EE 119 Homework 5 Solution

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1. Solution:

(a) We first find the numerical aperture on the object side

$$NA_1 = \sin(\tan^{-1}(\frac{0.0015}{535})) \approx 2.80\times 10^{-6}.$$

The diffraction-limited minimum feature size (resolution limit) is

$$R.L = \frac{0.61\lambda}{NA_1} = 0.12m = 12cm$$

Since the diameter of the coins is smaller than the diffraction-limited minimum feature size. Hence, Esunge could not have been able to see the coins clearly due to diffraction limit.

(b) The maximum separation between the cone cells in Esunge should be

$$\frac{0.08}{535} = 0.15mrad ,$$

which is approximately 1/2 of the average separation found in modern humans.

(c) Visual acuity (VA) is expressed as (Distance to target)/(Distance at which target element is 1min). Hence, for Esunge, the target element is 1 min at

$$\frac{0.08m}{1\min} = \frac{0.08m}{0.0003rad} = 267m$$

$$VA = \frac{535}{267} \approx \frac{20}{10}$$

So his VA is approximately twice as good as modern humans.

2. Solution: From the lecture note, we know that the overall power of a human eye is 58.6D.

$$\frac{n}{d_2} = \frac{1}{f} + \frac{1}{d_1} = 58.6 - \frac{1}{\infty} = 58.6$$

$$=> \quad d_2 \approx nf = 1.336\times\frac{1}{58.6}m = 0.0228m$$

$$m = \left|\frac{d_2}{nd_1}\right| = \frac{0.0228m}{1.336\times 150\times 10^9 m} = 1.14\times 10^{-13}$$

The size of the image formed on the retina is

$$D_{image} = m\times(2\times R_{sun}) = 0.16mm$$

The image on the retina is 0.16mm in diameter.

3. Solution:

(a) Rosie now has become near-sighted or has myopia. She needs a negative lens which would give a virtual image at infinity for an object placed at 15cm.

$$P = \frac{1}{f} = \frac{1}{d_2} - \frac{1}{d_1} = \frac{1}{\infty} - \frac{1}{0.15} = -6.67D$$

The power of the corrective lens needs to be -6.67 Diopters.

(b) First we calculate the power of Rosie's eye

$$P = \frac{1}{f} = \frac{n}{d_2} - \frac{1}{d_1} = \frac{1.336}{0.025} - \frac{1}{(-0.15)} = 60.11D$$

Now for an object at ∞,

$$\frac{1}{f} = \frac{n}{d_2} - \frac{1}{d_1} = \frac{n}{d_2} - \frac{1}{\infty} = 60.11D$$

$$=> \; d_2 = \frac{1.336}{60.11} = 0.0222m = 2.22cm$$

So the image forms at 0.26 cm in front of retina.

4. Solution:

(a) When the eye is focused on an object at infinity, the power that the eye has is

$$P = \frac{1}{f} = \frac{1}{d_2} - \frac{1}{d_1} = \frac{1}{0.02} - \frac{1}{\infty} = 50D$$

The minimum power of the eye is 50 Diopters.

(b) When the eye is focused on an object at 75cm, the power that the eye has is

$$P = \frac{1}{f} = \frac{1}{d_2} - \frac{1}{d_1} = \frac{1}{0.02} - \frac{1}{0.75} = 51.3D$$

The maximum power of the eye is 51.3 Diopters.

(c) As 51.3 – 50 = 1.3D, accommodation of 1.3D is required of the eye to focus on an object at 75cm.

(d) The total power needed to focus on an object at 25cm is

$$P = \frac{1}{f} = \frac{1}{d_2} - \frac{1}{d_1} = \frac{1}{0.02} - \frac{1}{(-0.25)} = 54D\,.$$

The eye can provide power of 51.3D. Hence, additional power of 2.7D is needed to focus comfortably at 25cm.

5. Solution:

(a) The shutter speed has increased by a factor of two. Hence, the F-number must decrease by $\sqrt{2}$ for the same exposure level.
So the F-number is f/11.

(b) The numerical aperture is

$$NA \approx \frac{1}{2F} = \frac{1}{2 \times 11} = 0.045$$

So the resolution limit is

$$R.L. = \frac{0.61\lambda}{NA} = 7.38um$$

Since the typical focal length of a lens used in camera is 50mm, then

$$\theta \cong \frac{7.38\mu m}{50mm} = 0.15mrad\ .$$

(c) Since the motorcycle speed is 5 times larger than that of the car on the street, the shutter speed has to be at least 5 times faster at the motorcycle than that she used to shoot the car. The new shutter speed should be faster than 1/160s. Therefore, Rosie should choose the shutter speed of 1/250s, and the corresponding F-number is $11/(\sqrt{2})^3 = 4$ (or $11/\sqrt{(250/32)} = 4$).

Yes, Rosie can take sharp pictures of Nikhil racing on his motorcycle at a speed of 150 mph with her new camera. The settings should be that the shutter speed is 1/250s, and F-number is f/4.