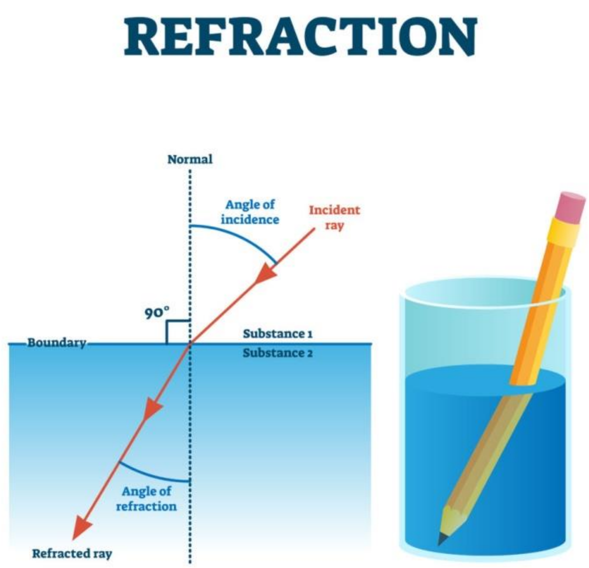
CLASS-9 REFRACTION OF LIGHT PLANE SURFACES PHYSICAL SCIENCE

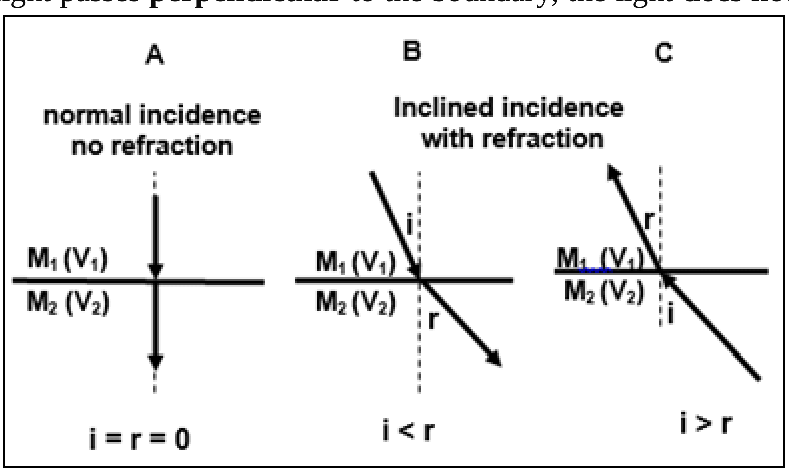
When light passes obliquely from a rarer medium (air) to a denser medium (water, glass), there is a change in its direction of propagation.

This bending of light at the boundary of two dissimilar media is called refraction.



At the **boundary** between two mediums, the rays of light change direction at an **angle from the normal** (which is the normal direction perpendicular to the surface). This **diffraction angle** depends on the densities of the two mediums through which the light rays pass.

- If the light passes from a **low** optical density medium to a **high** optical density medium, the light bends **towards** the normal line.
- If the light passes from a **high** optical density medium to a **low** optical density medium, the light bends **away** from the normal line.
    - When light passes **perpendicular** to the boundary, the light **does not bend**.



when light passes through the normal, it does not bend. On the right-hand side, you can see that when light passes at any other angle from a high optical density material to a low optical density material, the light bends away from the normal and vice versa.

The **speed of <u>light</u> depends on the medium** the <u>light</u> passes through. When light passes from a low-density medium to a high-density medium, the rays will **slow down**. This is because there will be more molecules in a high-density medium and therefore more obstacles that slow down the light. As a result, the light will bend towards the normal and away from the boundary.

<u>EXAMPLE:</u>

- Waves travel faster in deeper water. When approaching land, the wave will be displaced in a direction that is perpendicular to the shoreline.
- The rainbow is a phenomenon of the refraction of light when it passes through raindrops, which cause different wavelengths of light to bend. The bending intensity of each of the colours depends on their wavelengths.

<u>NOTE:</u> Speed and wavelength change during refraction, but the frequency of the wave remains constant.

What is the refractive index?

