Final Exam: Wednesday Dec 21, 2022 Name:_____

Allowed: Formula sheet (given), calculator, 3 hours

PART 1 – answer questions **1-10** in pencil/pen here or in your exam booklet **then** use your scratch card: One scratch = **100%**; two scratches **50%**; three scratches **33%**; four scratches **25%** (part 1 total is 60%)
PART 2 – answer **two** questions in the exam booklet provided (each of these questions is worth 20%)

Qu's 1–2) A double convex lens has a diameter of 5 cm and zero thickness at its edges. A point source on an axis through the center of the lens produces a real image on the opposite side. Both object and image distances are 35 cm, measured from a plane bisecting the lens. The lens has a refractive index of 1.51. We will employ the equivalence of optical paths to determine the thickness of the lens at its center.

1) If the lens has a total thickness at its centre of t cm, then which of the following expressions is the *optical path length* of the ray travelling from object to image that passes through the centre of the lens?

A. $70+0.51t$ cm **B.** 70 cm **C.** $70-0.51t$ cm

D. $70-1.51t$ cm **E.** $70+1.51t$ cm

2) By equating the optical path lengths for the rays that travel through the center, and also through the edge of the lens, which of the following is the value of t?

A. 5.5 mm **B.** 4. mm **C.** 3.5 mm **D.** 7. mm **E.** 8.5 mm

3) The light emitted by an LED is centred at 670 nm and has a wavelength spread of 0.9 nm. Which of the following is the this spread given as a frequency spread?

A. 450 GHz **B.** 220 THz **C.** 600 GHz **D.** 730 GHz **E.** 330 THz

4) The intensity of light from the Sun striking a surface perpendicular to the Sun's rays is about $0.135\ \text{W/cm}^2$. By approximating this light as a single harmonic wave, which of the following is the amplitude of the electric field for a wave with this intensity?

A. 450 V/m **B.** 8.7 V/m **C.** 870 V/m **D.** 10 V/m **E.** 1000 V/m

Qu's 5-6) For visible wavelengths, the index of refraction of a certain type of crown glass can be approximated in terms of the vacuum wavelength by the relation $n(\lambda_0) = 1.5255 + (8400\ \text{nm}^2)/\lambda_0^2$.

5) Which of the following is closest to the *phase velocity* for light with vacuum wavelength of 500 nm?

A. 1.90×10^8 m/s **B.** 1.92×10^8 m/s **C.** 1.97×10^8 m/s **D.** 1.79×10^8 m/s **E.** 1.49×10^8 m/s

6) Calculate as exactly as possible the *group velocity* for a light pulse with wavelength components centred at a vacuum wavelength of 500 nm. What is this value?

A. 1.84×10^8 m/s **B.** 1.86×10^8 m/s **C.** 1.88×10^8 m/s **D.** 1.90×10^8 m/s **E.** 1.92×10^8 m/s

7) Use the Stokes relations to determine which of the following sets of values for (r,t,r',t') are physically realistic for a beam striking an interface from one side, and its complementary, time-reversed beam striking the interface from the other side?

A. $(0.2, 1.2, 0.2, 0.8)$ **B.** $(-0.31, 0.69, 0.31, 1.31)$ **C.** $(0.31, -0.69, 0.31, 1.31)$

D. $(0.2, 0.8, -0.2, 0.8)$ **E.** $(0.2, 0.8, -0.2, 0.2)$

8) A sheet of fluorite (CaF_2) of index 1.434 is inserted normally into one beam of a Michelson interferometer. Using light of wavelength 589 nm, the fringe pattern near the axis is found to shift by 35 fringes. Which of the following is the thickness of this sheet?

A. 2.0 μm **B.** 12 mm **C.** 12 μm **D.** 2.4 mm **E.** 24 μm

9) The separation of a particular doublet is 0.0035 nm, centred at a wavelength of 490 nm. A variable-length Fabry-Perot interferometer is used to examine the doublet. For what length of the Fabry-Perot does the fringe of *m*-th interference order of one wavelength component coincide with that of the $(m+1)$-th interference order of the other?

A. 3.0 cm **B.** 2.6 cm **C.** 3.8 cm **D.** 3.4 cm **E.** 2.2 cm

10) The finesse of a Fabry-Perot interferometer indicates the ratio of the fringe separation to the fringe width at half-maximum, as evidenced by Eq. (1-10) on the formula sheet. By sketching the form of the intensity from a *Michelson interferometer* as a function of the phase difference between the two beams, which of the following is the analogous value for the finesse of a Michelson interferometer?

A. 2 **B.** 4 **C.** 8 **D.** 1 **E.** 16

PART II – answer <u>two</u> out of the following four questions in your exam booklet

11 a) With the help of a figure, show that, for a guided ray traveling at the steepest angle relative to the fiber axis, the skip distance can be expressed by

$$L_{s,\text{steepest}} = \frac{n_2 d}{\sqrt{n_1^2 - n_2^2}}$$

b) How many reflections occur per meter for such a ray in a step-index fiber with $n_1 = 1.460$, $n_2 = 1.457$, and $d = 50\ \mu\text{m}$?

12) Find the modal dispersion in a step-index fiber by calculating the difference in transit time through a 1 km fiber required by an axial ray and a ray entering at the maximum entrance angle of 35º. Assume a fused silica core refractive index of 1.446. What is the maximum frequency of input pulses that produce nonoverlapping pulses on output due this modal dispersion?

13) For a Nd:YAG laser, there are four energy levels that may be used for pumping. The levels are located at 1.53 eV, 1.65 eV, 2.12 eV, and 2.36 eV above the ground state energy level.
a) What is the wavelength associated with the photon energy required to populate each of these pump levels?
b) Knowing that a Nd:YAG laser emits photons of wavelength 1.064 μm, determine the *quantum efficiency* associated with each of these pump levels.

14 a) A 0.1 metre long Nd:YAG laser rod with refractive index of 1.82 is situated in a linear cavity with mirrors of reflectivity 0.99 and 0.95. Determine the longitudinal mode spacing if the cavity is *twice* the length as the laser rod.
b) A He-Ne laser, operating at $\lambda = 632.8\ \text{nm}$, has a beam waist at its output coupler with a diameter equal to about 0.75 mm. Estimate the diameter of the beam after it has travelled a distance of 1 km.