26.20 $\frac{n_1}{p}+\frac{n_2}{q}=\frac{n_2-n_1}{R}$ so $\frac{1.00}{\infty}+\frac{1.40}{21.0\text{ mm}}=\frac{1.40-1.00}{6.00\text{ mm}}$

and $0.0667=0.0667$

They agree. **The image is inverted, real and dimished**

***26.36** To properly focus the image of a distant object, the lens must be at a distance equal to the focal length from the film ($q_1 = 65.0$ mm). For the closer object:

$$\frac{1}{p_2}+\frac{1}{q_2}=\frac{1}{f}$$

becomes $$\frac{1}{2000\text{ mm}}+\frac{1}{q_2}=\frac{1}{65.0\text{ mm}}$$

and $$q_2=(65.0\text{ mm})\left(\frac{2000}{2000-65.0}\right)$$

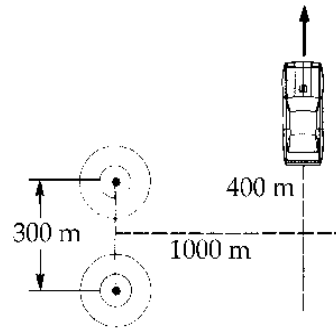
The lens must be moved **away from the film** by a distance

$$D=q_2-q_1=(65.0\text{ mm})\left(\frac{2000}{2000-65.0}\right)-65.0\text{ mm}=\boxed{2.18\text{ mm}}$$

27.1 $y_{\text{bright}}=\frac{\lambda L}{d}m$

For $m = 1$, $$\lambda=\frac{yd}{L}=\frac{(3.40\times10^{-3}\text{ m})(5.00\times10^{-4}\text{ m})}{3.30\text{ m}}=\boxed{515\text{ nm}}$$

27.3 Note, with the conditions given, the small angle approximation **does not work well.** That is, $\sin\theta$, $\tan\theta$, and θ are significantly different. The approach to be used is outlined below.



(a) At the $m = 2$ maximum, $\tan\theta = \dfrac{400\text{ m}}{1000\text{ m}} = 0.400$

$\theta = 21.8°$

so $\lambda = \dfrac{d\sin\theta}{m} = \dfrac{(300\text{ m})\sin 21.8°}{2} = \boxed{55.7\text{ m}}$

(b) The next minimum encountered is the $m = 2$ minimum;

and at that point, $d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

which becomes $d\sin\theta = \frac{5}{2}\lambda$

or $\sin\theta = \frac{5}{2}\dfrac{\lambda}{d} = \frac{5}{2}\left(\dfrac{55.7\text{ m}}{300\text{ m}}\right) = 0.464$

and $\theta = 27.7°$

so $y = (1000\text{ m})\tan 27.7° = 524\text{ m}$

Therefore, the car must travel an additional $\boxed{124\text{ m}}$.

27.4 $\lambda = \dfrac{340 \text{ m/s}}{2000 \text{ Hz}} = 0.170 \text{ m}$

Maxima are at $d \sin\theta = m\lambda$:

$m = 0$	gives	$\theta = 0°$	
$m = 1$	gives	$\sin\theta = \dfrac{\lambda}{d} = \dfrac{0.170 \text{ m}}{0.350 \text{ m}}$	$\theta = 29.1°$
$m = 2$	gives	$\sin\theta = \dfrac{2\lambda}{d} = 0.971$	$\theta = 76.3°$
$m = 3$	gives	$\sin\theta = 1.46$	No solution.

Minima are at $d \sin\theta = \left(m + \frac{1}{2}\right)\lambda$:

$m = 0$	gives	$\sin\theta = \dfrac{\lambda}{2d} = 0.243$	$\theta = 14.1°$
$m = 1$	gives	$\sin\theta = \dfrac{3\lambda}{2d} = 0.729$	$\theta = 46.8°$
$m = 2$	gives	$\sin\theta = 1.21$	No solution.

