# SI Physics - Full Discipline Demo

## Refractive Index of a Glass Slab

## Final Report - Answer Guide

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|---|---|
| **Institution** | Science Interactive University |
| **Session** | SI Physics - Full Discipline Demo |
| **Course** | SI Physics - Full Discipline Demo |
| **Instructor** | Sales SI Demo |

## Test Your Knowledge

**Order the materials from smallest refractive index to largest refractive index.**

≡ Air

1 **Correct answer:** Air

≡ Diamond

2 **Correct answer:** Water

≡ Glass

3 **Correct answer:** Quartz

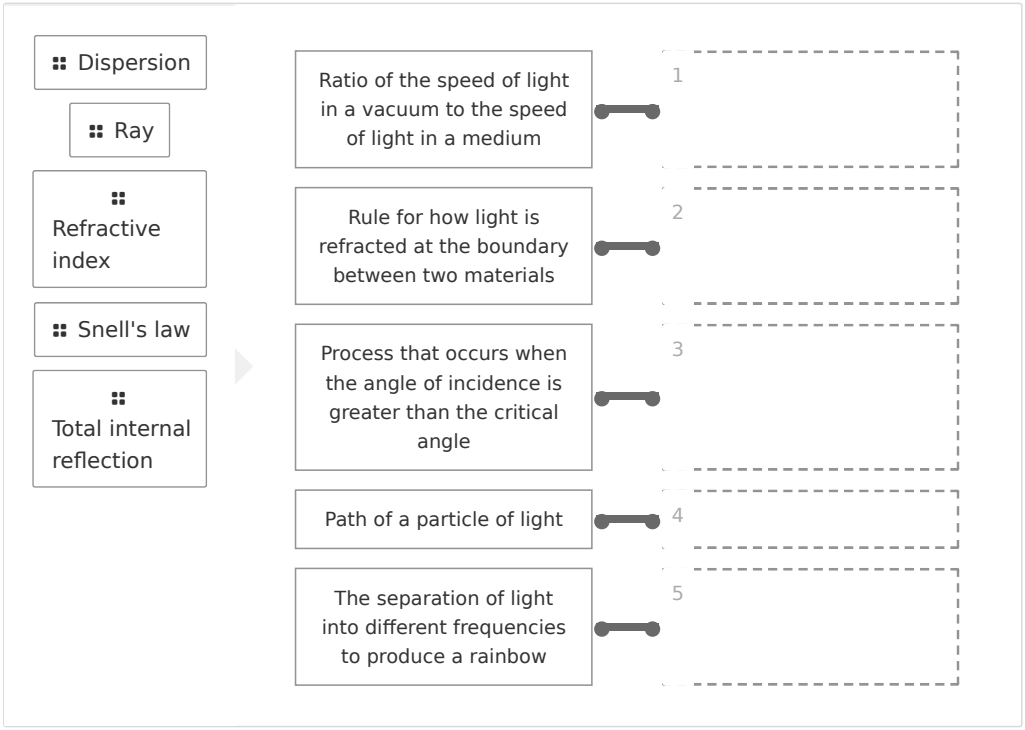
≡ Quartz

4 **Correct answer:** Glass

≡ Water

5 **Correct answer:** Diamond

**Match each term with the best description.**

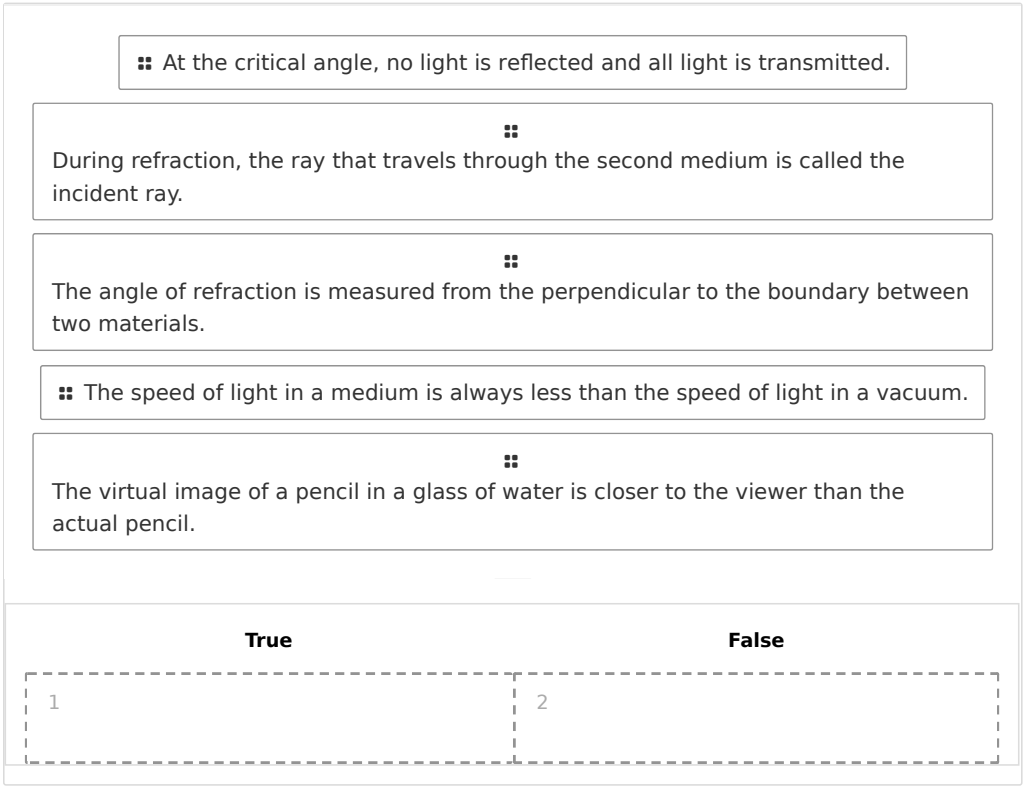



Correct answers:

1 Refractive index 2 Snell's law 3 Total internal reflection 4 Ray

5 Dispersion

**Categorize each statement as true or false.**




Correct answers:

1

The angle of refraction is measured from the perpendicular to the boundary between two materials.

The speed of light in a medium is always less than the speed of light in a vacuum.

The virtual image of a pencil in a glass of water is closer to the viewer than the actual pencil.

2 At the critical angle, no light is reflected and all light is transmitted.

During refraction, the ray that travels through the second medium is called the incident ray.

## Exploration

**Light is an electromagnetic wave and also a discreet particle.**

- [x] True ✔
- [ ] False

**The index of refraction depends on the _____.**

- [ ] speed of light in the medium
- [ ] frequency of light
- [ ] density of the medium
- [x] All of the above ✔

**Light bends when it enters a new medium because of its change in _____ as it crosses the boundary.**

- [x] speed ✔
- [ ] frequency
- [ ] color
- [ ] All of the above

**The bending of light as it passes from one medium to another is called _____.**

- [ ] reflection
- [ ] transmission
- [x] refraction ✔
- [ ] All of the above

