Gen. Phys. II Exam 4 - Chs. 27,28,29 - Wave Optics, Relativity, Quantum Physics Apr. 16, 2018

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. (3) When light of a given color passes from air into water, which two properties decrease?

   a. frequency and speed. b. frequency and wavelength. c. wavelength and speed.

2. (3) The scientist who formulated a rule for the diffraction limited resolution of a lens or mirror was

   a. Sir David Brewster. b. Lord Rayleigh. c. J. C. Maxwell. d. Heinrich Hertz. e. Albert Einstein.

3. (3) The polarization of a light beam refers to the direction of the

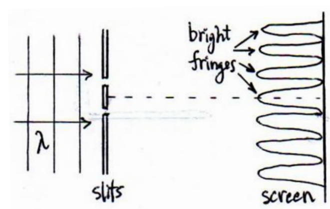
   a. velocity. b. electric field. c. magnetic field. d. photon momentum.

4. (3) **T F** A bright fringe in an interference pattern corresponds to constructive interference.

5. (3) **T F** In a double slit experiment, the interference pattern on the screen is wider for larger wavelength.

6. (3) **T F** A single polarizing filter transmits 25% of incident unpolarized light.

7. (12) In a setup of Young's double slit experiment, the two slits are 0.250 mm apart and the viewing screen is 3.00 m from the slits. Looking at the screen, you see that the tenth bright fringe falls 6.84 cm away from the central bright fringe (the centerline).



a) (6) Find the angle from the centerline to the tenth bright fringe.

b) (6) Determine the wavelength of the light being used, in nm.

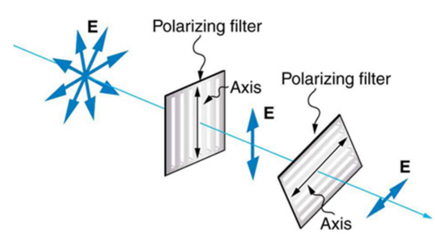
8. (12) Consider how diffraction through the human eye affects visual acuity, when the pupil (or iris) of your eye is opened to a diameter 6.00 mm. On a still night, your friends are 1.00 km away from you and hold two lit candles 0.50 m apart emitting around 550 nm average wavelength.

a) (6) How large is the angular separation (in radians) of the candles in your vision?

b) (6) Could you see the candles as distinct light sources, or are they unresolvable due to diffraction?

---

9. (8) A beam of initially *unpolarized* light of wavelength 620 nm, intensity $I_0 = 5.00\ \mathrm{W/m^2}$, passes through two ideal polarizers whose axes are misaligned by 45.0°. Determine the intensity of the light I_2 emerging from the second polarizer.



OpenStax Ch. 28 - Special Relativity **Name**______________________________________

1. (3) Which is a statement of Einstein's first postulate in his theory of special relativity?

   a. The laws of physics are the same in all inertial reference frames.
   b. The speed of light depends on the motion of the source and the observer.
   c. Velocities of moving objects add as vectors.
   d. Light is absorbed and emitted as quantized photons.

---

2. (3) If you are travelling at 1.0×10^8 m/s in a spaceship moving towards the sun, you receive its light at what speed relative to your spaceship?

   a. 1.0×10^8 m/s. b. 2.0×10^8 m/s. c. 3.0×10^8 m/s. d. 4.0×10^8 m/s.

---

3. (3) **T F** A clock that flies rapidly by you runs slower than the one on your wrist.

4. (3) **T F** The period of a "light clock" 0.30 m long, at rest, is 2.0 ns.

---

5. (14) You have just volunteered for the space mission to Proxima Centauri, 4.242 light-years from Earth. After a brief acceleration, your spaceship will travel at a speed $v = 0.600c$.

   a) (6) As viewed from Earth, how long (in years) does the one-way trip take?

   b) (8) For you in the spaceship, how much time (in years) does the one-way trip take?

6. (16) A proton (mass $= 1.6726 \times 10^{-27}$ kg) has been accelerated to a speed of $0.96c$.

a) (8) Calculate the rest energy for a proton, in MeV.

b) (8) Calculate the (relativistic) kinetic energy in MeV for a proton with this speed.

---

7. (8) The electric bill for my house shows an energy consumption of 950 kWh (kilowatt-hours) in one month. How much mass must (in micrograms) was converted into energy to supply my electricity needs for the month?

OpenStax Ch. 29 - Photons & Matter Waves **Name**____

1. (3) **T F** A photon of energy 5.0 eV has shorter wavelength than one of energy 2.5 eV.

2. (3) **T F** A photon of wavelength 100 nm has the same momentum as an electron of wavelength 100 nm.

3. (3) **T F** An electron's de Broglie wavelength increases with its kinetic energy.

