Exam Waves and Optics – 30 January 2015 – 9:00-12:00

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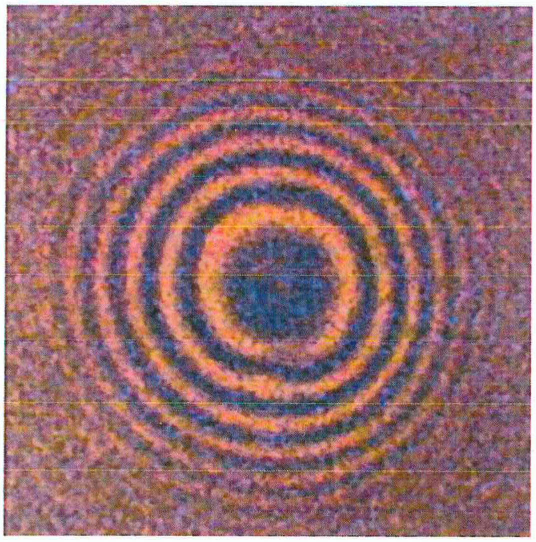
Questions and answers

A few **preliminary remarks**:

- Please answer questions 4, 5 & 6 on another (double) sheet of paper than questions 1, 2 & 3.
- Put your name and student number at the top of all sheets.
- Put your student card at the edge of the desk for checking by the assistants and show it when handing in your exam.

Question 1 (6 points): Interference: Newton's rings

Below a picture of Newton's rings, an example of a pattern of interference fringes of equal thickness, as taken during the demonstration in the lectures.



Questions:

1) Make a sketch of a setup that produces Newton's rings. Indicate which light rays are interfering to produce the interference pattern.
2) For larger radius of the rings in the interference pattern, the rings get closer together. Why is this ? Explain by referring to the sketch made under question 1). Extra points are given if you can also derive a (approximate) formula for the ring radii.

Question 2 (6 points): Reflectance and transmittance

Consider a beam of light incident on the interface between 2 media (see figure below). The following quantities are defined:

- A : surface area of the beam of light **in the interface**
- θ_i : angle of incidence
- θ_r : angle of reflection
- θ_t : angle of refraction (transmission)
- n_i : index of refraction of the medium in which the incident and reflected beams travel
- n_t : index of refraction of the medium in which the refracted (transmitted) beam travels

The power **per surface area** (unit: W/m^2) of a harmonic electromagnetic wave, the so-called irradiance, is given by $I = \frac{v\,\varepsilon}{2} E_0^2$, where v is the velocity and E_0 the amplitude of the wave and ε the permittivity of the medium in which the wave travels.

The reflectance R is defined as the ratio of reflected to incident power; the transmittance T is defined as the ratio of transmitted (refracted) to incident power.

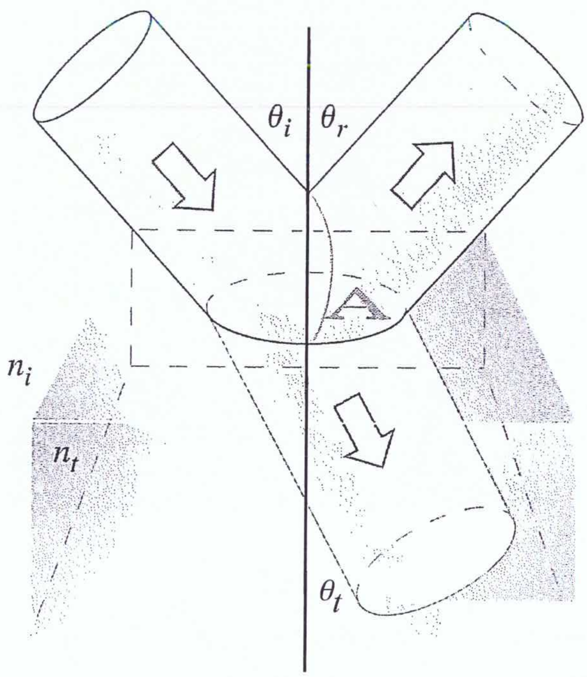


Figure 4.47 Reflection and transmission of an incident beam.