**The angles of incidence and refraction are measured from the _____ of the boundary between two materials.**

- parallel
- normal ✔
- 45 degree
- All of the above

**Snell's law depends on the refractive indexes of the materials as well as on the _____ of the angles of the light rays.**

- square roots
- sines ✔
- cosines
- None of the above

**Total internal reflection occurs only when $n_2$ is _____ $n_1$.**

- less than ✔
- equal to
- greater than
- All of the above

**The cladding of a fiber optic cable has a refractive index _____ the refractive index of the central glass cable.**

- less than ✔
- equal to
- greater than
- None of the above

**The angle of refraction for light passing from water into air is _____ the angle of incidence, causing the broken appearance of a pencil in a glass of water.**

- less than
- equal to
- greater than ✔
- None of the above

**A virtual image _____ appears on a screen placed at the location of the image.**

- always
- never ✔
- sometimes
- None of the above

## Exercise 1

**What is the relationship between the incident angle at the top of the block and the refracted angle at the bottom of the block? Explain using Snell's law and Data Table 1.**

The incident angle at the top of the block and the refracted angle at the bottom of the block are very similar for all trials, all within 1.5°. So, the ray that enters the block and the ray that leaves the block are parallel. This is reflected by Snell's law and simple geometry. Since the block's sides are parallel, the angles measured from each normal ($\Theta_{rT}$ and $\Theta_{iB}$), if done correctly, should be identical. Thus, Snell's law, which states $n_{air}sin(\Theta_{iT})=n_{block}sin(\Theta_{rT})$ *and* $n_{block}sin(\Theta_{iB})=n_{air}sin(\Theta_{rB})$. *Since* $\Theta_{rT}$ and $\Theta_{iB}$ *are identical, this can be simplified as* $n_{air}sin(\Theta_{iT})= n_{air}sin(\Theta_{rB})$. *Since the index of refraction is the same, this equation implies* $\Theta_{iT} = \Theta_{rB}$. *Thus the ray entering the block and the ray leaving the block are parallel.*