---

4. (4) Which of these phenomena is evidence that energy in light is quantized? Check all that apply.

a. diffraction. b. blackbody radiation spectrum. c. photoelectric effect. d. time dilation.

---

5. (3) Light incident on a certain metal is not producing photoelectrons. What should be done to initiate the emission of photoelectrons?

a. Increase the intensity of the light. b. Decrease the intensity of the light.
c. Increase the wavelength of the light. d. Decrease the wavelength of the light.

---

6. (12) Light of wavelength 426 nm incident on a certain metal produces photoelectrons with a maximum kinetic energy of 0.78 eV.

a) (6) Determine the work function of the metal, in eV.

b) (6) What is the maximum wavelength of light capable of producing photoelectrons for this metal?

7. (12) An electron microscope requires electrons with de Broglie wavelength equal to 1.00 nm. What kinetic energy in eV should the electrons have?

---

8. (12) The velocity of an electron along an x-axis is measured to be between 3.48×10^6 m/s and 3.52×10^6 m/s.

a) (4) What is your estimate of the uncertainty in the electron's velocity along that x-axis, Δv_x?

b) (8) According to Heisenberg's uncertainty principle, what is the minimum uncertainty in a simultaneous measurement of the electron's position, Δx, in nm?

 Ch. 27 = ___________/50 Ch. 28 = ___________/50 Ch. 29 = ___________/52

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 24 Equations - Electromagnetic Waves

Electromagnetic waves:

$|\vec{E}|/|\vec{B}| = c = 1/\sqrt{\epsilon_0\mu_0}$, (fields and speed)

$f\lambda = c$ (wave equation)

Energy density, intensity, power:

$u = \epsilon_0 E^2 = \frac{B^2}{\mu_0}$ (instantaneous energy density)

$\overline{u} = \frac{1}{2}\epsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0}$ (average energy density)

$I = \overline{u}c = \frac{1}{2}\epsilon_0 E_0^2 c$ (EM waves intensity)

$I = P/A = P/(4\pi r^2)$ (intensity definition)

Approximate wavelengths λ for types of EM waves:

0 (γ-rays) 30 pm (x-rays) 3 nm (uv) 400 nm (visible) 700 nm (ir) 300 μm (μ-waves) 3 cm (radio) ∞

$\longrightarrow$ $\longrightarrow$ $\longrightarrow$ increasing wavelength $\longrightarrow$ $\longrightarrow$ $\longrightarrow$

OpenStax Chapter 27 Equations - Wave Optics

Wave properties, interference:

$\lambda_n = \lambda_{\text{vacuum}}/n$ (wavelength 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:

$p = \gamma m_0 v$ (relativistic momentum)

$m_{\rm rel} = \gamma m_0$ (relativistic mass)

$E_0 = m_0 c^2$ (rest energy)

$E = \gamma m_0 c^2 = m_{\rm rel} c^2$ (relativistic energy)

$\mathrm{KE} = E - E_0 = (\gamma - 1) m_0 c^2$ (kinetic energy)

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

OpenStax Chapter 29 Equations - Quanta and Quantum Waves

Blackbody radiation, photons, photo-electric effect:

$\lambda_p T = 2.90\ \mathrm{mm{\cdot}K}$ (Wien's Law)

$I = \sigma T^4$ (intensity or power/area)

$E = nhf,\ n = 1, 2, 3...$ (quantized radiation energy)

$E = hc/\lambda = (1240\ \mathrm{eV \cdot nm})/\lambda$ (photons)

$E = hf = W_0 + \mathrm{KE}_{\rm max}$ (photo-electrons)

$hc/\lambda_{\rm max} = W_0$ (work function)

$\mathrm{KE}_{\rm max} = eV_0$ (stopping potential)

$v_{\rm max} = \sqrt{2\mathrm{KE}_{\rm max}/m}$ (max. speed)

Momentum, matter waves:

$p = h/\lambda$ (quantum momentum)

$\lambda' = \lambda + \frac{h}{mc}(1 - \cos\phi)$ (Compton effect)

$\lambda = h/p$ (de Broglie wavelength)

KE$= p^2/2m$ (kinetic energy, $v \ll c$)

$\Delta\mathrm{KE} + q\Delta V = 0$ (acceleration thru potential)

$v = \sqrt{2q\Delta V/m}$ (acceleration thru potential, $v \ll c$)

Heisenberg Uncertainty Principle:

$\Delta x\ \Delta p_x \geq \hbar/2$ (uncertainty principle)

$\hbar = \frac{h}{2\pi} = 1.05459 \times 10^{-34}\ \mathrm{J{\cdot}s}$

$\Delta E\ \Delta t \geq \hbar/2$ (energy-time form)

($\leftarrow$ These are approximate relations.)

$\Delta E = \Delta m \cdot c^2$ (Einstein's mass-energy equivalence)

($\leftarrow$ This one is exact.)