Physics 262 Spring 2013. For numeric answers, round to the nearest integer, and always choose 9 for 9 or greater. A couple questions, marked with asterisks, are a little challenging – skip them on your first time through.

Consider the plane electromagnetic wave in vacuum with an electric field given by
\[ \vec{E} = E_0 \cos(\omega t - kz) \hat{\mathbf{y}} \]

1. What is the direction in which this wave is propagating?
a) +x  b) -x  c) +y  d) -y  e) +z  f) -z  g) some other direction
   f) an electromagnetic wave with this polarization cannot exist

2. What is the direction of the magnetic field at the point z=0 at t=0?
a) +x  b) -x  c) +y  d) -y  e) +z  f) -z  g) some other direction

3. At which point is the electric field largest?
a) x = y = z = 0
b) x = 100 m, y = z = 0
c) x = y = 100 m, z = 0
(d) the electric field is the same at all these points
e) there is not enough information given

4. If the period of this wave is 3 seconds, what is \( \omega \), to the nearest s^{-1}?

\[ \frac{2 \pi}{\omega} = \frac{2 \pi}{T} \]

5. When light moves from vacuum into material of index n, the speed slows to c/n but the frequency remains constant. Compared to the wavelength in vacuum \( \lambda_0 \), the wavelength in the material is
a) \( \lambda = \lambda_0 n^2 \)  b) \( \lambda = \lambda_0 / n \)
c) \( \lambda = \lambda_0 \)  d) \( \lambda = n \lambda_0 \)  e) \( \lambda = n^2 \lambda_0 \)

6. A meniscus lens has the cross section shown, and is made from plastic with n = 1.15. Is the lens a converging or diverging lens, in air and under water
a) converging in air, converging in water
b) diverging in air, converging in water
(c) converging in air, diverging in water
d) diverging in air, diverging in water
e) converging in air, but can’t work as a lens underwater

7. Two converging lenses each have focal length +6 cm and are separated by 16 cm. The left lens makes an image of a candle 13 cm to its right.

Where is the image of the candle formed by both lenses?
a) to the left of both lenses  b) in between the lenses  c) to the right of both lenses

\[ \frac{1}{f} + \frac{1}{f'} = \frac{1}{s} \]

\[ s' = -f' \]
Two very narrow slits are separated horizontally; they are illuminated by a plane wave from below in the picture, and thus are emitting waves in phase. Crests are shown.

8. What is the difference in the path lengths to the two sources at point P?
   a) < \lambda/2   b) \lambda/2   c) \lambda   d) 3\lambda/2   e) 2\lambda
   f) 5\lambda/2   g) 3\lambda   h) 7\lambda/2   i) 4\lambda   j) >4\lambda

9. What is the approximate separation between the sources?
   a) < \lambda/2   b) \lambda/2   c) \lambda   d) 3\lambda/2   e) 2\lambda
   f) 5\lambda/2   g) 3\lambda   h) 7\lambda/2   i) 4\lambda   j) >4\lambda

10. What phasor diagram could represent the fields at point Q? Additional information: the intensity at Q is half the intensity at P.

11. How many degrees is Q to the right of the “central maximum” (as seen from the sources)? Answer to the nearest degree. Hints: use the small angle approximation for path length differences, and your answer to 8.

   \frac{\Delta \phi}{\lambda} = \frac{\Delta r}{\lambda} = \frac{1}{4} 
   B = \frac{1}{4} \cdot \frac{2}{7} \Rightarrow \text{angle} \approx 41^\circ

*12. The area between the slits is knocked out, leaving one “large” slit.
What is now the ratio of the intensity at Q to the intensity at the central maximum (at the same distance) (Choose the nearest answer)?
   a) 0   b) 0.1   c) 0.2   d) 0.3   e) 0.4   f) 0.5   g) 0.6   h) 0.7   i) 0.8   j) 0.9 or more

\[
\frac{E_Q}{E_C} = \frac{\sum r}{\frac{\pi}{2} r} \Rightarrow \frac{I_Q}{I_C} = \frac{2 \cdot 4}{\pi} = 0.81
\]
13. A soapy water film is held in a circular frame and drains. Just before breaking, the top of the film is very thin. When illuminated from the same side that it is viewed from, the very thinnest part of the soap film
(a) is black       (b) is white      (c) is blue

14. Which ray is correctly traced for the convex mirror with center of curvature shown? Or choose (d) more than one ray is correctly traced.

Relativity

15. The RailRunner train C is traveling quite fast and is exactly halfway between Santa Fe and Albuquerque when it passes an observer on the ground, B. At that instant, the observer on the ground sees light from lightning in Santa Fe and Albuquerque. There is also an observer on the ground (not moving with respect to the earth) in Santa Fe, A. What observers are in the same inertial reference frame?