The **refractive index**, denoted by n, is a property of a material that measures the amount by which light slows down when it passes through it. We can calculate the refractive index with the following equation:

Formula

$$n = \frac{c}{v}$$

n = refractive index

c = speed of light

v = phase velocity of light

<u>Light</u> travels through a vacuum at a constant speed. However, it **slows down when it passes through other substances**. A high refractive index value means that the material is optically dense, so light travels through that substance slower.

<u>NOTE:</u> The **refractive index should always be greater than 1** as the speed of light in any substance cannot exceed its speed in a vacuum. The refractive index of air can be assumed to be 1 if it is not given.

The law of refraction at a plane surface

Snell's law and formula

Snell's law states that the angle of the refracted ray of light and the incident ray compose the normal of the boundary at the point of refraction.

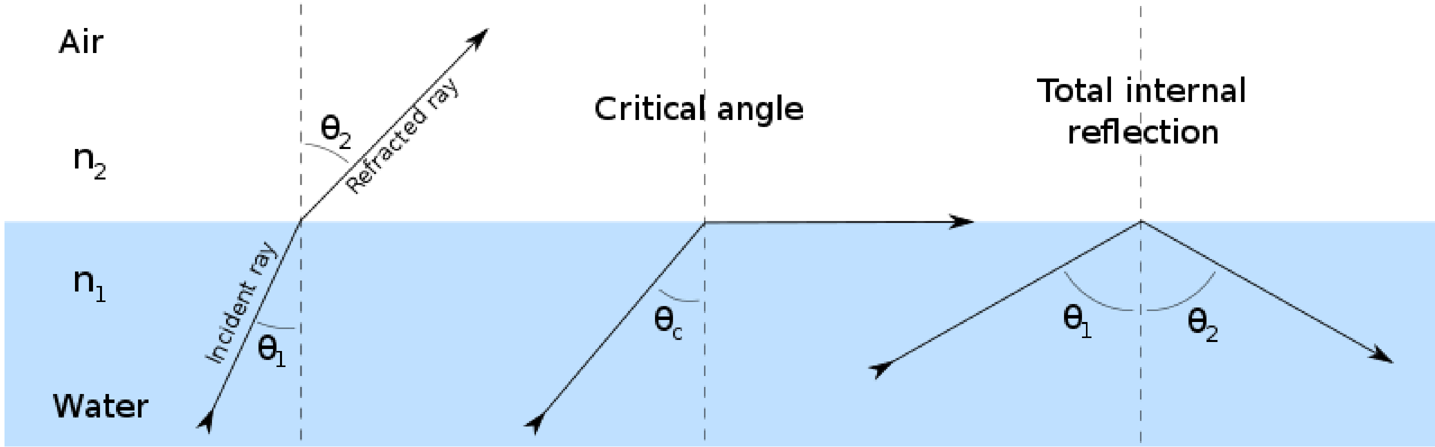
Since the refraction angle depends on the medium through which the light passes, there is a **relation between the angle of incidence, angle of refraction, and the refractive index**. This relation is described by Snell's law below, where n_1 and n_2 are the refractive indices of the two mediums, θ_1 is the angle of incidence, and θ_2 is the angle of refraction.

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

Try This: **A ray of light is directed at an angle of incidence of 45° and passes through glass, exiting at an angle of refraction of 32°. Find the refractive index of glass?**

What is Total internal reflection?

When the angle of incidence increases, the angle of refraction increases. When the refraction angle reaches 90°, the light is reflected along the boundary. This angle of incidence that causes **total internal reflection** is known as **critical angle θ_c**, and we can calculate it using the equation below, derived from Snell's law.

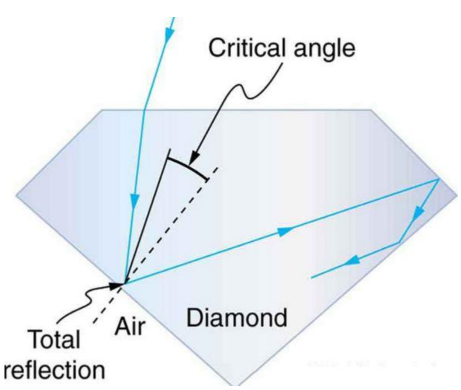


For total internal reflection to occur, two conditions must be:

1. The angle of incidence must be greater than the critical angle.
2. The refractive index n_1 must be greater than the refractive index n_2.

TryThis: A light beam passes from water to air. What is the critical angle between air and water if their refractive indices are 1.55 and 1, respectively?

