Gen. Phys. II Exam 4 - Chs. 27,28,29 - Wave Optics, Relativity, Quantum Physics Apr. 22, 2019

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. Bonus points possible by correctly using prefixes like 2.0 mV, 7.8 MW, 1.6 kΩ, 3.4 μT, etc., in lieu of scientific notation like 2.0×10^{-3} V.

OpenStax Ch. 27 - Wave Properties of Light

1. (3) Light of a wavelength λ most noticably exhibits diffraction effects when it

a. travels through vacuum. b. passes through an opening wider than λ.
c. travels through water. d. passes through an opening narrower than λ.

2. (3) The phrase, "Every point on a wavefront is a source of wavelets that spread out in the forward direction at the same speed as the wave itself" is contained in the statement of

a. Rayleigh's limit. b. Huygen's principle. c. Maxwell's idea. d. Young's dilema.

3. (3) Constructive interference of light passing through two slits occurs when the waves arrive on a screen

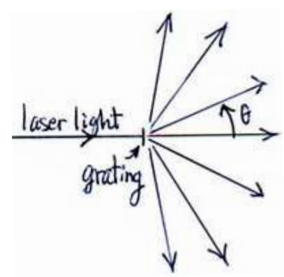
a. in-phase. b. 180° out-of-phase. c. shifted by half a wavelength. d. shifted by half a period.

4. (2) **T F** A dark fringe in an interference pattern corresponds to destructive interference.

5. (2) **T F** When the wavelength is increased, the central maximum of single slit diffraction gets wider.

6. (2) **T F** The polarization direction of a light beam can be rotated with a polarizing filter.

7. (10) A diffraction grating has 8.50×10^3 lines/cm. Light of unknown wavelength λ produces a 2^{nd} order bright fringe at a 48.0° angle from the axis.



a) (4) Determine the linear spacing between the lines on the grating.

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

8. (10) The headlights of a car (considered as point light sources) are 1.8 m apart and emit light primarily around wavelength 520 nm. You see the car coming 2500 m down the road, when the pupil of your eye is opened to a diameter of 8.0 mm. Your vision is diffraction limited but otherwise perfect.

a) (4) How large is the angular separation (in radians) of the headlights in your vision?

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

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9. (6) What angle is needed between the polarization direction of a light beam and the axis of a polarizing filter to cut the intensity in half?

1. (3) Which idea is not part of Einstein's theory of special relativity?

   a. The laws of physics are the same in all inertial reference frames.
   b. The speed of light is independent of the motion of the source and the observer.
   c. An inertial reference frame is one where Newton's first law is valid.
   d. There is a universal time that is the same for all observers.

2. (3) You view a star that is moving at speed $v = 0.90c$ away from Earth. The speed of the light that you see, relative to you, is

   a. $0.10c$. b. $0.50c$. c. $0.90c$. d. c. e. $1.90c$.

3. (6) A light clock consists of a lightbulb and mirror separated by a length D. The period is the time for a light pulse to travel from lightbulb to mirror and back.

   a) (2) **T F** A stationary light clock of 300 m length has a period of 2.0 μs.
   b) (2) **T F** When the light clock is at rest, its period is greatest.
   c) (2) **T F** When the light clock is moving at speed $v = 0.80c$, its period is 80% of its period when at rest.

4. (12) Finally in the year 9595, NASA sends astronauts in a relativistic rocket to travel at a speed of $v = 0.980c$ to Sirius, 8.58 lightyears from Earth. They stay 1.00 year doing research and return back to Earth at the same speed.

   a) (6) How many years pass on Earth until they return?

   b) (6) How much time passes on the clocks carried by the astronauts until they return?

5. (12) After the capsule of NASA's relativistic rocket reaches its cruising speed of $v = 0.980c$, the rest mass of $m_{\text{cap}} = 1.20 \times 10^3$ kg remains to travel all the way to Sirius.

a) (6) Find the kinetic energy of the capsule while cruising at speed $v = 0.980c$ to Sirius.

b) (6) The rocket uses nuclear power. How much mass was converted into energy in its nuclear reactor engine to produce the kinetic energy of the capsule?

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6. (6) How fast ($v/c = ?$) must a spaceship be moving towards Sirius so that its occupants see the 8.58 lightyears distance from Earth length-contracted to only 1.00 lightyear?

OpenStax Ch. 29 - Photons & Matter Waves   Name

1. (2) **T F** A photon from a red laser pointer has more energy than one from a green laser pointer.

2. (2) **T F** A photon and an electron with the same momentum have equal wavelengths.

3. (2) **T F** An electron's de Broglie wavelength increases as its speed is reduced.

4. (3) When a photon collides with a nearly stationary electron (Compton scattering), its wavelength

   a. decreases. b. increases. c. does not change. d. becomes a random value.

5. (3) 540 nm wavelength light of intensity 1.0 W/m^2 incident on a certain metal is not producing any 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. (5) A blackbody spectrum of light has the strongest intensity at a wavelength of 4.50 μm. What is the temperature of the emitting object, in Kelvin?

7. (8) Light of wavelength 401 nm incident on a certain metal produces photoelectrons with a maximum kinetic energy of 1.78 eV. What is the maximum wavelength of light capable of producing photoelectrons for this metal?

8. (8) Electrons in an electron microscope have been accelerated through a potential difference of 1250 V. How large is their de Broglie wavelength?

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9. (8) An electron with momentum $p = 2.5$ keV/c $= 1.33 \times 10^{-24}$ kg m/s is confined inside a “quantum dot” of length $L = 12.0$ nm, so that its uncertainty in position is about $\Delta x = L/2 = 6.0$ nm. The electron is moving slowly compared to the speed of light. Determine the approximate uncertainty Δv in the electron’s velocity.

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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) $\qquad$ $f\lambda = c$ (wave equation)

Energy density, intensity, power:

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

$I = \overline{u}c = \frac{1}{2}\epsilon_0 E_0^2 c$ (EM waves intensity) $\qquad$ $I = P/A = P/(4\pi r^2)$ (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) $\qquad$ $\Delta x = d\sin\theta$ (path difference in double slits)

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

Diffraction:

$D\sin\theta = m\lambda$ (single slit minima) $\qquad$ $y = L\tan\theta$ (position on a screen)

$d\sin\theta = m\lambda$ (diffraction grating maxima) $\qquad$ $d = 1/$(lines per meter).

Rayleigh's Diffraction Limit:

$\theta_{\min} = 1.22\lambda/D$ (resolution limit) $\qquad$ $\theta = s/r$ (angular separation in radians)

Polarization:

$I = I_0\cos^2\theta$ (transmission thru polarizer) $\qquad$ $I = \frac{1}{2}I_0$ (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)

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

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

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

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

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

OpenStax Chapter 29 Equations - Quanta and Quantum Waves

Blackbody radiation, photons, photo-electric effect:

$\lambda_p T = 2.90$ mm·K (Wien's Law)

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

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

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

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

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

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

$v_{\text{max}} = \sqrt{2\text{KE}_{\text{max}}/m}$ (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, $v \ll c$)

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

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

Heisenberg Uncertainty Principle:

$\Delta x\ \Delta p_x \approx h$ (approximate relation)

$h = 6.626 \times 10^{-34}$ J·s

$\Delta E\ \Delta t \approx h$ (approximate relation)

$\Delta x\ \Delta p_x \geq \hbar/2$ (has the minimum uncertainty)

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

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

$\Delta E = \Delta m \cdot c^2$ (Einstein's mass-energy equivalence) ← This has exact equality.