(a) A & B
(b) B & C
(c) A & C
d) all are in the same reference frame
e) each is in a different reference frame
16. What does the observer on the train see and what is true in his frame?
   a) He sees lightning from Albuquerque first, and Albuquerque lightning struck first
   b) He sees lightning from Albuquerque first, but Santa Fe lightning struck first
   c) He sees lightning from Albuquerque first, but the lightning strikes were simultaneous
   d) He sees lightning from Santa Fe first, and Santa Fe lightning struck first
   e) He sees lightning from Santa Fe first, but Albuquerque lightning struck first
   f) He sees lightning from Santa Fe first, but the lightning strikes were simultaneous
   g) He sees the lightning strikes at the same time, but Albuquerque struck first
   h) He sees the lightning strikes at the same time, but Santa Fe struck first
   i) He sees the lightning strikes at the same time, and the strikes were simultaneous.

17. On the Minkowski diagram below, what is v/c for the primed frame? Choose closest answer.
   a) 0  b) 0.1  c) 0.2  d) 0.3  e) 0.4  f) 0.5  g) 0.6  h) 0.7  i) 0.8  j) 0.9

18. On the Minkowski diagram below, what point on the ct' axis is simultaneous (according to primed observers) with event P?

19. What point on the ct axis is simultaneous (according to primed observers) with event P?

20. The ct axis is labeled in light-seconds. What is ct' for event P, to the nearest light-second?

   \[ ct' = \gamma \cdot ct = 1.25 \times 6.4 = 8 \]
21. A spaceship is moving at 0.94c with respect to Earth. Folks on the spaceship are playing snooker (pool on a giant table). Joe shoots the cue ball across the table, perpendicular to the ship's motion. According to clocks on the ship, the ball takes 1 s to drop into the pocket. How much time elapses on an earth clock, to the nearest second?

22. What is the angle the ball makes with respect to the spaceship motion, according to an earth frame observer, in degrees? The pool table is 10 m long. Answer to the nearest degree, use 9 for 9 or greater.

23. A particle with rest mass 5 MeV/c^2 has a momentum of 12 MeV/c. What is its kinetic energy, to the nearest MeV (use 9 for ≥9)?

\[ E = \sqrt{p^2c^2 + m^2c^4} - m \]

24. This particle decays by emitting a photon of energy 8 MeV directly forward. What is the mass of the particle that remains, to the nearest MeV/c^2 (use 9 for ≥9)?

\[ (13, 12) - (8, 8) = (5, 4) \]

25. What is the speed, v/c for the remaining particle?
a) 0  b) 0.1  c) 0.2  d) 0.3  e) 0.4  f) 0.5  g) 0.6  h) 0.7  i) 0.8  j) 0.9

26. Event A happens at the origin and event B happens 5 seconds later at a coordinate of +4 light-seconds (in the Earth frame.) Is there any frame at which these events are simultaneous?

a) yes  b) no  c) insufficient information

27. Is there any frame at which these events occur in the same place?

a) yes  b) no  c) insufficient information

28. In one frame, the separation between the events in space is 1 light second. What is the time separation, to the nearest second (use 9 for ≥9)?

\[ \frac{\Delta s^2 - c^2}{c^2} = \frac{\Delta \tau^2}{c^2} \approx 3. \]

Quantum

29. A certain special metal has a work function of 0.2 eV. What is the threshold wavelength of light (in microns) that can eject an electron from this metal? Give your answer to the nearest micron.

\[ \frac{1240 \text{ eV nm}}{0.2 \text{ eV}} = \frac{1240 \text{ nm}}{6200 \text{ nm}} = 6 \text{ nm} \]

30. Will light with wavelength shorter than the threshold or longer than the threshold eject electrons?

a) shorter  b) longer  c) insufficient information

31. According to the deBroglie hypothesis:

a) objects with higher momentum have shorter wavelength
b) objects with higher momentum have longer wavelength
c) only objects with masses less than an atom show wavelike behavior
d) the wavelength of an object depends only on its velocity
e) none are true
32. A Bohr orbit is shown. What is n? \( n = 3 \)

33. The "meaning" of the Bohr orbit (not the Schrödinger wave) is:
   a) electrons wiggle back and forth as they move in quasi-circular orbits
   b) the electron is less likely to be found where the orbit is inside the circle
   c) the electron is less likely to be found where the orbit crosses the circle
   d) exactly \( n \) de Broglie waves will fit around the circle

