Gen. Phys. II **Exam 4 - Chs. 27,28 - Wave Optics, Relativity** **Apr. 12, 2021**

Rec. Time **Name**

For full credit, make your work clear. Show formulas used, essential steps, and results with correct units and significant figures. Points shown in parenthesis. For TF and MC, choose the *best* answer.

OpenStax Ch. 27 - Wave Properties of Light

1. (4) Electromagnetic waves have many interesting properties that affect how they behave, including wave length, period, frequency, and polarization. The polarization of a light beam refers to the direction of its

a. energy flow. b. electric field vector. c. velocity. d. magnetic field vector.

2. (6) A compound microscope has an objective lens and an eyepiece lens. Which two changes would result in improving the resolving power of a microscope?

a. use a shorter wavelength of light.
b. use a longer wavelength of light.
c. use an objective lens with a smaller value of diameter over focal length.
d. use an objective lens with a larger value of diameter over focal length.

3. (6) Isaac Newton demonstrated that white light is composed from a whole rainbow of colors, which correspond to different wavelengths. When light of a given color passes from air into water, which two measurable quantities decrease?

a. the speed.
b. the frequency.
c. the wavelength.
d. the period of its oscillations.

4. (4) Various scientists have advanced our knowledge of the wave properties of light. Match the scientists with their famous accomplishments.

Lord Rayleigh	a. Sent monochromatic light through double slits to demonstrate constructive and destructive interference of light.
Thomas Young	b. Produced an equation describing the intensity of light sent through a polarizing filter.
Christiaan Huygens	c. Formulated a rule for the diffraction limited resolution of a lens or mirror.
Malus	d. Stated how waves move forward by generating sets of tiny wavelets.
	e. Discovered the law that describes how light is polarized upon reflection from a surface.

5. (4) In a double slit experiment where light passes through 2 slits and then onto a distant screen, what can be done to make the bright fringes closer together? Check all that apply.

a. decrease the wavelength.
b. increase the wavelength.
c. increase the slit spacing.
d. decrease the slit spacing.

6. (6) It's nighttime and your eyes' pupils are open to a diameter of 7.33 mm. What is the angular separation of two stars that your vision can just barely resolve, in *milliradians*, assuming your vision is only limited by diffraction, and the light from the stars has an average wavelength of 646 nm?

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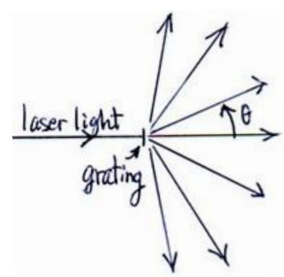
7. (10) This is the problem for which you must show your work in the file upload. A diffraction grating has 483 lines/mm. When light of an unknown wavelength is passed through it, the first order bright fringe is cast on a screen 2.00 m away at a distance of 33.9 cm from the centerline. Calculate the wavelength of the light in *nanometers*.



1. (4) An inertial reference frame is a coordinate system or a region like the room you are in now, where

a. all objects are acted upon by gravity. b. the objects in the system are undergoing centripetal acceleration.
c. Newton's first law of mechanics is valid. d. velocities add according to Galilean-Newtonian mechanics.

2. (4) The Altairians (the extraterrestrials from the planets around Altair, the brightest star in Aquila) have discovered Earth and are traveling straight towards Earth at 80.1% of the speed of light. When they are 15.1 light-years from Earth, they send a communication by radio waves to Earth. With what speed do those radio waves arrive at Earth? Give the answer as a percent of the speed of light.

3. (4) You have two identical clocks, A & B, ticking away synchronously on your desk. Now you accelerate clock B to 60% of the speed of light and keep watching both clocks. While clock A on your desk ticks off 15 seconds,

a. clock B will also tick off 15 seconds.
b. clock B will tick off less than 15 seconds.
c. clock B will tick off more than 15 seconds.

4. (4) Seeing a rocket flying by you at half the speed of light, you measure its length to be 32 m. That means you mark the locations of its two end points on a ruler, simultaneously on your clock. After the rocket slows down and lands next to you,

a. it length will still be 32 m.
b. its length will be less than 32 m.
c. its length will be more than 32 m.

5. (4) The *astronomical unit* (AU) is the average distance from Earth to the sun, 1.496×10^8 km. It is convenient and helpful to measure distances from the sun to all the planets in astronomical units. How far is an astronomical unit in **light-minutes**, where a light-minute is the distance light travels in 1 minute?

6. (6) The electron rest mass is 9.10938×10^{-31} kg, and its rest energy is 511.000 keV (kilo-electron-volts). How large is the kinetic energy of an electron with a speed of $v = 0.842c$, measured in units of keV?

7. (6) Sally's rocket is moving with respect to you at 98.5% of the speed of light. She watches a movie that is 58 minutes long, for her. How much time elapses on your desk clock, **in minutes**, while she watches the movie? Hint: The proper time Δt_0 is the time interval where beginning and end are both at rest for one observer.

