The University Of Sheffield.

DEPARTMENT OF PHYSICS AND ASTRONOMY

Spring Semester 2006-2007

OPTICS **2 HOURS**

Answer THREE Questions.

A formula sheet and table of physical constants is attached to this paper.

All questions are marked out of ten. The breakdown on the right-hand side of the paper is meant as a guide to the marks that can be obtained from each part.

TURN OVER

1.

(a) Determine how the type and magnification of an image formed by a biconvex lens varies as an object is positioned at:

(i) 5 times the focal length from the lens; [0.5]
(ii) 2 times the focal length; [0.5]
(iii) 0.5 times the focal length. [0.5]

(b) A lens is made from a material with refractive index 1.42 and has radii of curvature $|R_1| = 6$ cm and $|R_2| = 4$ cm.

(i) What is the focal length if the lens is biconvex? [0.5]
(ii) What is the focal length if it is biconcave? [0.5]
(iii) How will the focal lengths change if the lens is immersed in water ($n = 1.33$)? [0.5]

(c) Describe the physical origins of short and near sightedness in the human eye, and how they may be corrected using spectacle lenses. Your answer should be illustrated with appropriate sketches. [3]

(d) In a compound microscope the final image viewed is formed at the near point of the eye, assumed to be at 25 cm. Both objective and eyepiece are biconvex, have focal length of 1 cm, and are positioned 20 cm apart. Deduce:

(i) The distance between the object under examination and the objective lens. [2]
(ii) The total magnification produced by the microscope. [2]

2.

(a) Describe the physical differences between linearly, circularly and elliptically polarised light. [2]

(b) Explain how a quarter wave plate converts linearly into circularly polarised light. [2]

(c) Unpolarised light of intensity I_0 is incident on two ideal linear polarisers whose polarisation directions differ by 30°. Calculate the intensity of the transmitted light. [2]

(d) The state of polarisation of a beam of light is analysed using a linear polariser (the 'analyser') and a quarter wave plate.

(i) When the analyser alone is in the beam and is rotated, it is found that the intensity observed is independent of the angle of the analyser. Explain what can be deduced about the state of polarisation of the incident beam of light. [2]
(ii) The quarter wave plate is now included before the analyser, and the analyser is rotated. There are three possible outcomes as the analyser is rotated. Deduce the polarisation states of the incident light which may lead to these three outcomes. [2]

CONTINUED

3.

(a) Explain, within the framework of geometrical optics, the meaning of the term paraxial ray. [1]

(b) Explain why the breakdown of the paraxial approximation may lead to transverse and longitudinal spherical aberrations in a lens system. [1]

(c) Describe the physical origin of chromatic aberrations in an optical system. [1]

(d) Describe a simple method by which chromatic aberrations can be minimised. Your answer should include a discussion of the types of lenses in the system and why they are chosen. [2]

(e) Light of wavelength λ is diffracted by a circular aperture of diameter a. The first zero in the intensity pattern is observed for a value of $\rho = 3.832$, where ρ is defined as

$$\rho = \frac{\pi a \sin\theta}{\lambda}$$

and θ is the angle of diffraction.
Use this information to derive the mathematical expression for the Rayleigh criterion

$$\Delta\theta = \frac{1.22\lambda}{a},$$

and explain its physical basis. [3]

(f) A digital camera has an objective of 10 mm diameter. What is the largest distance at which the camera can resolve red and amber traffic lights which are positioned 50 cm apart? Based on this estimate, comment if diffraction has to be taken into account when photographing landscapes. [2]

TURN OVER

4.

(a) Derive the diffraction grating equation,

$$a \sin\theta = m \lambda,$$

from general geometrical considerations. Here a is the groove separation of the grating, λ the incident wavelength and m the order of diffraction. [2]

(b) Describe how a grating forms a line spectrum from incident light containing two discrete wavelengths. [2]

(c) A beam of light is diffracted by a 10 cm ×10 cm grating containing 100 groove/mm. It is then focused by a 1m focal length lens to form a diffraction pattern in the focal plane of the lens. The beam is normal to the plane of the grating. The beam contains light of two wavelengths: 550 and 500 nm.

(i) Calculate the distance between the peaks of the two different wavelengths in the diffraction pattern produced by the lens as a function of the diffraction order. [3]

(ii) What is the resolving power of the grating used in this experiment in its first order? [2]

(iii) What is the largest detector size which can be used to detect the wavelengths separately in the first and second diffraction orders? [1]

CONTINUED

5.

(a) What is the meaning of the coefficient of finesse F of a Fabry-Pérot interferometer defined by,

$$F = 4R^2 \big/ \left(1 - R^2\right)^2$$

where R is the reflection coefficient? [1]

(b) Sketch the transmitted intensity $I(\delta)$ through a Fabry-Pérot interferometer made from a material of refractive index n and having a thickness t, as a function of the phase difference δ, for different values of R.

[Remember that the transmitted intensity $I(\delta)$ may be written as,

$$I(\delta) = \frac{I_0}{1 + F\sin^2\dfrac{\delta}{2}}$$

where the phase difference $\delta = 4\pi nt\cos\theta/\lambda$ and I_0 is the incident intensity.] [2]

(c) Show that the full width at half maximum of the intensity of a particular fringe is given by

$$\gamma = \frac{4}{\sqrt{F}}.$$ [2]

(d) Explain the criterion for the resolving power (RP) of a Fabry-Pérot interferometer and show that it may be expressed as

$$RP = \frac{\lambda}{d\lambda} = \frac{m\pi\sqrt{F}}{2}$$

where m is the order of interference. [3]

(e) Calculate the coefficient of finesse and RP for a Fabry-Pérot interferometer with a reflection coefficient $R = 0.90$ for second order interference. [2]

END OF QUESTION PAPER