34. If you go to the next higher Bohr quantum state, does the wavelength increase or decrease? (Be careful... does \( r \) stay the same?)
   a) increase
   b) decrease
   c) no change

Consider the 2 lowest energy, stationary state Schrödinger waves for the infinite well:

\[
\psi_1(x, t) = \frac{2}{L} \sin \left( \frac{\pi x}{L} \right) e^{-iE_1 t/\hbar}
\]

\[
\psi_2(x, t) = \frac{2}{L} \sin \left( \frac{2\pi x}{L} \right) e^{-iE_2 t/\hbar}
\]

the energies are

\[
E_1 = \frac{\pi^2 \hbar^2}{2mL^2} \quad \text{and} \quad E_2 = \frac{4\pi^2 \hbar^2}{2mL^2}
\]

35. These are called "stationary states" because:
   a) The wave \( \psi \) does not change over time
   b) The magnitude and magnitude-squared of the wave \( \psi \) does not change over time
   c) A single measurement of the particle's momentum will give zero
   d) "Stationary" is just a more mathematical word for "sinusoidal"

36. Which is true:
   a) There is an instant in time when the real part of \( \psi_1 \) is zero everywhere
   b) There is an instant in time when the imaginary part of \( \psi_1 \) is zero everywhere
   c) There is an instant in time when \( \psi_1 \) is zero everywhere
   d) a and b only are true
   e) all are true

37. If a particle in an infinite well is in state \( \psi_2 \), and a measurement is made of its position, where is it most likely to be found?
   a) in the middle
   b) at points about \( \frac{1}{4} \) and \( \frac{3}{4} \) of the way across the well
   c) close to the ends
   d) it depends on when the measurement is made
38. After the position measurement, what is true?
a) the particle remains where it was when measured
b) the particle remains in the stationary state $\psi_2$
c) the particle drops down into state $\psi_1$
d) the particle ends up in another stationary state, but we can’t predict which one
e) none of these is true

Consider the wave formed by adding these two waves together (with appropriate normalization)

$$\psi(x,t) = \frac{1}{\sqrt{2}} \sqrt{\frac{2}{L}} \sin \frac{\pi x}{L} e^{-iE_1 t/\hbar} + \frac{1}{\sqrt{2}} \sqrt{\frac{2}{L}} \sin \frac{2\pi x}{L} e^{-iE_2 t/\hbar}$$

39. What is true for this wave?
a) it is also stationary
b) it is not a solution to the full Schrödinger equation
c) it is a solution to the full Schrödinger equation
d) the magnitude squared of this wave function doesn’t change with time
e) more than one answer is true.

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An infinitely deep potential energy well has a “shelf” in it on the right side, as shown. Suppose there is a stationary state with the energy shown as the dashed line.

40. Will the wavelength be shorter or longer in the deeper part of the well?
(a) Shorter
(b) Longer
c) Same in both parts

41. What is the ratio of the longer to the shorter wavelength? (Use 1 if they are the same.)

$$\frac{E_{l}}{E_{s}} = \frac{\hbar}{\lambda_{l}} = \frac{1}{q} \sqrt{\frac{1}{q}} = \frac{\hbar}{\lambda_{s}} \Rightarrow \frac{\lambda_{l}}{\lambda_{s}} = 3$$

42. If the position of the particle is measured, where is it more likely to be found?
a) left side  (b) right side  (c) same chance to be on either side
d) it depends on when the measurement is made

43. A potential well (of any shape) can have an infinite number of bound states only if it is infinitely deep.
(a) True  (b) False
44. The atomic spectrum of hydrogen contains some of the same colors obtained from He⁺. The n=3 to n=2 transition in hydrogen will give the same color as what transition in He⁺?
   a) n = 3 → 1  
   b) n = 4 → 2  
   c) n = 4 → 3  
   d) n = 6 → 2  
   e) n = 6 → 4  
   f) n = 9 → 4

*45. Suppose you want to design a solid state device that has a 1D finite square well for an electron that has only one bound state. If the depth of the well is $0.0001 \text{ eV} = 10^{-4} \text{ eV}$, use Heisenberg to estimate the minimum spread in the bound electron position, in Angstroms. What is its order of magnitude?
   a) $\sim 1 \text{ Å}$  
   b) $\sim 10 \text{ Å}$  
   c) $\sim 100 \text{ Å}$  
   d) $\sim 0.1 \text{ µm}$  
   e) $\sim 1 \text{ µm}$  
   f) $\sim 10 \text{ µm}$  
   g) $\sim 100 \text{ µm}$

$$\frac{\Delta p^2}{2m} \approx 10^{-4} \text{ eV} \quad \Rightarrow \quad \Delta p = \left( \frac{10^6 \text{ eV} \cdot 10^{-4} \text{ eV}}{c} \right) = 10 \text{ eV/c}$$

$$\Delta x \Delta p \geq \frac{h}{2}$$

$$\Delta x = \frac{h}{\Delta p} = \frac{6 \times 10^{-34} \text{ eV s}}{10 \text{ eV/c}} = 9 \times 10^{-24} \text{ m} = 90 \text{ Å}$$