**Why must the slope of your graph in Graph 1 be greater than 1? What would a slope of less than 1 indicate? Consider the definition of index of refraction.**

The slope must be greater than 1 because the index of refraction must always be greater than one. The index of refraction is defined as the ratio of the speed of light in vacuum to the speed of light in a material. The speed of light in a material can never exceed the speed in vacuum, meaning the index of refraction can never be greater than 1.

**What is the index of refraction of an unknown material if a light ray travels from water (n=1.33) at an incident angle of 30° from the normal and bends in the material at an angle 20° from the normal? Show all calculations in your answer.**

Snell's law states: $n_1 sin\Theta_1 = n_2 sin\Theta_2$. This can be rearranged to be: $n_2 = n_1 sin\Theta_1 / sin\Theta_2$. So: $n_2 = 1.33 sin(30)/sin(20) = 1.33*0.5/0.34 = 1.94$.

Data Table 1: Index of Refraction from Individual Incident Angles
(SAMPLE ANSWER BELOW)

| Incident Angle $\Theta_{iT}$ (°) | Refracted Angle $\Theta_{rT}$ (°) | Incident Angle $\Theta_{iB}$ (°) | Refracted Angle $\Theta_{rB}$ (°) | Index of Refraction (from top) | Percent Error (from top) (%) | Index of Refraction (from bottom) | Percent Error (from bottom) (%) |
|---|---|---|---|---|---|---|---|
| 30 | 20.0 | 19.0 | 31.0 | 1.46 | 1.89 | 1.58 | 6.17 |
| 45 | 29.0 | 28.0 | 45.5 | 1.46 | 2.11 | 1.52 | 1.96 |
| 60 | 37.0 | 36.0 | 61.5 | 1.44 | 3.42 | 1.50 | 0.34 |

Photo 1: Incident Angle of 30°
(SAMPLE ANSWER BELOW)

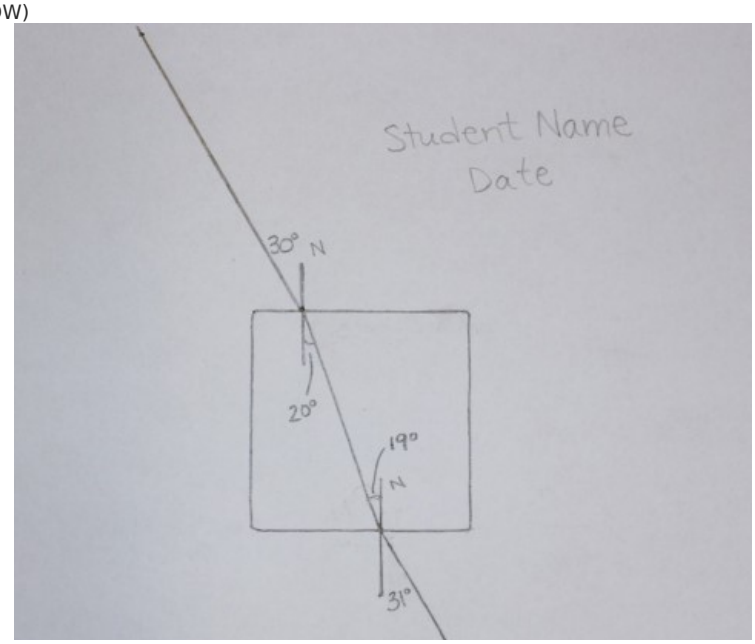


Photo 2: Incident Angle of 45°

(SAMPLE ANSWER BELOW)