So we have maxima at 0°, 29.1°, and 76.3°; minima at 14.1° and 46.8°

***27.6** At 30.0°, $d \sin\theta = m\lambda$

$(3.20 \times 10^{-4} \text{ m}) \sin 30.0° = m(500 \times 10^{-9} \text{ m})$ so $m = 320$

There are 320 maxima to the right, 320 to the left, and one for $m = 0$ straight ahead.

There are 641 maxima.

***27.8** $\phi = \frac{2\pi}{\lambda} d \sin\theta \approx \frac{2\pi}{\lambda} d\left(\frac{y}{L}\right)$

(a) $\phi = \frac{2\pi}{\left(5.00 \times 10^{-7} \text{ m}\right)}\left(1.20 \times 10^{-4} \text{ m}\right)\sin(0.500°) = \boxed{13.2 \text{ rad}}$

(b) $\phi = \frac{2\pi}{\left(5.00 \times 10^{-7} \text{ m}\right)}\left(1.20 \times 10^{-4} \text{ m}\right)\left(\frac{5.00 \times 10^{-3} \text{ m}}{1.20 \text{ m}}\right) = \boxed{6.28 \text{ rad}}$

(c) If $\phi = 0.333 \text{ rad} = \frac{2\pi d \sin\theta}{\lambda}$ $\theta = \sin^{-1}\left(\frac{\lambda \phi}{2\pi d}\right) = \sin^{-1}\left[\frac{\left(5.00 \times 10^{-7} \text{ m}\right)(0.333 \text{ rad})}{2\pi\left(1.20 \times 10^{-4} \text{ m}\right)}\right]$

$\theta = \boxed{1.27 \times 10^{-2} \text{ deg}}$

(d) If $d \sin\theta = \frac{\lambda}{4}$ $\theta = \sin^{-1}\left(\frac{\lambda}{4d}\right) = \sin^{-1}\left[\frac{5 \times 10^{-7} \text{ m}}{4\left(1.20 \times 10^{-4} \text{ m}\right)}\right]$

$\theta = \boxed{5.97 \times 10^{-2} \text{ deg}}$

27.12 Light reflecting from the first surface suffers phase reversal. Light reflecting from the second surface does not, but passes twice through the thickness t of the film. So, for constructive interference, we require

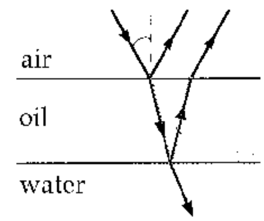
$$\frac{\lambda_n}{2} + 2t = \lambda_n$$

where $\lambda_n = \frac{\lambda}{n}$ is the wavelength in the material.

Then $2t = \frac{\lambda_n}{2} = \frac{\lambda}{2n}$

$$\lambda = 4nt = 4(1.33)(115 \text{ nm}) = \boxed{612 \text{ nm}}$$

27.13 (a) The light reflected from the top of the oil film undergoes phase reversal. Since 1.45 > 1.33, the light reflected from the bottom undergoes no reversal. For constructive interference of reflected light, we then have



$$2nt = \left(m + \frac{1}{2}\right)\lambda$$

or $$\lambda_m = \frac{2nt}{m + \frac{1}{2}} = \frac{2(1.45)(280 \text{ nm})}{m + \frac{1}{2}}$$

Substituting for m gives: $m = 0$, $\lambda_0 = 1620$ nm (infrared)

$m = 1$, $\lambda_1 = 541$ nm (green)

$m = 2$, $\lambda_2 = 325$ nm (ultraviolet)

Both infrared and ultraviolet light are invisible to the human eye, so the dominant color in reflected light is $\boxed{\text{green}}$.