Question:

Deduce formulae for R and T as a function of the amplitude reflection and transmission coefficients (r and t, the Fresnel coefficients) and the relevant angles and indices of refraction. Assume that both media have the same permeability μ.

Question 3 (4 points): Fresnel zones

Consider diffraction at an aperture in a screen. The surface A of the low-order Fresnel zones is constant (so independent of ℓ, the number or order of the Fresnel zone) and equal to:

$$A = \frac{\pi \rho r_0 \lambda}{\rho + r_0}$$

with ρ the distance from the point source to the aperture, r_0 the distance from the aperture to the screen where the diffraction pattern is observed and λ the wavelength of the light used.

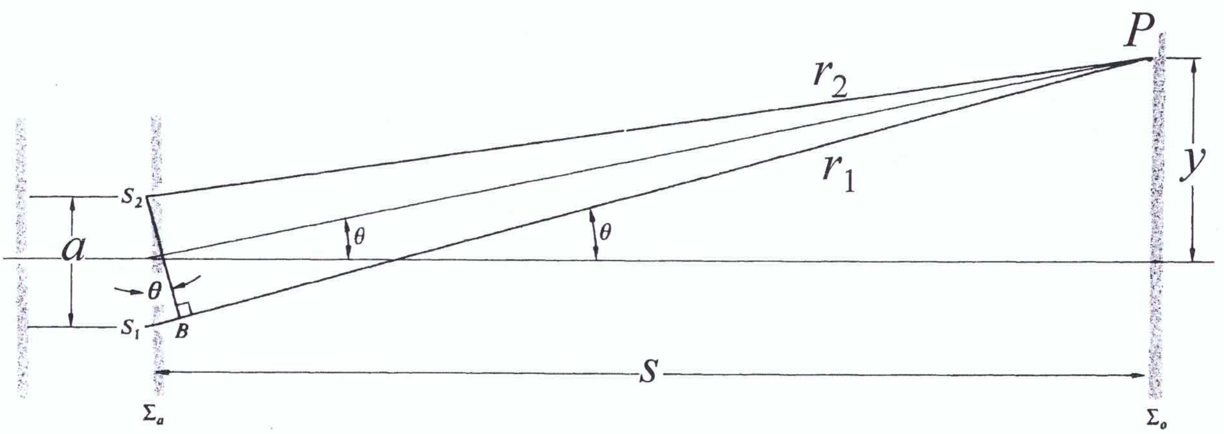
Question:

Show that when a circular aperture falls within the first Fresnel zone, we are in a situation of Fraunhofer diffraction.

Please answer questions 4, 5 & 6 on another (double) sheet of paper than questions 1, 2 & 3.

Question 4 (5 points): Interference of two narrow slits / Young's experiment

When considering the inferference of light from two long narrow slits (see figure below), the difference in distance from the point P (at coordinate y on the screen) to both slits can be approximated by: $r_1 - r_2 = \frac{a}{s} y$.



Sunlight incident on two long narrow slits 0.20 mm apart casts an interference pattern on a white sheet of paper 2.0 m beyond the slits.

Question:

What is the distance on the sheet separating the first-order violet ($\lambda_0 = 400$ nm) from the second-order red ($\lambda_0 = 600$ nm) irradiance maximum ?

Question 5 (4 points): Coherence length

Consider a He-Ne laser (wavelenght 632.8 nm) with a frequency stability of 2×10^{-10}.

Question:

What is the coherence length of the light from this laser ?

Question 6 (5 points): Resolution of imaging systems

The Fraunhofer diffraction pattern of a circular lens (the so-called Airy pattern) has its first minimum at a distance q_1 from the center of the pattern given by $q_1 = 1.22\frac{f\lambda}{D}$, with *f* the focal length of the lens, *D* the diameter of the lens and λ the wavelength of the light used.

Consider a person looking from a distance at the headlights of a car. The two headlights are 1.50 m apart and emit light with a wavelength of 550 nm. The eye pupil of the person has a diameter of 5 mm.

Question:

What is the maximum distance from the car at which the person is still able to resolve the headlights ?

Note: making a sketch of the situation can be helpful.