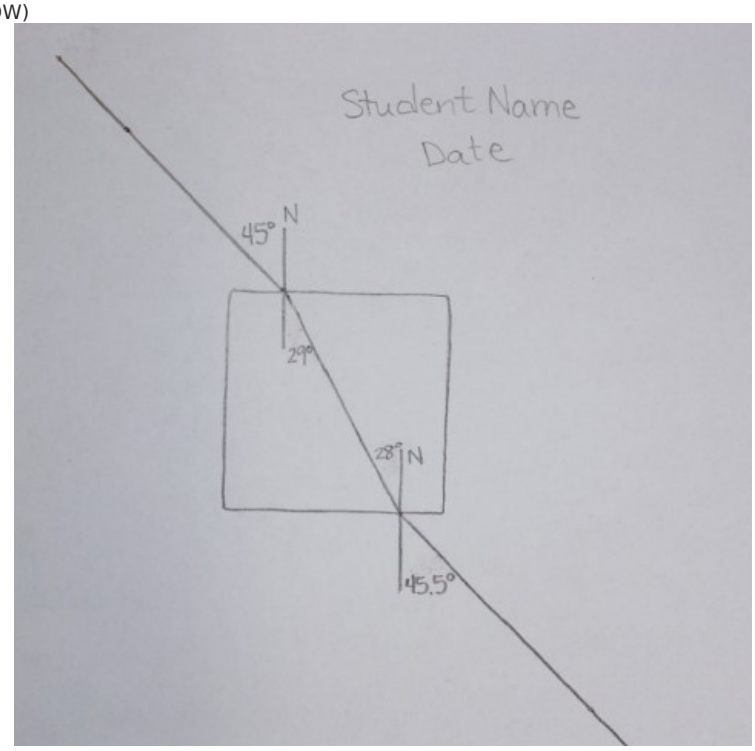
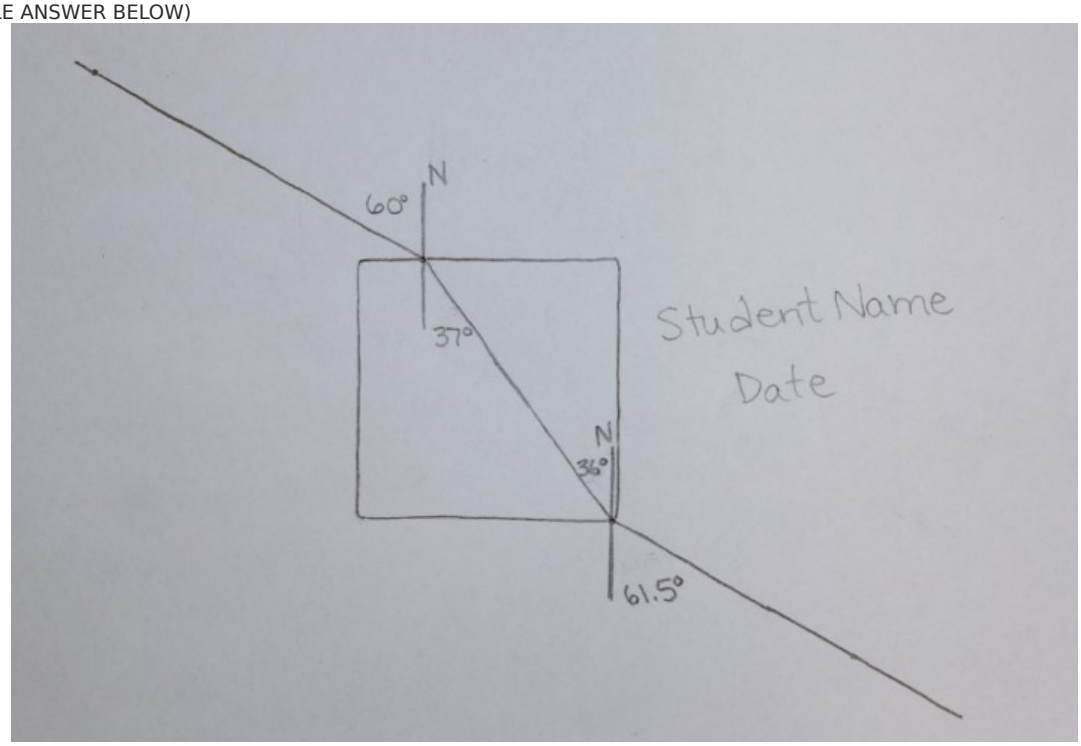


