# Midterm Exam : Waves & Optics

10 December 2018, 9:00-11:00

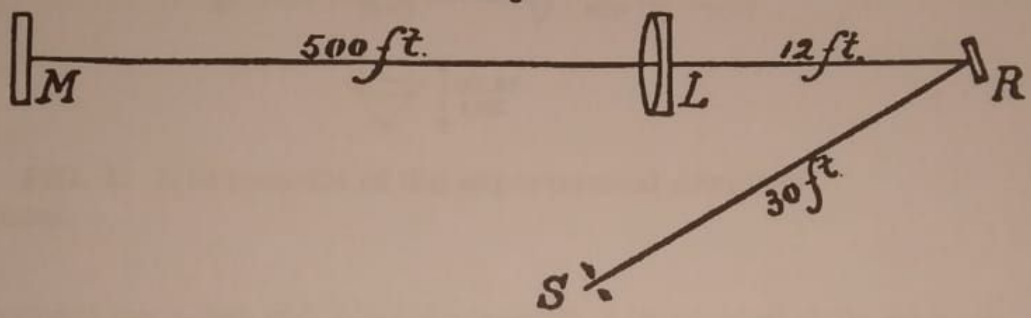
- Put your name and student number on each answer sheet.
- Answer all questions short and to the point, but complete; write legible.
- Final point grade = 9(total number of points/36) + 1

1. **Speed of Light (12 points)**
consider the paper *Experimental Determination of the Velocity of Light* by Michelson.

a) In the paper various experiments in which the speed of light is measured are mentioned. For Foucault the light traveled 20 m, for Cornu 2x14 miles (=2x22.5 km), and for Michelson 2x500 ft (=2x153 m). If with modern equipment you can measure the travel time with a precision of 1 ps ($=10^{-12}$ s), what would the precision in the measured speed of light be in each of these three cases? Assume the light travels in vacuum. **(3 points)**

b) In the article a schematic of the experimental setup is given (reproduced below). What kind of wave best describes the light traveling from the slit **S** to the rotating mirror **R**? And between the lens **L** and the mirror **M** (see figure below)? For both give a complete expression of the wavefunctions for light with wavelength $\lambda$ and velocity $v$. **(4 points)**

**Fig. 1.**




c) The article states that *"The image (from the rotating mirror) is displaced more and more as the revolution becomes more rapid, the displacement being twice as great as the displacement of the mirror, during the time required for the light to travel from R to M and back again."* Explain the origin of the factor 2. **(2 points)**

d) The experiment is done in air, which may contain water vapour. Several differences are observed on a humid day compared to a dry day. **(3 points)**

(a) the (relative) amount of reflected light goes down and gets a reddish tint; what mechanism is causing this? Explain.

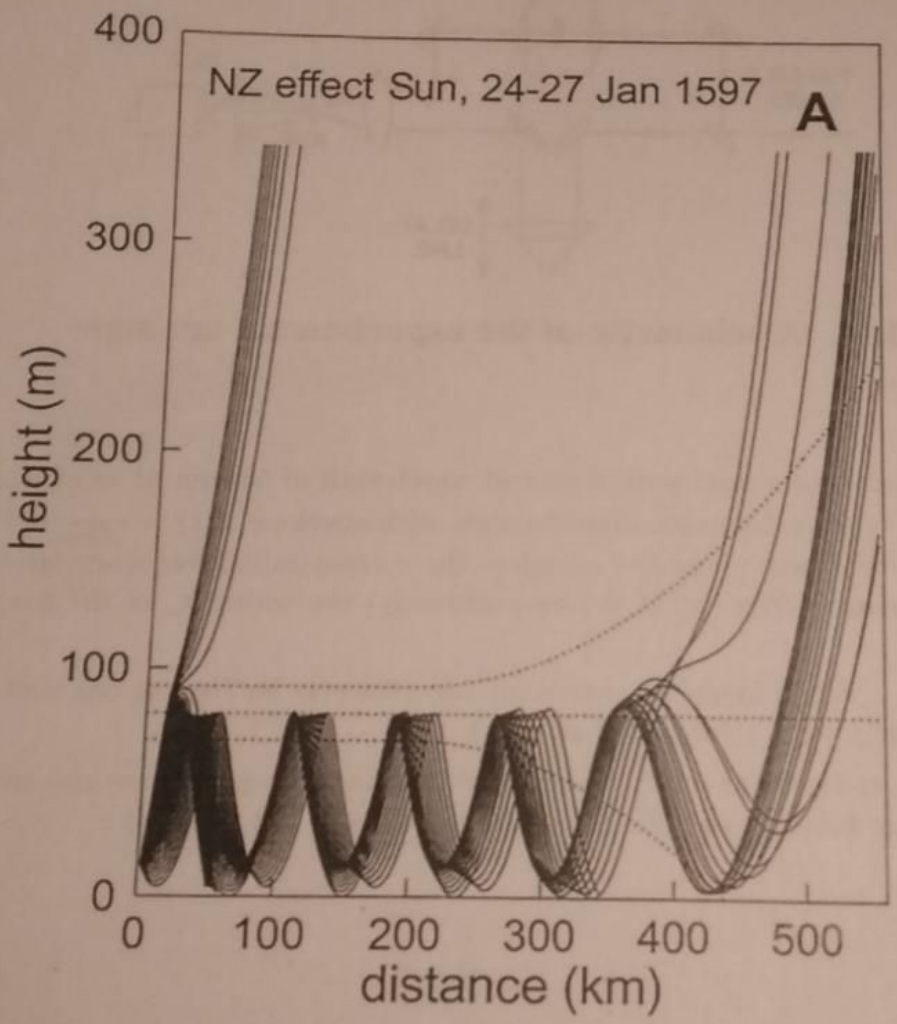
(b) the measured speed of light goes down for higher humidity; why?

