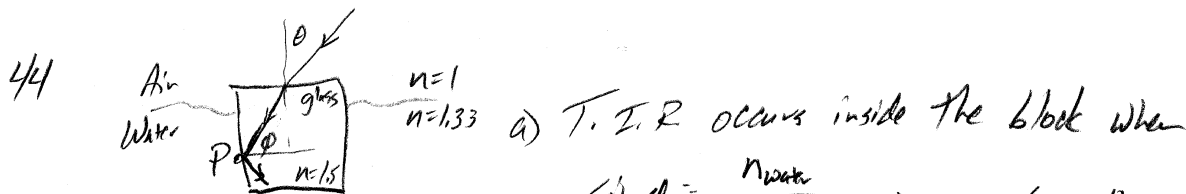


Presumably, the observer can't see the light because it undergoes total internal reflection for all allowed angles  $\theta > \theta_c$ , where

$$\sin \theta_c = \frac{1}{n}. \text{ Since } \tan \theta_c = \frac{r}{d}, \frac{1}{n} = \frac{r}{\sqrt{r^2 + d^2}}, \text{ or } \boxed{n \approx 1.3}$$



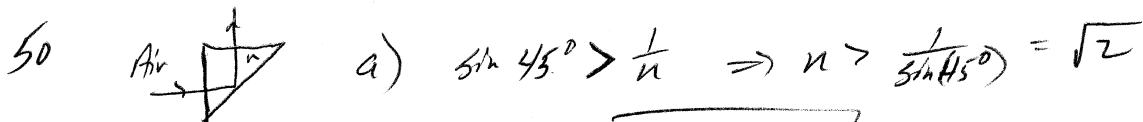
$$\sin \phi = \frac{n_{\text{water}}}{n_{\text{glass}}} \Rightarrow \phi \approx 62.45^\circ$$

since  $n_{\text{air}} \sin \theta = n_{\text{glass}} \sin(90^\circ - \phi) = n_{\text{glass}} \cos \phi$

$$\Rightarrow \sin \theta = n_{\text{glass}} \cos \phi \approx 0.6936 \Rightarrow \boxed{\theta \approx 44^\circ}$$

b) No water  $\Rightarrow$  T.I.R. angle is  $\sin \phi = \frac{n_{\text{air}}}{n_{\text{glass}}} \Rightarrow \phi \approx 41.8^\circ$

Since  $62.45^\circ > 41.8^\circ$ , the light will still be T.I.R.



$$\text{so } \boxed{n \geq 1.414}$$

b) Still T.I.R. for  $\sin 45^\circ > \frac{1.15}{n} \Rightarrow n \geq 1.6$

No T.I.R. for  $\sin 45^\circ < \frac{1.33}{n} \Rightarrow n \leq 1.9$