Photo 3: Incident Angle of 60°

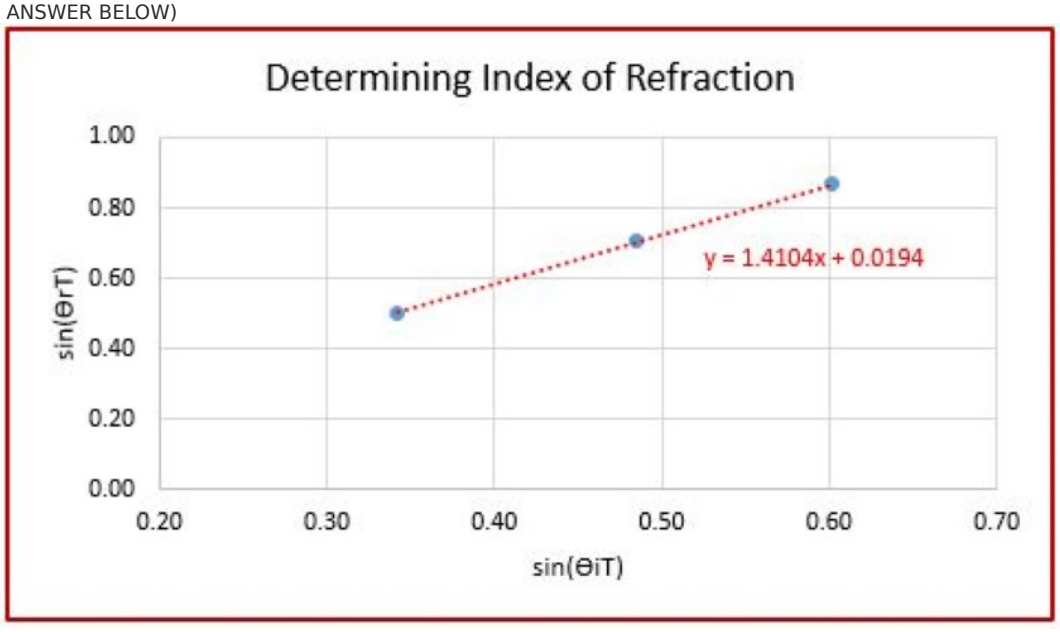
(SAMPLE ANSWER BELOW)



Data Table 2: Index of Refraction with the slope of a Graph
(SAMPLE ANSWER BELOW)

| Incident Angle $\Theta_{iT}$ (°) | Refracted Angle $\Theta_{rT}$ (°) | $\sin(\Theta_{iT})$ | $\sin(\Theta_{rT})$ | Index of Refraction | Percent Error (%) |
|---|---|---|---|---|---|
| 30 | 20.0 | 0.50 | 0.34 | 1.41 | 5.37 |
| 45 | 29.0 | 0.71 | 0.48 | | |
| 60 | 37.0 | 0.87 | 0.60 | | |

Graph 1: Index of Refraction
(SAMPLE ANSWER BELOW)



## Exercise 2

**Would total internal reflection occur if the top material was air and the bottom material was water? Explain your answer using the equation for critical angle.**

No. Total internal reflection (TIR) cannot occur when light travels from a material of lower index of refraction to higher index of refraction. This is a direct result of the equation used to find the critical angle: $\Theta_c = arcsin(n_{bottom}/n_{top})$, when entering from the top material to the bottom material. If the index of refraction of the bottom of the material is larger than that of the top material, the ratio of refractive indices inside the arcsine if greater than 1. However, the value of sine can never exceed 1. So, the bottom material's index of refraction must be larger for TIR to occur. Since air has a lower index of refraction than water, TIR can never occur when light travels from air to water (but does from water to air).

**What is the critical angle for a ray of light traveling from glass (n=1.5) to water (n=1.33)? Show all calculations in your answer.**

$\Theta_c = \arcsin(n_2/n_1) = \arcsin(1.33/1.5) = \arcsin(0.887) = 62.5°.$

Data Table 3: Determining Critical Angle
(SAMPLE ANSWER BELOW)

| Material | Index of Refraction | Measured Critical Angle (°) | Calculated Critical Angle (°) |
|---|---|---|---|
| Water | 1.33 | 49 | 48.8 |
| Glass | 1.50 | 42 | 41.8 |

Data Table 4: Determining Index of Refraction from Critical Angle
(SAMPLE ANSWER BELOW)

| Material | Measured Critical Angle (°) | Index of Refraction | Predicted Material |
|---|---|---|---|
| Mystery A | 25 | 2.37 | Diamond |
| Mystery B | 46 | 1.39 | Sellaite |

