible in examples (b) and (c) since these are the only diagrams in which the refracted ray bends away from the normal.

If the angles of incidence were increased, then total internal reflection would occur in medium B in diagram (b) and in medium A in diagram (c)