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8. (8) This is the question for which you must show your work in the file upload.
A very large cargo ship like the Ever Given that was stuck in the Suez canal recently has a mass of 200 million kg. If the ship uses 284 TJ of energy per month, supplied by diesel fuel to run its engines, what amount of mass is converted to energy to supply the required energy for one year. Give the result in **grams**.

 Ch. 27 = __________/40 Ch. 28 = __________/40

Prefixes

a=10^{-18}, f=10^{-15}, p=10^{-12}, n=10^{-9}, $\mu = 10^{-6}$, m=10^{-3}, c=10^{-2}, k=10^{3}, M=10^{6}, G=10^{9}, T=10^{12}, P=10^{15}

Physical Constants

$k = 1/4\pi\epsilon_0 = 8.988$ GNm^2/C^2 (Coulomb's Law)

$\epsilon_0 = 1/4\pi k = 8.854$ pF/m (permittivity of space)

$e = 1.602 \times 10^{-19}$ C (proton charge)

$\mu_0 = 4\pi \times 10^{-7}$ T·m/A (permeability of space)

$m_e = 9.11 \times 10^{-31}$ kg (electron mass)

$m_p = 1.67 \times 10^{-27}$ kg (proton mass)

$c = 3.00 \times 10^{8}$ m/s (speed of light)

$c = 2.99792458 \times 10^{8}$ m/s (exact value in vacuum)

$h = 6.62607 \times 10^{-34}$ J·s (Planck's constant)

$\hbar = 1.05457 \times 10^{-34}$ J·s (Planck's constant/2π)

$\sigma = 5.67 \times 10^{-8}$ W/(m^2·K^4) (Stefan-Boltzmann const.)

hc =1239.84 eV·nm (photon energy constant)

Units

$N_A = 6.02 \times 10^{23}$/mole (Avogadro's #)

1 u = 1 g/N_A = 1.6605×10^{-27} kg (mass unit)

1.0 eV = 1.602×10^{-19} J (electron-volt)

1 V = 1 J/C = 1 volt = 1 joule/coulomb

1 F = 1 C/V = 1 farad = 1 C^2/J

1 H = 1 V·s/A = 1 henry = 1 J/A^2

1 A = 1 C/s = 1 ampere = 1 coulomb/second

1 Ω = 1 V/A = 1 ohm = 1 J·s/C^2

1 T = 1 N/A·m = 1 tesla = 1 newton/ampere·meter

1 G = 10^{-4} T = 1 gauss = 10^{-4} tesla

OpenStax Chapter 27 Equations - Wave Optics

Wave properties, interference:

$v = c/n$ (wave speed in a medium)

$\lambda = \lambda_{\text{vacuum}}/n$ (wavelength in a medium)

$f\lambda = v$ (wave equation in a medium)

$\Delta x = d \sin\theta$ (path difference in double slits)

$d \sin\theta = m\lambda$ (double slits bright fringes)

$d \sin\theta = (m + 1/2)\lambda$ (double slits dark fringes)

Diffraction:

$D \sin\theta = m\lambda$ (single slit minima)

$y = L \tan\theta$ (position on a screen)

$d \sin\theta = m\lambda$ (diffraction grating maxima)

$d = 1/(\text{lines per meter})$.

Rayleigh's Diffraction Limit:

$\theta_{\min} = 1.22\lambda/D$ (resolution limit)

$\theta = s/r$ (angular separation in radians)

Polarization:

$I = I_0 \cos^2\theta$ (transmission thru polarizer)

$I = \frac{1}{2} I_0$ (transmission of unpolarized light)

OpenStax Chapter 28 Equations - Special Relativity

Time dilation and length contraction:

$\Delta t = \gamma \Delta t_0 = \Delta t_0/\sqrt{1 - v^2/c^2}$

$L = L_0/\gamma = L_0\sqrt{1 - v^2/c^2}$

$\gamma = 1/\sqrt{1 - v^2/c^2}$ (relativistic factor)

$v/c = \sqrt{1 - 1/\gamma^2}$ (velocity)

Dyanmics, mass, energy:

$p = \gamma m v$ (relativistic momentum)

$m_{\text{rel}} = \gamma m$ (relativistic mass)

$E_0 = mc^2$ (rest energy)

$E = \gamma mc^2 = m_{\text{rel}} c^2$ (relativistic energy)

$\text{KE} = E - E_0 = (\gamma - 1)mc^2$ (kinetic energy)

$E = E_0 + \text{KE} = \sqrt{p^2c^2 + m^2c^4}$ (relativistic energy)

$\Delta(E_0 + \text{KE}) + \Delta\text{PE} = 0$ (conservation of energy)

$\Delta\text{PE}_{\text{elec}} = q\Delta V$ (electric potential energy)