APPLICATIONS OF TOTAL INTERNAL REFLECTION:



Diamond Total internal reflection is the main cause of the brilliance of the diamond. The refractive index of diamond with respect to air is 2.42. Its critical angle is 24.41°. When light enters a diamond from any face at an angle greater than 24.41° it undergoes total internal reflection. Light is traveling more slowly in the first medium than the second medium. By cutting the diamond suitably, multiple internal reflections can be made to occur. This means that the first medium has the largest index of refraction.

Total internal reflection occurs when the critical angle is increased such that the light is reflected back into the same medium and is not refracted out into the other medium. Total internal reflection occurs when the angle of incidence is equal to or greater than the critical angle.

Examples of total internal reflection

- Underwater reflection of a turtle.
- Mirage is the image of some distant object that appears.
- A fish that looks like water above as a mirror.

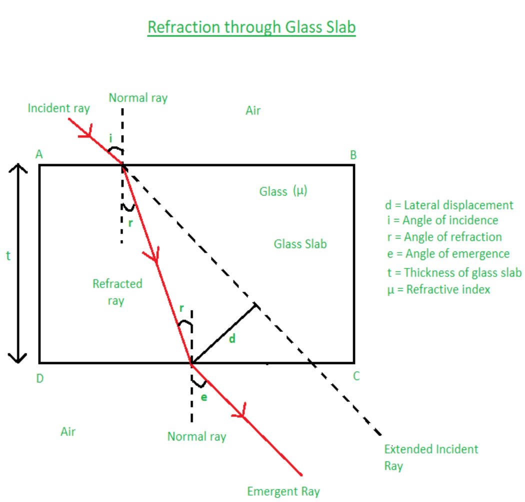
Other Applications of total internal Reflection

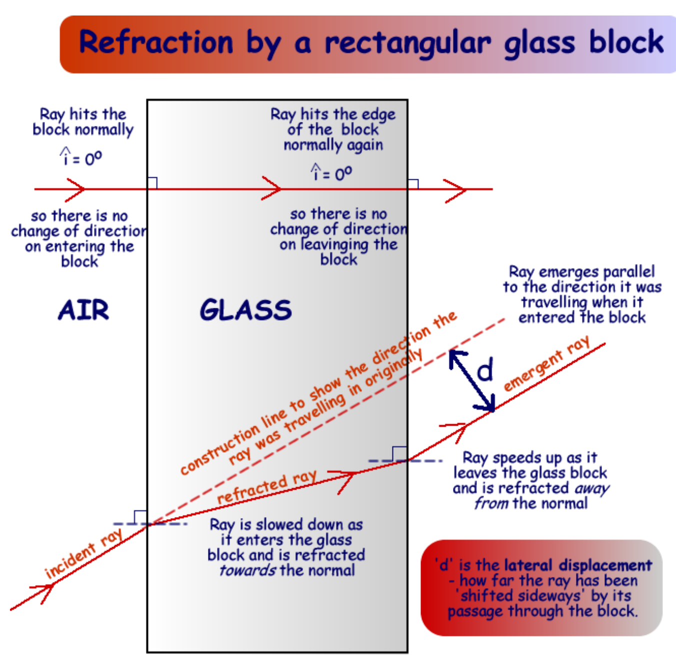
- Optical fibers
- Endoscope
- Periscope
- Binoculars
- Prisms

What is Glass Slab? A glass slab is a substance with a cuboidal shape that is made of glass. A glass slab is made of glass with three dimensions length, breadth, and height.

Some important properties of a glass slab can be stated as 1. The glass slab does not deviate from the light rays passing through it. 2. The glass slab does not disperse the light rays passing through it.Since it does not deviate and disperse the light rays passing through it that's why the incident ray and the emergent ray emerging from the glass slab are parallel. The glass slab only produces a lateral displacement to the direction of light.

Refraction through the Glass Slab: When the incident ray is incident on the surface of the glass slab from air to the glass making an angle of incidence i with the normal the refracted ray bends towards the normal as the ray enters from rarer to denser medium.





Now, after traveling the glass slab the refracted ray makes an angle of incidence r on the other surface of the glass slab resulting in the emergent ray which bends away from the normal as it travels from glass (denser medium) to air (rarer medium) forming an angle of emergence e between the emergent ray and normal.

