1. Red arrives first. The red light takes 0.05193 seconds to arrive while blue light takes 0.05229 seconds to arrive. When the red light arrives, the blue light is still 73.541 kilometers away.

2. It is not possible to define a sensible refractive index for water waves since the phase velocity $c(\omega) = g/\omega$ diverges as $\omega \to 0$ so there is no c_{max}. We find $c(\lambda) = \sqrt{\lambda g/2\pi}$, so large waves move faster than small waves.

3. $d = (h_s/(h_s + h_r))\ell$

4. The vector from the source is $d\hat{x} - h_s\hat{y}$ and the vector to the receiver is $(\ell - d)\hat{x} + h_r\hat{y}$, so the solutions are those of:

$$\cos^{-1}\left(\frac{\epsilon d^2 - h_s}{\sqrt{d^2 + h_s^2}}\right) = \cos^{-1}\left(\frac{\epsilon(\ell - d)d + h_r}{\sqrt{(\ell - d)^2 + h_r^2}}\right)$$

We note $\cos^{-1}(\theta) \approx \pi/2 - \theta$, so:

$$\frac{\epsilon d^2 - h_s}{\sqrt{d^2 + h_s^2}} = \frac{\epsilon(\ell - d)d + h_r}{\sqrt{(\ell - d)^2 + h_r^2}}$$

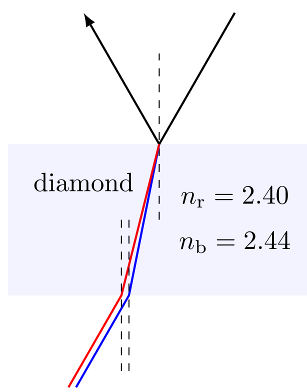
Dropping terms proportional to ϵ:

$$\frac{-h_s}{\sqrt{d^2 + h_s^2}} = \frac{h_r}{\sqrt{(\ell - d)^2 + h_r^2}}$$

Whose solutions are $d = (h_s/(h_s \pm h_r))\ell$, and we see that in this approximation, there are two distinct angles at which light can be sent from the source to the receiver.

5. Refracted blue light goes out at 11.82° while refracted red light goes out at 12.02°, so the angular separation is 0.20°. The most important characteristic for dispersing the colors of light to create rainbows is the *variation* of the index of refraction over the visible spectrum rather than just the magnitude of the index of refraction.

6. The figure is (with exaggerated separation of blue and red):



7. $\theta_{\text{water}} = 32.23°$, $\theta_{\text{air}} = 23.58°$, so we see the internal angles of the polygon must be greater than $180° - 23.58° = 156.42°$. Now the interior angles of a polygon with s sides are $((s-2)/s) \cdot 180°$, so we see that if $s = 16$, then the interior angles are 157.5° and this is the smallest number of sides for which total internal reflection will occur in the glass.

8. $I_0/8$

9. The intensity is zero. This is perhaps surprising because removing a polarized which allegedly removes light results in there being *more* light absorbed. This can be understood by thinking molecularly: polarizers are made of highly-ordered one dimensional polymers arranged in one direction, electrons can move in the strand direction but not other directions. Light is then absorbed and some is re-emitted as described by Malus's Law. No photons make it through a filter–all are absorbed, and then some are re-emitted.

10. The units of the absorption coefficient are $[1/m]$. $\omega/c = k$, so we see $\alpha = 2\kappa k$, or 2κ sets the absorption per period (in an exponential decay way–see the next problem) and k specifies the number of periods per unit length.

    Here, we have $\alpha = 4\pi\kappa/\lambda = 1.01 \times 10^7$ [1/m].

11. 0 to *very* good approximation

12. $R = 0.0985$. A shiny metal would have a large κ relative to n, so that $\kappa^2 \gg n^2$ and then $R \sim 1$.