(b) The dominant wavelengths in the transmitted light are those that produce destructive interference in the reflected light. The condition for destructive interference upon reflection is

$$2nt = m\lambda$$

or $$\lambda_m = \frac{2nt}{m} = \frac{812 \text{ nm}}{m}$$

Substituting for m gives: $m = 1$, $\lambda_1 = 812$ nm (near infrared)

$m = 2$, $\lambda_2 = 406$ nm (violet)

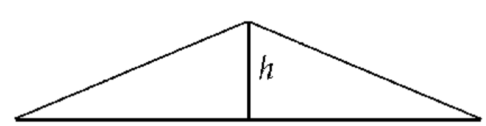
$m = 3$, $\lambda_3 = 271$ nm (ultraviolet)

Of these, the only wavelength visible to the human eye (and hence the dominate wavelength observed in the transmitted light) is 406 nm. Thus, the dominant color in the transmitted light is $\boxed{\text{violet}}$.

***27.16** $2nt = \left(m + \frac{1}{2}\right)\lambda$ so $t = \left(m + \frac{1}{2}\right)\frac{\lambda}{2n}$

Minimum $t = \left(\frac{1}{2}\right)\frac{(500 \text{ nm})}{2(1.30)} = \boxed{96.2 \text{ nm}}$

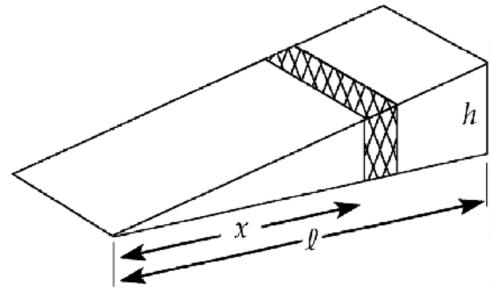
27.44 $2\sqrt{(15.0 \text{ km})^2 + h^2} = 30.175$ km



$(15.0 \text{ km})^2 + h^2 = 227.63$

$h = \boxed{1.62 \text{ km}}$

27.45 For dark fringes, $2nt = m\lambda$



and at the edge of the wedge, $t = \frac{84(500\text{ nm})}{2}$.

When submerged in water, $2nt = m\lambda$

$$m = \frac{2(1.33)(42)(500\text{ nm})}{500\text{ nm}}$$

so $m + 1 = \boxed{113\text{ dark fringes}}$

27.17 $\sin\theta = \frac{\lambda}{a} = \frac{6.328\times10^{-7}}{3.00\times10^{-4}} = 2.11\times10^{-3}$

$\frac{y}{1.00\text{ m}} = \tan\theta \approx \sin\theta = \theta$ (for small θ)

$2y = \boxed{4.22\text{ mm}}$

27.18 The positions of the first-order minima are $y/L \approx \sin\theta = \pm\lambda/a$. Thus, the spacing between these two minima is $\Delta y = 2(\lambda/a)L$ and the wavelength is

$$\lambda = \left(\frac{\Delta y}{2}\right)\left(\frac{a}{L}\right) = \left(\frac{4.10\times10^{-3}\text{ m}}{2}\right)\left(\frac{0.550\times10^{-3}\text{ m}}{2.06\text{ m}}\right) = \boxed{547\text{ nm}}$$

27.23 Following Equation 27.16 for diffraction from a circular opening, the beam spreads into a cone of half-angle

$$\theta_{\min} = 1.22\frac{\lambda}{D} = 1.22\left(\frac{632.8\times10^{-9}\text{ m}}{0.00500\text{ m}}\right) = 1.54\times10^{-4}\text{ rad}$$

The radius of the beam ten kilometers away is, from the definition of radian measure,

$$r_{\text{beam}} = \theta_{\min}\left(1.00\times10^{4}\text{ m}\right) = 1.544\text{ m}$$

and its diameter is $d_{\text{beam}} = 2r_{\text{beam}} = \boxed{3.09\text{ m}}$

27.25 By Rayleigh's criterion, two dots separated center-to-center by 2.00 mm would overlap

when $\theta_{\min} = \frac{d}{L} = 1.22\frac{\lambda}{D}$

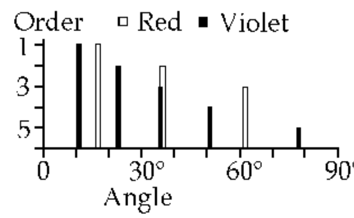
Thus, $L = \frac{dD}{1.22\lambda} = \frac{\left(2.00\times10^{-3}\text{ m}\right)\left(4.00\times10^{-3}\text{ m}\right)}{1.22\left(500\times10^{-9}\text{ m}\right)} = \boxed{13.1\text{ m}}$