The emergent ray is parallel to the incident ray and the perpendicular distance between them is called lateral displacement.

Since the angle of incidence is equal to the angle of emergence, therefore the emergent ray is parallel to the incident ray.

In the glass slab, the light ray gets refracted two times firstly, from rarer to denser medium and secondly from denser to rarer medium. The displacement created in the emergent ray is due to refraction.

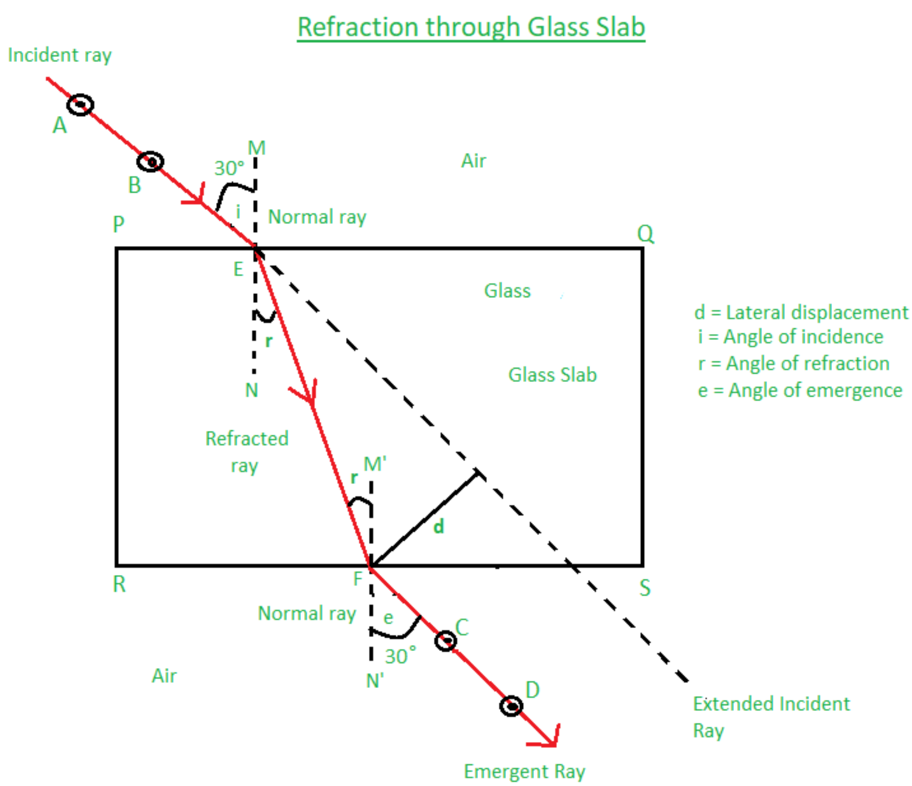
Therefore, the formula for the lateral displacement d is given by,

$d = [t \sin(i - r)]/ \cos r = t \sin(i - r) \sec r$ where t is the thickness of the glass slab, i is the angle of incidence, r is the angle of refraction.

<u>Experiment to Trace the path of a ray of light passing through a glass slab</u>

Aim: Tracing the path of a ray of light passing through the glass slab.

Materials Required:- Drawing board, all pins, white paper, rectangular glass slab, protractor, scale, pencil, thumb pins.



Procedure:

Fix the white paper on the drawing board with the help of thumb pins.

Place the glass slab on the paper at the center and draw an outline of the glass slab and label it PQRS.

Draw a point E on PQ and draw perpendicular MN and label it as a normal ray.

Draw one angle of 30° with a protractor with MN. Fix pins A and B, 4-5 cm apart from each other on the ray that is obtained by formed angle.

Place the glass slab on the outline PQRS and see through the glass slab from side RS and fix C and D pins such that A, B, C, and D should lie on the same line.

Draw small circles on A, B, C, and D and remove the pins.

Join C, D such that it meets at point F on RS and draw perpendicular M'N' at point F.

Now, join the points E and F.

Measure the angles formed at PQ and RS which are the angle of incidence, angle of refraction, and angle of emergence.

The lateral displacement d is obtained by extending the ray AB in the dotted line parallel to FCD and then, measuring it.

Conclusion: The angle of incidence is almost equal to the angle of emergence.