(c) rainbow-like effects are observed in the light reflected off the rotating mirror; why and because of what phenomenon?

(d) BONUS (1pt): is the red end of the rainbow most likely deflected more or less than the blue end? Explain.

2. **Novaya Zemblya Effect (12 points)**
refers to paper *Gerrit de Veer's true and perfect description of the Novaya Zemlya effect, 24–27 January 1597* by van der Werf, Könthe, Lehn, Steenhuisen, and Davidson.

a) From Fig. 3 of the paper (see below) we can deduce that the angle between the rays and the temperature inversion layer is about 2 mrad (0.1°) just before the ray is reflected. Assume that we are dealing with total internal reflection on a sharp interface. For which values of the ratio of the refractive indices above and below the inversion layer is this possible? **(3 points)**




b) How does the height of the isotherm determine where you see the sun? Give a relation or explanation. **(3 points)**

c) If there would be no temperature inversion, but only a gradually decreasing density of the air, you would actually see the sun *closer* to the horizon than it really is. Explain if this statement is correct or not. **(3 points)**

d) Consider a moment later in the year, when the sun can be well above the horizon and with the inversion layer still present. Astronauts in the international space station (which flies above the inversion layer) observe the reflection of the sun on this layer and notice that the electric field of the reflected light oscillates precisely horizontally (usually is has a random orientation). How is this possible? Calculate the observation angle. **(3 points)**

3. **Anharmonic Waves (12 points)**
consider the paper *Linear Pulse Propagation in an Absorbing Medium* by Chu and Wong.

a) Fig. 1 in the paper (reproduced below) shows a schematic representation of the setup used to measure the pulse delay through the GaP:N sample with a refractive index $n(\omega)$. For a harmonic wave with frequency $\omega$ derive how the irradiance measured by the PMT depends on the thickness $D$ and index of refraction $n(\omega)$ of the GaP:N sample and the variable length $L$ of the delay line. **(4 points)**

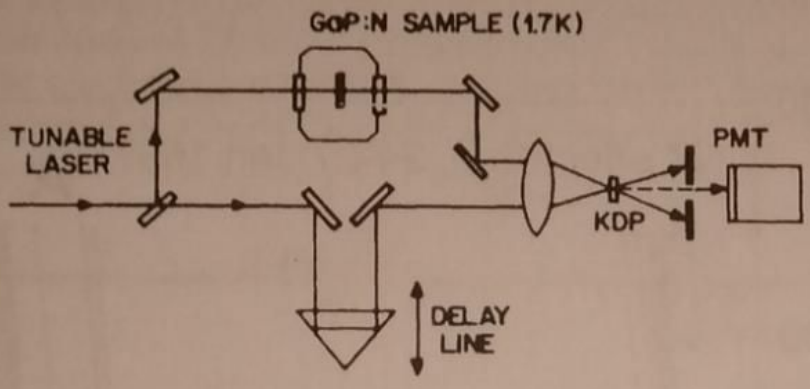



**FIG. 1. A schematic of the experimental arrangement.**

b) The experiment uses a laser with a central wavelength of 534 nm of which the amplitude is modulated to form Gaussian-shaped pulses with envelope $A(t) = \frac{1}{\sqrt{2\pi}\sigma_t} e^{-\frac{1}{2}(t/\sigma_t)^2}$. Give an expression that can be used to calculate the corresponding frequency spectrum. If the pulse width is $\sigma_t = 30$ ps, what is (approximately) the width $\sigma_\omega$ of the frequency peak? **(3 points)**

c) Can a pure, *i.e.* single frequency, harmonic function ever be "on" at one time and "off" at another? Explain your answer. **(2 points)**

d) Using the forced-oscillator model, explain why weaker damping gives rise to a potentially larger difference between the phase and group velocity. **(3 points)**