## Competency Review

**The index of refraction is always less than or equal to one.**

- True
- False ✔

**The ray that passes from one medium to another during refraction is called the _____ ray.**

- transmitted
- reflected
- refracted ✔
- None of the above

**According to Snell's law, the medium with the larger index of refraction will have the larger angle.**

- True
- False ✔

**Snell's law can be used to solve for the index of refraction of a medium if the _____ is known.**

- angle of incidence
- angle of refraction
- index of refraction of the other medium
- All of the above ✔

**Total internal reflection occurs when the angle of incidence is _____ the critical angle.**

- greater than
- equal to
- greater than or equal to ✔
- None of the above

**Total internal reflection is possible when light travels from air into water.**

- True
- False ✔

**The critical angle for total internal reflection is the angle of incidence that causes an angle of refraction of exactly _____ degrees.**

- 90 ✔
- 45
- 0
- None of the above

**The virtual image of a fish in a pond as viewed from above the pond is _____ the surface than the actual location of the fish in the pond.**

- closer to ✔
- farther from
- perpendicular to
- None of the above

**When $n_2$ is greater than $n_1$, the image distance will be _____ the object distance.**

- less than
- greater than ✔
- equal to
- None of the above

**For an object in water with a refractive index of 1.33 located 1.0 meters from an observer in air with a refractive index of 1.0, the image distance is _____ meters.**

- 0.67
- 1.33
- 0.75 ✔
- None of the above

**When light passes through a rectangular block the emergent ray is parallel to the _____ ray.**

- refracted
- incident ✔
- reflected
- None of the above

**The refracted angle at the top of a refraction block is _____ the incident angle at the bottom of the block.**

- greater than
- less than
- equal to ✔
- None of the above

**The incident angle for a light ray traveling from water (n=1.33) into an unknown substance is 30 degrees. The refraction angle is 21 degrees so the index of refraction for the unknown substance is _____.**

- 1
- 1.9 ✔
- 1.4
- None of the above

**When the slope of a graph is the index of refraction for a material and light is refracted from air into that material, the vertical axis of the graph is _____.**

- the sine of the angle of incidence ✔
- the angle of incidence
- the sine of the angle of refraction
- None of the above

**Sapphire has an index of refraction of 1.77. The critical angle for sapphire in air with an index of refraction of 1.0 is _____ degrees.**

- 3
- 90
- 34 ✔
- None of the above

**Total internal reflection will not occur for any angle when light shines from air (n=1.0) into a sapphire (n = 1.77).**

- [x] True ✔
- [ ] False

**An unknown substance has a critical angle of 43 degrees, so its index of refraction is _____.**

- [x] 1.47 ✔
- [ ] 1.33
- [ ] 1
- [ ] None of the above

**Total internal reflection only occurs when the second medium _____.**

- [ ] is air
- [x] has an index of refraction less than the first medium ✔
- [ ] has an index of refraction greater than the first medium
- [ ] None of the above

## Extension Questions

**Does a fish appear closer or farther from a person wearing swim goggles with an air pocket in front of their eyes than the fish really is? Does the fish see the person's face closer or farther than it really is? Explain your answer.** (SAMPLE ANSWER BELOW)

The fish appears closer than it really is because light from the fish is refracted away from the normal as it enters the air pocket in the goggles. This is because air has a smaller index of refraction than water. The person will trace rays back to an image point in front of the actual fish. The fish will see the person's face exactly where it actually is because the light from the face is not refracted as it travels through water only, and does not change from one medium to another.

**Light rays from stars bend toward smaller angles as they enter Earth's atmosphere. a. Explain why this happens using Snell's law and the speed of light. b. Where are the actual stars in relation to their apparent position as viewed from the Earth's surface?** (SAMPLE ANSWER BELOW)

a. Snell's law says that the angle of refraction will be smaller than the angle of incidence when the index of refraction of the second medium is greater than that of the first. Light from stars enters the atmosphere from the vacuum of space, so the index of refraction of the atmosphere is greater than that of a vacuum. The index of refraction of a vacuum is one exactly, while it is slightly

greater than 1 for the atmosphere.  This is because the speed of light in a vacuum is c, and the speed of light in the atmosphere is a little bit lower than c. b. The actual stars are slightly closer than they appear as viewed through the atmosphere because the image distance is larger than the object distance when the index of refraction of the second medium is larger than that of the first medium.