27.26 $1.22\frac{\lambda}{D} = \frac{d}{L}$ $\lambda = \frac{c}{f} = 0.0200\text{ m}$

$D = 2.10\text{ m}$ $L = 9000\text{ m}$

$$d = 1.22\frac{(0.0200\text{ m})(9000\text{ m})}{2.10\text{ m}} = \boxed{105\text{ m}}$$

27.31 The grating spacing is $d = \frac{1.00\times10^{-2}\text{ m}}{4500} = 2.22\times10^{-6}\text{ m}$



In the 1st-order spectrum, diffraction angles are given by

$\sin\theta = \frac{\lambda}{d}$: $\sin\theta_1 = \frac{656\times10^{-9}\text{ m}}{2.22\times10^{-6}\text{ m}} = 0.295$

so that for red $\theta_1 = 17.17°$

and for violet $\sin\theta_2 = \frac{434\times10^{-9}\text{ m}}{2.22\times10^{-6}\text{ m}} = 0.195$

so that $\theta_2 = 11.26°$

The angular separation is in first-order, $\Delta\theta = 17.17° - 11.26° = \boxed{5.91°}$

In the second-order spectrum, $\Delta\theta = \sin^{-1}\left(\frac{2\lambda_1}{d}\right) - \sin^{-1}\left(\frac{2\lambda_2}{d}\right) = \boxed{13.2°}$

Again, in the third order, $\Delta\theta = \sin^{-1}\left(\frac{3\lambda_1}{d}\right) - \sin^{-1}\left(\frac{3\lambda_2}{d}\right) = \boxed{26.5°}$

Since the red does not appear in the fourth-order spectrum, the answer is complete.

27.33 $d = \frac{1}{800 \text{ mm}^{-1}} = 1.25 \times 10^{-6} \text{ m}$

The blue light goes off at angles $\sin\theta_m = \frac{m\lambda}{d}$: $\theta_1 = \sin^{-1}\left(\frac{1 \times 5.00 \times 10^{-7} \text{ m}}{1.25 \times 10^{-6} \text{ m}}\right) = 23.6°$

$\theta_2 = \sin^{-1}(2 \times 0.400) = 53.1°$

$\theta_3 = \sin^{-1}(3 \times 0.400) = \text{nonexistent}$

The red end of the spectrum is at $\theta_1 = \sin^{-1}\left(\frac{1 \times 7.00 \times 10^{-7} \text{ m}}{1.25 \times 10^{-6} \text{ m}}\right) = 34.1°$

$\theta_2 = \sin^{-1}(2 \times 0.560) = \text{nonexistent}$

So only the first-order spectrum is complete, and **it does not overlap** the second-order spectrum.

27.37 $2d\sin\theta = m\lambda$: $\sin\theta = \frac{m\lambda}{2d} = \frac{1(0.140 \times 10^{-9} \text{ m})}{2(0.281 \times 10^{-9} \text{ m})} = 0.249$

and $\boxed{\theta = 14.4°}$

***27.53** (a) We require $\theta_{min} = 1.22\frac{\lambda}{D} = \frac{\text{radius of diffraction disk}}{L} = \frac{D}{2L}$.

Then $\boxed{D^2 = 2.44\lambda L}$

(b) $D = \sqrt{2.44(500 \times 10^{-9} \text{ m})(0.150 \text{ m})} = \boxed{428\ \mu\text{m}}$