As the light travels from rarer to a denser medium, the angle of refraction will be lesser than the angle of refraction.

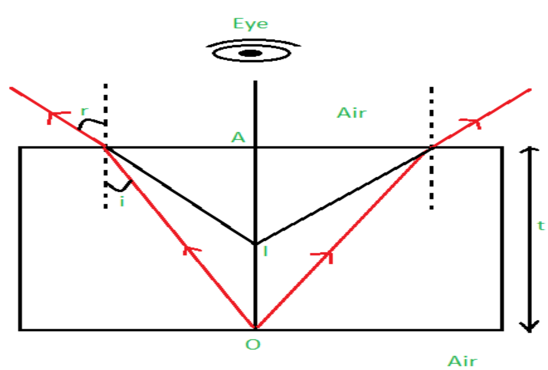
For different angles of incidence, the lateral displacement will be the same.

The light bends towards the normal when it travels from rarer to denser medium.

Different Cases of Refraction through Glass Slab

Case 1: Refraction when the object is in a denser medium and the observer is in a rarer medium

Consider a glass slab with refractive index and thickness μ and t respectively. The observer (eye) is in the air and the object (O) is in the glass slab.

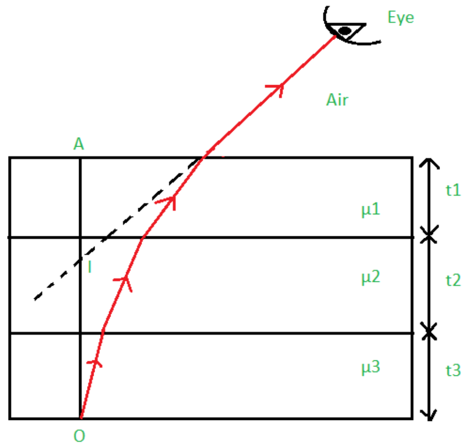


Hence for this case,

Virtual Depth = t / μ and Virtual displacement (OI) = OA – AI = t[1-(1/ μ)]

Case 2: Refraction through the successive slabs with different thicknesses and refractive index

Consider three successive slabs s1, s2, and s3 with thickness t1, t2, t3, and refractive indices μ1, μ2, and μ3 respectively. These slabs are arranged one after the other with s1 at the top, s2 at the middle, and s3 at the bottom. The object(O) is in s3 and the observer (eye) is outside in the air (rarer medium).



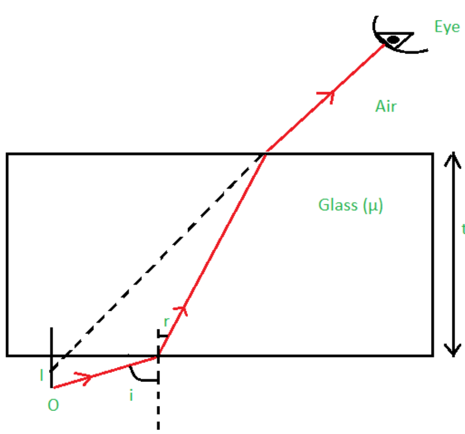
Hence for this case,

Virtual depth (AI) = (t1/ μ1) + (t2/ μ2) + (t3/ μ3) + ……. and

Virtual displacement (OI) = t1[1 – (1/ μ1)] + t2[1 – (1/ μ2)] + t3[1 – (1/ μ3)] + ………

Case 3: Refraction when object and observer both are in a rarer medium

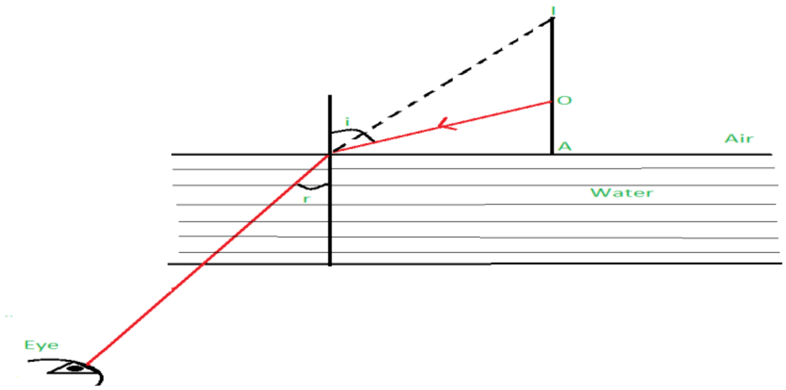
Consider a glass slab with thickness t and refractive index μ. In this case, the object (O) and observer(eye) both are in a rarer medium (air) separated by the glass slab.