Note: $\frac{p^2}{2m} \approx 10^{-4} \text{ eV}$ and $\Delta p \approx 2p$, so if $\Delta x \approx 100 \text{ Å}$ is also OK.

46. In spectroscopic notation, what is the ground state of sodium (Z=11)?
   a) $1s^2 2p^6 3d^3$  
   b) $1s^1 2s^1 2p^3 3s^1 3p^3 3d^2$  
   c) $2s^1 2p^5 6p^1 1s^1$  
   d) $1s^2 2s^2 2p^6 3s^1$
   e) $1s^2 1p^6 2s^2 2p^1$  
   f) $1s^2 1p^6 1d^3$  
   g) none of these is correct

47. Estimate the ionization energy for the first electron of sodium, assuming the remaining electrons screen the nuclear charge. Give your answer in eV, to the nearest eV.

$$E = \frac{-1}{3^2} \cdot 13.6 \text{ eV} = 1.51 \text{ eV} \quad \text{(2)}$$

48. Which is an allowed set of quantum numbers for an electron in an atom?
   a) n=3, l=-1, m=-1, ms=1/2  
   b) n=2, l=1, m=1, ms=0  
   c) n=0, l=0, m=0, ms=1/2  
   d) n=2, l=1, m=0, ms=1/2  
   e) n=2, l=2, m=2, ms=1/2  
   f) more than one set shown is allowed
49. If \( l = 6 \), what is the minimum spread \( \Delta L_x \)? (Answer in terms of \( \hbar \)-bar, to the nearest integer. This is a trick question.)

50. If \( l = 6 \) and \( m_l = 6 \), what is the spread \( \Delta L_x \)? (Be careful: the full spread includes both + and – values for \( L_x \).)
   \[
   L = \sqrt{6(6+1)} \hbar \\
   L_z = 6 \hbar
   \]
   \[
   \frac{1}{z} \Delta L_x = 2.45 \hbar \\
   \Delta L_x = 4.9 \hbar \approx 5 \hbar
   \]

51. The strong force
   a) has infinite range (like electric forces, \( 1/r^2 \))
   b) has a range about as large as an atom
   c) has a range about as large as a nucleus
   d) has a range about as large as a proton
   e) has a range about as large as an electron

52. Rutherford’s test of the plum pudding model of the atom was surprising in that:
   a) alpha particles were deflected at all
   b) alpha particles were deflected at high angles
   c) alpha particles were absorbed by the nuclei
   d) alpha particles caused nuclear fission
   e) the alpha particles tasted just like plums after bombarding the pudding

53. Why aren’t nuclei with hundreds of neutrons stable?
   a) neutrons have a magnetic moment that gives long range repulsion
   b) the strong force requires that particles have some charge
   c) neutrons can decay to protons, which lowers the overall energy if there are fewer protons
   d) they ARE stable, but are very hard to find because they have high mass and little charge

54. Bohrium 270 (it really exists, and has a lifetime of 61 seconds!) has atomic number 107 and atomic weight 270. What is the ratio of the Bohrium nuclear diameter to the nuclear diameter of Beryllium-10? Answer to the nearest integer.
   \[
   \left( \frac{107}{10} \right)^{\frac{1}{3}} = 3
   \]

55. Polonium-218 (\(^{218}\text{Po}_{84}\)) can radioactively decay in more than one step to Thallium-210 (\(^{210}\text{Tl}_{81}\)). Which of the following could be the complete list of radioactive decay products?
   a) 3 \( \beta^+ \)
   b) 1 \( \alpha \) and 3 \( \beta^- \)
   c) 2 \( \alpha \) and 2 \( \beta^+ \)
   d) 2 \( \alpha \) and 1 \( \beta^- \)
   e) 4 \( \alpha \)
   f) 8 \( \beta^- \)
   g) none of these could be the set of decay products

56. Different isotopes of the same element:
   a) have the same # of protons and different #s of neutrons
   b) have the same # of neutrons and different #s of protons
   c) have the same # of neutrons and protons, but different # of electrons
   d) each hit more home runs per season than Babe Ruth.