## Physics 111

Fall 2007
Wave Optics

1. The pupil of a cat's eye narrows to a vertical slit of width 0.500 mm in daylight. What is the angular resolution for horizontally separated mice? Assume that the average wavelength of the light is 500 nm .
2. Many cells are transparent and colorless. Structures of great interest in biology and medicine can be practically invisible to ordinary microscopy. An interference microscope reveals a difference in refractive index as a shift in interference fringes to indicate the size and shape of cell structures. The idea is exemplified in the following problem. An air wedge is formed between two glass plates in contact along one edge and slightly separated at the opposite edge. When the plates are illuminated with monochromatic light from above, the reflected light has 85 dark fringes. Calculate the number of dark fringes that appear if water ( $n=1.33$ ) replaces the air between the plates.
3. The Very Large Array (VLA) is a set of 27 radio telescope dishes in Caton and Socorro counties, New Mexico, and one of them is shown below. The antennas can be moved apart on railroad tracks, and their combined signals give the resolving power of a synthetic aperture 36.0 km in diameter.
(a) If the detectors are tuned to a frequency of 1.40 GHz , what is the angular resolution of the
 VLA?
(b) Clouds of hydrogen radiate at this frequency. What must be the separation distance of two clouds at the center of the galaxy, 26000 lightyears away, if they are to be resolved?
(c) As the telescope looks up, a circling hawk looks down. Find the angular resolution of the hawk's eye. Assume that that the hawk is most sensitive to green light having wavelength 500 nm and that it has a pupil of diameter 12.0 mm.
(d) A mouse is on the ground 30.0 m below. By what distance must the mouse's whiskers be separated if the hawk can resolve them?
4. Iridescent peacock feathers are shown in figure a below. The surface of one microscopic barbule is composed of transparent keratin that supports rods of dark brown melanin in a regular lattice, represented in figure b. (Your fingernails are made of keratin, and melanin is the dark pigment giving color to human skin.) In a portion of the feather that can appear turquoise, assume that the melanin rods are uniformly separated by $0.25 \mu \mathrm{~m}$, with air between them.
(a) Explain how this structure can appear blue-green when it contains no blue or green pigment.
(b) Explain how it can also appear violet if light falls on it in a different direction.
(c) Explain how it can present different colors to your two eyes at the same time, a characteristic of iridescence.
(d) A compact disc can appear to be any color of the rainbow. Explain why this portion of the feather cannot appear yellow or red.
(e) What could be different about the array of melanin rods in a portion of the feather that does appear to be red?

5. Electrons are ejected from a metallic surface with speeds ranging up to $4.60 \times 10^{5} \mathrm{~m} / \mathrm{s}$ when light with a wavelength of 625 nm is used.
(a) What is the work function of the surface?
(b) What is the cutoff frequency for this surface?
6. X-rays having an energy of 300 keV undergo Compton scattering from a target. The scattered rays are detected at $37.0^{\circ}$ relative to the incident rays. Find
(a) the Compton shift at this angle,
(b) the energy of the scattered x-ray, and
(c) the energy of the recoiling electron.
7. After learning about de Broglie's hypothesis that particles of momentum $p$ have wave characteristics with wavelength $\lambda=h / p$, an $80.0-\mathrm{kg}$ student has grown concerned about being diffracted when passing through a $75.0-\mathrm{cm}$-wide doorway. Assume that significant diffraction occurs when the width of the diffraction aperture is less than 10.0 times the wavelength of the wave being diffracted.
(a) Determine the maximum speed at which the student can pass through the doorway so as to be significantly diffracted.
(b) With that speed, how long will it take the student to pass through the doorway if it is in a wall 15.0 cm thick? Compare your result to the currently accepted age of the Universe, which is $4 \times 10^{17} \mathrm{~s}$.
(c) Should this student worry about being diffracted?
8. A radio station operating at 106.5 MHz broadcasts from two identical antennae at same elevation but separated by an $8.0-\mathrm{m}$ horizontal distance $d$, as shown below. A maximum signal is found along the midline, perpendicular to $d$ at its midpoint

extending horizontally in both directions. If the midline is taken as $0^{\circ}$, at what other angle(s) $\theta$ is a maximum signal detected? A minimum signal? Assume all measurements are made much farther than 8.0 m from the antenna towers.
9. Light of wavelength $5.0 \times 10^{-7} \mathrm{~m}$ passes through two parallel slits and falls on a screen 4.0 m away. Adjacent bright bands of the interference pattern are 2.0 cm apart.
(a) Find the distance between the slits.
(b) The same two slits are next illuminated by light of a different wavelength, and the fifth-order minimum for this light occurs at the same point on the screen as the fourth-order minimum for the previous light. What is the wavelength of the second source of light?
10. In a double-slit experiment, each slit has a width of 0.02 mm and they are spaced 0.14 mm apart. The pattern of light when a coherent 550 nm beam is incident on the slits is observed on a screen 4 m away.
a. Find the spacing between interference fringes on the screen.
b. Find the full width of the central diffraction maximum on the screen.
c. How many fringes are visible within the central diffraction maximum?
d. What happens to the pattern if the entire apparatus is immersed in water? Find new answers to each of the above parts.
11. In a double-slit experiment with 500 nm light, the slits each have a width of 0.1 mm .
a. If the interference fringes are 5 mm apart on a screen which is 4 m from the slits, determine the separation of the slits.
b. What is the distance from the center of the pattern to the first diffraction minimum on one side of the pattern?
c. How many interference fringes will be seen within the central maximum in the diffraction pattern? Draw a sketch of the pattern.
12. In a double slit experiment with two slits of width $1.0 \mu \mathrm{~m}$ spaced $4 \mu \mathrm{~m}$ apart, suppose a beam of electrons is incident on the slits after being accelerated from rest through a potential difference of 100 V .
a. What is the wavelength of the electrons?
b. If the pattern of detected electrons is observed on a fluorescent screen 20 m from the slits, what is the width of the central diffraction maximum?
c. How many interference fringes will be observed within the central diffraction maximum?