Hence for this case, Virtual displacement (OI) = [t – (1/ μ)]

Case 4: Refraction when the object is in a rarer medium and the observer is in a denser medium

Consider the observer(eye) is in water(denser medium) and the object (O) is in the air (rarer medium).



Hence for this case, Real height / Virtual height = 1 / μ   or Virtual displacement (OI) = AI – AO = (μ – 1)AO

<u>TRYTHIS:</u> 1: Determine the position of the object kept at bottom of the glass slab with the thickness of 12 cm and the refractive index of glass is 1.5.

2: Two immiscible liquids of refractive indices 3/2 and 4/3 filled in the vessel up to 9 cm and 12 cm then, What will be the virtual depth of the bottom of the vessel.

3. Why emergent ray is parallel to the incident ray in the refraction through the glass slab.
4. What is lateral displacement. State the factors on which it depends.

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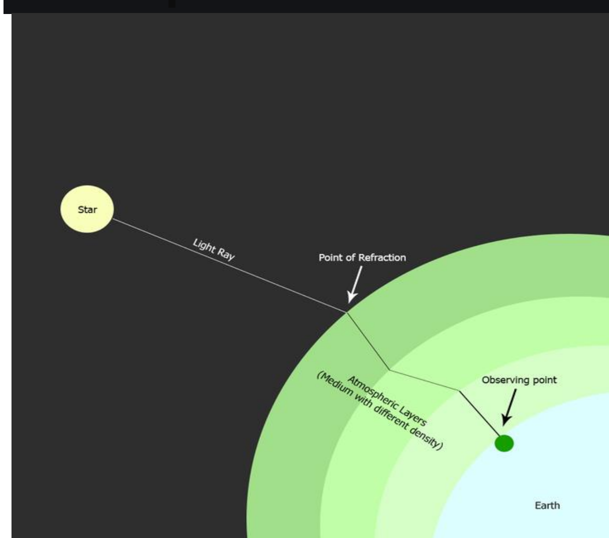

Since we know the change in medium causes refraction likewise our earth is covered with the atmosphere having different layers, and these layers possess different temperatures at different heights, some atmospheric layers are warm and some are cold. Now the warmer layer of the atmosphere behaves like an optically rarer medium whereas the cooler layer behaves like an optically denser medium. So now we again have different media thus when light passes through different layers of the atmosphere it gets refracted.

In short, the refraction cause due to the earth's atmosphere is called atmospheric refraction.

Examples of Atmospheric Refraction

Twinkling of stars: As we discussed earlier the temperature of the atmosphere's layer is different at a different height which creates different media for refraction. Also, the air is not constant which led to a change in temperature and causes refraction. So, when the atmosphere refracts more light to us the star seems bright. However, when the atmosphere refracts less light than the star seems dim, and this process happens so fast that it seems to us twinkling.

Advanced sunrise and Delay in the sunset: When we see sunsets, the light ray coming from the sun goes under refraction and bends towards us. At that time, the sun already crossed the horizon. The sun, we see, is an image that is formed due to refraction that is actually higher than its actual position. This result in the delay of sunset and the same thing happen during sunrise which makes it earlier than the actual one.

The apparent position of the stars: As we discussed in the twinkling of a star that our atmosphere has different layers which cause light to refract, so our atmosphere bends the starlight towards normal, which causes the apparent position of the star to appear to be slightly different from its actual position.

The Rainbow: A rainbow after the rain. The formation of a rainbow involves Reflection, Refraction, and Dispersion. Firstly, the sunlight enters into the water droplet during which it undergoes refraction as well as dispersion. But here we are only concerned about refraction. So, the light bends inside the droplet (due to change in medium) and performs total internal reflection and then comes out where the light again refracts which results in the formation of a rainbow.

TRYTHIS: **1. Explain why stars seem higher than their actual position?**
2. Why only stars twinkle in the night but not the planet?
3. Write at least three applications of atmospheric refraction?